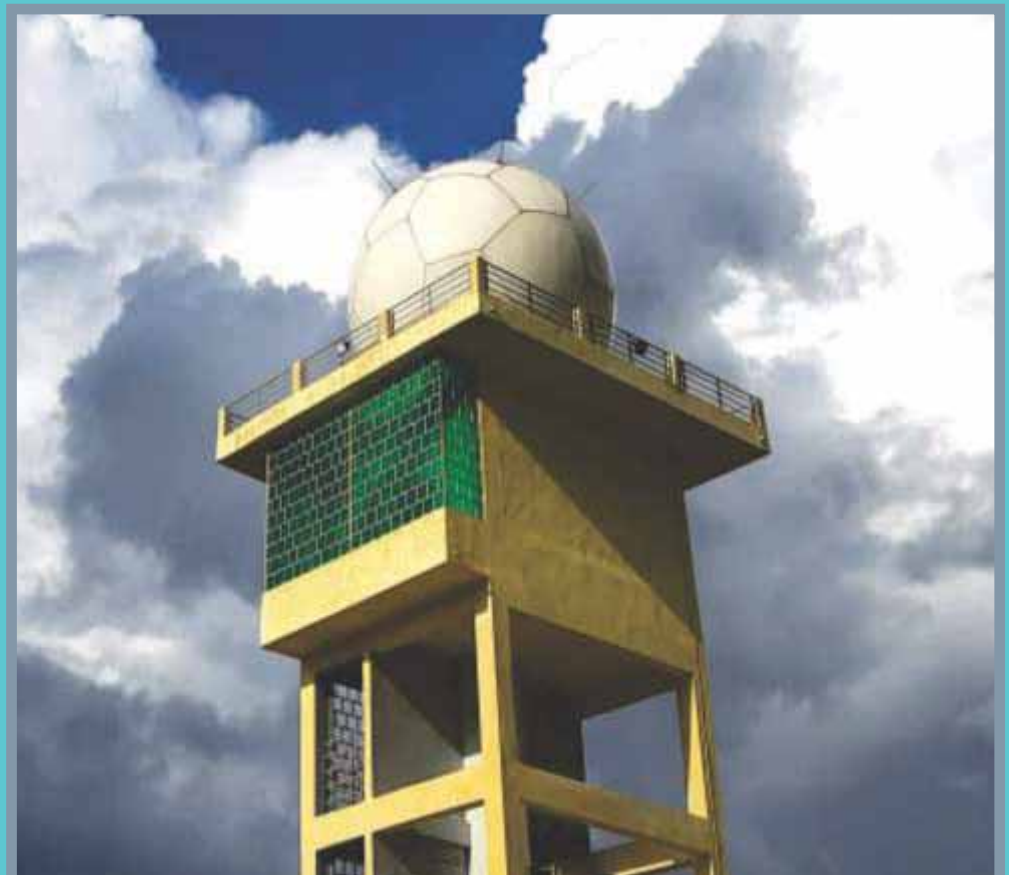
ISSN: 0250-6017

Annual Report
2020-2021

भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
Indian Institute of Tropical Meteorology



Annual Report 2020-21

Indian Institute of Tropical Meteorology

(An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India)
Dr. Homi Bhabha Road, Pashan, Pune - 411 008, Maharashtra, India
https://www.tropmet.res.in Phone: 91-020-25904200
E-mail: lip@tropmet.res.in Fax: 91-020-25865142

GOVERNING COUNCIL

Chairman (*Ex-Officio*)

Dr. M. Rajeevan
Secretary
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi – 110003

Members *(Ex-Officio)*

Additional Secretary & Financial Adviser/ Joint Secretary & Financial Adviser
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Additional Secretary/Joint Secretary
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Director General of Meteorology
India Meteorological Department (IMD)
Mausam Bhavan, Lodi Road
New Delhi - 110003

Prof. J. Srinivasan
(Chairman, RAC of IITM)
Indian Institute of Science
Bangaluru - 560012

Members

Prof. Sulochana Gadgil
A-18, Spring Flowers,
Panchvati, Pashan,
Pune-411008

Prof. S.K. Dubey
Vice Chancellor
Amity University, Jaipur

Dr. V.K. Dadhwal
Director
IIST, Thiruvananthapuram
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Mr. J.M. Mauskar, IAS (Retd.)
C-1, Flat No. 39
35 Supercon Residency Apartments
Shirine Garden, Aundh
Pune – 411007

Permanent Invitee *(Ex-Officio)*

Programme Head (IITM)
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Invitee

NITI Aayog Representative

Member Secretary

Director
Indian Institute of Tropical Meteorology
Pune - 41108

FINANCE COMMITTEE

Chairman *(Ex-Officio)*

Additional Secretary & Financial Adviser/ Joint Secretary & Financial Adviser
Ministry of Earth Sciences
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Members *(Ex-Officio)*

Additional Secretary/Joint Secretary
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi – 110003

Programme Head (IITM)
Ministry of Earth Sciences (MoES)
Prithvi Bhavan, Lodi Road
New Delhi – 110003

Director (Finance) / Deputy Secretary (Finance)
Ministry of Earth Sciences
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Director
Indian Institute of Tropical Meteorology
Pune - 411008

Senior Administrative Officer
Indian Institute of Tropical Meteorology
Pune - 411008

Finance Officer / Accounts Officer
Indian Institute of Tropical Meteorology
Pune - 411008

RESEARCH ADVISORY COMMITTEE

Chairman

Prof. J. Srinivasan
Hon. Professor
Indian Institute of Science
Bengaluru

Members

Dr. Satish Shenoi
Former Director, INCOIS
Hyderabad

Prof. P.P. Chakravarti
Former Director, IIT, Kharagpur

Prof. G.S. Bhat
Indian Institute of Science
Bengaluru

Dr. K. Rajeev
Space Physics Laboratory
VSSC, ISRO
Thiruvananthapuram

Dr. Sivanand Pai
India Meteorological
Department Pune

Dr. Kamal Puri
BOM, Australia

Dr. Arun Kumar
NCEP, USA

Dr. Peter Bechtold
ECMWF, UK

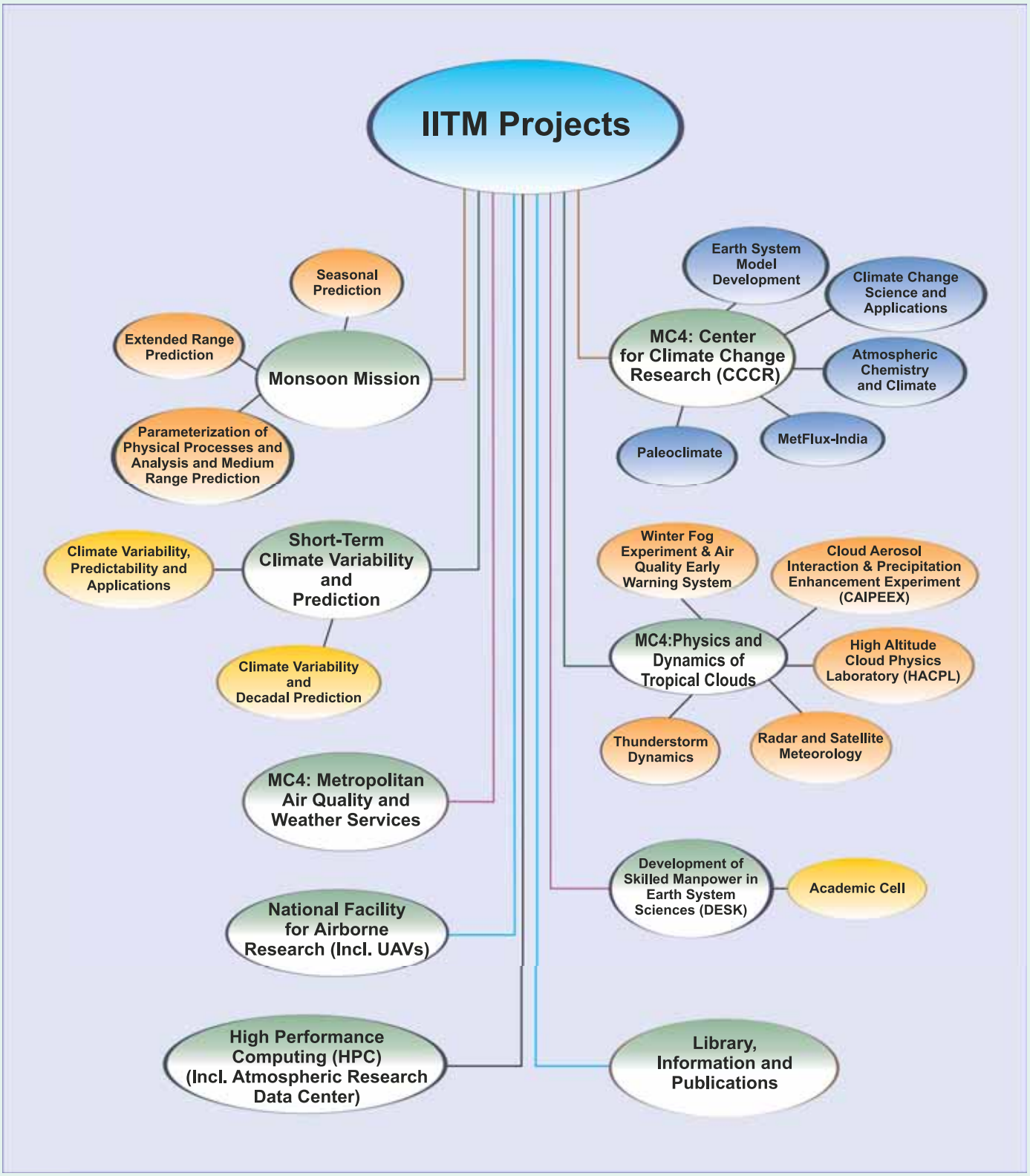
Prof. Ravi S. Nanjundiah
Director
Indian Institute of Tropical Meteorology Pune

Member *(Ex-Officio)*

Head
National Centre for Medium Range Weather Forecasting (NCMRWF)
Noida

Member Secretary

Dr. Shivsai Dixit
Indian Institute of Tropical Meteorology
Pune



Organizational Flow Chart of R&D Activities

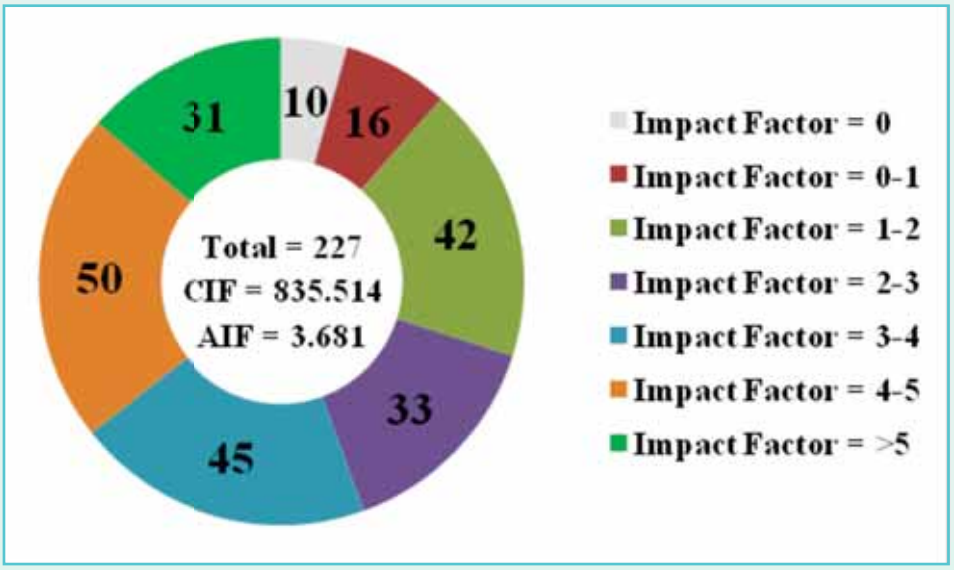
CONTENTS

IITM Research Publications at a Glance .....
Foreword .....
Executive Summary .....
Glimpses of Important Events .....
Overview of R&D Activities
1. Centre for Climate Change Research (CCCR) 1
1.1. Earth System Model Development 3
1.2. Climate Change Science and Applications 6
1.3. Atmospheric Chemistry and Climate 11
1.4. Paleoclimate 14
1.5. Metflux India 15
2. Short Term Climate Variability and Prediction 16
2.1. Climate Variability, Predictability and Applications 18
2.2. Climate Variability and Decadal Prediction 22
3. Monsoon Mission 27
3.1. Seasonal Prediction 29
3.2. Extended Range Prediction 35
3.3. Parameterization of Physical Processes and Analysis 42
4. Physics and Dynamics of Tropical Clouds 50
4.1. Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) 52
4.2. High Altitude Cloud Physics Laboratory (HACPL) 57
4.3. Radar and Satellite Meteorology 61
4.4. Thunderstorm Dynamics 64
5. National Facility for Airborne Research (NFAR) 70
6. High Performance Computing System (HPCS) 73
7. Metropolitan Air Quality and Weather Services (MAQWS) 78
8. India-UK Water Centre (IUKWC) 85
9. Winter Fog Campaign (WIFEX) and Air Quality Early Warning System for Delhi 87
10. International CLIVAR Monsoon Project Office (ICMPO) 89
Human Resource Development and Capacity Building
11. Development of Skilled Man power in Earth System Sciences (DESK) 92
12. Academic Cell 93
Other Activities
13. Important Events and Activities 95
14. Awards and Honours 107
15. Seminars 113
16. Deputations Abroad 125
17. Regular Staff 126
18. Publications 129
Appendices 151
Audited Statement of Accounts 158

IITM Research Publications at a Glance



Growth of IITM publications in peer-reviewed journals since 2000



Impact Factor wise distribution of IITM publications during the year 2020-21

Summary of Publications during the year 2020-21	
Total No. of papers published in Journals	227
Papers with Impact Factor	217
Papers without Impact Factor	10
Cumulative Impact Factor	835.513
Average Impact Factor	3.681

Foreword



It gives me immense pleasure to present the annual progress and activities of the Indian Institute of Tropical Meteorology (IITM), Pune during the financial year 2020-21. In weather and climate sciences, IITM is one of the foremost research organisations in the world. With excellent contributions in the fundamental and applied research in Meteorology, Atmospheric Sciences and Climate, IITM is consistently aspiring to further improve India's capabilities in predicting weather and climate events, with emphasis on the Indian summer monsoon.

In 2020-21, the Institute achieved remarkable progress in all its projects and brought out 227 research publications in reputed national and international journals. The report presents glimpses of the major research results, activities and achievements of the Institute during the year. The significant achievements of various R&D projects are briefly highlighted in the Executive Summary of this report.

The Monsoon Mission has played an important role in better understanding the Indian monsoon and improving its forecasts on different space-time scales. Its continuation was very much needed for further enhancing our prediction capabilities, especially for the extreme weather events, where we are already working on improving skill in predicting tropical cyclones. I am happy to share that MoES' Independent Review Committee has rightly recommended the continuation of Monsoon Mission to its 3rd phase (2020-24).

It is also heartening to know that a report prepared by NCAER, New Delhi has highlighted that the investment in Monsoon Mission and HPC facilities has improved forecasts bringing economic benefits to the country to the tune of more than Rs. 50,000 Crores, which is an economic return of more than 50 times the investment.

We have also developed a new early health warning system with reasonable skill in providing a climate-health outlook about possible disease incidences at least two weeks in advance for any location or grid over India.

Our efforts in short range prediction through GFS/GEFS models have proven to be very successful in predicting the recent tropical cyclones over India with higher precision and considerable lead time. Such predictions well in advance helped in saving many lives and minimising damage to property.

With the help of the first Indian Earth System Model (IITM-ESM) developed at IITM Centre for Climate Change Research (CCCR), India has contributed climate simulations and projections to the CMIP6 and the upcoming assessment report of the IPCC. CCCR's efforts in this regard have been documented as the first assessment report from India and published in the form of an open book 'Assessment of Climate Change over the Indian Region.'

Our lightning location network is being further expanded, and a map of lightning prone areas has been prepared and shared with National Disaster Management Authority (NDMA). We are making progressive efforts toward establishing a UAV system for exploring the lower atmosphere. Work for establishing an atmospheric research testbed facility near Bhopal in central India has been initiated.

Through several studies, exciting results have come out that will further add to our efforts to understand weather and climate better and improve our prediction capabilities.

While the COVID-19 pandemic-forced restrictions and lockdowns affected several R&D activities, it also provided an excellent opportunity to study air quality with reduced emissions from transport and industry. We hope that observations under SAFAR would provide interesting insights into air quality.

Even during this pandemic and lockdowns, we attempted to keep running several of our R&D efforts, including observations under CAIPEEX and HACPL and support services such as High Performance Computing facilities.

I take this opportunity to thank the entire IITM family for their excellent efforts and contributions even in this COVID-19 pandemic and lockdown situation. I thank our administration, general administration, security and other support services for ensuring appropriate COVID-19 behaviour, hygiene, sanitisation and social distancing guidelines of the government for ensuring the safety of all involved. I also thank Computer Division, DESK and LIP Division for their contributions in making necessary arrangements for conducting various interactions and transactions virtually, and the Accounts Section for paying bills and salaries in time.

I express my gratitude to the Ministry of Earth Sciences, Government of India for advisory and funding support, and the Governing Council, the Finance Committee and the Research Advisory Committee of the Institute for their constant support and guidance. I also thank the Ministry of Science & Technology, the Ministry of Environment, Forests and Climate Change, and the Indian Space Research Organisation for their continuing support and sponsoring some important scientific projects. I also acknowledge the contributions of our national and international collaborators through their scientific and technical cooperation.

I hope IITM continues to expand its scope, capabilities and expertise with the changing times and to excel in providing scientific leadership in weather and climate research and services at the national and global levels.



Ravi S. Nanjundiah

Director

Executive Summary

During the financial year 2020-21, the Indian Institute of Tropical Meteorology (IITM) made considerable research contributions in different areas of atmospheric sciences, meteorology, monsoons – predictions and variability and climate change. During this period, the scientists of the institute published 227 papers in peer-reviewed journals with a Cumulative Impact Factor of 835.513 and the Average Impact Factor of 3.861. Some of the most important research contributions and achievements of the year 2020-21 are summarised below:

Monsoon Mission

After a critical review, the Independent Review committee (IRC) constituted by MoES has recommended the continuation of Monsoon Mission to its 3rd phase (2020-24).

MoES commissioned report prepared by NCAER, New Delhi has clearly brought out that the investment in Monsoon Mission and HPC facilities has improved forecasts bringing economic benefits to the country to the tune of more than Rs. 50,000 Crores, which is an economic return of more than 50 times the investment.

Real-time operational forecast runs are being carried out on regular basis for the Dynamical System for Lightning Prediction developed at IITM.

An investigation of the role of microphysics in association with two different convection schemes for better simulation of Indian summer monsoon rainfall (ISMR) and monsoon intra-seasonal oscillation (MISO) revealed that mixed-phase processes are more important for capturing the difference between active and break composites, while convection parameterization is relatively more important for the intra-seasonal variance analyses.

Impact of horizontal resolution on sea surface temperature bias and air-sea interactions over the tropical Indian Ocean in CFSv2 coupled model has been investigated. The high-resolution atmospheric model was able to resolve convection centres reasonably well, resulting in better simulation of winds and so enabling better prediction of ocean mixed layer.

Real-time extended range prediction of active/break spells of Indian summer monsoon (ISM) for the 2020 monsoon season (June-September) was prepared by using the real time weekly operational forecast generated by IMD using the Multi Model Ensemble (MME) prediction system developed at IITM.

A new multi-physics ensemble prediction strategy for extended range prediction provides a better probabilistic forecast for extreme weather anomalies. The new system exhibits a gain of 2-4 days predictability over its predecessor at a sub-division level.

An assessment of prediction skill and predictability of Madden-Julian Oscillation (MJO) suggests that even the state-of-the-art models (IITM-ERP and ECMWF) are not free from systematic errors/biases, and that MJO prediction skill can be further improved by reducing these errors/biases in the dynamical model and error in the initial condition.

An analysis and comparison of selected cyclonic storms over the north Indian Ocean (NIO) for the period 1989-2018 reveal that the newly introduced genesis potential index 'improved genesis potential parameter (IGPP)' provides a better option than KGPP for real-time prediction of cyclogenesis and storm evolution over NIO.

Another investigation reveals the adequacy of dynamical downscaling of multi-model ensemble prediction system using WRF model in improving prediction of cyclonic storms over the north Indian Ocean.

Based on an unsupervised pattern recognition technique that uses meteorological parameters as inputs and which can be applied to any geographical location over India, a new method is proposed for probabilistic forecasting of the disease incidences in extended range time scale (2-3 weeks in advance) over India. This early health warning system is found to be a useful tool with reasonable skill providing the climate-health outlook about possible disease incidences at least two weeks in advance for any location or grid over India.

A method based on the calculation of the E-vector components and co-spectra analysis is introduced to diagnose the zonally asymmetric climatological patterns of extratropical to the tropical (E2T) transport and its subseasonal variability. A set of indices identifying the subseasonal temporal variation of the E2T transfer mechanism was defined, which could be used to operationally track the E2T eddy flux transfer both in observation and in forecast models.

A quantitative illustration of the segregation of forecast errors and their growth arising from different PBLs of the Weather Research and Forecasting (WRF) model provides guidance for the model community and operational agencies to make an optimal choice of Planetary boundary layer parameterizations, particularly for the monsoon forecast.

With an aim to build a high resolution GFS in cubic octahedral (Tco) grid for improving the forecast over India, efforts were made to develop and implement GFS at Tco765 grid resolution with grid size at equator very close to 12.5 km much similar to that of GFS T1534. The Tco765 showed equivalent fidelity as that of GFS T1534.

Performance of GFS at T1534 (~12.5 km) horizontal resolution was evaluated. It is revealed that the GFS T1534 with modified conversion parameter showed better fidelity in forecasting the mean summer monsoon rainfall over the Indian subcontinent region as compared to default GFS T1534. Various skill score analyses suggest that the former had better skill in predicting moderate and heavier category rainfall with longer lead time over the Indian subcontinent region, suggesting the incorporation of the modified conversion parameter in the present operational GFS T1534 model.

Two simulations in CFSv2, one with default revised RSAS convection scheme and another with modified RSAS, were investigated. It is showed that both the top of the atmosphere and surface energy imbalances are improved in the simulation with the modified RSAS. The active phase of Indian summer monsoon was better simulated in the modified RSAS, and hence it helped in simulating a better seasonal rainfall.

The skill of the GEFS T1534 model in predicting tropical cyclones was evaluated by considering 13 cases during 2018, 2019 and 2020. It is found that as compared to the deterministic prediction, the ensemble prediction system based on GEFS had a higher skill in predicting tropical cyclones at longer lead time.

The results of an extensive analysis of radiative flux biases in the Climate Forecast System Model Version 2 (CFSv2) are reported. Large regional biases in shortwave and longwave radiations were observed over convectively active zones in the tropics, and a plausible prescription is provided for correcting the source of these biases.

Centre for Climate Change Research (CCCR)

The IITM Earth System Model (IITM-ESM) has contributed to the CMIP6 and IPCC AR6 by conducting multi-century simulations for pre-industrial, present-day conditions and climate projections. A suite of

experiments using IITM-ESM includes the CMIP6 designated-DECK experiments, historical simulations, future scenario simulations till the end of 21st century, and the Model Inter-comparison Project (MIP) experiments have been completed. The observed and projected changes in surface air temperature and precipitation over the globe as well as exclusively over the Indian region are presented in the 'Assessment of Climate Change over the Indian Region'. It is the first climate change report over the Indian region from the Ministry of Earth Sciences, Government of India, and its preparation was led and coordinated by CCCR-IITM. A salient feature of this report is the inclusion of introductory results based on the CMIP Phase 6 (CMIP6) projections of the IITM-ESM – the first climate model from India.

Efforts are on to incorporate the Community Ice-sheet Model (CISM) in the IITM-ESM. IITM-ESM Simulations will be performed with CISM implementation with focal areas of Greenland and Antarctic regions.

An investigation of how large volcanic eruptions (LVE) influence the nonlinear behaviour of the ENSO and Indian monsoon dynamical systems provided new insights into the physical mechanism underlying the LVE-induced enhancement of ENSO-Indian monsoon coupling and strengthened the prospects for improved seasonal monsoon predictions.

In order to assess the impact of long-term soil moisture changes on temperature extremes over the Indian region, 67-year period (1948-2014) hydro-meteorological datasets were analysed. An interesting observation is that the hot-spot region of land-atmosphere coupling (north-central India) is a region where soil moisture variations can significantly influence temperature extremes.

Results from a study exploring the variability of aerosols and water vapour near the tropopause based on balloon-borne aerosol backscatter measurements from Nainital and radiosonde measurements from Guwahati and Delhi are presented. It is found that a variety of factors impacting the Asian Tropopause Aerosol Layer (ATAL), and that air masses contributing to the ATAL are a mixture of different origins. Rising trends in Asian aerosol emission point to the thickening of the ATAL, which impacts the radiative balance of the atmosphere and reduces Earth's surface temperatures.

Tree-ring width index chronologies of different species from the western Himalayas were prepared to understand climate fluctuations. The results indicate that increasing heat index during May might lead to dry soil by accelerating the potential evapotranspiration which creates the moisture deficiency to plants over the region. The Standardized Precipitation Index (SPI) showed a significant positive relationship with tree growth, indicating that tree growth in the western Himalayas is moisture sensitive. It suggests potential usability of SPI in monitoring dry and wet periods before the instrumental period. The reconstructed SPI back to 1778 shows climate variability, on both interannual and inter-decadal time scale.

Results from a study of measuring concentrations of greenhouse gases (GHG) such as CO_2 and CH_4 at Sinhagad in the Western Ghats are presented. It is found that the average concentrations of CO_2 and CH_4 exhibit significant seasonal variability at this site. It is suggested that the GHG dynamics in the western region of India are significantly influenced by monsoon circulation, especially during the summer season.

For the first time, the net ecosystem exchange (NEE) in a mangrove ecosystem at Pichavaram (southeast India) was estimated by using the eddy covariance method in 2017-18. The mangrove forest appeared to be a modest sink of atmospheric CO_2, with an annual average net ecosystem productivity of 183 gC m^{-2}. However, in the summer months, it acted as a source. It is observed that the mangrove CO_2 fluxes strongly responded to environmental factors such as temperature, rainfall, and salinity. Also, it is noteworthy that the carbon sink capability may decline in the future due to rising temperatures, decreasing rainfall patterns, variation in salinity, and changes in tidal inundation patterns.

Short-Term Climate Variability and Prediction

An investigation of the influence of swapping the Pacific and Atlantic Niños on north central India summer monsoon by using observational data analysis and numerical experiments revealed a pathway of the changing ENSO influences on north central India rainfall.

The role of an Indian Ocean heating dipole anomaly in the transition of the North Atlantic-European (NAE) circulation response to ENSO from early to late winter was analysed. It is shown that in early winter a warm (cold) ENSO event is connected through an atmospheric bridge with positive (negative) rainfall anomalies in the western Indian Ocean and negative (positive) anomalies in the eastern Indian Ocean.

Projections of heat stress and associated work performance over India in response to global warming are provided. A 30-40% decline in the work performance is projected over India by the end of the century due to the elevated heat stress levels which pose great challenges to policy-makers to design the safety mechanisms and to protect people working under continuous extreme hot weather conditions.

Development of a decadal prediction system using IITM-ESM has been initiated. Significant progress has been made in this direction. Most of the tide gauge datasets revealed that Indian Ocean sea level and the global decadal climate modes such as Pacific Decadal Oscillation (PDO) and/or Atlantic Multidecadal Oscillation (AMO) are closely associated. An anti-phase sea level evolution with PDO index is also identified in the regions such as west coast of India, east coast of India and the western coast of Australia.

An analysis of interannual and decadal variability of sea level over the Indo-Pacific region in CMIP5 historical simulations and future projections revealed that the local wind forcing plays a dominant role in the sea level variability over the Indo-Pacific region on both interannual and decadal timescales.

The decadal to multidecadal variability in the equatorial Indian Ocean subsurface temperature and related forcing mechanisms has been studied. It is highlighted that decadal variability in the Tropical Indian Ocean (TIO) sea surface temperature (SST) influences the monsoon dynamics and moist thermodynamics leading to near in-phase changes in the rainfall over the monsoon core zone and the Western Ghats region.

An evaluation of the skills of CMIP6 models in representing Indian monsoon climate and TIO variability revealed that the models with better representation of latent heat flux and zonal wind, produced better TIO SST variability compared to other models. Therefore, better representation of latent heat flux and zonal wind in coupled models is advocated for accurate simulation of interannual and decadal variability in TIO SST.

Physics and Dynamics of Tropical Clouds (PDTC)

Observational campaign at the Solapur and Tuljapur sites is continued for having long term observations over the cloud seeding study area. There were some challenges in continuing observations due to COVID-19 and lockdown conditions.

Asymptotic scaling of drag in flat-plate turbulent boundary layers is investigated. A new asymptotic power-law scaling is derived and two models are proposed for the universal drag curve. A new universal model having significant potential toward accurate estimation of friction factor or flow rate in smooth pipe flows is also proposed.

Results from continuous aerosol and cloud condensation nuclei (CCN) measurements carried out under CAIPEEX at the ground observational facility situated in a rain-shadow region during the Indian summer monsoon are discussed. An important observation is that size-dependent aerosol composition plays a

role in CCN activity, indicated by overestimation of CCN and less hygroscopicity of accumulation mode aerosols during the marine air mass.

An investigation of the switching patterns of intermittently occurring turbulent fluctuations from one state to another revealed that the persistence patterns for heat and momentum fluxes are widely different. It adds a new understanding of the connection between flow organization and flux generation mechanisms, two cornerstones of turbulence research.

Results from a new study highlighted the importance of implementing new ice nucleating particle parameterization in a real-time forecast model to improve the regional climate model forecasting.

Role of droplet size classes on the cloud droplet spectral dispersion over the Western Ghats is investigated using ground-based *in-situ* measurements. An important finding is that, at higher liquid water content, both smaller and medium size droplets have a significant role in the total dispersion of cloud droplet size distribution.

The effect of relative humidity and temperature on the sub-micron aerosol variability and its ageing process was investigated at a high altitude site, Mahabaleshwar. Dominance of photochemical ageing processes during high temperature conditions was observed, with the extent of photochemical ageing was found to be higher during summer season as compared to winter season. Also, it was revealed that the mass concentration during winter was majorly contributed by distant sources from north east direction while during summer the local sources were more dominant.

First results from the Doppler weather radar observations over Mumbai during 2018 monsoon are discussed. It provides an understanding of the inter-seasonal relationship between the morphology of clouds, microphysics of precipitation and the occurrences of lightning.

A new attenuation correction procedure improves the reflectivity measurement in ground-based radars. The corrected reflectivity can improve the quantitative application of reflectivity data to determine the precipitation product, separation of precipitation into different types, storm structure analysis, storm top-height, severe weather monitoring and nowcasting, and assimilation in numerical weather prediction models.

The Mumbai Mesonet with automatic rain gauges has been established. The datasets generated are being used for NCCR's Integrated Flood Warning System (iFLOWS), NCMRWF's validation efforts for model simulation, and nowcasting efforts of IMD.

Work for civil infrastructure for establishing the Atmospheric Research Testbed facility in the Central India is initiated.

A new study using measurements of electric field and Maxwell current density below thunderstorms suggests inductive charging mechanism can contribute to thunderstorm electrification in the dissipation stage of a thunderstorm.

By analysing nine different proxies based on thermodynamic variables of the lower atmosphere, a new relationship is proposed that the lightning flash rate (LFR) is proportional to a product of the Bowen ratio and the sum of precipitation and evaporation rates. It explained 90% of the variance in the monthly-averaged time series of the total LFR over the study area.

For the first time, influence of the local meteorological parameters and pollution on atmospheric electric field in in the Kashmir valley is examined by using measurements. Results about the diurnal and seasonal variations in fair-weather electric field (potential gradient) are discussed.

A map of lightning prone areas has been prepared and shared with National Disaster Management Authority (NDMA). An observatory is being established at Sanjay Ghodawat University (SGU), Kolhapur to study atmospheric electricity along with micro-meteorological parameters.

High Performance Computing Services

Adequate efforts were made to run both the HPC systems (Aaditya and Pratyush) at IITM and to maintain uptime, resolving the issues of users within the stipulated time frame even during the lockdown period. Emergency services were kept on in the lockdown time and users were supported through email and a web-based system as a one-stop solution. Additional disk storage and necessary software were procured for HPC Pratyush and HPC Mihir.

Metropolitan Air Quality and Weather Forecasting Services (MAQWS)

Ceilometer observations during lockdown in Delhi were made to measure cloud based. It is suggested that the cloud bases propagate from lower to higher levels due to large reduction (47%) in cloud condensation nuclei (CCN). Cloud base height is found to have an inverse correlation with CCN and NO_2/NH_3 concentrations. Also, observations from 34 stations in Delhi during lockdown provided an opportunity to assess the minimum level of pollution in Delhi achieved by almost nullifying the emission from transport and industrial sectors.

Covid-19 lockdown induced base level PM2.5 and mortality rate per million is found to be highly correlated (> 0.8) as per the evaluation over 4 SAFAR cities and metropolis Chennai and Kolkata. It is suggested that keeping track of evolving carbon-intensive pathways can help inform government responses to the COVID-19 pandemic to prioritize controls of emissions sources.

Air quality observations during the nationwide lockdown also suggest a dramatic decline in major sources of emissions, except for household cooking, over Delhi and Mumbai. During lockdown, over Mumbai and Pune, surface Ozone generation tended to be controlled by volatile organic compounds (VOCs), suggesting that air pollution mitigation strategies should target VOC reduction under low vehicular emission scenario.

A laboratory-based experiment provided an understanding of CCN activation of carbonaceous aerosols from various sources of emissions such as combustion of wood, cow dung cake, wood-coal burning and diesel generator. It is indicated that the carbonaceous aerosols originating from direct emission sources have the potential to get activated as CCN at high super-saturation.

A study based on biomass emission inventory, model and satellite observations proposes that if the crop residue burning period is preponed by about a month from mid-September to mid-October, it could avoid extreme air pollution events over Delhi.

National Facility for Airborne Research (NFAR)

An unmanned aerial system laboratory/facility for lower atmospheric research and developmental activity, named as LARUS, has been established at IITM. Unique identity numbers for IITM's UAV systems have also been obtained from DGCA. Standard operating procedures for UAV operations in India for atmospheric research were submitted to DGCA for vetting/concurrence. INSAT-3D Fog data was used to study the evolution, spatial and temporal variability of fog over the Indo-Gangetic Basin for the winter months of December 2016 and January 2017 in conjunction with surface measurements. The important findings of this study are highlighted. Also, cloud fraction time series for 24 hours over a complex terrain of the Western Ghats using a TIR Sky Imager was constructed. CF Diurnal cycle (24 hours) over the Western Ghats showed huge variability in all seasons except in monsoon.

However, aircraft procurement could not be achieved in 2020-21 due to paucity of funds. Therefore, NFAR project is temporarily suspended. UAV activities will be carried out under Ministry's newly approved 'Atmospheric Research Test-bed (ART)' sub-project of Monsoon Convection, Clouds and Climate Change (MC4) under ACROSS programme.

WIFEX and AQEWS

The 6th phase of winter fog experiment was conducted at IGI Airport New Delhi and Hissar during November 2020 – March 2021. Several new instruments were installed at IGI Airport and Hissar measurement site. All the sensors were connected to IITM, Pune server through GSM modem for providing real-time access to data. The fog forecasting system developed for Delhi (2 km and 400 m resolution) and northern region of India (4 km resolution) is providing now-casting and forecasting information for IGI Airport, New Delhi and visibility forecast for Varanasi, Lakhnow, Amritsar and Jaipur airports. A new 21 member ensemble probability fog forecast system for visibility has been developed during the 2020-2021 WIFEX campaign.

As mandated by MoES, IITM has developed a unique integrated technology for Air Quality Early Warning System (AQEWS) for the country under the Smart Cities Mission (NP15) that is contributing to the Sustainable Development Goals (SDGs) laid down by the NITI Aayog. This programme is designed to enable and provide air quality forecasting and information services at a very high spatial resolution (400 m) over Delhi in a globally harmonized and standardized way, tailored to the needs of society and policy makers. In this regard, an information dissemination system has also been developed (https://ews.tropmet.res.in). While disseminating air quality forecasts to the public and decision-makers, it also provides near real-time observations of air quality for Delhi, Bengaluru, Pune, Mumbai, Hyderabad, Luchnow, Kolkata and Ahmadabad along with warning messages, alerts, and bulletins. These efforts have made Indian agencies rank ahead of any other operational agency across the globe that makes such air-quality forecasts.

Capacity Building and Human Resource Development

The Institute is taking proactive efforts toward capacity building and human resource development in weather and climate sciences. Under DESK, continuous efforts are being made for developing trained manpower in Earth System Sciences. This includes implementing the MoES Research Fellow Programme (MRFP) for recruiting and training JRF/SRF for all the institutes under MoES, pre-PhD coursework for IITM's regular JRF/SRF, and conducting specialized short-term training programmes.

Seven students graduated with PhD, while three have submitted their doctoral thesis during the year. The M.Sc. and M.Tech. programmes in Atmospheric and Space Sciences in collaboration with S.P. Pune University, Pune are continued. Many students of different UG/PG courses in science and engineering from various colleges, universities and institutions from across the country were provided research guidance and facilities for their short-term project/internship under the guidance of IITM scientists through remote/online mode only, keeping in view the COVID-19 situation. IITM organized several national and international virtual workshops, seminars, conferences, meetings, and short term training programmes on different aspects of weather and climate sciences during the year.

SCIENCE POPULARIZATION

National Science Day Celebrations



National Science Day - 2021 webinar by (L-R) Dr. Phani Murali Krishna R., Mr. S. Chowdhuri, Ms. Deepa J.S. and Dr. Ayantika Dey Choudhury, and hosted and moderated by Mr. Abhay SD Rajput.

World Meteorological Day Celebrations



Introduction by
Mr. Abhay SD Rajput



Address by
Prof. Ravi S. Nanjundiah



WMO Day - 2021 Lecture by
Dr. T. Srinivasa Kumar

Indian International Science Festival 2020 (IISF 2020)







Webinar on a curtain raiser of IISF 2020:
(L-R) Welcome Address by Prof Ravi S. Nanjundiah, Dirctor, IITM,
Inaugural Address by Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences,
Lecture by Dr. K.J. Ramesh, Former DGM

59th FOUNDATION DAY CELEBRATIONS



Welcome Address by
Prof. Ravi S. Nanjundiah



Foundation Day Lecture by
Dr. Shailesh Nayak



Golden Jubilee Award Lecture by
Dr. P. Mukhopadhyay



Silver Jubilee Award
Lecture by
Ms. J.S. Deepa



Best Student Research
Paper Award Lecture by
Mr. K. Sujith



Best PhD Thesis Award
Lecture by
Dr. Gangiredla Srinivas





(L-R) Mrs. S.R. Inamdar and Mrs. M.V. Deshpande
Awardees of the 'IITM Excellent Performance Award'

MoES FOUNDATION DAY CELEBRATIONS









(L-R) Dr. Sachin Ghude received the 'Certificate of Merit 2020', Mrs. A.A. Desai, Mr. Sandip Kulkarni and
Mr. Vikas V. Bamble received the 'Best Employee Award 2020' of Ministry of Earth Sciences, Govt. of India

PROF. R. ANANTHAKRISHNAN COLLOQUIUM



Dr. S.A. Dixit



Dr. S.S. Fadnavis



Dr. Anoop Mahajan



Dr. Vinu Valsala



Dr. Nils P. Wedi

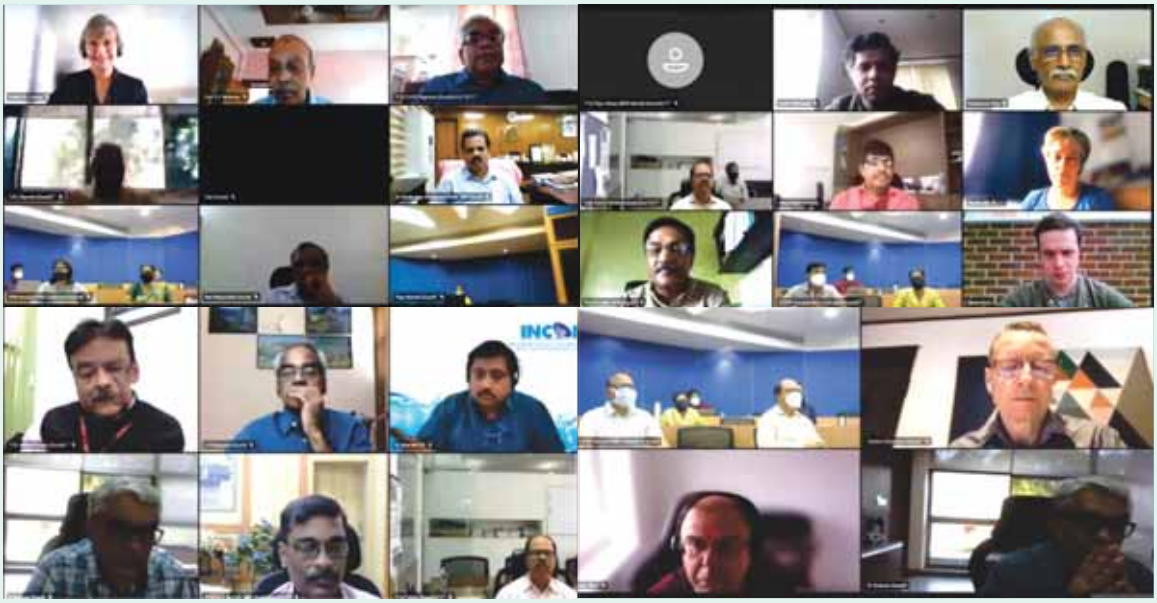


Dr. Milind Mujumdar



Dr. Aditi Sen

WEBINAR: 'FUTURE DIRECTIONS OF SUBSEASONAL TO SEASONAL PREDICTION OVER SOUTH ASIA'



Session in Progress





Felicitation of Dr. A.K. Sahai on his Superannuation

LAUNCHING OF FLOOD WARNING SYSTEM FOR MUMBAI






Launching of Flood Warning System for Mumbai by Dr. Harsh Vardhan, Hon'ble Union Minister for Health & Family Welfare, Science & Technology and Earth Sciences, Govt. of India and Shri Uddhavji Balasaheb Thackeray, Hon'ble Chief Minister, Government of Maharashtra

MoES WEBINAR ORGANIZED BY IITM


Dr. J. Vivekanandan
USA


Dr. M.A. Atmanand
NIOT, Chennai


Dr. S.C. Shenoi
INCOIS, Hyderabad


Dr. M. Mohapatra
DGM, IMD


Dr. Balakrishnan Nair
INCOIS, Hyderabad


Dr. V. Nandakumar
NCESS, Kerala


Dr. D. S. Pai
IMD, Pune


Dr. M. Ravichandran
NCPOR, Goa


Prof. Ravi S. Nanjundiah
IITM, Pune


Dr. R. Krishnan
IITM, Pune


Dr. G. Beig
IITM, Pune


Dr. A.K. Sahai
IITM, Pune


Dr. C. Gnanaseelan
IITM, Pune


Dr. Thara Prabhakaran
IITM, Pune


Dr. S. Chakraborty
IITM, Pune


Dr. G. Pandithurai
IITM, Pune

SWACHHATA PAKHWADA CELEBRATIONS



Dr. Smitha B.R.
CMLRE, Kochi



Dr. K. Anoop Krishnan
NCESS, Trivandrum



Dr. Pravakar Mishra
NCCR, Chennai



Dr. M. Mujumdar
IITM, Pune



Dr. O. N. Shukla
IITM, Pune



Dr. Ojaswini Valsangkar
IITM, Pune

HINDI KAVI SAMMELAN



Mr. Vineet Pandey



Mrs. Sarita Gupta



Mr. Gajendra Solanki



Mr. Manoj Abusaria
MoES, New Delhi



Prof. Ravi S. Najundiah
IITM, Pune



Dr. O. N. Shukla
IITM, Pune

WEBINAR ON VIGILANCE AWARENESS WEEK



Mr. T. P. Sharma
OSD, CVC



Dr. P. K. Dhakephalkar
ARI, Pune



Mr. Akhtarul Hanif
Dy. Secretary, MoRTH

IITM – Environmental Information System (ENVIS)



National Pollution Control Day
Lecture by
Dr. Rajnarayan Tiwari, NIREH, Bhopal



National Science Day
Lecture by
Dr. Ravi Yadav, IITM, Pune



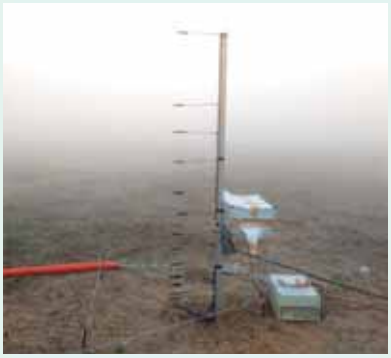
World Environment Day
Lecture by
Dr. G. Beig, IITM, Pune

Winter Fog Experiment (WIFEX)









Instrumental setup for Winter Fog Experiment at Indira Gandhi International Airport, New Delhi

IUKWC UEI 3 : WATER RESOURCE MANAGEMENT & SCIENCE – SUPPORTING ONE ANOTHER



Prof. Harry Dixon
UK



Dr. A.K. Sahai
IITM, India



Dr. Andrew Mckenzie
UK



Prof. Ian Holman
Cranfield Univ., UK



Dr. Jonathan Evans,
UKCEH, UK



Prof. Alexander Densmore
Univ. of Durham, UK



Mr. Sunil Kumar
CWC, India



Prof. Subimal Gosh
IIT Bombay, India



Prof. Rajiv Sinha
IIT Kanpur, India



Dr. Kaushal Garg
ICRISAT, India



Dr. Gopal Krishan
NIH, India



Dr. Milind Mujumdar
IITM, India

OVERVIEW

Chapter 1
Centre for Climate Change Research (CCCR)

Project Director : Dr. R. Krishnan
Deputy Project Director : Dr. S. Chakraborty

Objectives

- To identify and explore new areas of research that will contribute to the fundamental understanding of the Earth's climate system.
- Enhancement of knowledge on regional climate change over the Indian subcontinent.
- To understand the nature of biogeochemical interactions and their response to environmental change.
- To understand impacts of global warming on planetary scale phenomena like monsoon and El Niño.
- To understand the interactions of atmospheric chemistry with the tropical and monsoon climatic processes using chemistry-climate model simulations and observations.
- To understand past climatic and monsoon rainfall variations by reconstructing responsive climate parameters, going back to a few thousand years, using a wide network of high resolution proxies such as tree-ring, historical records, speleothems, corals etc. over different parts of India and Asian Monsoon region.
- To understand and quantify the processes that control net eco-system exchange (NEE) of CO_2, energy, water vapor and quantification of these fluxes at different time scales by establishing Eddy Covariance (EC) flux towers at a variety of ecosystems and making measurements of atmospheric CO_2 and other greenhouse gases.
- To create and update information reservoirs for better assessment of changes and impacts.
- To generate technology based knowledge products based on climate studies.
- Building linkages with national and international research groups to optimally leverage scientific capabilities for climate change research.

Highlights of Major Achievements:

- Updates on IITM Earth System Model (ESM) are presented.
- Efforts are being made for incorporating the Community Ice-sheet Model (CISM) in the IITM-ESM.
- New insights about the coupling of El Niño-Southern Oscillation (ENSO) and the Indian monsoon.
- The individual and combined effects of greenhouse gas and anthropogenic aerosols forcing on the South Asian Monsoon precipitation response were examined in IITM-ESMv2.
- India's first report on Assessment of Climate Change over the Indian Region is published.
- Investigation of the linkage between soil moisture variability and temperature extremes over the Indian region.
- The Indian Ocean Observing System has been redesigned.
- A new study reveals a rising trend of double tropopauses over South Asia in a warming environment.
- Results from tree-ring width index chronologies from the western Himalayas are presented.
- Results of CO_2 and CH_4concentrations measured at Sinhagad are reported.
- The first estimation of net ecosystem exchange (NEE) in a mangrove ecosystem at Pichavaram, southeast India is presented.

Sub-Projects

- Earth System Model Development
- Climate Change Science and Applications
- Atmospheric Chemistry and Climate
- Paleoclimate
- MetFlux India : GHG Observation and Modeling

1.1. Earth System Model Development

Developmental Activities

1.1.1. Updates on IITM Earth System Model (ESM)

The IITM-ESM has contributed to the CMIP6 and IPCC AR6 by conducting multi-century simulations for pre-industrial, present-day conditions and climate projections. A suite of completed experiments using IITM-ESM includes the CMIP6 designated Diagnostic, Evaluation and Characterization of Klima (DECK) experiments, historical simulations (1850-2014), future scenario simulations (four tier-1 scenario runs, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) till the end of 21st century, and the Model Inter-comparison Project (MIP) experiments *viz.,* Global Monsoon MIP (GMMIP), Detection and Attribution MIP (DAMIP), Flux Anomaly Forcing MIP (FAFMIP). Datasets from IITM-ESM simulations are available in the public domain through the ESGF node (http://cccr.tropmet.res.in/home/esgf_data.jsp; https://esgf-data.dkrz.de/search/cmip6-dkrz). The observed and projected changes in surface air temperature and precipitation over the globe as well as exclusively over the Indian region are presented in the 'Assessment of Climate Change over the Indian Region', a report prepared for the Ministry of Earth Sciences (Krishnan et al. 2020). In addition to the above, various studies using the IITM-ESM are also conducted to assess the impacts of Greenhouse gases (GHG) and anthropogenic aerosols on the Indian monsoon (Choudhury et al. 2020), volcanic forcing on ENSO, and Indian monsoon coupling (Singh et al. 2020), weakening of the Atlantic meridional overturning circulation (AMOC) on the South Asian monsoon (Sandeep et al. 2020) and projected changes in the global temperature and precipitation from a suite of CMIP6 models including IITM-ESM (Tebaldi et al. 2021).

1.1.2. Implementation of land-ice model, Community Ice-sheet Model (CISM) in IITM-ESM

Work is currently underway incorporating the Community Ice-sheet Model (CISM), which will serve as the dynamic ice component in the IITM-

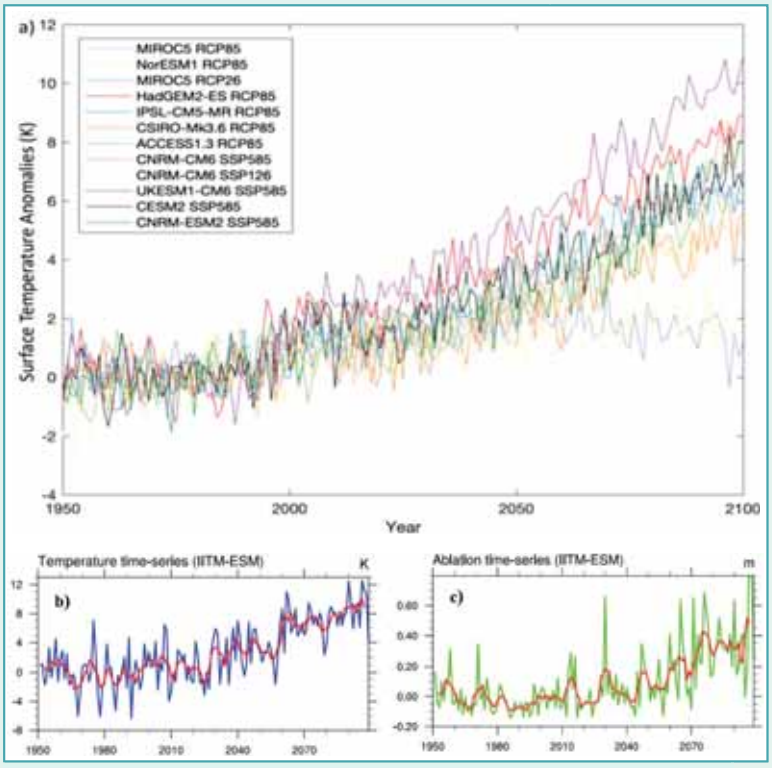


Fig. 1.1: *(**a**). Time-series of annual mean surface air temperature anomaly (K) over the Greenland region from ISMIP CMIP6 projections. (**b**) Same as described in (**a**), but for the IITM-ESM SSP-585 projections. The baseline period for estimating the anomaly is 1950-2000. (**c**) Time-series of ablation (m) over Greenland from IITM-ESM SSP-585 projections.*

ESM. IITM-ESM Simulations will be performed with CISM implementation with focal areas of Greenland and Antarctic regions. CISM is a community ice-sheet model following the description given in Lipscomb et al. (2019). This effort will aid to understand the sea-level contributions from the melting of Greenland and Antarctic Ice Sheets, glacier mass release due to the enhanced GHG emissions, and thermal expansion projections. Some preliminary results from incorporating CISM in IITM-ESM and comparisons with ISMIP (Ice sheet model intercomparison project) from the CMIP6 (Nowicki et al. 2020) are shown in **Fig. 1.1**. The projected ablation over Greenland region over the 21st century from IITM-ESM can be noted from **Fig. 1.1c** and corresponding increase in surface temperature (**Fig.1.1b**) is comparable with the ISMIP projections (**Fig. 1.1a**).

Basic Research

1.1.3. Volcanic Forcing and the ENSO-Indian Monsoon Coupling

Innovative insights are provided about the coupling of El Niño-Southern Oscillation (ENSO) and the Indian monsoon (IM) which is central to seasonal predictions of summer rainfall over the Indian subcontinent, following the notion that a non-stationary relationship between two nonlinear phenomena can restrict seasonal predictability. Radiative effects of volcanic aerosols injected into the stratosphere during large volcanic eruptions (LVEs) tend to alter ENSO evolution, however, their impact on ENSO-IM coupling remained unclear. Therefore, it was investigated how LVEs influence the nonlinear behaviour of the ENSO and IM dynamical systems by using historical data, 25 paleoclimate reconstructions, last-millennium climate simulations, large-ensemble targeted climate sensitivity experiments, and advanced analyses techniques (see **Fig. 1.2**). Findings showed that LVEs promote a significantly enhanced phase-synchronization of ENSO and IM oscillations, due to an increase in the angular frequency of ENSO (see Fig. 1.2). The results shed new insights into the physical mechanism underlying the LVE-induced enhancement of ENSO-IM coupling and strengthen the prospects for improved seasonal monsoon predictions. [***Singh M., Krishnan R.,*** *Goswami B.,* ***Choudhury A.D., Swapna P., Vellore R., Prajeesh A.G., Sandeep N., Venkataraman C.,*** *Donner R.V., Marwan N., Kurths J., Fingerprint of Volcanic Forcing on the ENSO-Indian Monsoon Coupling,* ***Science Advances****, 6: eaba8164, September 2020, DOI:10.1126/ sciadv.aba8164*]

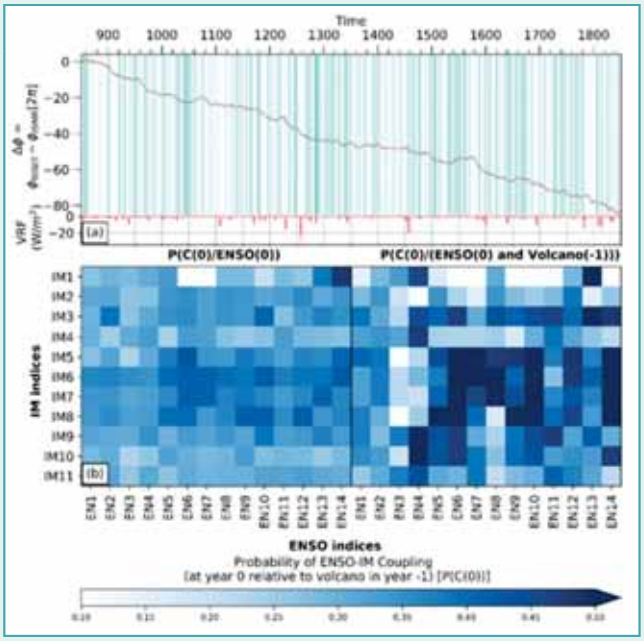


Fig. 1.2: *LVE-induced ENSO-IM phase coherence during the last millennium: (**a**) Phase Coherence Analysis of ENSO and Indian Monsoon (IM) using IPSL PMIP3 last millennium simulations (850-1850 AD). Time series of the phase difference between the instantaneous phases of ENSO and IM (top panel). The green shading shows periods of phase coupling between ENSO and IM (bottom panel). (**b**) Bayesian Analysis - Probability of ENSO-IM phase coupling for the year (0) conditioned on ENSO (0) (left panel) and ENSO (0) and Volcano (-1) (right panel). The paleoclimate reconstructions of 14 ENSO indices and 11 IM indices are used for computing the Bayesian probabilities.*

1.1.4. Understanding the combined effects of global warming and anthropogenic aerosol forcing on the South Asian monsoon

There is growing evidence that northern hemisphere (NH) anthropogenic aerosols (AA) influence the observed regional climate change over the Asian region in the recent few decades. However, the scientific rationale behind this

mechanism is yet elusive. The IITM Earth System Model version 2 (IITM-ESMv2) was utilized to examine the individual and combined effects of greenhouse gas (GHG) and AA forcing on the South Asian Monsoon (SAM) precipitation response. Three sets of 50-year simulations were performed for this purpose based on the CMIP6 forcing (a) AER: simulations in which the atmospheric CO_2 concentration is fixed to the pre-industrial values (i.e., year 1850) and AA levels correspond to the year 2005; (b) GHG: where CO_2 concentration corresponds to 2005 while AA levels correspond to 1850; and (c) COMB: Both CO_2 concentrations and AA levels correspond to 2005. The results from these three experiments were compared against the pre-industrial control (PICTL) run of the IITM-ESMv2. Results showed that there was an enhanced SAM precipitation in response to GHG (**Fig. 1.3b**), while AER exhibited weakening of monsoon circulation and decline in SAM precipitation (**Fig. 1.3a**). The results indicated that absorption of shortwave radiation above the atmospheric boundary layer over the Asian region creates surface radiation deficit and stabilizes the lower troposphere leading to a slowdown of monsoonal winds, reduced evaporation over the Indian Ocean and decreased moisture convergence over the regions of South and Southeast Asia. A striking insight emerged that enhanced inter-hemispheric asymmetry in radiative forcing under the combined influence of the elevated CO_2 and AA forcing reinforces suppression of SAM precipitation (**Fig. 1.3c**) and organized monsoon convection. [***Ayantika D.C., Krishnan R., Singh M., Swapna P., Sandeep N., Prajeesh A.G., Vellore R.***, *Understanding the combined effects of global warming and anthropogenic aerosol forcing on the South Asian monsoon,* ***Climate Dynamics****, 56, March 2021, DOI:10.1007/s00382-020-05551-5, 1643-1662*]

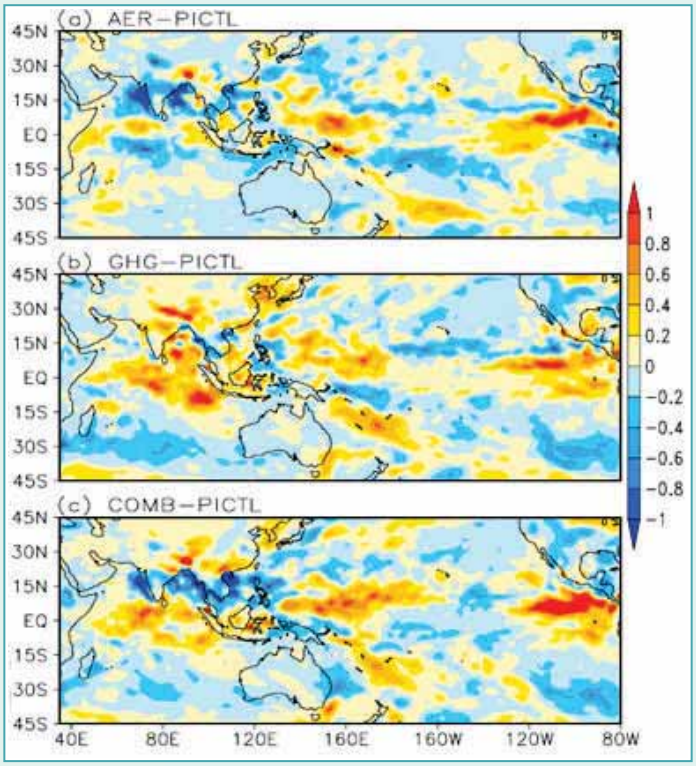


Fig. 1.3: *Spatial distribution of changes (relative to PICTL) in boreal summer mean precipitation (mm day^{-1}) for the sensitivity experiments* ***(a)*** *AER,* ***(b)*** *GHG, an* ***(c)*** *COMB.*

1.2. Climate Change Science and Applications

Basic Research

1.2.1. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences, Government of India

This important assessment report published as a book discusses the influence of human-induced global climate change over the Indian subcontinent and the regional monsoon, the adjoining Indian Ocean, and the Himalayas. Future projections of regional climate change are also covered in the book. The IPCC assessment reports, published every 6-7 years, provide important reference material for major policy decisions on climate change, adaptation, and mitigation. While the IPCC assessment reports largely provide a global perspective on climate change, comprehensive assessments on regional aspects of climate change generally tend to be limited. Regional climate change aspects over the Indian subcontinent, especially relating to the Indian monsoon, are unique to the region as compared to other places on the globe. In particular, the climate in this region is shaped by the Himalayas, the Western Ghats, the Tibetan Plateau, the Indian Ocean, the Arabian Sea, and the Bay of Bengal. Climatic variations in this region are influenced by (a) Interactions between the atmosphere, ocean, land-surface, cryosphere, and biosphere on different time-scales; (b) remote effects from natural modes of climate variability such as the El Nino/Southern Oscillation, North Atlantic Oscillation, Indian Ocean Dipole, Madden Julian Oscillation, etc.; and (c) human-induced climate change. This report also briefly discusses policy-relevant information based on robust scientific analysis and assessments of the observed and future projected climate change over the Indian region.

The assessments presented in this book are based on peer-reviewed scientific publications, published IPCC reports, analyses of long-term observed climate records, paleoclimate reconstructions, reanalysis datasets, and climate model projections from the World Climate Research Program (WCRP) Coupled Model Intercomparison Project (CMIP) and the COordinated Regional climate Downscaling Experiment (CORDEX) over South Asia scientific programmes. Future projections of the regional climate are assessed based on two Representative Concentration Pathway (RCP) scenarios of the IPCC – viz., RCP 4.5 (an intermediate scenario where emissions peak around 2040, then decline) and RCP 8.5 (an extreme scenario where GHG emissions continue to rise throughout the 21st century) (**Fig. 1.4**). Since AR5, the RCP 8.5 has been thought to be very unlikely, while the intermediate RCP 4.5 scenario seems to provide more realistic guidance at least in the coming 2-3 decades.

A salient feature of this report is the inclusion of introductory results based on the CMIP Phase 6 (CMIP6) projections of the IITM Earth System Model (IITM-ESM) – the first climate model from India, developed at the CCCR-IITM, that is contributing to the Sixth IPCC Assessment Report (i.e., IPCC AR6) to be released in 2021. This book is the first climate change report over the Indian region from the Ministry of Earth Sciences, Government of India, and its preparation was led and coordinated by CCCR-IITM.

This assessment report highlights that since the middle of the twentieth century, India has witnessed a rise in average temperature; a decrease in monsoon precipitation; a rise in extreme temperature and rainfall events, droughts, and sea levels; and an increase in the intensity of severe cyclones, alongside other changes in the monsoon system (**Fig. 1.5**). There is compelling scientific evidence that human activities have influenced these changes in regional climate. Human-induced climate change is expected to continue apace during the twenty-first century. To improve the accuracy of future climate projections, particularly in the context of regional forecasts, it is essential to develop strategic approaches for improving the knowledge of Earth system processes and to continue enhancing observation systems and

climate models. [***Krishnan R., Sanjay J., Gnanaseelan C., Mujumdar M., Kulkarni A., Chakraborty S.*** *(Eds), Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India,* ***Springer Nature****, 2020, 226pp,* https://link.springer.com/book/10.1007%2F978-981-15-4327-2]

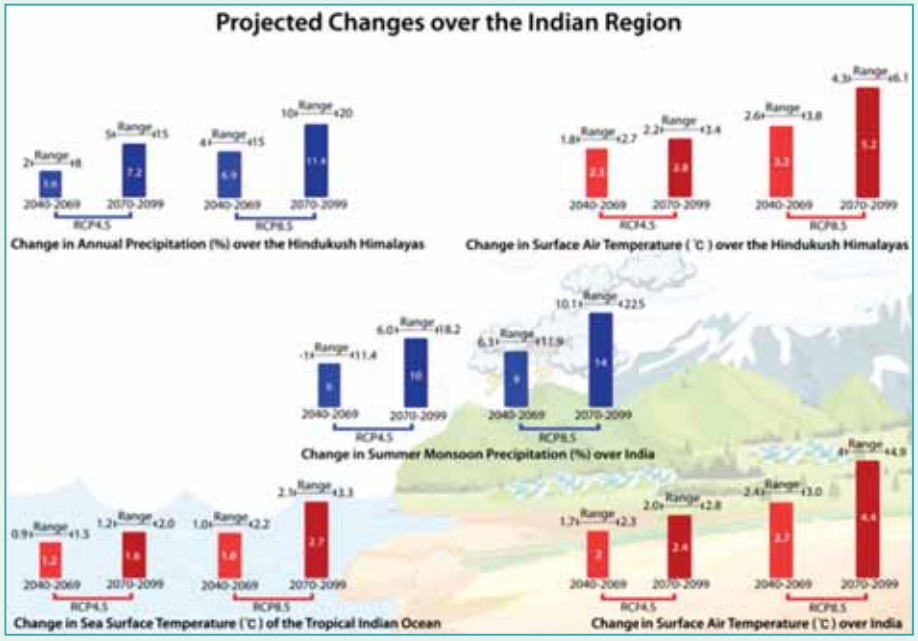


Fig. 1.4: *Best estimate and range in climate model projections of future changes over India, the tropical Indian Ocean, and over the Hindu Kush Himalayas. Adapted from Figure 1 in the cited report.*

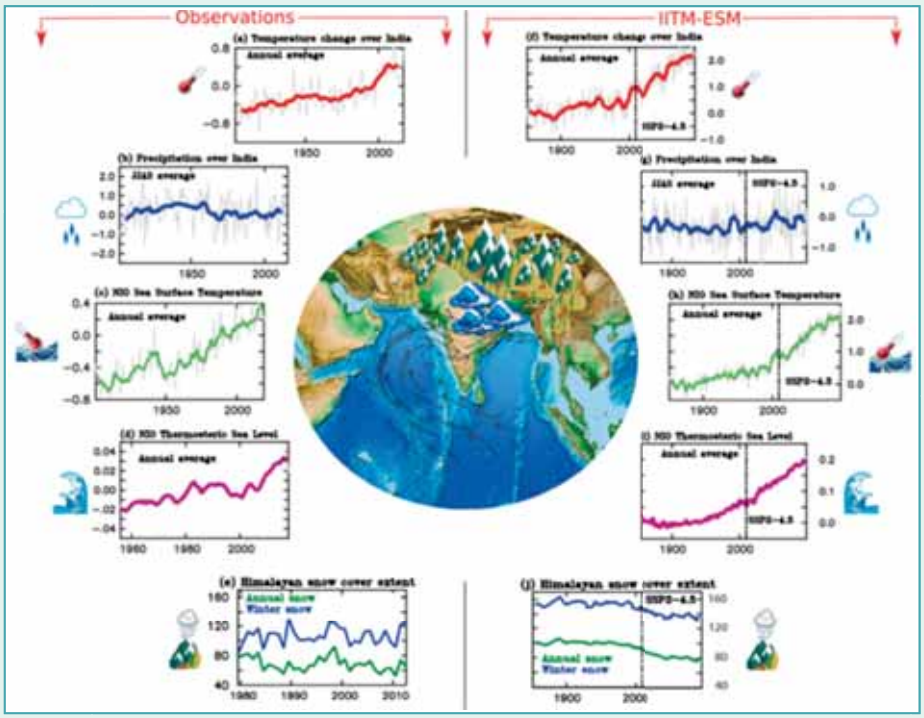


Fig. 1.5: *Temporal variation of selected climate variables from observations (panels on the left) and IITM-ESM projections (panels on the right). Adapted from Figure 1.6 in the cited report.*

1.2.2. Understanding the linkage between soil moisture variability and temperature extremes over the Indian region

Soil moisture (SM) and near-surface temperature variations are intrinsically linked through land-atmosphere interactions. While previous studies examined the association between temperature extremes and large-scale atmospheric circulation variability, the role of land-atmosphere coupling on temperature extremes over the monsoon-rain fed region of India is not clear yet. To address this, an analysis of 67-year period (1948-2014) hydro-meteorological datasets is presented to assess the impact of long-term soil moisture changes on temperature extremes over the Indian region. Findings indicate the hot-spot regions of land-atmosphere coupling, i.e., north-central India (NCI) is a region where SM variations can significantly influence temperature extremes (see **Fig. 1.6**). It is also noted that the NCI region experienced a significant SM declining trend (about 1.1 mm decade^{-1}) during 1948-2014, in association with the decreasing trend of monsoon precipitation. Findings suggest that long-term decrease of SM over the NCI has favoured increased incidence of temperature extremes through strengthening (weakening) of sensible (latent) heat fluxes; while the loss of soil moisture memory has additionally promoted increased variability of temperature extremes. The frequency, duration and variability of extreme temperatures are found to increase significantly by 1-2 occurrences, 5-6 days and 43%, respectively, in association with a decrease of 10 mm SM over NCI. The Generalized Extreme Value (GEV) distributions are fitted to extreme temperature duration (ExTD) using SM as a covariate to quantify the role of SM on temperature extremes over NCI. GEV analysis reveals that drier SM conditions (10th percentile) lead to an increase in the 67-year return value of ExTD by 9-10 days, relative to wet SM conditions (90th percentile) over NCI. Furthermore, it is interesting to note that the rise in temperature extremes over NCI in the recent three decades has been more prominent during the monsoon and post-monsoon seasons as compared to the pre-monsoon months. [***Ganeshi N.G., Mujumdar M., Krishnan R., Goswami M.,*** *Understanding the linkage between soil moisture variability and temperature extremes over the Indian region,* ***Journal of Hydrology****, 589: 125183, October 2020, DOI:10.1016/j.jhydrol.2020.125183*]

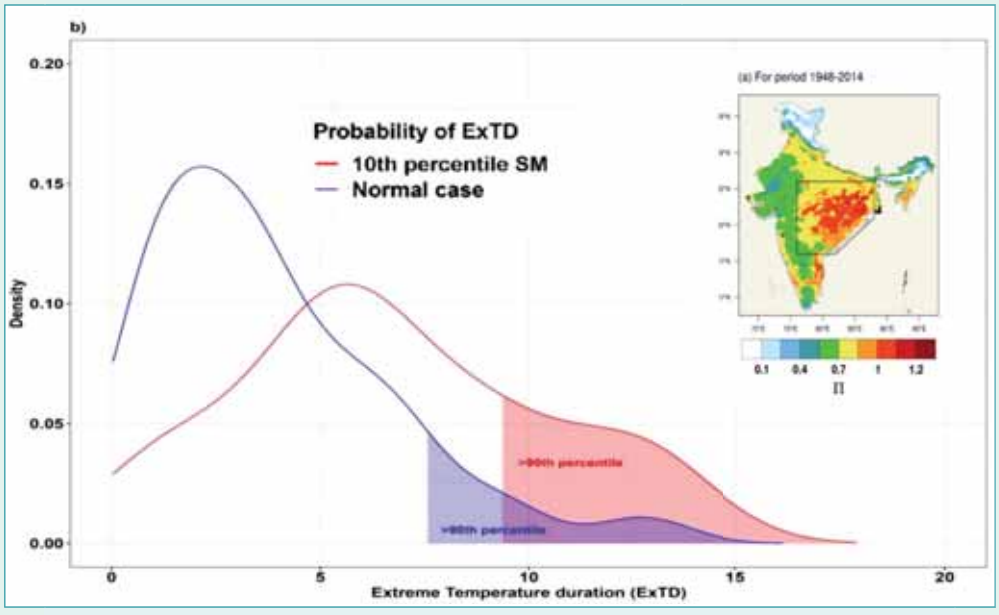


Fig. 1.6: *Probability density functions of ExTD (number of days) in two different cases (blue is normal probability density function and red is probability density function of ExTD for dry condition with 10th percentile SM). The regions above the 90th percentile quantiles of ExTD are shaded. The region of strong soil moisture-temperature coupling (Π) is shown at the top right corner with a polygon.*

1.2.3. An observational equatorial Atlantic Ocean constraint on Indian monsoon precipitation projections

Based on the historical simulations and Representative Concentration Pathway 8.5 experiments (RCP 8.5) in the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model ensemble, it is found that models with lesser (larger) summer mean precipitation wet bias over the equatorial eastern Atlantic (EEA) Ocean tend to project a larger (lesser) increase in summer monsoon precipitation over central India (CIND) under increased greenhouse gas forcing. This excessive summer precipitation error over the equatorial Atlantic is physically consistent with the present understanding of the cold tongue error over the EEA and its teleconnection with the Indian summer monsoon in the CMIP5 models. The present analysis applied an observational constraint of the EEA precipitation on this present-future emergent relationship to reduce the inter-model spread in the projected summer monsoon precipitation over CIND. This proposed emergent constraint resulted in a more robust magnitude of projected increases in future summer monsoon precipitation over CIND (**Fig. 1.7**). [***Shamal M., Sanjay J.***, *An observational equatorial Atlantic Ocean constraint on Indian monsoon precipitation projections,* ***Climate Dynamics****, Online, February 2021, DOI:10.1007/s00382-021-05703-1*]

1.2.4. Constraining global changes in temperature and precipitation from observable changes in surface radiative heating

Changes in the atmospheric composition alter the magnitude and partitioning between the downward propagating solar and atmospheric longwave radiative fluxes heating the Earth's surface. These changes are computed by radiative transfer codes in Global Climate Models and measured with high precision at surface observation networks. Changes in radiative heating signify changes in the global surface temperature and the hydrologic cycle. Here, an effort is made to develop a conceptual framework using an Energy Balance Model to show that first-order changes in the hydrologic cycle are mainly associated with changes in solar radiation, while those in surface temperature are mainly associated with changes in atmospheric longwave radiation. These insights are used to explain a range of phenomena including observed historical trends, biases in climate model output, and the intermodel spread in climate change projections. These results may help identify biases in future generations of climate models.

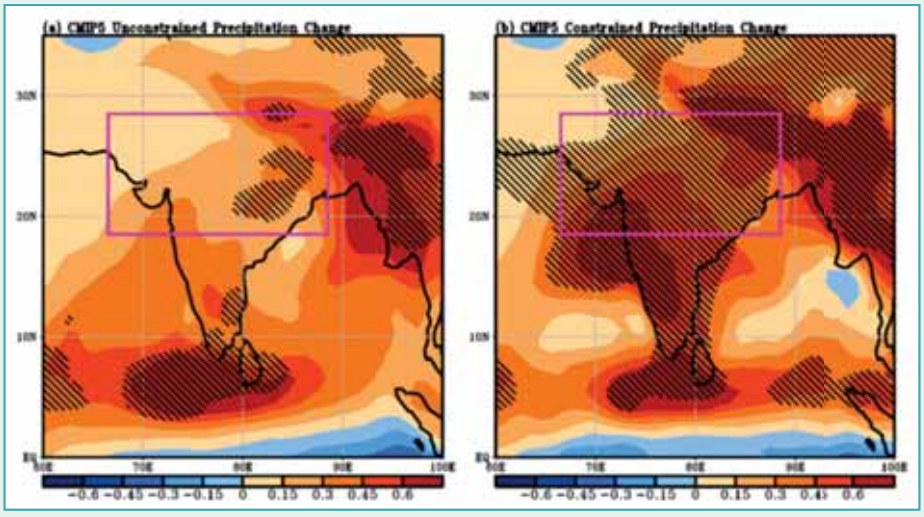


Fig. 1.7: *Spatial pattern of the CMIP5 multi-model ensemble (MME) mean projected change in the summer season (June–September) climatological mean precipitation per degree of global mean SST warming (mm day^{-1} K^{-1}) under RCP 8.5 scenario (**a**) the unconstrained, and (**b**) the constrained MME mean summer precipitation projected change. The hashed region shows the locations where the magnitude of the projected trend signal (MME mean change) to noise (inter-model standard deviation) ratio (SNR) is greater than one. The box denotes the central India (CIND; 66.5° E–88.5° E, 18.5° N–28.5° N) region.*

[***Dhara C.**, Constraining global changes in temperature and precipitation from observable changes in surface radiative heating, **Geophysical Research Letters**, 47:e2020GL087576, May 2020, DOI:10.1029/2020GL087576*]

1.2.5. Redesigning the Indian Ocean Observing System (IndOOS)

During the last four years, the CLIVAR/IOC-GOOS Indian Ocean Region Panel has been working towards a review and redesign of the Indian Ocean Observation System (IndOOS). IndOOS (**Fig. 1.8**) is a network of all the sustained observations in the Indian Ocean – the ARGO, RAMA, tide gauges, XBT, GO-SHIP, drifters, and other components like the satellites, and emerging technologies. For India and IITM/IMD, IndOOS is a key factor for the seasonal and MISO/MJO forecasts and monsoon monitoring.

The existing IndOOS design was established on the basis of an implementation plan drafted by the Indian Ocean Panel in 2006. Since then, societal and scientific priorities have changed, and measurement technologies have evolved, many practicalities of implementation have been learned, and the pace of climatic and oceanic change has accelerated. A rapidly warming ocean is resulting in extreme weather events over the Indian Ocean rim that is surrounded by densely populated countries that are vulnerable and at a high risk to these weather events. However, there are several gaps in the infrastructure that prevents us from monitoring and predicting these changes and events efficiently. Keeping this in mind, the Indian Ocean network has been reviewed and a new plan for its future is presented as the IndOOS-2. This has been done through three international workshops, sixty authors, and an expert review panel of six, and sponsored by WCRP, IO-GOOS, IOC-UNESCO, US NOAA, and IUGG.

The benefits from upgrading the IndOOS are immense. It will help in predicting droughts and floods in Africa, South and East Asia, and Australia. Hence essentially, IndOOS is a key to managing the food, water and energy requirements of the Indian Ocean region. IndOOS plays a key role in monitoring the formation and track of cyclones in the Indian Ocean also. A recent assessment shows that floods, droughts and cyclones have killed about 1.4 lakh people in India during the past five decades. [*Beal L.M., Vialard J., **Roxy M.K.**, et al., A roadmap to IndOOS-2: Better observations of the rapidly-warming Indian Ocean. **Bulletin of the American Meteorological Society**, 101, November 2020, DOI:10.1175/BAMS-D-19-0209.1, E1891-E1913*]

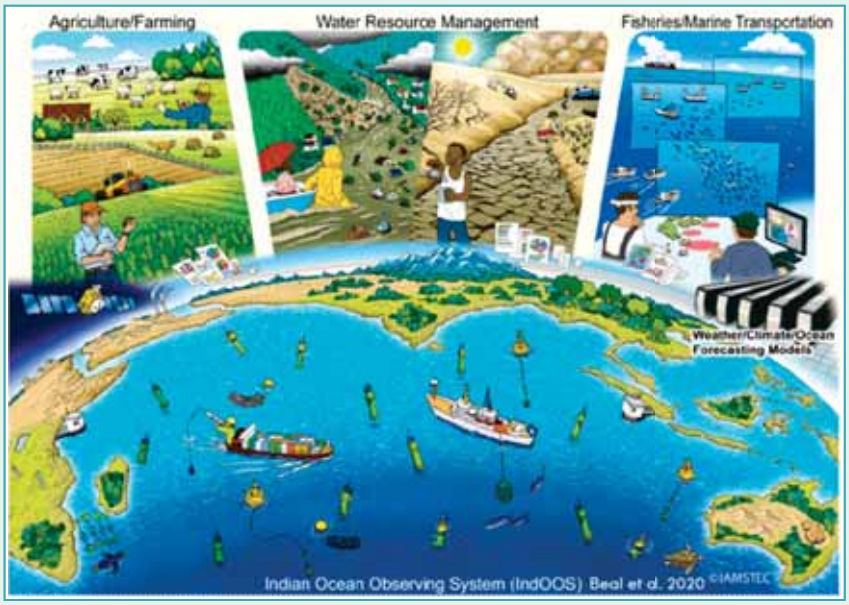


***Fig. 1.8:** The Indian Ocean Observing System (IndOOS).*

1.3. Atmospheric Chemistry and Climate

Basic Research

1.3.1. Variability of the Asian Tropopause Aerosol Layer (ATAL) and double tropopauses over the Indian region

Balloon-borne aerosol backscatter measurements at Nainital in August 2016 and radiosonde measurements at Guwahati and Delhi for the past 40 years (1977-2017) were analysed to understand the variability of aerosols and water vapor near the tropopause. A variety of factors impacting the aerosol layer near the tropopause (ATAL), e.g., convection, cyclones, and stratospheric intrusions are shown. It is found that air masses contributing to the ATAL are a mixture of different origins (**Fig. 1.9a-c**). Strong ATAL cases have high contributions from the Tibetan Plateau. Rising trends in Asian aerosol emission points to the thickening of the ATAL. The ATAL impacts the radiative balance of the atmosphere and reduces Earth's surface temperatures. Double tropopauses (DTs) were used as a proxy to understand water vapor variation in the UTLS. An association of occurrence frequency DTs with convective clouds and water vapor in the UTLS is presented. **Fig. 1.9d** shows evidence of DTs at Delhi and Guwahati. These DT days are associated with an enhanced amount of water vapor (0.6-1.65 ppm above the lower tropopause) (**Fig. 1.9d-f**). The estimated

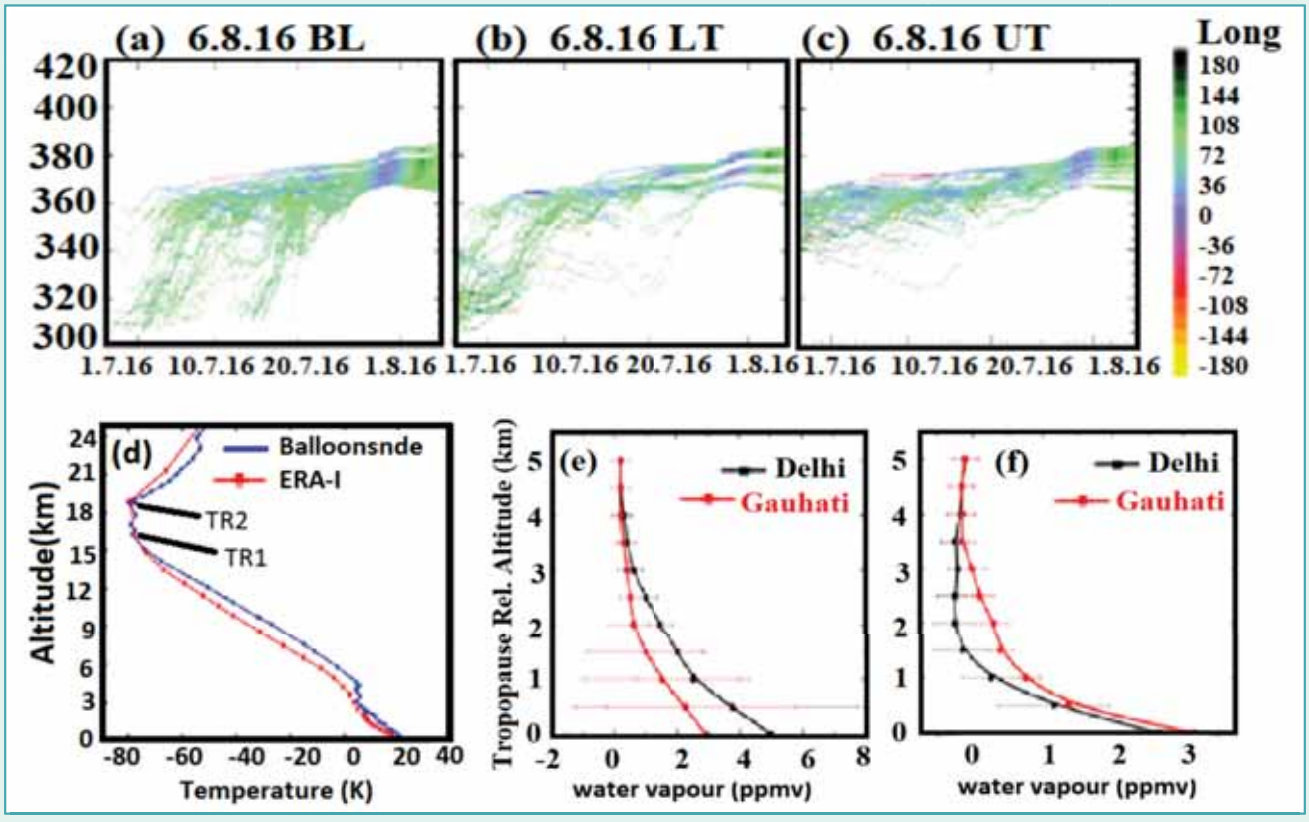


*Fig. 1.9: Forty-day backward trajectories initialized on 6 August 2016 at the location of the ATAL measurement. The trajectories are sorted by air mass origin in the boundary layer (**a**), in the lower troposphere (**b**), in the upper troposphere (**c**) and in the lower stratosphere. Radiosonde and ERA-Interim (ERA-I) temperature profile at (**d**) Delhi at 00 UTC on 18 January 2013. First (TR1) and second (TR2) tropopauses are indicated by arrows. Profiles of water vapor (DT-ST) [ppmv] from MLS (composite of 2004 – 2016) plotted at altitude (0 to +5 km) above the tropopause at Guwahati and Delhi in (**e**) August (**f**) December. Horizontal lines on each profile indicate standard deviation.*

trend in water vapor for DT days is 0.04-0.24 ppm decade-1 above the lower tropopause. The increasing trend in the water vapor in the UTLS may enhance long-wave radiation coming back down to warm the troposphere and exacerbate the global warming effect. It is also inferred that the wetter stratosphere produces stratospheric cooling and thinning of the ozone layer. [*Hanumanthu S., Vogel B., Müller R., Brunamonti S.,* ***Fadnavis S.****, Li D., Ölsner P., Naja M.,* ***Singh B.B.****, Ravi Kumar K.,* ***Sonbawne S.****, Jauhiainen H., Vömel H., Luo B., Jorge T., Wienhold F.G., Dirkson R., Peter T., Strong day-to-day variability of the Asian Tropopause Aerosol Layer (ATAL) in August 2016 at the Himalayan foothills,* ***Atmospheric Chemistry and Physics****, 20, November 2020, DOI:10.5194/acp-20-14273-202, 14273-14302*; and ***Fadnavis S.****, Sioris C.E., Wagh N.,* ***Chattopadhyay R.****, Tao M., Chavan P., Chakraborty T., A rising trend of double tropopauses over South Asia in a warming environment: implications for moistening of the lower stratosphere,* ***International Journal of Climatology****, 41, January 2021, DOI:10.1002/joc.6677, E200-E215*]

1.3.2. Quantifying fluxes of reactive halogens in the Indian and Southern Ocean marine boundary layer

Iodine chemistry has significant impact on the oxidising capacity of the marine boundary layer (MBL) through the depletion of ozone (O_3) and changes to HO_x (OH/HO_2) and NO_x (NO/NO_2) ratios. Hitherto, studies have shown that the reaction of atmospheric O_3 with surface seawater iodide (I^-) contributes to the flux of iodine species into the MBL mainly as hypoiodous acid (HOI) and molecular iodine (I_2). National Centre for Polar and Ocean Research (NCPOR), a part of the Ministry of Earth Sciences (MOES), organised Indian Scientific Expeditions to the Southern Ocean (ISESOs) and the 2nd International Indian Ocean Expedition (IIOE-2), the first concomitant observations of iodine oxide (IO), O_3 in the gas phase, and sea surface iodide concentrations are presented. The results from three field campaigns in the Indian Ocean and the Southern Ocean were used to compute reactive iodine fluxes in the MBL. Observations of atmospheric IO by multi-axis differential optical absorption spectroscopy (MAX-DOAS) showed active iodine chemistry in this environment, with IO values up to 1 pptv (parts per trillion by volume) below latitudes of 40°S (**Fig. 1.10a**). In order to compute the sea-to-air iodine flux supporting this chemistry, previously established global sea surface iodide parameterisations were compared with new region-specific parameterisations based on the new iodide observations. It is shown that regional changes in salinity and sea surface temperature play a role in surface seawater iodide estimation. Sea-air fluxes of HOI and I_2, calculated from the atmospheric ozone and seawater iodide concentrations (observed and predicted), failed to adequately explain the detected IO in this region (**Fig. 1.10c-d**). This discrepancy highlights the need to measure direct fluxes of inorganic and organic iodine species in the marine environment. Amongst other potential drivers of reactive iodine chemistry investigated, chlorophyll a showed a significant correlation (**Fig. 1.10e**). This correlation might be indicative of a biogenic control on iodine sources in this region, which has not been recognised till date. [***Inamdar S.****, Tinel L., Chance R., Carpenter L.J., Sabu P., Chacko R., Tripathy S.C., Kerkar A.U., Sinha A.K., Bhaskar P.V., Sarkar A., Roy R., Sherwen T.T., Cuevas C., Saiz-Lopez A., Ram K.,* ***Mahajan A.S.****, Estimation of reactive inorganic iodine fluxes in the Indian and Southern Ocean marine boundary layer,* ***Atmospheric Chemistry and Physics****, 20, October 2020, DOI:10.5194/acp-20-12093-2020, 12093-12114*]

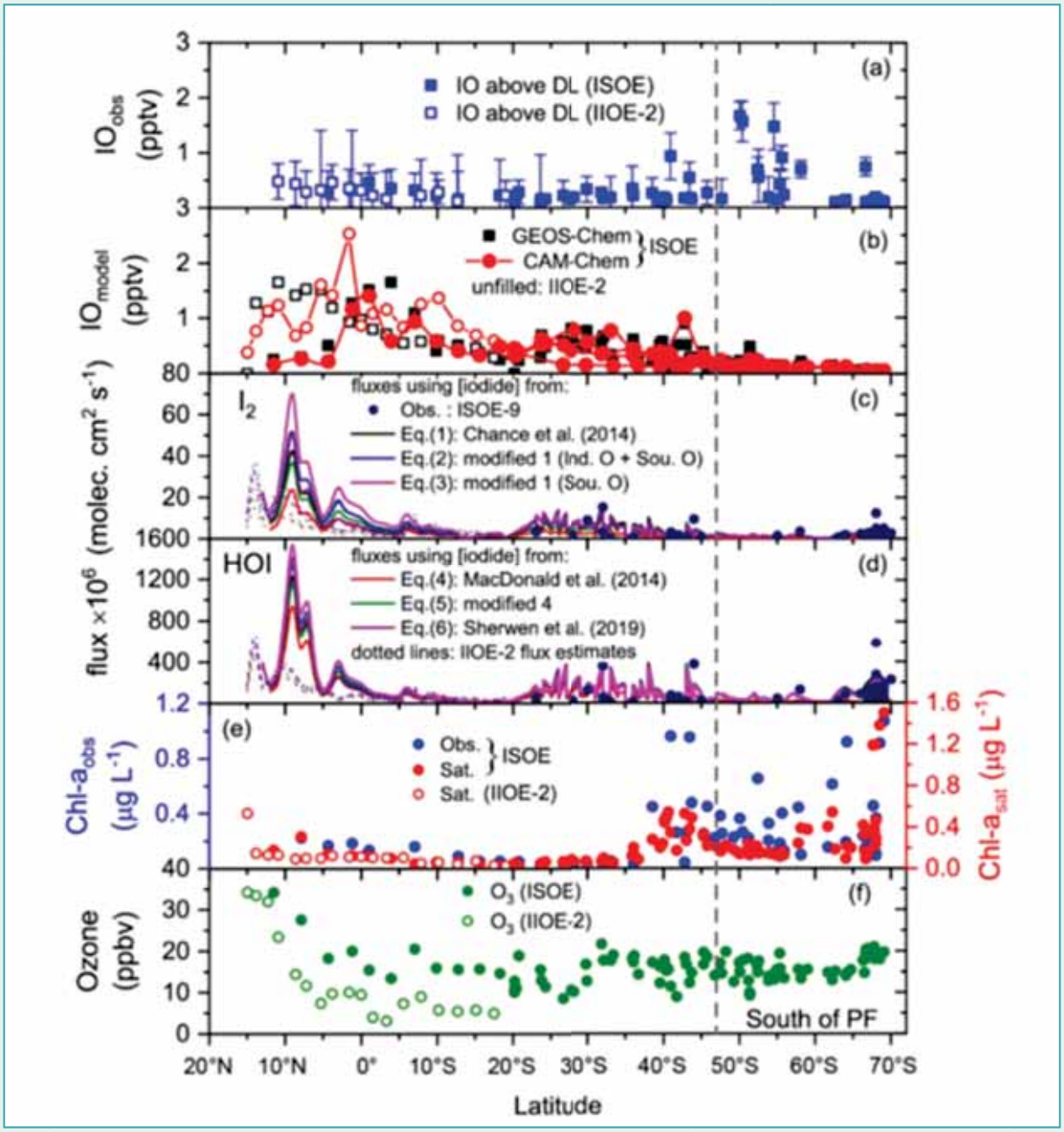


Fig. 1.10: *Daily averaged atmospheric and oceanic parameters combined from cruises in the Indian Ocean and Southern Ocean. Data marked with "ISOE" represent combined data from the Indian Scientific Expeditions to the Southern Oceans. Unfilled markers and dotted lines show values for the 2nd International Indian Ocean Expedition (IIOE-2). (**a**) IO above the detection limit from ISOE-8, ISOE-9 and IIOE-2. (**b**) Surface IO values from the GEOS-Chem and CAM-Chem models. Panels (**c**) and (**d**) comprise HOI and I_2 fluxes estimated using laboratory parameterisations. Fluxes are colour-coded for different sea surface iodide (SSI) datasets used for their estimation. Black, blue, red, and green correspond to fluxes calculated using SSI estimation from past studies while the purple represents the use of model SSI predictions, and filled circles in dark blue correspond to measured SSI from ISOE-9 for each observation. (**e**) Chlorophyll a observations from ISOE-8 and ISOE-9 (blue circles) as well as satellite data for all campaigns (red circles). (**f**) Ozone mixing ratios from campaigns ISOE and IIOE-2. The dashed line marks the polar front at 47°S. The vertical dashed line through the figure indicates the PF (polar front).*

1.4. Paleoclimate

Basic Research

1.4.1. Standardized Precipitation Index reconstruction during the last two centuries over western Himalaya, India: deduced by tree ring-width records

Tree-ring width index chronologies of different species (*Cedrus deodara*, *Abies Pindrow* and *Picea smithiana)* from the western Himalayas have been carried out in relation to understand the climate fluctuations. The first principal component developed based on the above species showed significant positive relationship with Standardized Precipitation Index (SPI) and negative with Heat Index (HI) during pre-monsoon months, but the highest correlation coefficients of tree growth with heat and SPI were observed during May, are -0.52 and 0.60 respectively, which are highly significant at 0.1% level. The results indicate that increasing heat index during May might lead to dry soil by accelerating the potential evapotranspiration which creates the moisture deficiency in plants over the region. In case of SPI, which showed a significant positive relationship with tree growth, indicates that tree growth of the western Himalaya is moisture sensitive, which enables us to extend SPI to monitor dry and wet periods before the instrumental period. The reconstructed SPI back to 1778 shows climate variability, on both interannual and inter-decadal time scale. The reconstruction showed increasing wetness in the twentieth century and recent few decades. Extreme and severe dryness noticed during 1921 (-2.4) and 1892 (-2.0) in the entire reconstruction has been associated with very low tree growth during the corresponding year over the western Himalaya. [***Somaru Ram, Yadav R.K., Singh H.N.***, *Srivastava M.K., Standardized Precipitation Index reconstruction during the last two centuries over western Himalaya, India: deduced by tree ring-width records,* ***Himalayan Geology****, 41, July 2020, 202-207*]

1.5. MetFlux India: GHG Observation and Modeling

Basic Research

1.5.1. Study of GHGs at a semi-urban environment in western India

Amongst all the anthropogenically produced greenhouse gases (GHGs), carbon dioxide (CO_2) and methane (CH_4) are the most important, owing to their maximum contribution to the net radiative forcing of the earth. India is undergoing rapid economic development, where fossil fuel emissions have increased drastically in the last three decades. Apart from the anthropogenic activities, the GHGs dynamics in India are governed by the biospheric process as well as by monsoon circulation; however, these aspects are not well addressed yet. Towards this, CO_2 and CH_4 concentrations were measured at Sinhagad, located on the Western Ghats in peninsular India. The average concentrations of CO_2 and CH_4 observed during the study period are 406.05 + 6.36 and 1.97 + 0.07 ppm ($\mu + 1\sigma$), respectively. They also exhibit significant seasonal variabilities at this site. CH_4 (CO_2) attains its minimum concentration during monsoon (post-monsoon), whereas CO_2 (CH_4) reaches its maximum concentration during pre-monsoon (post-monsoon). CO_2 poses significant diurnal variations in monsoon and post-monsoon. However, CH_4 exhibits a dual-peak-like pattern in pre-monsoon. It is suggested that the GHG dynamics in the western region of India are significantly influenced by monsoon circulation, especially during the summer season. [***Metya A., Datye A. Chakraborty S., Tiwari Y.K., Sarma D.**, Bora A., Gogoi N., Diurnal and seasonal variability of CO2 and CH4 concentrations in a semi-urban environment of western India, **Scientific Reports**, 11: 2931, February 2021, DOI:10.1038/s41598-021-82321-1*]

1.5.2. Study of the carbon transfer process in a mangrove ecosystem of south India

Mangrove ecosystems play a crucial role in the global carbon cycle. However, the carbon fluxes in the mangrove ecosystems found in the Indian subcontinent are not well understood. Here, for the first time, the net ecosystem exchange (NEE) in a mangrove ecosystem at Pichavaram, southeast India was estimated by using the eddy covariance method for the period October 2017 to September 2018. The half-hourly daytime NEE varied from -11.05 µmol m^{-2} s^{-1} in the winter months (January-March 2018) to -6.06 µmol m^{-2} s^{-1} during the summer (April 2018). The estimated annual evapotranspiration during the study period was 610 mm, whereas the precipitation was 653 mm (dryer than the long-term average). The half-hourly NEE data were gap filled and partitioned to estimate the gross primary productivity (GPP) and ecosystem respiration (R_{eco}). The estimated annual GPP was 1466 gC m^{-2} and R_{eco} was 1283 gC m^{-2}. The mangrove forest appeared to be a modest sink of atmospheric CO2, with an annual average net ecosystem productivity of 183 gC m^{-2}. However, in the summer months, it acted as a source. It is observed that the mangrove CO_2 fluxes strongly responded to environmental factors such as temperature, rainfall, and salinity. However, it is noteworthy that the carbon sink capability may decline in the future due to rising temperatures, decreasing rainfall patterns, variation in salinity, and changes in tidal inundation patterns. [*Gnanamoorthy P., Selvam V., **Deb Burman P.K., Chakraborty S.**, Karipot A., Nagarajan R., Ramasubramanian R., Song Q., Zhang Y., Grace J., Seasonal variations of net ecosystem (CO2) exchange in the Indian tropical mangrove forest of Pichavaram, **Estuarine Coastal and Shelf Science**, 243: 106828, September 2020, DOI:10.1016/j.ecss.2020.106828*]

Chapter 2
Short-Term Climate Variability and Prediction

Project Directors: Dr. Ashwini Kulkarni and Dr. C. Gnanaseelan

Objectives

- To conduct basic research on Indian summer monsoon rainfall (ISMR) variability and tele-connections.
- To continue ongoing efforts in identifying the regional and global climate drivers for monsoon inter-annual and decadal variability.
- To study the impact of low frequency oceanic variability on monsoon variations and to investigate the associated processes using observations and models.
- To understand the role of low frequency feedbacks involving land-atmosphere interactions relevant to the Indian monsoon variability.
- To identify predictors for monsoon variability using observations and models.
- To examine the projected changes in climate over India.
- Decadal variability and prediction.

Highlights of Major Achievements:

- The influence of swapping the Pacific and Atlantic Niños on north central India summer monsoon is investigated.
- The role of an Indian Ocean heating dipole anomaly in the transition of the North Atlantic-European (NAE) circulation response to ENSO from early to late winter is analysed.
- Projections of heat stress and associated work performance over India in response to global warming are provided.
- Development of a decadal prediction system using IITM-ESM has been initiated.
- Hindcasts prepared using the current version of decadal prediction system based on IITM-ESM.
- Evaluation of the skills of CMIP6 models in representing Indian monsoon climate and TIO variability.
- The decadal to multidecadal variability in the equatorial Indian Ocean subsurface temperature and related forcing mechanisms has been studied.

Sub-Projects

- Climate Variability, Predictability and Applications
- Climate Variability and Decadal Prediction

2.1. Climate Variability, Predictability and Applications

Basic Research

2.1.1. Swapping of the Pacific and Atlantic Niño influences on north central India summer monsoon

The highly populated north central India receives 90% of annual rainfall during June to September. The interannual variation of summer monsoon rainfall is less studied compared to central and western India, due to its weak signal with the El-Niño-Southern Oscillation (ENSO). Previous studies have reported a marked decadal variation in the ENSO influences on north India rainfall, but the teleconnections of this variation are not satisfactorily understood. A pathway of the changing ENSO influences on north central India rainfall is revealed from observational data analysis and numerical experiments. While La Niña like conditions produced anomalous northeasterly wind over India and reduced the tropospheric wind shear (**Fig. 2.1(a)**), the emergence of the Atlantic Niño appears to overtake this ENSO influence. The Atlantic Niño intensifies the meridional stationary wave affecting pressure anomaly over northwest Europe. This excites the Eurasian Rossby wave train along the mid-latitude producing upper-troposphere high pressure anomaly, subsequently affecting north India (**Fig. 2.1(b)**). Future work should examine the extent to which these

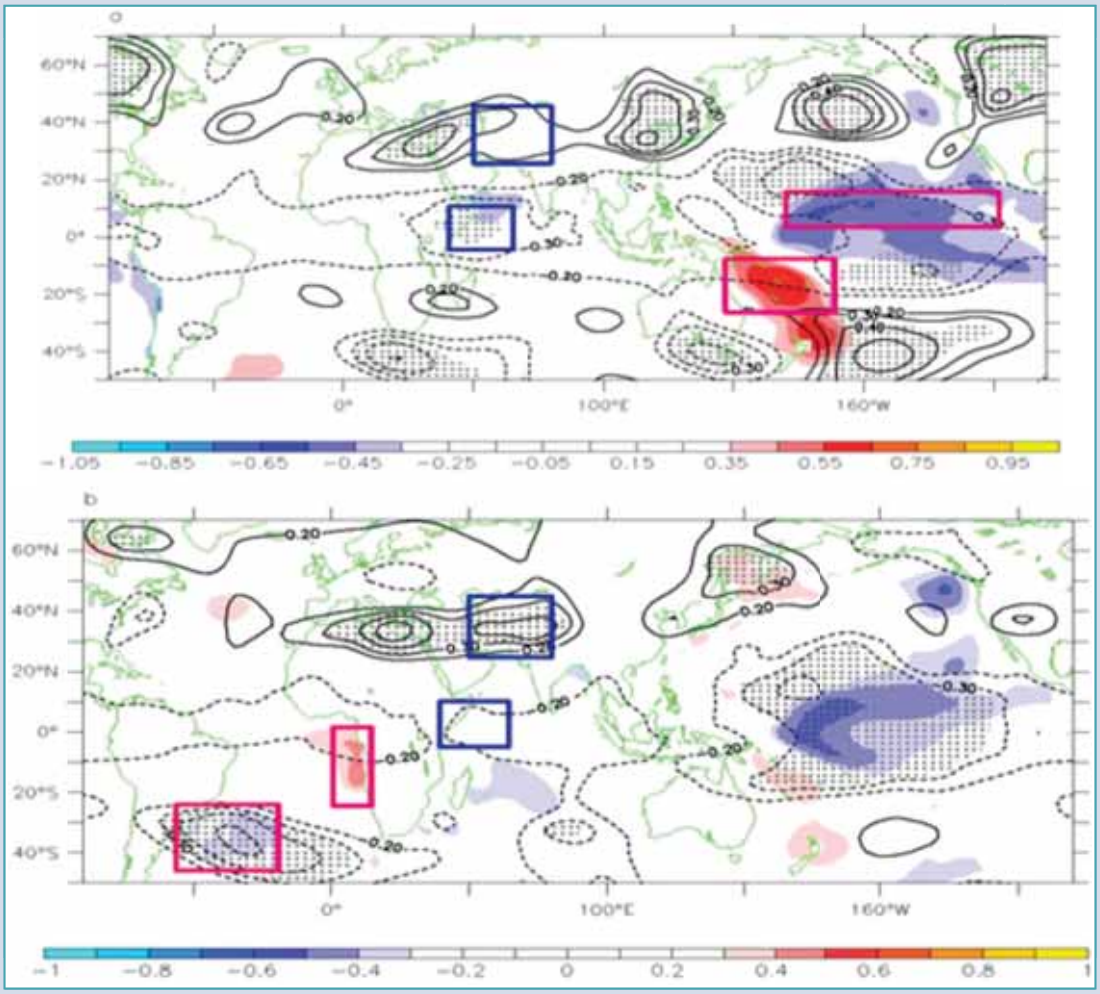


Fig. 2.1: *Contiguous correlation of north central ISM with SST (color shaded) and 250-hPa GPH (contours) for (**a**) period 1: 1948-78, and (**b**) period 2: 1979-2016. The blue boxes depict the 250-hPa pressure gradient regions and pink boxes SST dipoles.*

teleconnections are represented in climate forecast models to aid the seasonal prediction of north central India rainfall. [***Yadav R.K.**, Simon Wang S.-Y., Wu C-H., Gillies R.R., Swapping of the Pacific and Atlantic Niño influences on north central India summer monsoon, **Climate Dynamics**, 54(9), May 2020, 4005-4020, DOI: 10.1007/s00382-020-05215-4*]

2.1.2. The role of an Indian Ocean heating dipole in the ENSO teleconnection to the North Atlantic European region in early winter during the twentieth century in reanalysis and CMIP5 simulations

The role of an Indian Ocean heating dipole anomaly in the transition of the North Atlantic-European (NAE) circulation response to El Niño-Southern Oscillation (ENSO) from early to late winter is analyzed using a twentieth-century reanalysis and simulations from CMIP5 database. It is shown that in early winter a warm (cold) ENSO event is connected through an atmospheric bridge with positive (negative) rainfall anomalies in the western Indian Ocean and negative (positive) anomalies in the eastern Indian Ocean (**Fig. 2.2**). The early winter heating dipole, forced by a warm (cold) ENSO event, can setup a wave train emanating from the subtropical South Asian jet region that reaches the North Atlantic (**Fig. 2.3**) and leads to a response that spatially projects onto the positive (negative) phase of the North Atlantic Oscillation (**Fig. 2.4**). Further, the CMIP5 multi-model ensemble reproduced the early winter Indian Ocean heating dipole response to ENSO and its transition in the North Atlantic region to some extent, but with weaker amplitude. [***Joshi M.K.**, Abid M.A., Kucharski F., The role of an Indian Ocean heating dipole in the ENSO teleconnection to the North Atlantic European Region in early winter during the twentieth century in reanalysis and CMIP5 simulations, **Journal of Climate**, 34(3), February 2021, 1047-1060. DOI: 10.1175/JCLI-D-20-0269.1*]

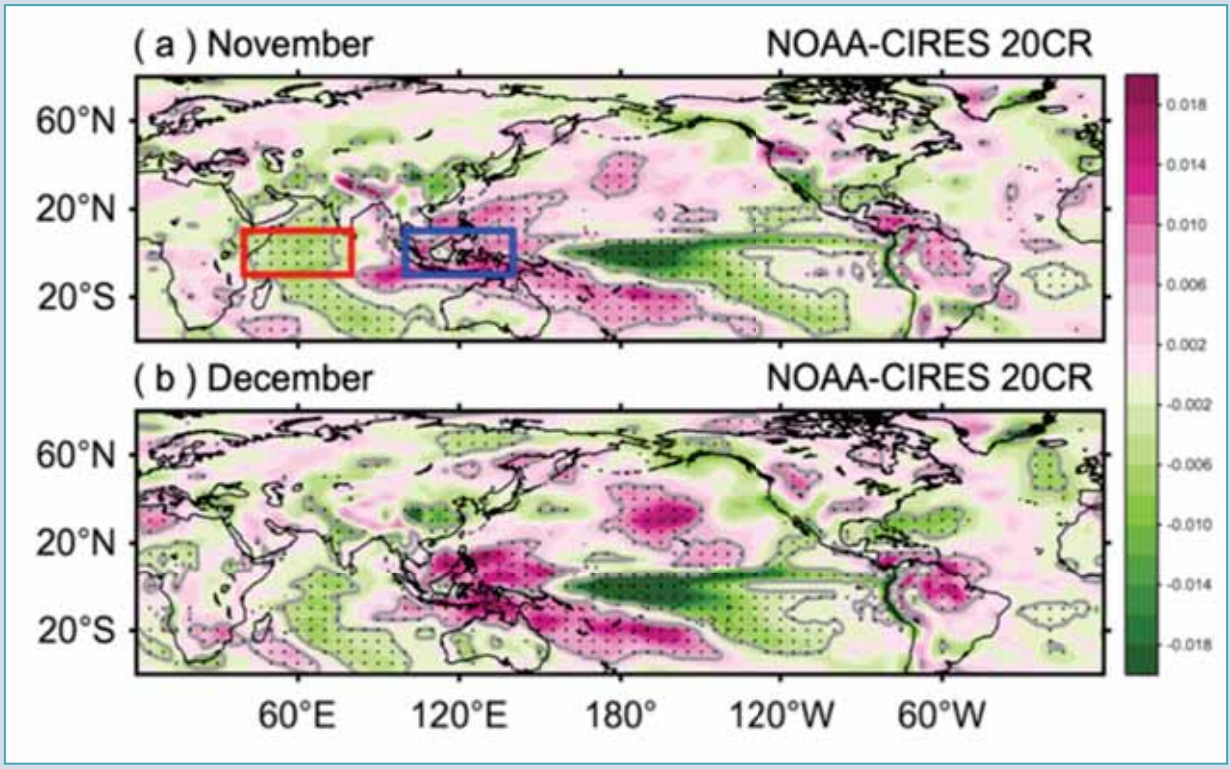


***Fig. 2.2:** Regression maps of omega anomalies at 500 hPa onto the standardized Niño-3.4 index for (**a**) November, and (**b**) December. The black stippling indicates the grid points where the regression coefficients are statistically significant at the 90% confidence level, whereas the gray contours indicate the significance at the 95% confidence level. The unit of regression coefficients is Pa s^{-1} per standard deviation.*

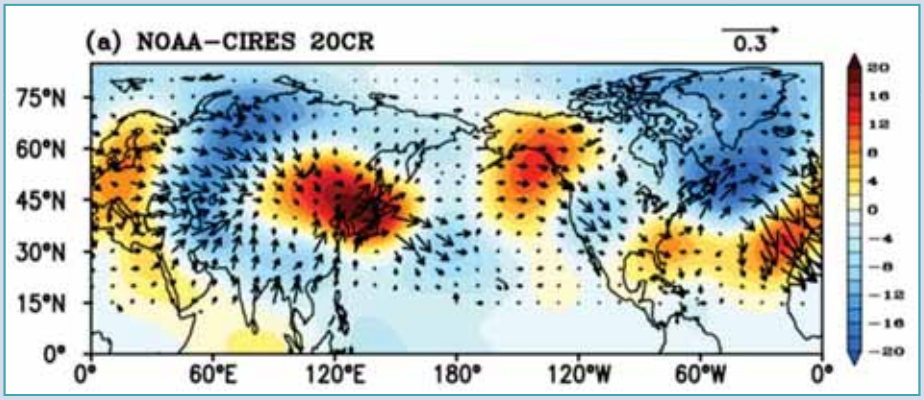


Fig. 2.3: *Regression map of geopotential height (m) anomalies at 200 hPa onto the standardized "pure" tropical western eastern Indian Ocean index (independent of ENSO) for NOAA-CIRES 20CR for December. The vectors represent the wave activity flux ($m^2 s^{-2}$) calculated with regressed anomalies. The units of regression coefficients are per standard deviation.*

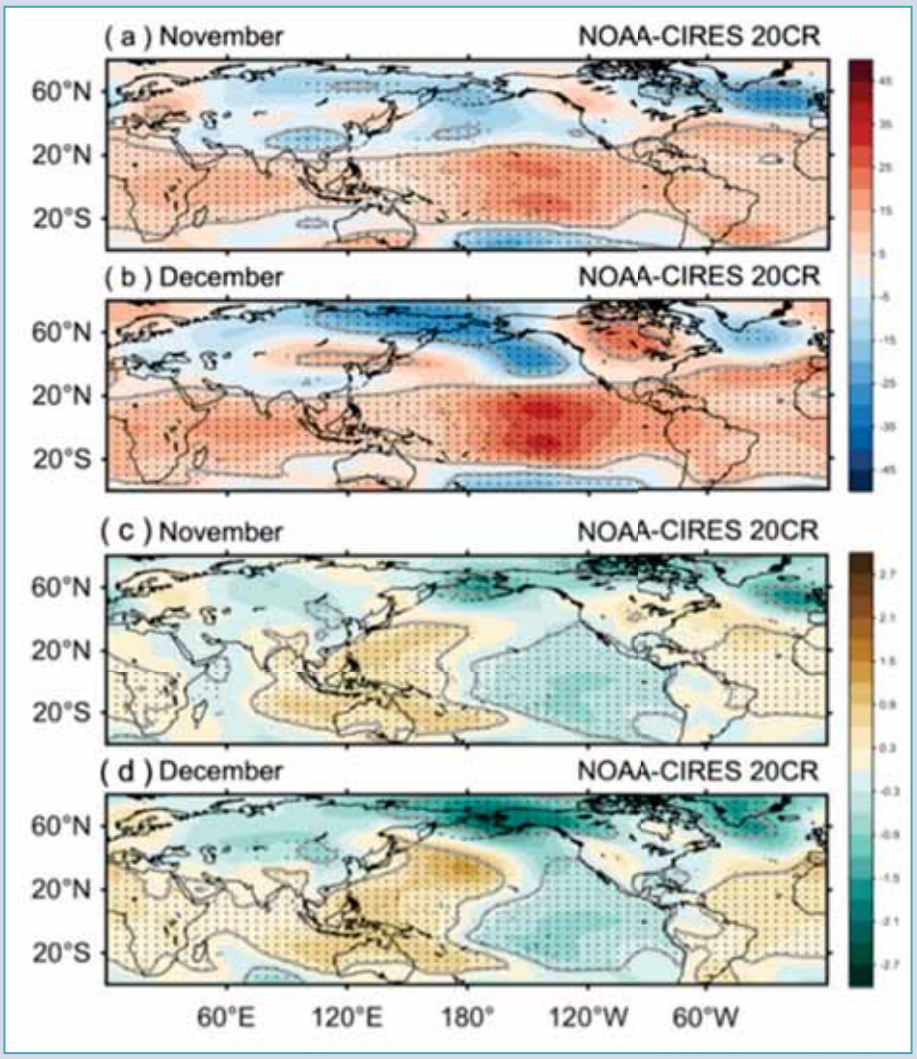


Fig. 2.4: *Regression maps of (**a-b**) geopotential height anomalies at 200 hPa (m per standard deviation) and (**c-d**) SLP anomalies (hPa per standard deviation) onto the standardized Niño-3.4 index for November and December. The black stippling indicates the grid points where the regression coefficients are statistically significant at the 90% confidence level, whereas the grey contours indicate the significance at the 95% confidence level.*

2.1.3. Projections of heat stress and associated work performance over India in response to global warming

Future projections of summertime heat stress days (%) from Multi-Model Mean (MMM) of CMIP5 models showed unprecedented increasing levels in the RCP 4.5 and RCP 8.5 emission scenarios over India (**Fig. 2.5**). The estimated heat stress is found to have more impact with an increased probability of extreme caution to danger days over the coastal regions of India. The explicit amount of change in temperature, and increase in the duration and intensity of warm days along with the modulation in large scale circulation in future are seemingly connected to the increasing levels of heat stress over India. A decline of 30 to 40% in the work performance is projected over India by the end of the century due to the elevated heat stress levels which pose great challenges to policy-makers to design the safety mechanisms and to protect people working under continuous extreme hot weather conditions. Decline in work performance associated with the detectable trends of heat stress over India point out the dire need to frame the sage work procedures, preventing the heat-based illness to reduce the health hazards as well as to maintain the work performance. [***Koteswara Rao K.***, *Lakshmi Kumar T.V.,* ***Kulkarni Ashwini,*** *Ho C-H., Mahendranath B., Desamsetti S.,* ***Patwardhan S., Dandi A.R.****, Barbosa H.,* ***Sabade S.****, Projections of heat stress and associated work performance over India in response to global warming,* ***Scientific Reports****, 10:16675, October 2020, https://doi.org/10.1038/s41598-020-73245-3*]

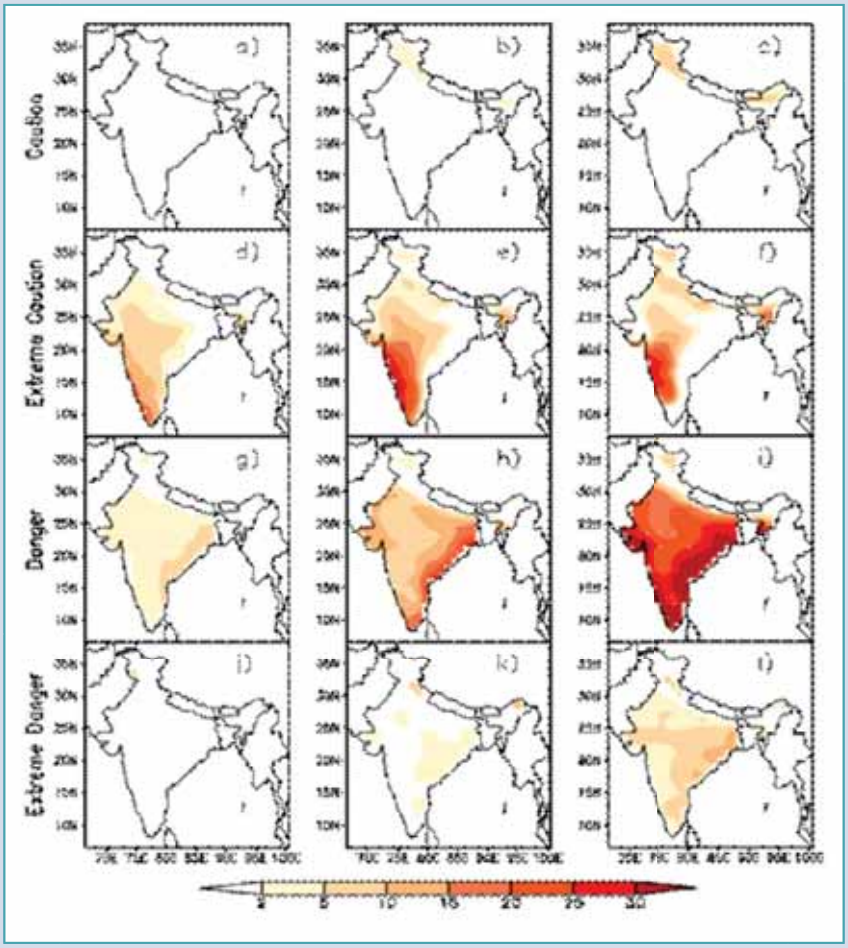


Fig. 2.5: *Projected changes in four categories of summertime heat stress days (%) under HIGH emission scenario (RCP8.5) for the three-time epochs of 2016-2035 (left column), 2046-2065 (middle column) and 2080-2099 (right column) with respect to 1986-2005.*

2.2. Climate Variability and Decadal Prediction

Basic Research

2.2.1. The impact of global decadal and multidecadal climate modes on the Indian Ocean tide gauge derived sea level variability

Decadal sea level variability of the Indian Ocean is studied using long-term tide gauge observations along the coast of India and other Indian Ocean rim countries. The existence of close association between Indian Ocean sea level and the global decadal climate modes such as Pacific Decadal Oscillation (PDO) and/or Atlantic Multidecadal Oscillation (AMO) is revealed in most of the tide gauge datasets. An anti-phase sea level evolution with PDO index is identified in the regions such as west coast of India, east coast of India and the western coast of Australia. On the other hand, the tide gauge station in Mumbai with more than 100 years of data shows an in-phase relationship with AMO index on the decadal timescales, whereas such relationship is very weak at the tide gauge station Fremantle where similar long-term data is available. The analysis of sea level pressure (SLP), rainfall and winds over the tropical Indian Ocean indicates existence of strong relationship with AMO especially over the Arabian Sea region, strongly suggesting that the variability observed at the tide gauge station Mumbai, as a response to AMO, may have larger spatial signatures **(Fig. 2.6)**. During the positive phase of AMO, the Arabian Sea region is characterized by large fall in SLP and a strong cross equatorial flow towards the Indian land mass, which are primarily responsible for the positive sea level anomalies (SLAs) at the Mumbai tide gauge station and the adjacent regions and positive rainfall anomalies over India. [***Deepa J.S., Gnanaseelan C.***, *The decadal sea level variability observed in the Indian Ocean tide gauge records and its association with global climate modes,* ***Global and Planetary Change****, 198: 103427, March 2021, DOI: 10.1016/j.gloplacha. 2021.103427*]

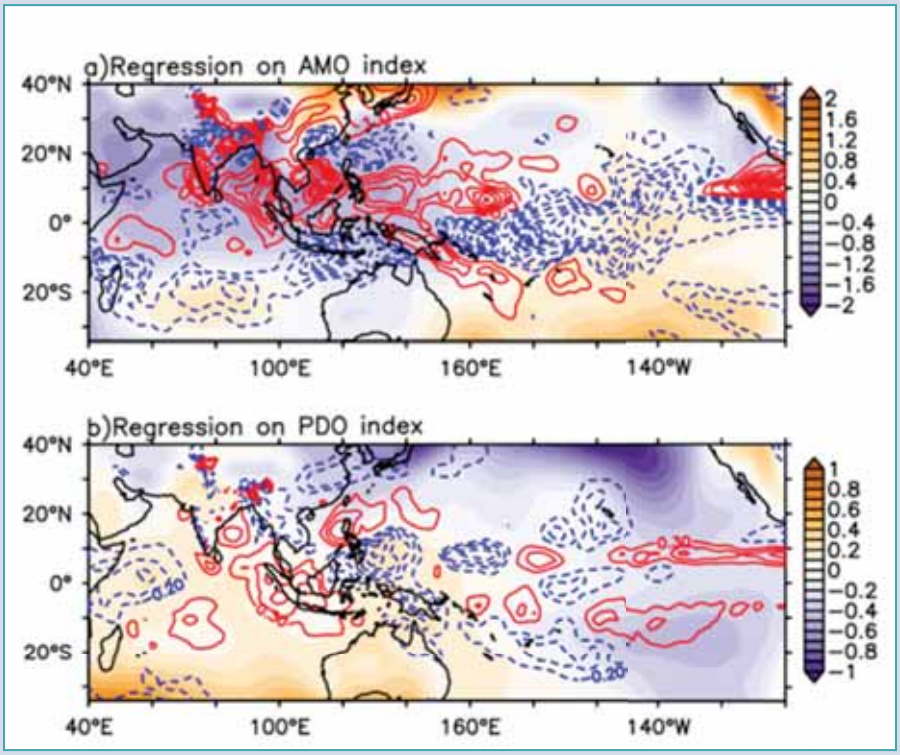


Fig. 2.6: *Regression of SLP (hPa, shaded) and rainfall (mm/day, contours) anomalies on the (**a**) AMO index, and (**b**) PDO index, on the decadal timescales. The regression map on the AMO and PDO indices are computed for the periods 1871-2012 and 1900-2012 respectively. The datasets are linearly detrended for the whole period 1871-2012 and anomalies are computed based on the climatology for the period 1960-2012.*

2.2.2. The Indo-Pacific sea level variability and projections in CMIP5 models

The representation of interannual and decadal variability of sea level over the Indo-Pacific region in the Coupled Model Intercomparison Project Phase 5 (CMIP5) historical simulations and future projections is examined. The thermocline ridge region of the Indian Ocean (TRIO) shows strong sea level variability on both the interannual and decadal timescales in the CMIP5 historical simulations. Meanwhile, in the Pacific, prominent interannual variability is seen in the tropical western Pacific and central to eastern equatorial Pacific regions, whereas, the decadal sea level variability is dominant in the North Pacific and western Pacific regions. CMIP5 models project similar spatial patterns of sea level variability over the Indo-Pacific region for the twenty-first century under the mid-range and high future emission scenarios, although with some differences in the amplitude and inter-model disagreement. In the interannual timescale, there is a regional contrast in the projected future variability between the Pacific (with increase in variability with increasing greenhouse gas emissions) and TRIO (with decrease of ~ 6% of variability), which is evident in both RCP4.5 and RCP8.5 future emission scenarios with inter-model consensus. On the other hand, increase in decadal sea level variability (~ 6% and ~ 8% in RCP4.5 and RCP8.5 scenarios respectively) is projected over the North Pacific region **(Fig. 2.7)**. In the Indian Ocean, increase in decadal sea level variability is projected over the northwestern region including Arabian Sea, though it is not a region of large decadal variability. Analysis revealed that the local wind forcing plays a dominant role in the sea level variability over the Indo-Pacific region on both interannual and decadal timescales. [***Deepa J.S., Gnanaseelan C., Parekh A.**, The sea level variability and its projections over the Indo-Pacific Ocean in CMIP5 models, **Climate Dynamics**, online, February 2021, DOI: 10.1007/s00382-021-05701-3*]

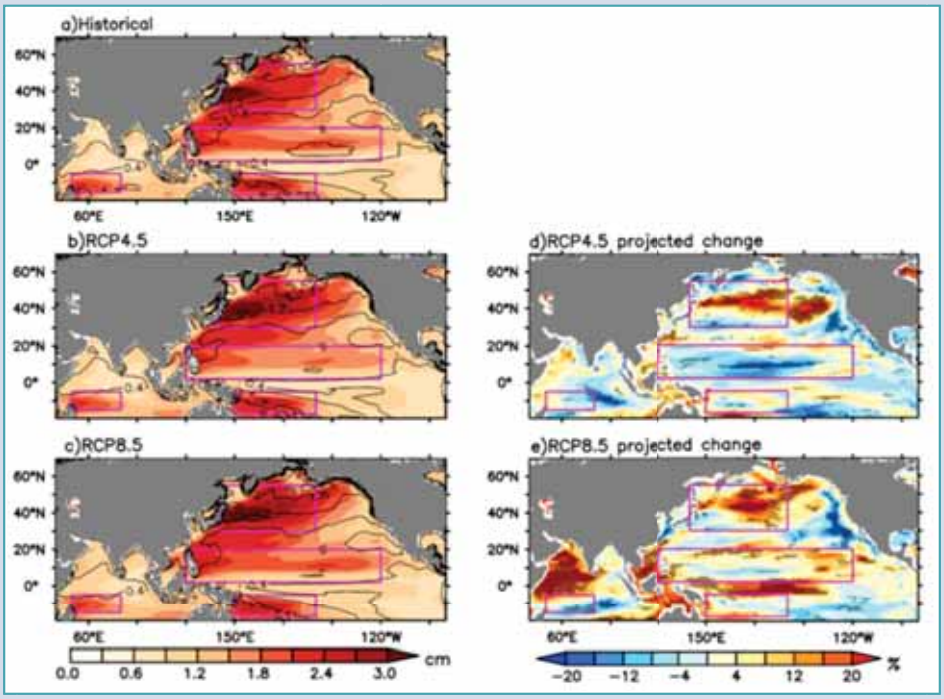


Fig. 2.7: *The multi-model mean standard deviations of SLAs (cm, shaded) and anomalous wind stress curl (× 10^{-7} N/m^3, contours) from (**a**) historical simulation for the period 1911-2005, and (**b**) RCP4.5 scenario for the period 2006-2100, on the decadal timescales. (**d**) The multi-model mean SLA standard deviation difference (shaded, % change) in the RCP4.5 scenario with respect to historical simulations. (**c**) and (**e**) are same as (**b**) and (**d**), but for RCP8.5 scenario. The multi-model mean is based on the selected 15 models and the stippling indicates the grid points where more than 10 out of these 15 models agree on the sign of SLA standard deviation changes.*

2.2.3. Decadal variability of tropical Indian Ocean sea surface temperature and its impact on the Indian summer monsoon

The decadal climate variability over the Indian Ocean and its possible impact on the summer monsoon received relatively less attention. An attempt is made to explore the decadal variability of the Tropical Indian Ocean (TIO) sea surface temperature (SST) and its associations with the Indian summer monsoon rainfall (ISMR) variability. More than a hundred years of observed monthly SST data from Extended Reconstructed sea surface temperature and rainfall data from India Meteorological Department were used for the analysis. In addition to these, century reanalysis fields of winds, moisture, vertical velocity, tropospheric temperature, and sea level pressure were used for diagnosing different processes. Time series and wavelet analysis confirmed the presence of decadal variability (~ 9 to 30 years) in the TIO SST.

Figure 2.8(a) shows the spatial distribution of the TIO SST variance for decadal variability. It shows high variance to the south eastern part of Indian Ocean and north Arabian Sea. However, rainfall variance (**Fig. 2.8(b)**) shows high variance over the Western Ghats, north east India, and some part of the foot hills of the Himalayas and the monsoon core zone (MCZ). **Figure 2.8(c)** shows the first mode of decadal variability in TIO SST during the study period (*i.e.,* 1854 to 2016). The first mode of EOF is basin-wide mode explaining 49.3% of total variance. The second mode is dipole-like mode explaining 10.6% of total variance. **Figure 2.8(d)** shows the first mode of ISMR decadal variability during 1900 to 2016 over the India. The first mode explains about 16% of the total variance and has positive phase almost over India. **Figure 2.8(e-f)** shows the respective principal components for the first mode of SST and rainfall. Principal components (**Fig. 2.8(e)**) of filtered SST anomaly, as well as

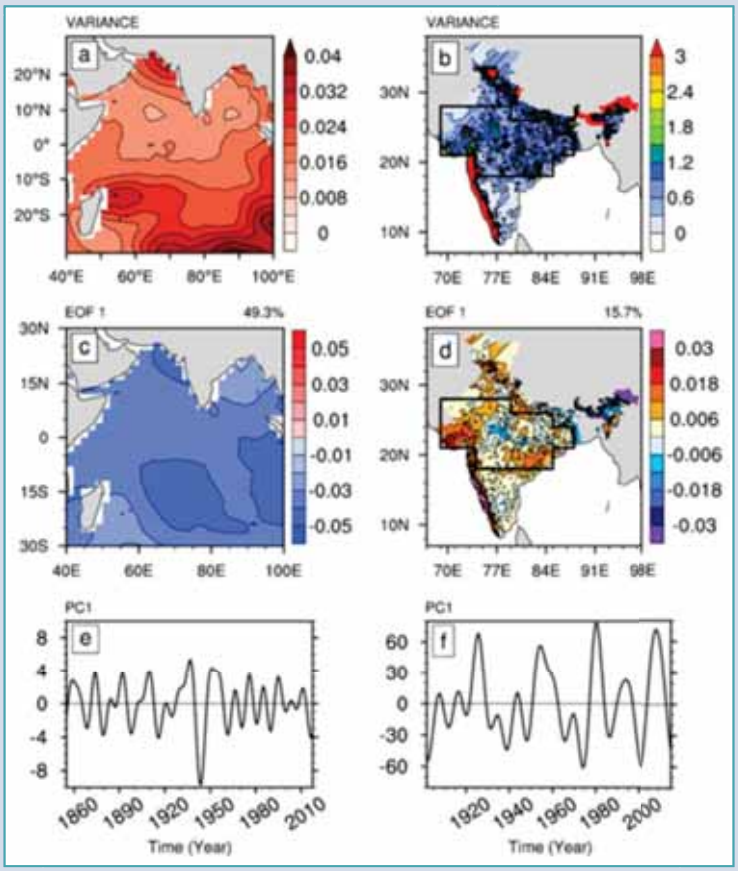


Fig. 2.8: Variance of decadal variability of (**a**) TIO SST $(°C)^2$ and (**b**) ISMR$(mm/day)^2$, (**c**) EOF first mode of TIO SST (°C) decadal variability, and (**d**) EOF first mode of ISMR (mm/day) decadal variability and corresponding principal components are shown in (**e**) and (**f**). The boxes displayed in (**b**) and (**d**) represent the MCZ region.

wavelet analysis, confirmed that first mode was strongest during 1940-60 and rainfall also had significant variability during the same period. To understand how the decadal variability of TIO SST influences the ISMR, monsoon features during strong warm and cold phase were studied. During the warm phase, MCZ and the Western Ghats received more rain than normal and vice versa for cold phase. This is consistent with strong south westerly winds, strong pressure gradient, and strong convergence over the MCZ for the warm phase. Also, during the warm phase, positive anomaly of mid-troposphere temperature, vertical velocity, and moist static energy are found to be associated with excess convective activity. Apart from this, larger scale zonal (Walker) and meridional (Hadley) circulation fields are also in phase with the TIO SST and rainfall variability. This study advocates that decadal variability in TIO SST influences the monsoon dynamics and moist thermodynamics leading to near in-phase changes in the rainfall over the MCZ and Western Ghats region. [***Vibhute, A., Halder, S., Singh, P., Parekh, A., Chowdary, J.S. and Gnanaseelan, C.***, *Decadal variability of tropical Indian Ocean sea surface temperature and its impact on the Indian summer monsoon,* ***Theoretical and Applied Climatology****, 141, July 2020, 551-566, DOI: 10.1007/s00704-020-03216-1*]

2.2.4. Assessment of CMIP6 models' skill for tropical Indian Ocean sea surface temperature variability

The ability of Coupled Model Inter-comparison Project phase 6 (CMIP6) models is examined in representing the dominant modes of Tropical Indian Ocean (TIO) sea surface temperature (SST) variability on the interannual and decadal time scale. Historical simulations from 27 CMIP6 models were assessed against Extended Reconstructed SST over the period of 1854 to 2014. Spectrum analysis revealed that many models reproduce interannual and decadal variability of TIO SST but underestimate the amplitude of variability with some disparity in the periodicity. **Figure 2.9** shows the leading/first mode of TIO (9 year low pass) filtered SST anomaly from observation and 27 CMIP6 models. All models reproduced the dominant basin-wide mode of decadal variability (ID-IOBM) of TIO SST reasonably well. Observed ID-IOBM explains 43% of the total decadal variance. All the models captured ID-IOBM of decadal variability, but overestimated the percentage of total variability except for the following four models ACCESS-ESM1-5 (31%), CNRM-CM6-1 (41%), CNRM-ESM2-1 (35%) and NorCPM1 (34%). The analysis revealed that the models, in general, could simulate the basin-wide spatial mode of IA-IOBM and ID-IOBM of TIO SST. Skill score analysis of TIO SST variability revealed that KACE-1-0-G has highest skill, followed by FGOALS-f3-L, EC-Earth3-Veg-LR, ACCESS-ESM1-5, CanESM5-CanOE on the interannual timescale and FGOALS-f3-L, CanESM5- CanOE, KACE-1-0-G and CanESM5, respectively, showed highest skills for decadal variability. Taylor diagram analysis revealed that all the models exhibit better skill for the radiative flux; however, skill for the latent heat and momentum flux varies from model to model. It is important to note that the models with better representation of latent heat flux and zonal wind, produced better TIO SST variability compared to other models. A higher discrepancy in latent heat and zonal momentum flux leads to improper wind-evaporation-SST and wind-circulation-SST feedback, which in turn restricts the model skill. Besides, model that has realistic central and eastern Pacific SST variability showed better skill for TIO SST variability in both interannual and decadal time scales. Therefore, it is advocated that better representation of latent heat flux and zonal wind in coupled models is important for the accurate simulation of interannual and decadal variability in TIO SST. [***Halder S., Parekh A., Chowdary J.S., Gnanaseelan C., Kulkarni A.***, *Assessment of CMIP6 models' skill for tropical Indian Ocean sea surface temperature variability,* ***International Journal of Climatology****, 41, March 2021, DOI:10.1002/joc.6975, 1-21, 2568-2588*]

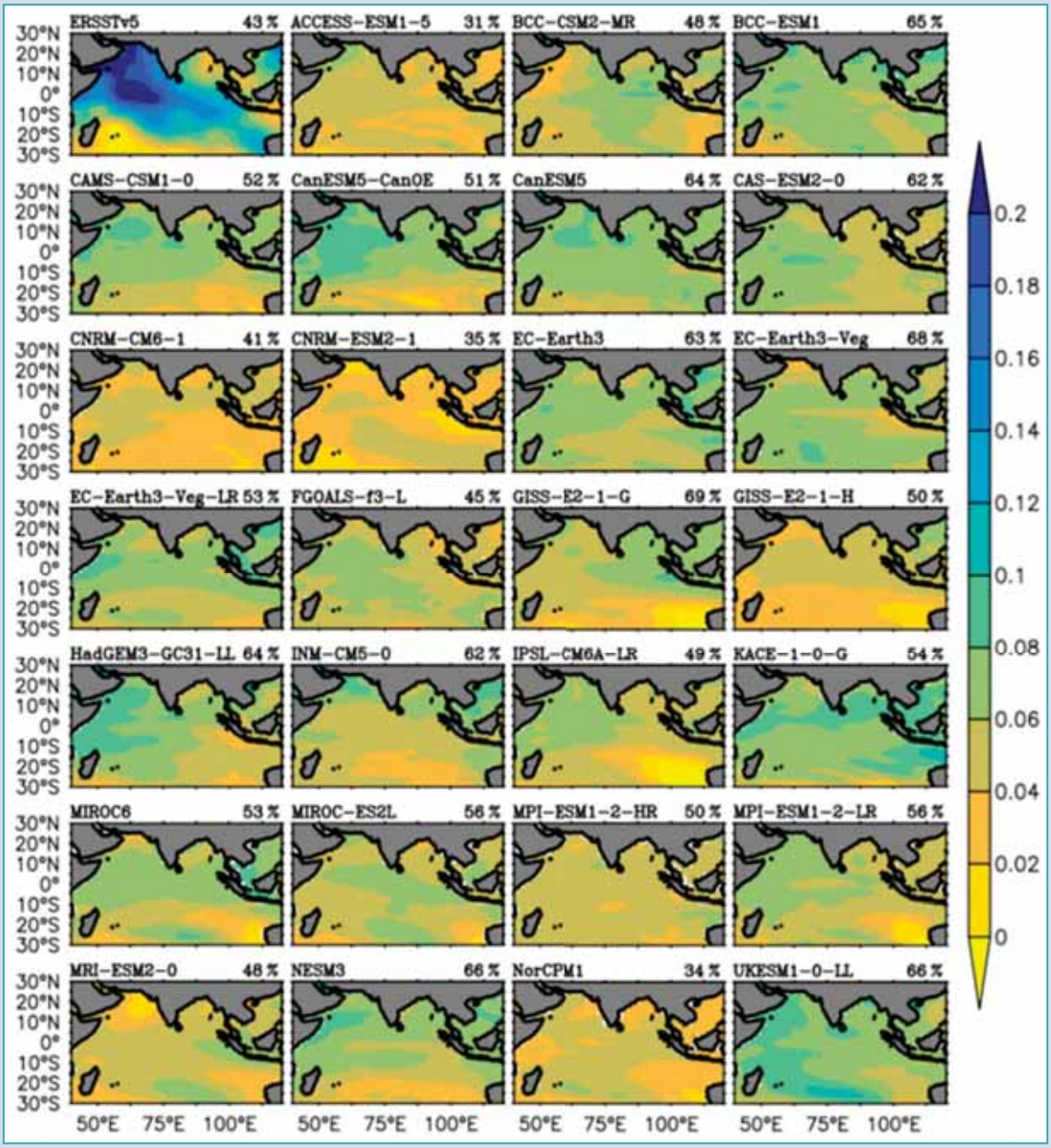


Fig. 2.9: *EOF leading/first mode of TIO 9 years low pass filtered SST anomaly from observation and 27 CMIP6 models. The top right corner shows the percentage of variability explained by EOF1.*

Chapter 3
Monsoon Mission

OVERVIEW

Project Directors: Dr. A.K. Sahai, Dr. A. Suryachandra Rao and Dr. P. Mukhopadhyay

Objectives

The overall objective of monsoon mission is to improve monsoon prediction over India on all time scales. The Specific objectives are as follows:

- To build a working partnership between the academic and R&D organizations (both national and international) and the MoES organizations to improve the operational monsoon forecast skill over the country and to develop relevant climate applications for agriculture, hydrology and power sectors.
- To develop and improve a state-of-the-art dynamical modelling framework for improving prediction skill of (a) Seasonal and Extended range predictions and (b) Short and Medium range (up to two weeks) prediction.
- To develop a system for thunderstorm/ lightning prediction using high resolution regional climate model (such as WRF).
- To improve extreme monsoon forecast using coupled GCM and dynamical downscaling.
- To develop short range ensemble forecast at 12 km resolution and improve the parameterization of physical processes for improving the short range forecast of monsoon.

Highlights of Major Achievements

- An Independent Review Committee constituted by MoES has recommended the continuation of Monsoon Mission to its 3rd phase (2020-24).
- MoES commissioned report prepared by NCAER, New Delhi highlights the economic benefits of the investment in Monsoon Mission and HPC facilities.
- Real-time operational forecast runs are being carried out on regular basis for the Dynamical System for Lightning Prediction developed at IITM.
- Investigation of the role of convective and microphysical processes in simulating monsoon intra-seasonal oscillation.
- Impact of horizontal resolution on sea surface temperature bias and air-sea interactions over the tropical Indian Ocean in CFSv2 coupled model has been studied.
- IITM MME prediction system was used by IMD for providing real-time extended range prediction of active/break spells of Indian Summer Monsoon for the 2020 monsoon season.
- A new multi-physics ensemble prediction strategy for extended range prediction provides a better probabilistic forecast for extreme weather anomalies.
- Prediction skill and predictability of Madden-Julian Oscillation (MJO) is assessed by using the state-of-the-art models (IITM-ERP and ECMWF).
- The newly introduced genesis potential parameter (IGPP) provides a better option than KGPP for real-time prediction of cyclogenesis and storm evolution over NIO.
- Dynamical downscaling of a multi-model ensemble prediction system is attempted for tropical cyclones.
- Development of a probabilistic early health warning system based on meteorological parameters.
- Development and implementation of the GEFS based ensemble tropical cyclone tracker, cone of uncertainty and strike probability.
- Development of a modified version of SAS convection scheme suitable for improving extreme precipitation.
- Development and implementation of operational river basin wise probabilistic precipitation forecast.

Sub-Projects

- Seasonal Prediction
- Extended Range Prediction
- Parameterization of Physical Processes and Analysis



3.1. Seasonal Prediction

Basic Research

3.1.1. Major achievements of Monsoon Mission

The major achievements of the Monsoon Mission are discussed here for larger dissemination. Monsoon Mission Programme was launched in 2012 by MoES with a definite target to improve the weather and climate forecasts over India. Monsoon Mission Phase-I was started in 2012 and concluded in 2017, while Monsoon Mission Phase-II was started in 2017 and is expected to conclude in 2021. Prior to the launch of the Mission, MoES institutes responsible for providing and improving weather and climate forecasts were using stand-alone dynamical models. Monsoon Mission Phase-I provided them an opportunity for the first time to work with coupled dynamical models and also to work on very high-resolution models (30 km climate models and 12.5 km weather models). As a result of Monsoon Mission, India now runs the highest resolution models for both weather and climate prediction (~12.5 km ensemble prediction system for short-to-medium range forecasts; 38 km climate coupled models for extended and seasonal forecast). Also, Monsoon Mission provided an opportunity to the global monsoon community to come together and explore the predictive capability of monsoon and design ways to improve the same. Monsoon Mission has realized its dream of setting up a reliable dynamical modelling framework with reasonable skill in predicting extremes at different scales; and Indian models' skill in predicting monsoon weather and climate is now comparable to any other leading weather and climate centre in the world. Despite this quantum jump in modelling capability, some gap areas still remain that need to addressed in the future phases of Monsoon Mission, including: (a) systematic biases in rainfall, SST, (b) predicting extremes with long leads, (c) enhancing the usefulness of the forecasts generated in different sectors to minimize the losses due to natural disasters, and (d) enhancing the prediction skills of extremes at different spatial and temporal scales. It is expected that future phases of the Mission will develop a unified, seamless coupled dynamical system for making forecasts from weather to decadal time scales with strongly coupled analysis for initialization. [***Rao S.A.**, Sahai A.K., Mukhopadhyay P., Mitra A.K., Prasad V.S., Francis P.A., Pai D.S., Pattanaik D.R., Major Achievements of Monsoon Mission, **CLIVAR Exchanges**, No. 79, Special issue on India's Monsoon Mission, **November 2020**, p. 10-15, DOI: 10.36071/clivar.79.2020*]

3.1.2. Role of convective and microphysical processes on the simulation of monsoon intra-seasonal oscillation

The role of microphysics (*i.e.*, warm and mixed-phase) in association with two different convection schemes is investigated for better simulation of Indian summer monsoon rainfall (ISMR) and monsoon intra-seasonal oscillation (MISO). Sensitivity experiments have been performed with CFSv2 using different microphysics (with and without ice-phase processes) and convective parameterization schemes. Results reveal that the ice-phase (i.e. mixed-phase; called as ICE) microphysics parameterization scheme performs better in the simulation of active and break composites of the ISMR as compared to ice-free runs (warm phase; called as NOICE). The difference between ICE and NOICE can be attributed to the availability of copious cloud condensate at the upper level. Better depiction of cloud condensate further leads to correct representation of specific humidity and realistic modulation of atmospheric circulation in active and break phases. As a result, better simulation of active and break phases occurs in the ICE run. In contrast, NOICE run fails to depict upper-level cloud condensate in the active phase and further it leads to an improper representation of specific humidity, unrealistic circulation features, and suppressed convection in active phases. Hadley and Walker circulation was simulated relatively better in ICE runs as compared to NOICE runs. The north-south space-time spectra of daily rainfall anomaly are also better captured by ICE run

as compared to NOICE run. Results indicate that mixed-phase processes are more important for capturing the difference between active and break composites, while convection parameterization is relatively more important for the intra-seasonal variance analyses. It is emphasized that proper feedback between convective and microphysics processes plays an essential role in the better simulation of MISO in coupled climate models. Further improvements in ice-phase microphysics parameterization with better convection schemes in models will be helpful for the betterment of MISO and will lead to the improved simulation of monsoon. (**Fig. 3.1 & 3.2**) [*Dutta U., **Chaudhari H.S.**, **Hazra A., Pokhrel S., Saha S.K., Veeranjaneyulu C.**, Role of Convective and Microphysical Processes on the Simulation of Monsoon Intra-seasonal Oscillation, **Climate Dynamics**, 55, November 2020, 2377-2403*]

3.1.3. Advances in coupled data assimilation, ensemble forecasting, and assimilation of altimeter observations

The predictions from coupled models are highly sensitive to the errors in initial conditions. With the purpose of improving the accuracy of ocean and atmospheric initial conditions, an ensemble-based flow-dependent data assimilation system was developed to the operational Climate Prediction System (CFSv2) coupled model. The data assimilation technique implemented in this case was the Local Ensemble Transform Kalman Filter (LETKF). The ocean model component was MOM4p1 coupled with LETKF, and the atmospheric component was GFS coupled with LETKF. The ocean observations assimilated were the global vertical profiles of temperature and salinity (obtained from the Indian National Centre for Ocean

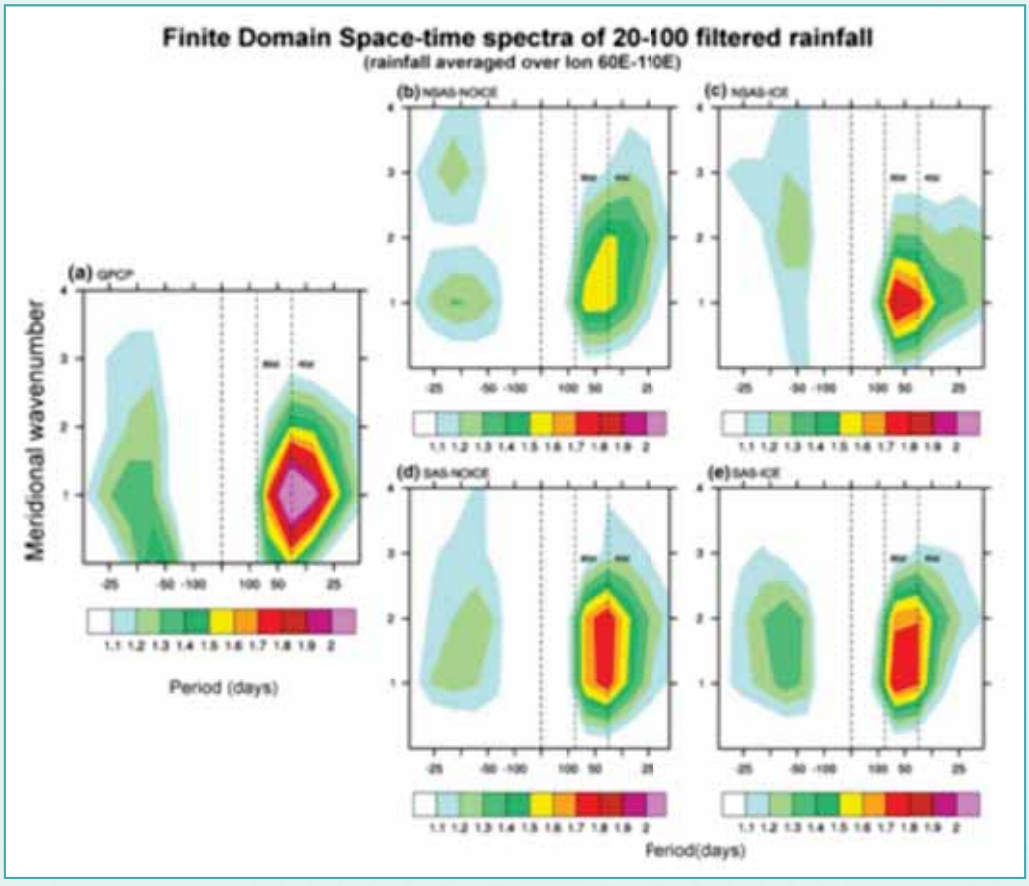


***Fig. 3.1**: North-South space time spectra for 20-100 day filtered rainfall anomaly (averaged over 60°E - 110°E).*

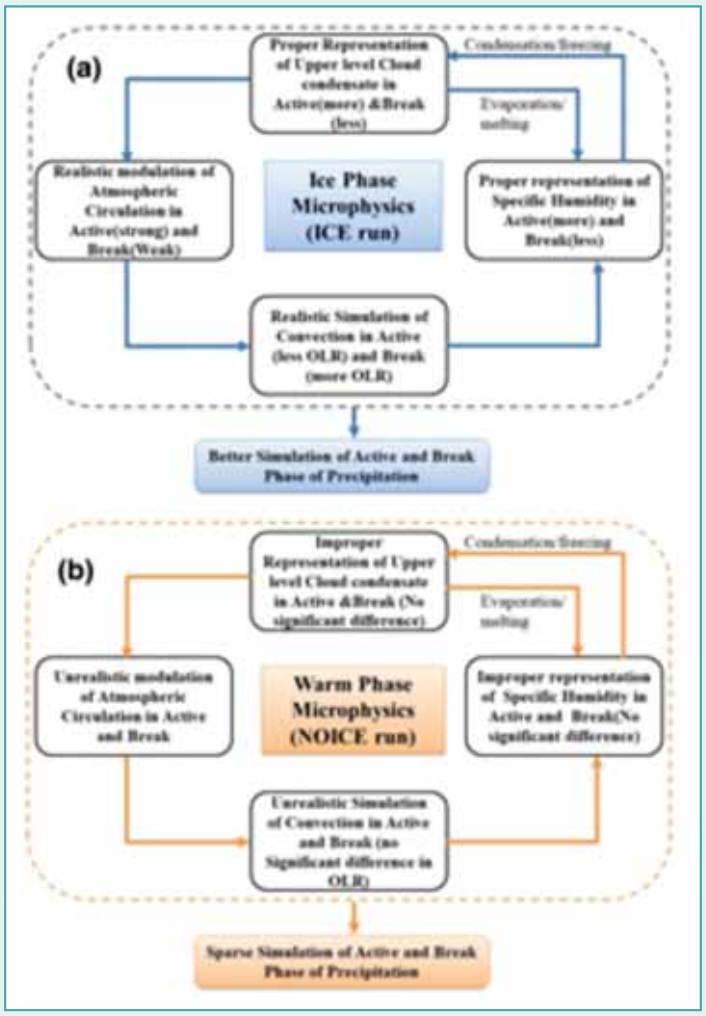


Fig. 3.2: *Schematic diagram illustrating possible mechanism.*

Information Services, INCOIS) and global high-resolution satellite-derived blended SST. The atmospheric observations assimilated were surface pressure, temperature, humidity, and horizontal winds (obtained from NCEP PrepBUFR). **Fig. 3.3** shows the analysis error (bias) and root mean square error (RMSE) in surface (15 m) zonal current for IITM-UMD WCDA and INCOIS GODAS. Here, the truth considered was Ocean Surface Current Analysis Real-time (OSCAR) currents at 15 m depth. The INCOIS GODAS has large errors in zonal currents especially in the equatorial regions of the world oceans. The analysis errors have been significantly reduced in CFS-LETKF ocean analysis compared to INCOIS GODAS. The RMSE has also improved in CFS LETKF. The atmospheric analysis of CFS LETKF (T126, ~108 km) also showed improvements in the precipitation and relative humidity, when compared to the higher resolution ERA-Interim (T255, ~80 km) atmospheric analysis. The precipitation analysis of the CFS-LETKF showed improvements in RMSE compared to ERA-INTERIM analysis (T255, ~80 km) (**Fig. 3.4**), except in the West Coast where the IITM-UMD system is too dry. [***Sreenivas P., Gade S.V., Rao S.A.,*** *Da C., Bhargava K., Chang C.C., Bach E., Eugenia K., and Travis S., Advances in Coupled Data Assimilation, Ensemble Forecasting, and Assimilation of Altimeter Observations,* ***CLIVAR Exchanges****, No. 79, Special issue on India's Monsoon Mission,* ***November 2020****, p. 27-30, DOI: 10.36071/clivar.79.2020*]

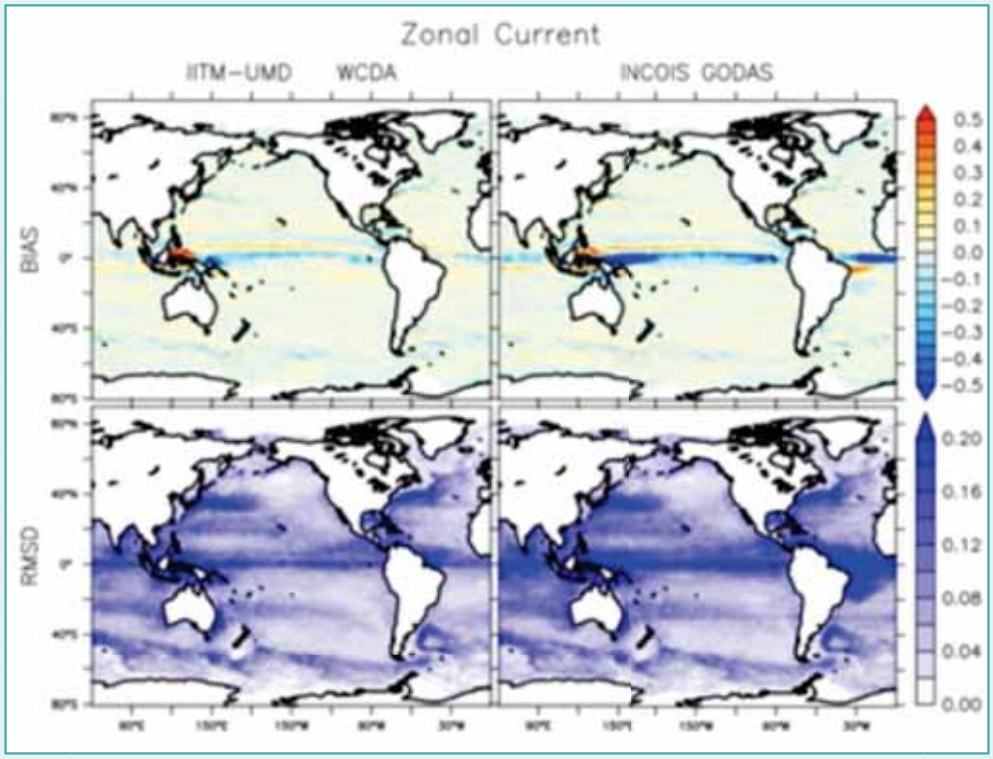


***Fig. 3.3**: Analysis error (bias) in the zonal current (m/sec) at 15 m depth, for a) ITM-UMD CFS-LETKF, b) INCOIS GODAS. Lower panels represent RMSE (m/sec); analysis period 2003 to 2009. For truth, we considered the OSCAR currents at 15 m. The large analysis errors that were observed in INCOIS GODAS decreased in magnitude with CFS LETKF. In addition, the new coupled analysis has better represented the variability (RMSE) in ocean surface currents compared to INCOIS GODAS.*

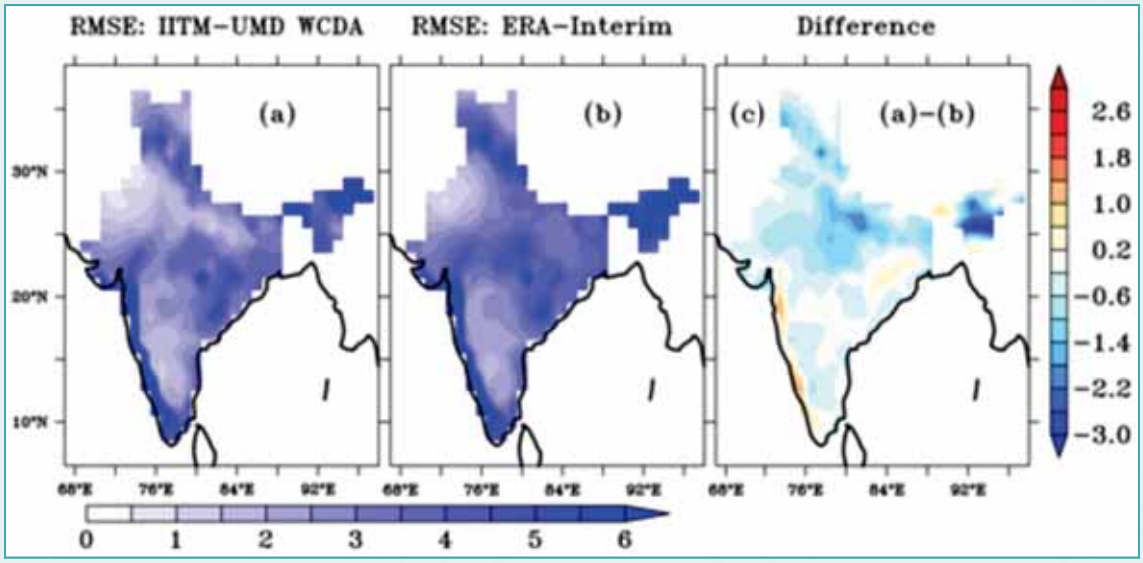


***Fig. 3.4:** RMSE in the analysis of precipitation (mm/day) for (**a**) IITM-UMD WCDA (T126, ~108 km); (**b**) ERA-Interim (T255, ~80 km); and (**c**) Difference in RMSE (IITM-UMD WCDA minus ERA-Interim). Analysis period: 2003-2009; truth considered: IMD gridded rainfall data. The RMSE in precipitation improved in CFS LETKF when compared with relatively high resolution ERA-Interim analysis.*

3.1.4. Impact of horizontal resolution on sea surface temperature bias and air-sea interactions over the tropical Indian Ocean in CFSv2 coupled model

The high resolution (T382, ~38 km) configuration of GFS in CFSv2 has reasonably reduced the SST cold bias (−0.8 to −0.2 °C) over southern Tropical Indian Ocean (TIO) and (−0.69 to 0.07 °C) over northern TIO (**Fig. 3.5**) compared to low resolution (GFS T126, ~100 km). A mixed layer heat budget analysis was conducted to understand the causative factors responsible for improved SST simulation. The improvement in net heat fluxes resulted in reduced biases in SST over TIO in T382 simulation. Better simulation of the entrainment process has further improved SST over Southern TIO. The high-resolution atmospheric model was able to resolve convection centres reasonably well; therefore, it resulted in better simulation of winds, which enabled better prediction of ocean mixed layer. The low and middle clouds were also better resolved in high resolution run, the total cloud cover is well predicted by the T382 run (**Fig. 3.6**), hence the biases in radiative and heat fluxes decreased

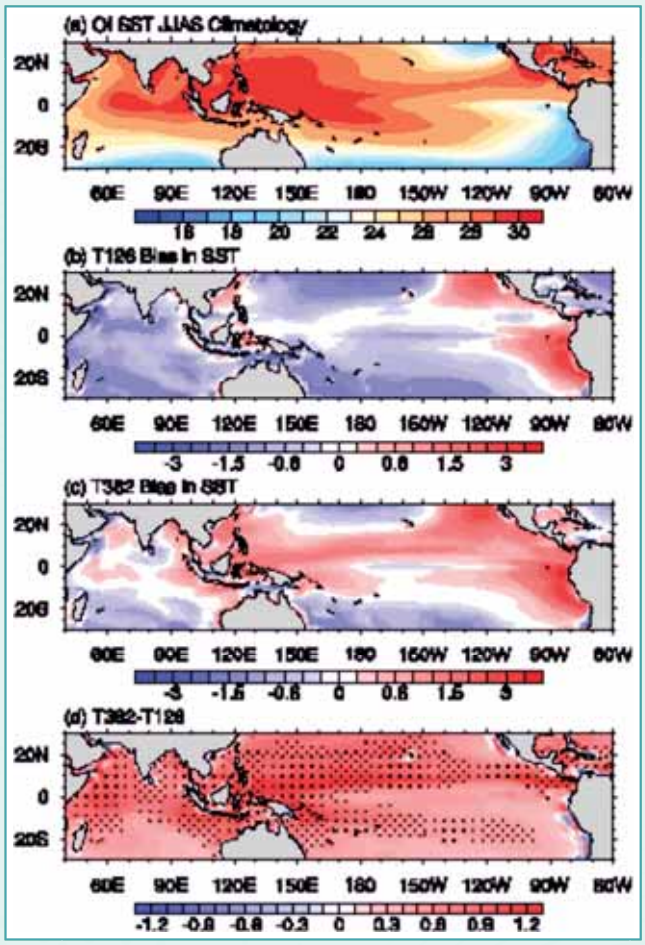


*Fig. 3.5: (**a**) Climatological seasonal (JJAS) mean SST (°C) from observation (OI); bias in predicted SST (°C) from (**b**) T126 run, (**c**) T382 run; the biases are computed with respect to observations, (**d**) difference between biases (T382 minus T126), statistically significant (95% confidence level) differences are dotted. The cold biases in SST is reduced in CFSv2 (T382 atmosphere) compared to CFSv2 (T126 atmosphere).*

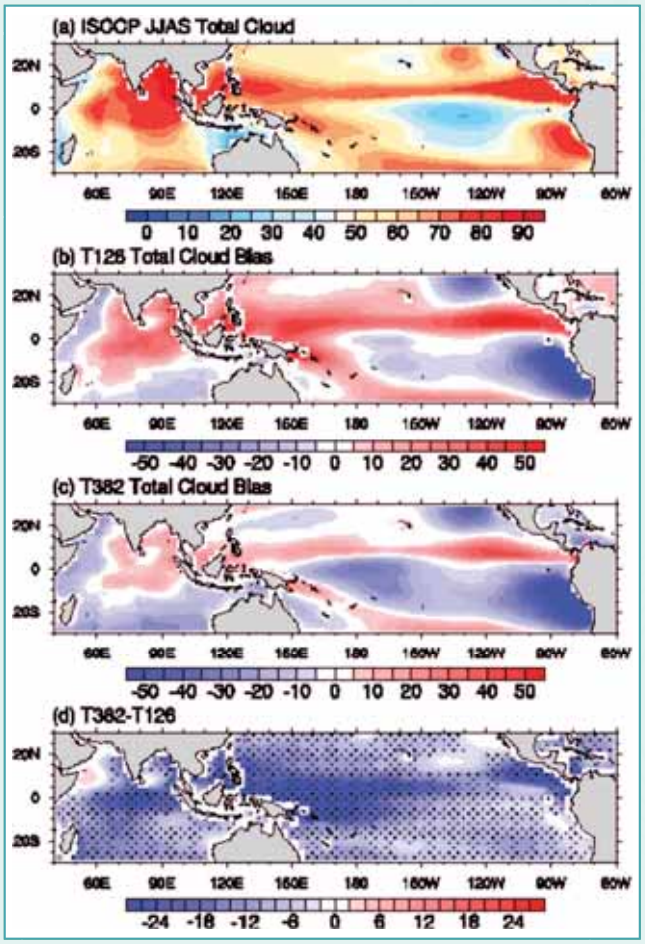


*Fig. 3.6: (**a**) Climatological seasonal (JJAS) mean of percentage of total cloud cover from observation (ISCCP); bias in percentage of total cloud cover predicted from (**b**) T126 run, (**c**) T382 run; the biases were computed with respect to observations, (**d**) difference between biases (T382 minus T126), statistically significant (95% confidence level) differences are dotted. The high resolution configuration of CFSv2 atmospheric model (T382) has well resolved the clouds, thereby improved the simulation of radiation fluxes. In addition, the T382 configuration has accurately simulated the convection centres, winds. These improvements in T382 were responsible for the observed accurate simulation of MLD and SST in high resolution configuration compared to low resolution configuration (T126).*

significantly compared to its lower resolution model, which improved the radiation fluxes and was responsible for the observed improvement in SST and mixed layer prediction. The dominance of biases in net shortwave radiation resulted in moderate positive SST biases over the Northern tropical Pacific Ocean. [***Hari K.B.R.R., Sreenivas P., Rao Suryachandra A., George G., Salunke K., Krishna P.M., Dandi A.R., Rao D.N.***, *Impact of horizontal resolution on sea surface temperature bias and air-sea interactions over the tropical Indian Ocean in CFSv2 coupled model,* ***International Journal of Climatology****, 40, September 2020, 4903-4921*]

Developmental Activities

3.1.5. Continuation of Monsoon Mission: The Monsoon Mission has significantly contributed for national development plans of the Government of India and has benefitted several Ministries and Departments of Govt. of India, National Disaster Management, various important sectors, farmers, fishermen and the common public of the country in general. The achievements and contributions of the Monsoon Mission Phase-II have been highly appreciated by the Independent Review committee (IRC) constituted by the Ministry of Earth Sciences (MoES), Govt. of India. After the critical review, the Committee recommended the continuation of Monsoon Mission Phase-II (14th Finance commission, 2017-20) to Monsoon Mission Phase-III (15th Finance Commission, 2020-24).

3.1.6. NCAER Report on Monsoon Mission and HPC: The Ministry of Earth Sciences (MoES) commissioned the National Council for Applied Economic Research (NCAER), New Delhi to conduct a study on estimating the economic benefits of MoES' investment in Monsoon Mission and High Performance Computing facilities. A report on this subject based on the NCAER study was published in July 2020. NCAER has clearly brought out the improvement in skill of the forecasts, its acceptability and its importance in various sectors and has mentioned that Monsoon Mission, augmented with HPC expenses, produced economic benefits to the country to the tune of more than Rs. 50,000 Crores, which is an economic return of more than 50 times the investment on this programme by the Government of India.

3.1.7. Development of a Dynamical System for Lightning Prediction: Evaluations of the dynamical system based on dynamical lightning parameterization (DLP) scheme, and several diagnostic methods have been completed. Various simulation/forecasting strategies (e.g., four nested, two nested or single domain approach with explicit microphysics) have been rigorously tested to reduce computation time without compromising efficacy in the results. Real-time operational forecast runs are being carried out on regular basis from March 2019 onward. The first version of the dynamical system has already been handed over to IMD in 2019, with installation and sharing of the full codes. Efforts are on to publish the scientific results in peer-reviewed journals. Verification of lightning forecast, obtained by Dynamical System for Lightning Prediction, has utilized observations of lightning occurrences.

3.2. Extended Range Prediction

Developmental Activities

3.2.1. Real-time Extended Range Prediction of 2020 monsoon

Real-time Extended Range Prediction of active/break spells of Indian Summer Monsoon (ISM) for the 2020 monsoon season (June-September) was prepared by using the real time weekly operational forecast generated by IMD using the Multi Model Ensemble (MME) prediction system developed at IITM. Onset of monsoon over Kerala and slightly rapid progress was captured well in advance. Transition from normal to weaker phase in July, active phase of monsoon in August, revival of monsoon in the second half of September and delayed withdrawal were well predicted in two to three weeks in advance. Quantitatively, the extended range prediction showed very good skill up to two weeks on all India level. Over the country as a whole and over the five different homogeneous regions of India, the MME forecast provided useful guidance indicating more promising results with the correlation coefficient (CC) between observed and forecasted rainfall departure (**Fig. 3.7**). The CCs were found to be significant till two weeks lead time.

3.2.2. Development of multi-physics ensemble prediction for extended range

The new extended range prediction strategy's primary aim is to accomplish skill by developing a physics-based ensemble in which the spread in the ensembles emerges from the model physics. The earlier studies have suggested that the physics-ensemble has a larger spread than the initial-condition-ensemble. Hence, it provides a better probabilistic forecast for the extreme weather anomalies. The multi-physics strategy uses a combination of convection and microphysics parameterization schemes in NCEP's Climate Forecast System (CFS). It runs at seamless resolution mode for 36 days, where a higher resolution of T574 (~23 km) transitions into T382 (~38 km) after 15 days. The new system exhibits a gain of 2-4 days predictability over its predecessor at a sub-division level. Further assessment of the new system will improve the understanding of this physics-based ensemble's strengths and limitations and help refine the prediction strategy.

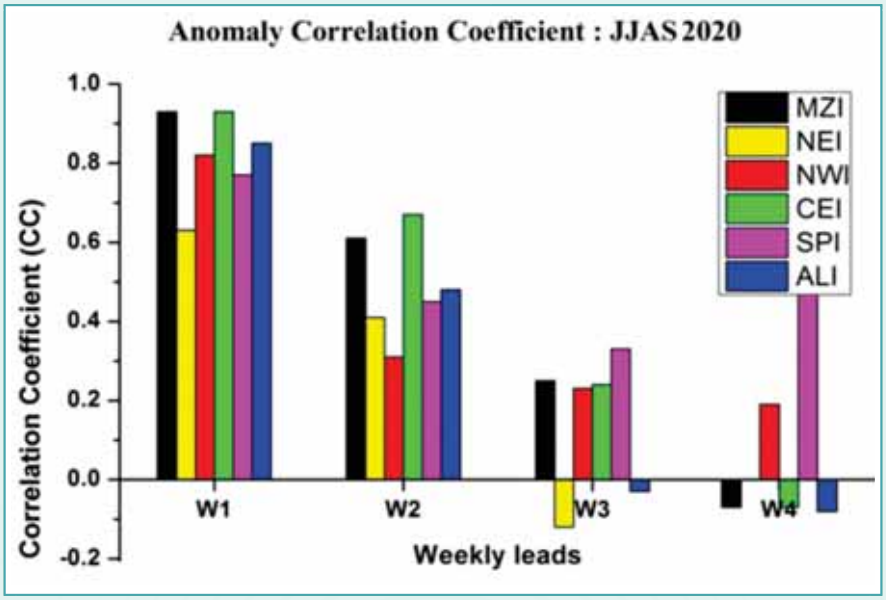


Fig. 3.7: *Anomaly Correlation Coefficient between predicted and observed weekly-averaged rainfall over 5 homogeneous regions of India [monsoon zone of India (MZI), central India (CEI), northeast India (NEI), northwest India (NWI), and south peninsular India (SPI)] and All over India (ALI).*

Basic Research

3.2.3. MJO prediction skill using IITM extended range prediction system and comparison with ECMWF S2S

Eastward propagating Madden-Julian Oscillation (MJO) is a dominant mode of the intra-seasonal variability and hence a potential source of intra-seasonal predictability. Therefore, advancing MJO prediction using the state-of-the-art dynamical model is of utmost importance for improving intra-seasonal prediction. The prediction skill and predictability of MJO are assessed using 44 members ensemble hindcast (16 years data; 2001-2016) of CFSv2 based extended range prediction (ERP) system of IITM as well as 10 member ensemble hindcast (16 years data; 2001-2016) of ECMWF S2S dataset. The MJO is diagnosed using a newly developed Extended Empirical Orthogonal Function (EEOF) analysis. Near equatorial (15° S - 15° N) model anomaly fields are projected onto the leading pair of observed Eigen modes. The leading pair of observed Eigen modes is obtained based on the EEOF analysis of the combined field of zonal wind at 200 hPa (U200), zonal wind at 850 hPa (U850) and velocity potential at 200 hPa (chi200). Model forecasted principal components (PCs) are quantitatively compared with observed PCs using bivariate correlation coefficient and root mean square error (RMSE). It was found that MJO could be predicted up to around 22 days (around 31 days) for IITM-ERP system (ECMWF S2S dataset) as measured by anomaly correlation coefficient remains larger than 0.5 and RMSE remains lower than 1.4. This prediction skill is quite low compared to potential predictability, which is estimated as more than 40 days both for IITM-ERP and ECMWF system. MJO prediction skill varies with initial MJO phase, particularly at the longer lead. This variation is more significant for the ECMWF system. Model (both for IITM-ERP and ECMWF) predicted amplitude drops at a faster rate and phase propagation speed for almost all initial phase is slower and amplitude is weaker compared to the observation. It could be concluded that even the state-of-the-art models [IITM-ERP (basically NCEP CFSv2) and ECMWF] are also not free from systematic errors/biases. Hence, there is an enormous space for improving MJO prediction skill by reducing these errors/biases in the dynamical model and error in the initial condition. (**Fig. 3.8**) [***Dey A., Chattopadhyay R., Sahai S.K., Mandal R.,***

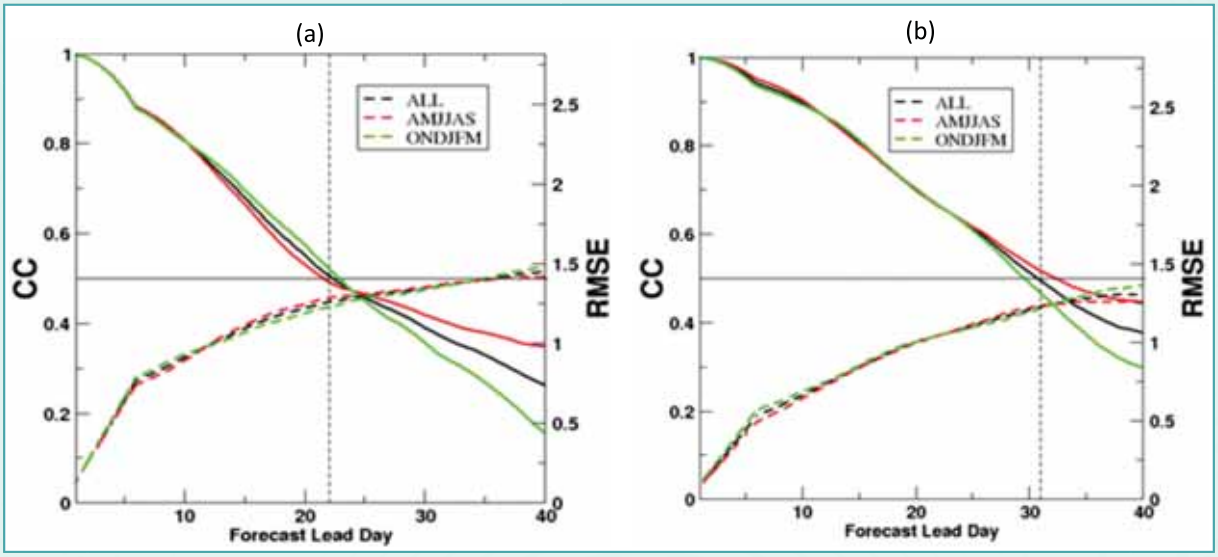


Fig. 3.8: *Bivariate Anomaly Correlation Coefficient (ACC; solid line) and Root Mean Squared Error (RMSE; dashed line) for (**a**) IITM-ERP and (**b**) ECMWF. Different colours represent different seasons (Green for boreal winter, red for boreal summer, and black for all seasons). The horizontal line intersects at 0.5 on correlation axis (left) and at 1.41 along RMSE axis (right).*

***Joseph S., Phani M.K.**, Pattanaik D.R., MJO Prediction Skill Using IITM Extended Range Prediction System and Comparison with ECMWF S2S, **Pure and Applied Geophysics**, 177, October 2020, 5067-5079, DOI: 10.1007/s00024-020-02487-z*]

3.2.4. An improved cyclogenesis potential and storm evolution parameter for north Indian Ocean

Flawless subseasonal prediction of tropical cyclogenesis and evolution over the narrow basin of north Indian Ocean (NIO) demands accurate rendition of the crucial parameters that influence the development of cyclonic storms. While many genesis potential indices are used for climatological monitoring and prediction of cyclogenesis globally, their skill in subseasonal prediction of individual storm development, especially near coastlines are limited. Thus, an improved genesis potential parameter (IGPP) is introduced in here which can capture both cyclogenesis and daily evolution of cyclonic systems over NIO. The IGPP is a revised version of Kotal-Genesis Potential Parameter (KGPP) implemented by India Meteorological Department (IMD) for short-range operational cyclogenesis prediction over NIO. Daily averaged ERA-5 and

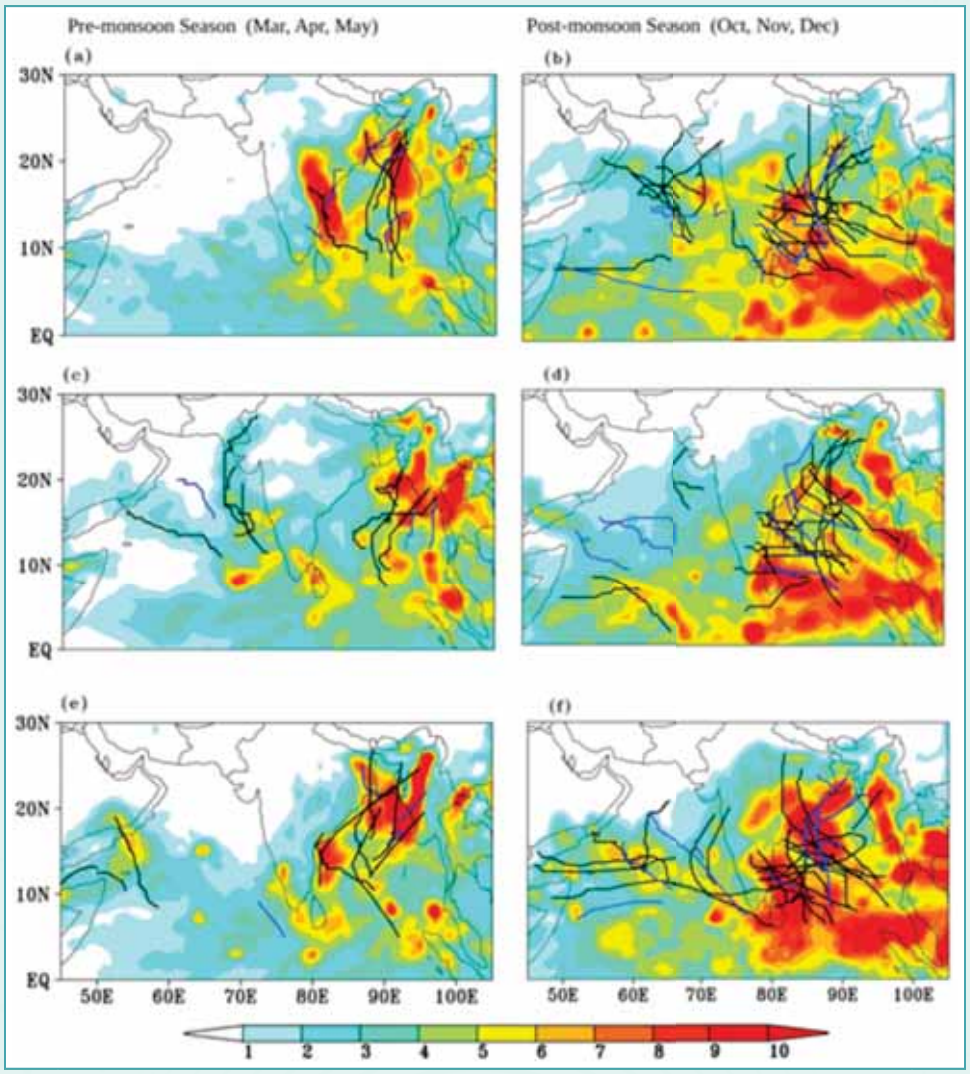


***Fig. 3.9:** Seasonal climatology for Improved Genesis Potential Parameter (IGPP) (shaded) over NIO during pre-monsoon and post-monsoon seasons of past three decades: (**a-b**) 1989-1998, (**c-d**) 1999-2008, and (**e-f**) 2009-2018 years. IGPP analysis is overlaid with corresponding observed best tracks of developing (black) and non-developing (blue) storms during the periods.*

ERA-Interim datasets are used for analysis and comparison of selected cyclonic storms over NIO for the period 1989-2018. Results reveal that false alarms and over-estimation of values present in KGPP are remarkably reduced by using IGPP for all the analyzed storms. Moreover, IGPP outperforms KGPP in distinguishing between developing and non-developing storms by accurately representing the storm genesis, evolution, rapid intensification and intensity variations. Thus, IGPP can be implemented operationally for improving the real-time prediction of cyclogenesis and storm evolution over NIO. (**Fig. 3.9**) [***Ganesh S.S., Abhilash S., Joseph S., Kaur M., Dey A., Raju M., Phani R., Chattopadhyay R.***, *Pattanaik D.R.,* ***Sahai A.K.****, An Improved Cyclogenesis Potential and Storm Evolution Parameter for North Indian Ocean,* ***Earth and Space Science****, 7: e2020EA001209, October 2020, DOI: 10.1029/2020EA001209*]

3.2.5. Dynamical downscaling of a multi-model ensemble prediction system: Application to tropical cyclones

Dynamical downscaling is attempted to improve north Indian Ocean (NIO) tropical cyclone prediction from a global multi-model ensemble prediction system using weather research and forecasting (WRF) model. A total of 16 ensembles were used in the WRF simulations, these ensembles were bias corrected prior to downscaling for model climatological errors. The ensemble mean constructed from the output of all downscaled ensembles was analyzed for added value to global predictions. This mean was also compared against observation as well as high-resolution (12 km) deterministic forecast from global forecast system (GFS). Two devastating NIO tropical cyclone cases of the year 2017, which were not reliably predicted by global systems, were studied. The results showed that downscaled predictions well simulated the intensity and spatial distribution of the rainfall and relative vorticity associated with these cyclonic storms. The wind and temperature vertical profiles during cyclone mature stage were also captured more accurately than raw prediction and high-resolution global deterministic forecast. The study affirmed the adequacy of dynamical downscaling in predicting cyclonic storms over global real-time weather forecasting system. (**Fig. 3.10**) [***Kaur M., Krishna R.P.M., Joseph S., Dey Avijit, Raju M., Chattopadhyay R., Sahai A.K., Mukhopadhyay P.****, Abhilash S, Dynamical downscaling of a multimodel ensemble prediction system: Application to tropical cyclones,* ***Atmospheric Science Letters****, 21: e971, August 2020, DOI:10.1002/asl.971*]

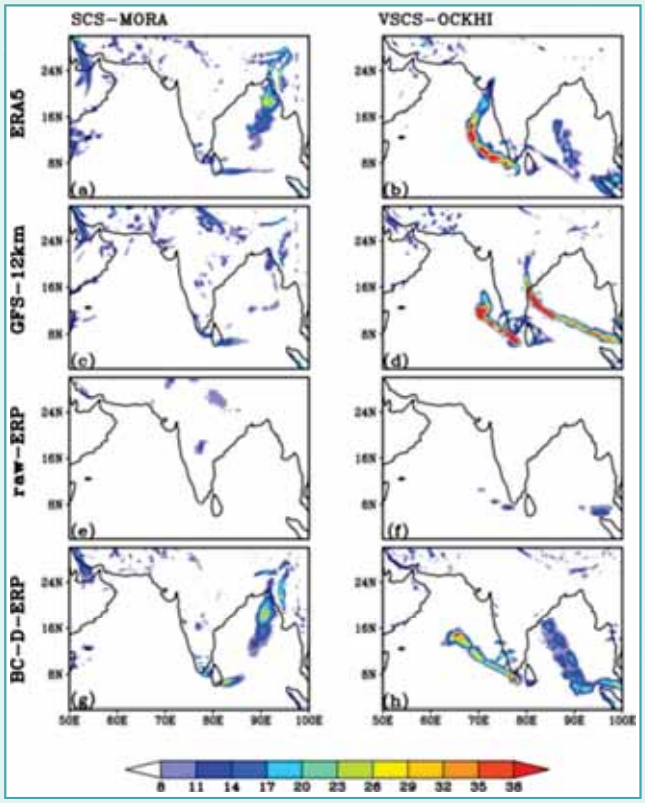


Fig. 3.10: *Maximum values of 850 hPa vorticity ($\times 10^{-5}$ s^{-1}) during the evolution of cyclone Mora (left column) and cyclone Ockhi (right column) for (top to bottom) ERA-5 reanalysis (**a-b**), GFS-12km (**c-d**), raw-ERP (**e-f**), and BC-D-ERP (**g-h**), respectively.*

3.2.6. Development of a probabilistic early health warning system based on meteorological parameters

Among other diseases, malaria and diarrhoea have a large disease burden in India, especially among children. Changes in rainfall and temperature patterns likely play a major role in the increased incidences of these diseases across geographical

locations. A method is proposed for probabilistic forecasting of the disease incidences in extended range time scale (2-3 weeks in advance) over India based on an unsupervised pattern recognition technique that uses meteorological parameters as inputs and which can be applied to any geographical location over India. To verify the robustness of this newly developed early warning system, detailed analysis has been made in the incidences of malaria and diarrhoea over two districts of the State of Maharashtra. It is found that the increased probabilities of high (less) rainfall, high (low) minimum temperature and low (moderate) maximum temperature were more (less) conducive for both diseases over these locations, but had different thresholds. With the categorical probabilistic forecasts of disease incidences, this early health warning system is found to be a useful tool with reasonable skill providing the climate-health outlook about possible disease incidences at least two weeks in advance for any location or grid over India. (**Fig. 3.11**) [***Sahai A.K., Mandal R.,***

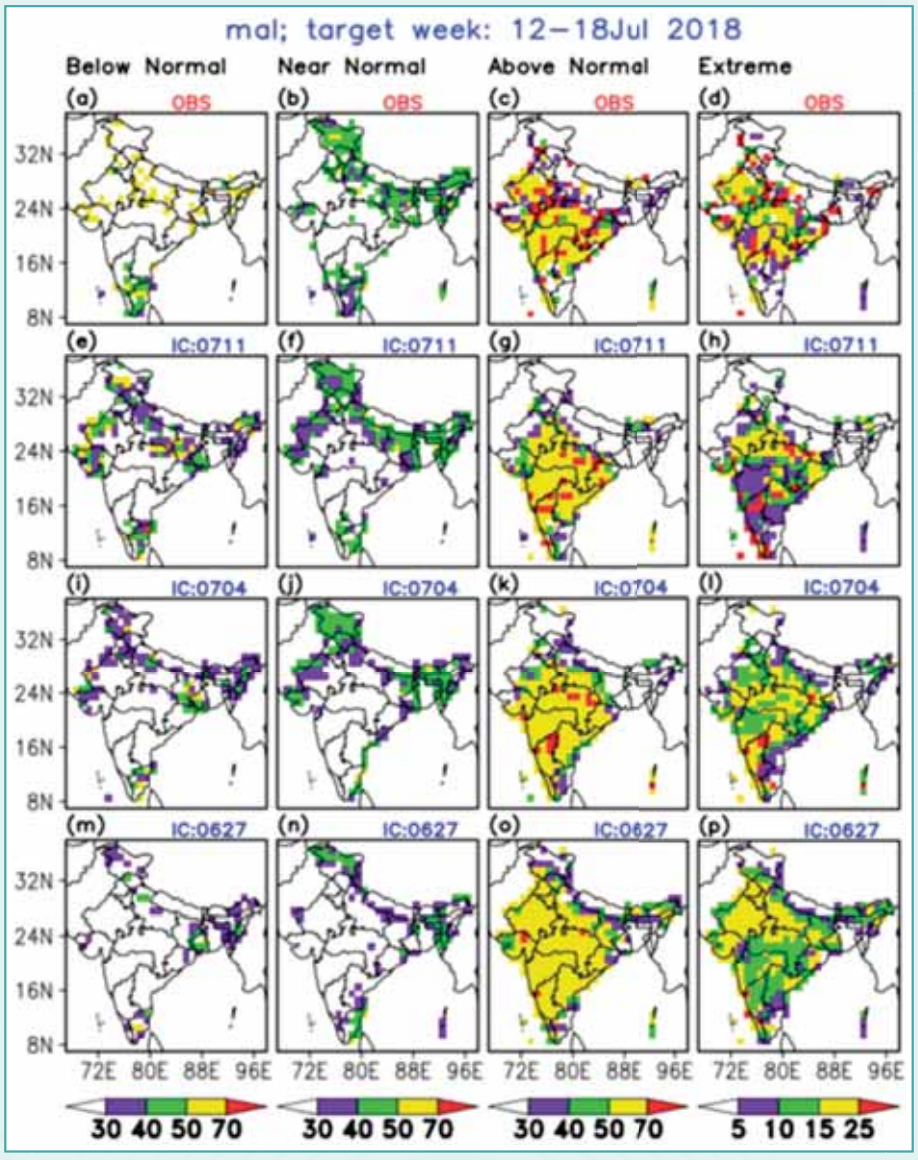


Fig. 3.11: *Probabilities of Below Normal, Near Normal, Above Normal, and Extreme categories of occurrences of Malaria during 12-18 July 2018 for observation (**a-d**) and forecasts from initial conditions 11th July (**e-h**), 4th July (**i-l**) and 27th June (**m-p**) of 2018.*

***Joseph S.**, Saha S., Awate P., Dutta S., **Dey A., Chattopadhyay R., Phani R.**, Pattanaik D.R., Despande S, Development of a probabilistic early health warning system based on meteorological parameters, **Scientific Reports**, 10:14741, September 2020, DOI:10.1038/s41598-020-71668-6*]

3.2.7. Climatological patterns of subseasonal eddy flux transfer based on the co-spectral analysis over the Indian region and the derivation of an index of eddy transfer for operational tracking

The heat and momentum flux transfer by transient eddies from the extratropical to the tropical (E2T) region causes a significant variation of weather and climate in the tropical region. Such transports also cause a regional departure from zonally symmetric large scale circulation patterns caused by the Hadley type transports. During boreal summer monsoon season, the zonally symmetric Hadley type circulation is typically considered in theoretical as well as modelling studies. A method based on the calculation of the E-vector components and co-spectra analysis is introduced to diagnose the zonally asymmetric climatological patterns of E2T transport and its subseasonal variability. The spectral analysis identifies the climatological as well as low and high frequency patterns of the transient eddy heat and momentum flux transfer over the Indian region and compares the result with traditional Eliassen-Palm (EP) flux based stationary eddy patterns. The zonal, seasonal, and vertical asymmetries in the transport of transient eddy heat and momentum flux were identified. Also, the seasonality and frequency dependence of northeast to the southwest tilt of transient eddies transporting momentum and heat flux were clearly categorized. Based on the climatological patterns, the wavelet transform approach was used to study the subseasonal variability of the eddy transport indices. A set of indices was defined, which identifies the subseasonal temporal variation of the E2T transfer mechanism. These indices could be used to operationally track the E2T eddy flux transfer both in observation and in forecast models. (**Fig. 3.12**) [***Kalshetti M., Chattopadhyay R., Phani R., Joseph S., Sahai A.K.**, Climatological patterns of subseasonal eddy flux transfer based on the co-spectral analysis over the Indian region and the derivation of an index of eddy transfer for operational tracking, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6821, E1906-E1925*]

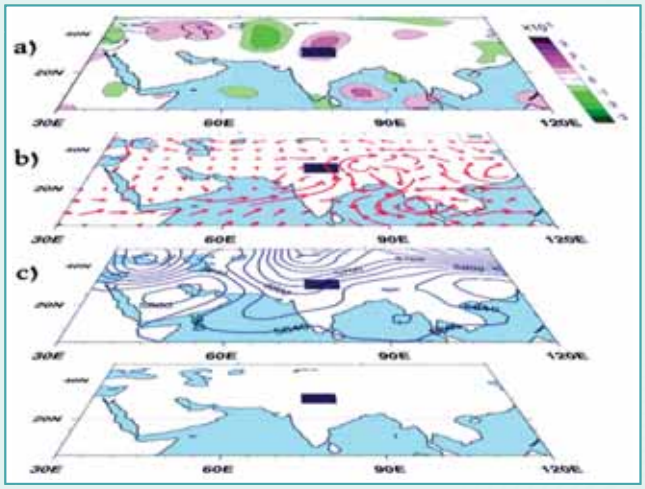


***Fig. 3.12:** Composites of (**a**) Divergence at 200hPa, (**b**) Vertically integrated (1000-300hPa) moisture transport, and (**c**) Geopotential Height at 500hPa during 16-18 June 2013. The black rectangular region represents area under influence of extratropical-tropical interaction.*

3.2.8. Segregation of forecast errors in the planetary boundary layer parameterization over the state of Odisha and neighboring regions in India during summer monsoon season

Planetary boundary layer parameterization (PBL) is a key factor influencing weather forecast skills. A quantitative illustration of the segregation of forecast errors and their growth arising from different PBL schemes of the Weather Research and Forecasting (WRF) model is provided. A total of 1112 simulations were carried out using four PBL schemes, *i.e.*, Yonsei University (YSU), Mellor-Yamada-Nakanishi-Niino (MYNN), Asymmetric Convective Model version 2 (ACM2), and medium-range forecast (MRF) for two contrasting monsoon seasons, *i.e.*, 2013 (normal) and 2014 (deficit). The overall results suggested the errors in thermodynamical variables (*i.e.*, temperature and

relative humidity) were large compared to the dynamical variable (*i.e.*, wind). For the normal monsoon year (*i.e.*, 2013), the MRF and MYNN exhibited the lowest root mean square error (RMSE) of temperature compared to ACM2 and YSU, whereas MRF (MYNN) showed the lowest (highest) error growth at 24-48 h (72-96 h). The deficit year (2014) had a higher temperature error compared to that of the normal monsoon year (2013), which might be due to frequent monsoon break periods. The spatial distribution of wind exhibited the lowest systematic error for MRF with lead time up to 48 h. The subsequent decrease (increase) of convergence (divergence) of error flux over northern Odisha and increase (decrease) of the same over southern Odisha suggested that the error propagation occurs from north to south. In general, both the convergence and divergence of error energy were found to be weak in MRF and MYNN, attributable to the lower error growth rate and hence, the smaller systematic errors compared to ACM2 and YSU for both these monsoon seasons. Also, it was found that the systematic component of the linear (nonlinear) error growth rate is contributed by the physics (dynamics) components of the model. These findings will provide guidance for the model community and operational agencies to make an optimal choice of PBL parameterizations, particularly for the monsoon forecast. (**Fig. 3.13**) [*Hazra V., Pattnaik S.,* ***De S.,*** *Vishwakarma V., Segregation of Forecast Errors in the Planetary Boundary Layer Parameterization Over the State of Odisha and Neighboring Regions in India During Summer Monsoon Season,* ***Pure and Applied Geophysics****, January 2021, 178, 583-601, DOI: 10.1007/s00024-020-02651-5]*

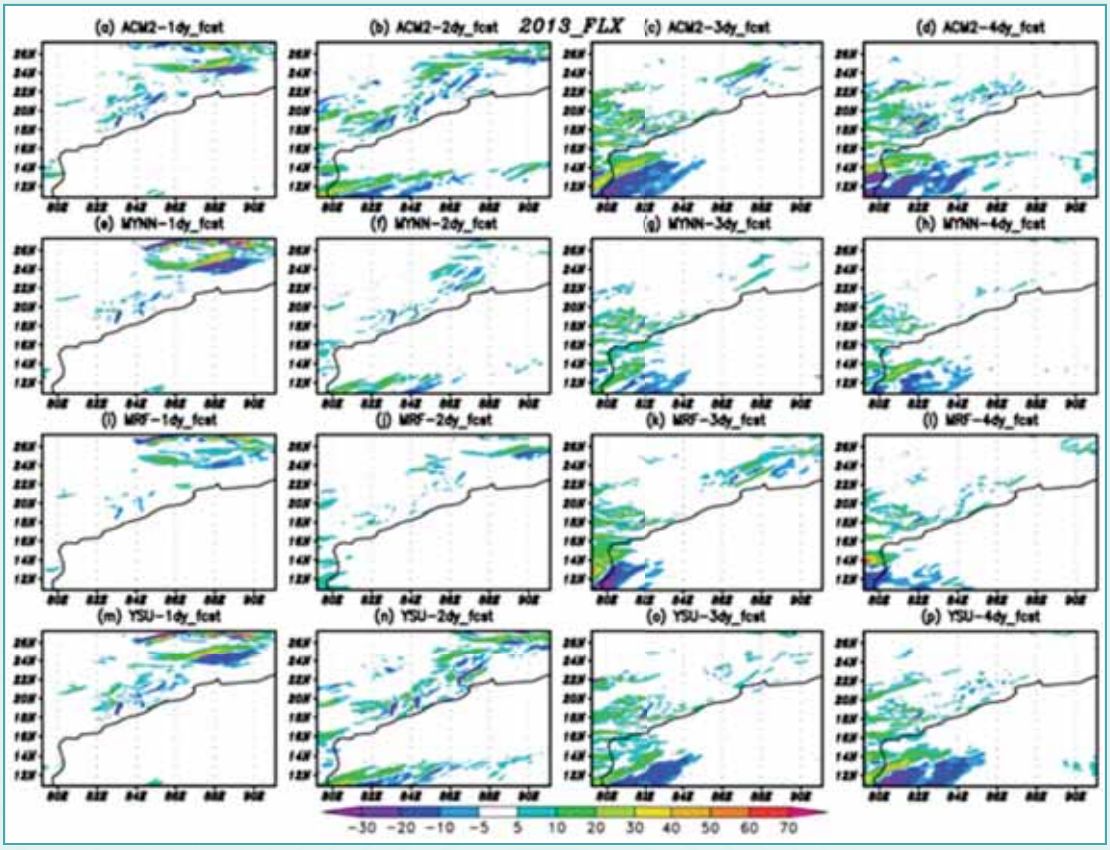


Fig. 3.13: *Spatial distribution of nonlinear systematic error energy flux (m^2/Sec.^{3}) of WRF model for different boundary layer schemes over the state of Odisha and neighbourhood during 2013.*

3.3. Parameterization of Physical Processes and Analysis

Developmental Activities

3.3.1. Development of global forecast system (GFS) with spectral cubic octahedral (Tco) dynamic core

In contrast to the Gaussian linear grid system that makes the grid almost uniform across the globe (*e.g.*, GFS T1534; ~12.5 km), the spectral grid in cubic octahedral framework has a non-uniform grid size which gradually enhances toward the equator (**Fig. 3.14**). The Tco grid provides certain advantage over that of the conventional Gaussian linear grid including the scalability which makes it a better candidate particularly for the utilization of high power computer (HPC). With an aim to build a high resolution GFS in Tco grid for improving the forecast over India, efforts were made to first test the GFS in an equivalent Tco grid resolution as that of T1534 over equator, and then built the GFS at Tco765 which makes the grid size at equator very close to 12.5 km much similar to that of GFST1534. The GFS Tco765 is being run for the monsoon season of 2019 and compared with the operational GFS T1534. The precipitation forecast bias (mm day^{-1}) for GFS T1534 (**Fig. 3.15**, left panels) and GFS Tco765 (**Fig. 3.15**, right panels) is shown for day 1, day 3 and day 5 lead time. The forecast precipitation bias of both the models appears to be similar. The dry bias over the Bay of Bengal is evident in both the versions. Wet bias over the central Bay of Bengal is present in both the versions. However, the wet bias over the equatorial Indian Ocean seen in GFS T1534 is reduced in GFS Tco765 forecast. The Tco765 is showing equivalent fidelity as that of GFS T1534 and the next level of development would be carried out on higher cubic octahedral truncation for enhancing the resolution of GFS over the tropics.

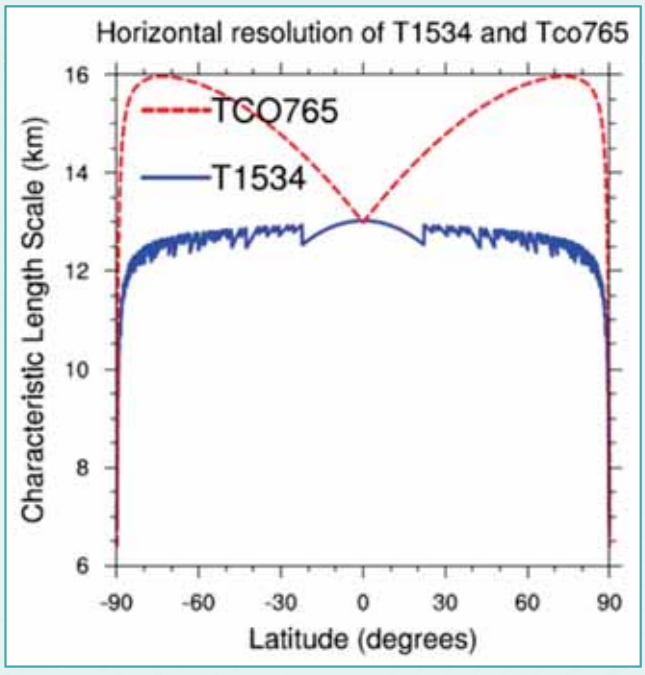


Fig. 3.14: *Variation of horizontal resolution (characteristic Length Scale) with latitude in T1534 and Tco765.*

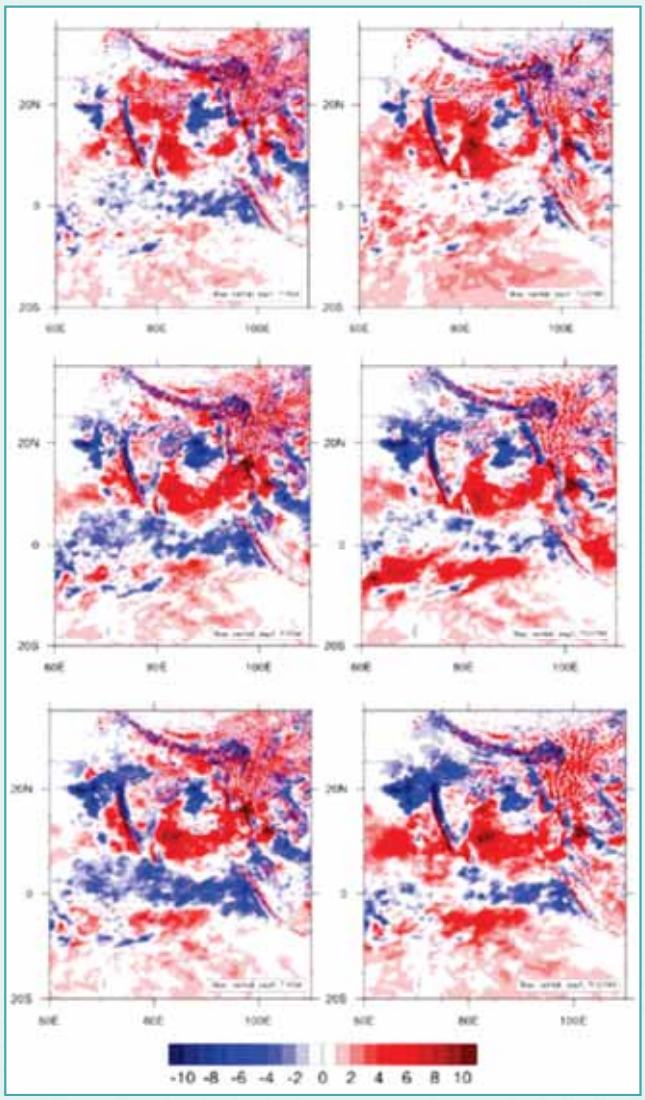


Fig. 3.15: *Day 1 (upper panel), day 3 (middle Panel) and day 5 (lower panel) lead mean rainfall bias (JJAS mean) over ISM region (Left panels for GFS T1534 and right panels are for GFSTco765).*

Basic Research

3.3.2. The impact of modified rate of precipitation conversion parameter in the convective parameterization scheme of operational weather forecast model (GFS T1534) over Indian summer monsoon region

The performance of the present operational global forecast system (GFS) at T1534 (~12.5 km) horizontal resolution with modified fractional cloud condensate to precipitation conversion parameter in the revised simplified Arakawa-Schubert (RSAS) convection scheme is evaluated for the summer monsoon seasons of 2018 and 2019 over the Indian region. The modified parameter has the form of an exponentially decreasing function of temperature above the freezing level. In contrast, below the freezing level, it is constant and is similar to default conversion parameter. The results revealed that the GFS T1534 with modified conversion parameter (EXPT) shows better fidelity in forecasting the mean summer monsoon rainfall over the Indian subcontinent region as compared to default GFS T1534 (CTRL). The rainfall probability distribution function analysis indicates a notable improvement in forecasting moderate and heavier category rainfall in EXPT as compared to CTRL. The improved distribution of total rainfall is found to be contributed by the proper forecasting of convective and large-scale rainfall in EXPT (**Fig. 3.16**) which has eventually improved the total rainfall probability distribution function in EXPT (**Fig. 3.17**). It is likely that the reduced rate of conversion of cloud condensate to convective precipitation above the freezing level leads to a reduction in the convective rainfall, which eventually increases moisture in the upper level through detrainment and hence, enhances the large-scale precipitation. Further, EXPT showed relative improvement in forecasting outgoing longwave radiation, wind circulation, cloud fraction, dynamical

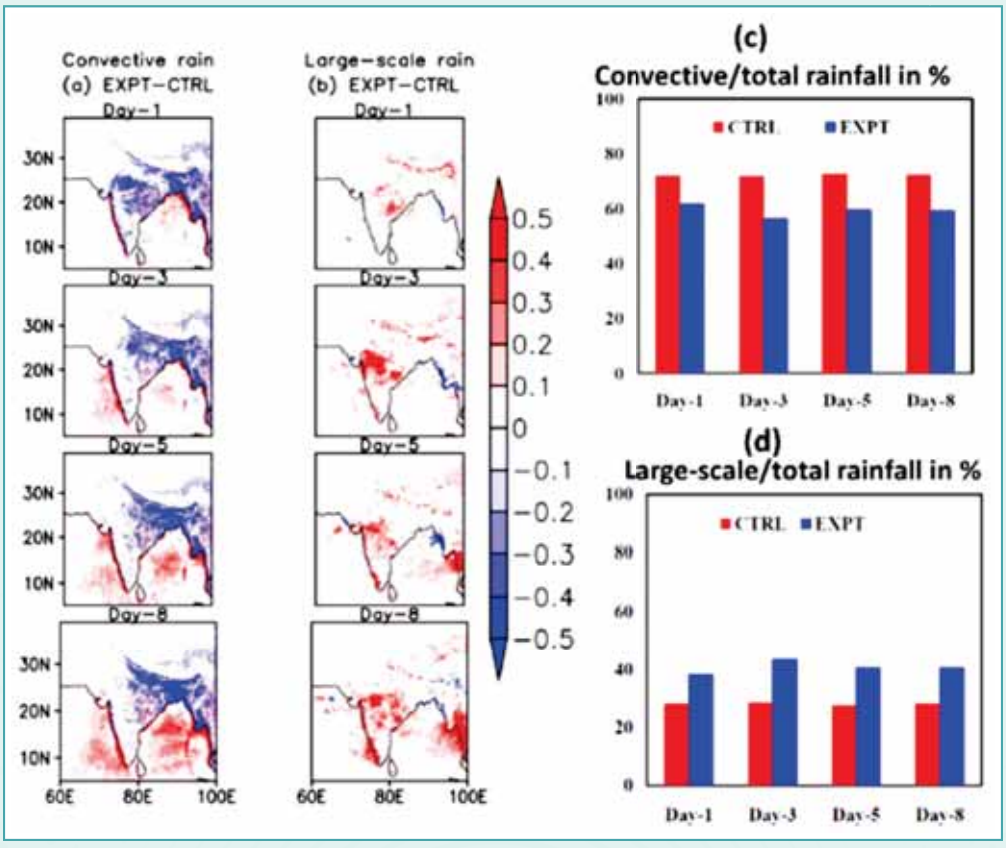


Fig. 3.16: *Spatial distribution of (**a**) convective rainfall (cm day^{-1}) and (**b**) large-scale rainfall (cm day^{-1}) in EXPT with respect to CTRL for different lead times. (**c**) and (**d**) denote convective and large-scale rain fraction over the continental Indian region for various lead days, respectively.*

thermodynamical processes, and moist-convective feedback through improved lower tropospheric moistening over the Indian region. Finally, various skill score analyses suggest that EXPT shows better skill in predicting moderate and heavier category rainfall with longer lead time over the Indian subcontinent region. Considering the large socioeconomic impact of heavy and extreme precipitation over India, the modified conversion parameter can be incorporated in the present operational GFS T1534 model. [***Ganai M., Tirkey S., Krishna R.P.M., Mukhopadhyay P.,*** *The impact of modified rate of precipitation conversion parameter in the convective parameterization scheme of operational weather forecast model (GFS T1534) over Indian summer monsoon region,* ***Atmospheric Research****, 248: 105185, January 2021, DOI: 10.1016/j.atmosres.2020.105185*]

3.3.3. How changing cloud water to rain conversion profile impacts on radiation and its linkage to a better Indian summer monsoon rainfall simulation?

Effect of modifying cloud water to rain conversion factor above freezing level on radiation flux is

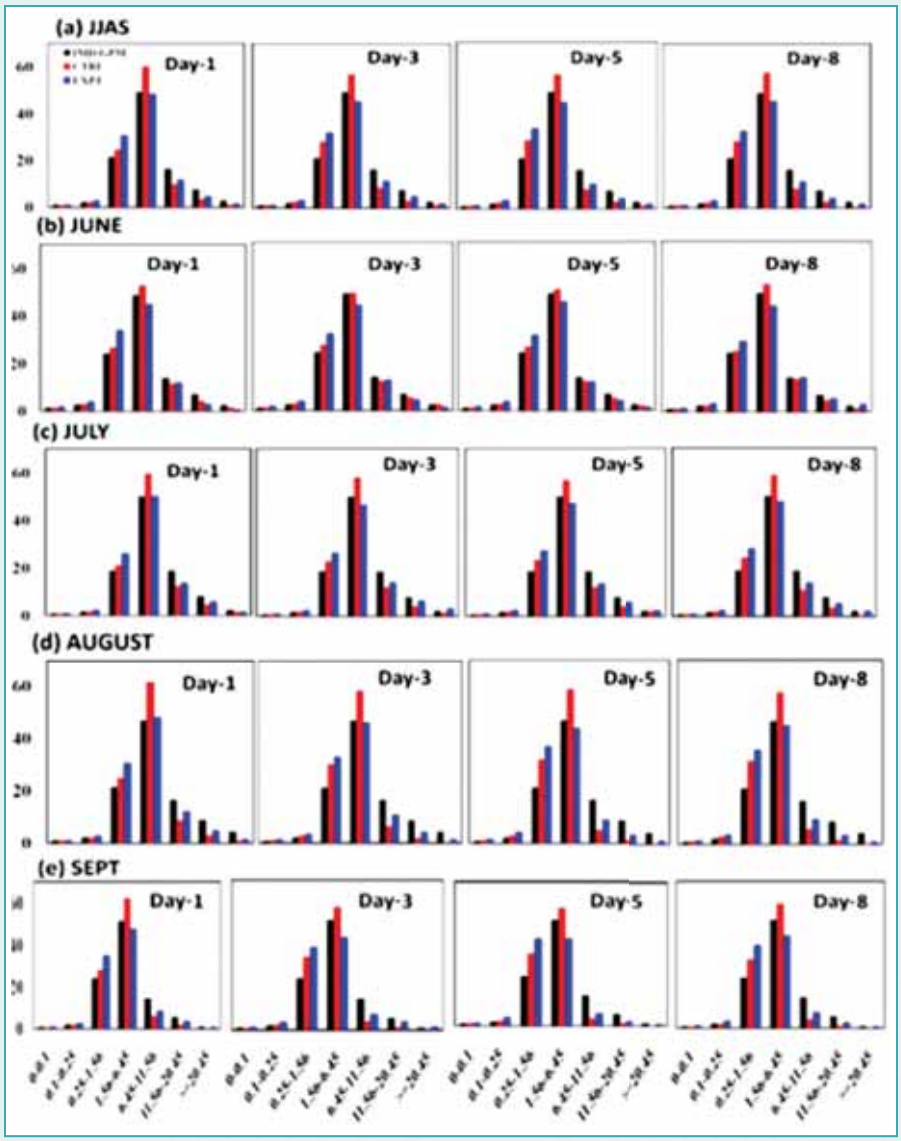


Fig. 3.17: *All India rainfall probability distribution function (%) vs. rain rate (cm day^{-1}) categories during (**a**) JJAS, (**b**) June, (**c**) July, (**d**) August, and (**e**) September for different lead times derived from CTRL and EXPT forecast and compared with IMD-GPM merged gridded data.*

studied. The linkage of cloud radiation interaction with a better Indian summer monsoon (ISM) rainfall simulation has also been investigated. Two simulations were performed with Climate Forecast System version 2 (CFSv2), one with default revised simplified Arakawa-Schubert (RSAS) convection scheme and another with modified RSAS (RSAS-mod) in which the cloud water to precipitation conversion factor is revised. It is observed that both top of the atmosphere (TOA) and surface energy imbalances are improved in the RSAS-mod simulation. The major contribution seems to come from the enhanced reflected shortwave radiation at the TOA. In RSAS-mod, more shortwave radiation is getting reflected at the TOA and thus, less shortwave is available to reach at the surface. It has happened as a consequence of enhanced planetary albedo in RSAS-mod. It is also observed that high cloud cover has increased in RSAS-mod and there is a decrease in low cloud cover. As a result of increased high cloud cover, outgoing longwave radiation has decreased significantly in RSAS-mod. It is also found from the multivariate empirical orthogonal function (MV-EOF) analysis that the composite of longwave cloud radiative forcing corresponding to phases 4 and 5 of boreal summer intraseasonal oscillation (BSISO), which signifies the active phase of ISM, is better simulated in RSAS-mod (**Fig. 3.18**). This has helped in simulating a better seasonal rainfall. [***Goswami T., Mukhopadhyay P., Ganai M., Krishna R.P.M., Mahakur M.***, *Han J., How changing cloud water to rain conversion profile impacts on radiation and its linkage to a better Indian summer monsoon rainfall simulation,* ***Theoretical and Applied Climatology****, 141, August 2020, 947-958, DOI:10.1007/s00704-020-03222-3*]

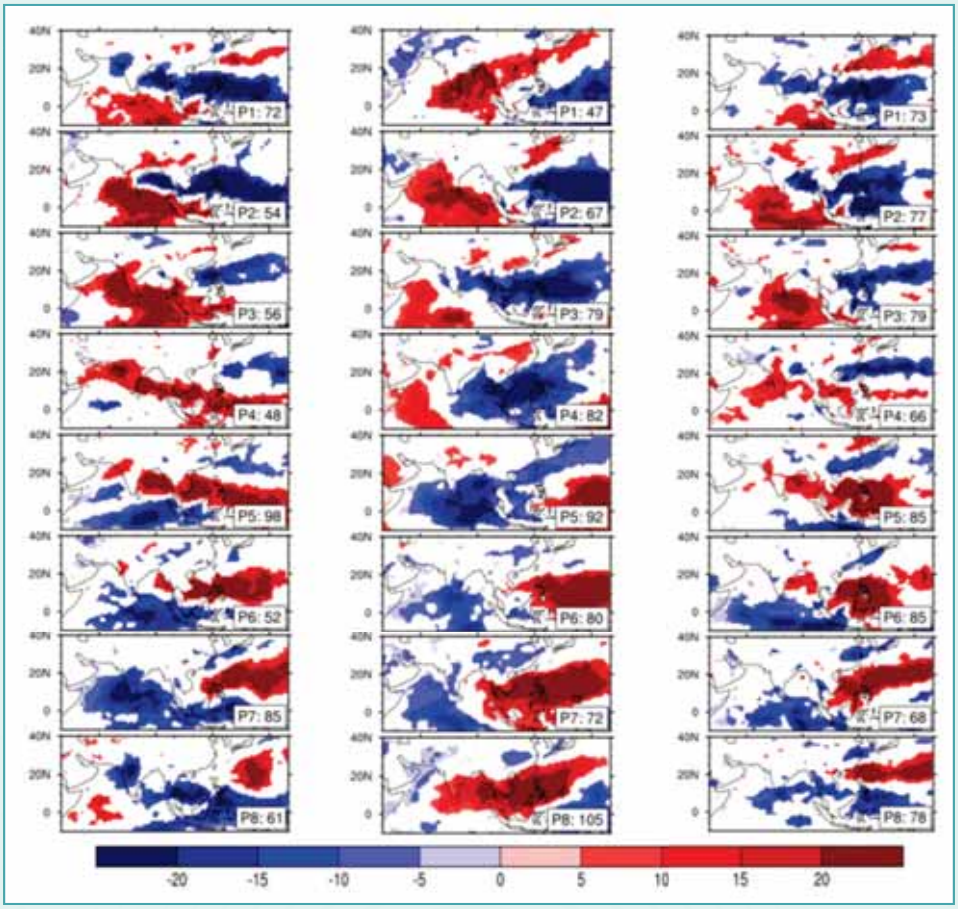


Fig. 3.18: *Composite of longwave cloud radiative forcing anomaly corresponds to the eight phases of BSISO, constructed based on the PC1 and PC2 of MV-EOF of outgoing longwave radiation and zonal wind at 850 hPa. The first, second, and third columns represent the observation, RSAS, and RSAS-mod results, respectively.*

3.3.4. Global ensemble forecast system (GEFS T1534) evaluation for tropical cyclone prediction over the north Indian Ocean

The high-resolution global ensemble prediction system was implemented at IITM in June 2018 and handed over to India Meteorological Department (IMD) for operational running. During the tropical cyclone (TC) season over the north Indian Ocean, real time forecasts of ensemble tracks, intensity and strike probability of TCs are provided to IMD. Here, the skill of the model is evaluated in predicting TCs during 2018, 2019 and two cases in 2020. A total of 13 cases were considered and various skill scores were calculated for the TC predictions. Based on the evaluation, and the importance of the ensemble prediction system for tropical cyclone forecasting is highlighted. The key finding from this analysis is the higher skill of ensemble prediction system based on GEFS at longer lead time as compared to the deterministic prediction (**Fig. 3.19**). This is particularly beneficial for operational forecasters for issuing early warnings. [***Deshpande M., Kanase R., Krishna R,P.M., Tirkey S., Mukhopadhyay P.***, *Prasad V.S., Johny C.J., Durai V.R., Devi S.,* ***Mohapatra M.****, Global Ensemble Forecast System (GEFS T1534) evaluation for tropical cyclone prediction over the North Indian Ocean,* ***Mausam****, 72, January 2021, 119-128*]

3.3.5. Assessment of climate models in relation to the low-level clouds over the southern Indian Ocean

Against the backdrop of limited fidelity of climate models in capturing low-level cloud variability, the representation of the southern Indian Ocean (SIO) marine boundary layer (MBL) clouds and their transition from low to deep cloud were investigated. A historical run of 26 models – that featured in the Coupled Model Intercomparison Project Phase 5 (CMIP5), and the National Centers for Environmental Prediction (NCEP)'s Climate Forecast System version 2.0 (CFSv2) models –

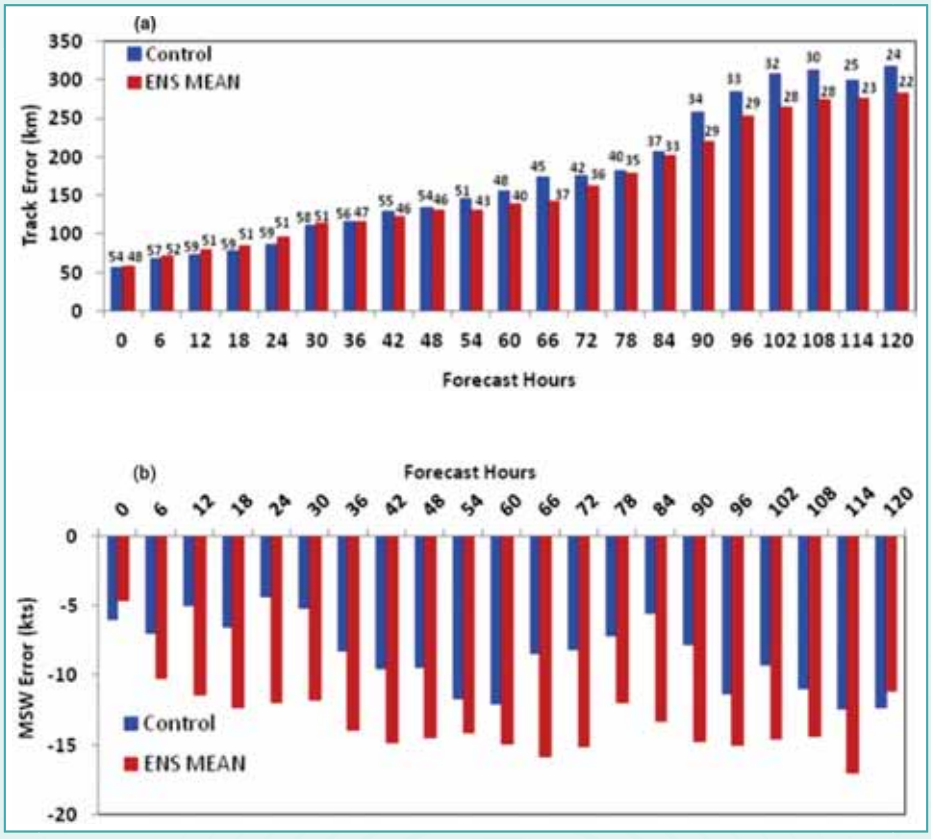


Fig. 3.19: *(**a**) Track Error and (**b**) Maximum Sustained Wind (MSW) Speed for ENS mean and control with forecast lead hours for all the cyclones during 2018-2020.*

have been analysed along with different observational and reanalysis products. Observations clearly show the prominent occurrence of MBL low-level clouds over the SIO in a 30-10°S latitudinal and 80-100°E longitudinal belt. Furthermore, there is a gradual transition from low to deep cloud towards the north of the Equator (**Fig. 3.20**). The results revealed that the CMIP5 models were hardly able to capture the MBL low-level clouds due to inaccurate temperature inversion and lower-tropospheric stability (LTS) simulations. As compared to observations, the CMIP5 models showed limited fidelity in capturing the transition from low to deep cloud at the north of the Equator. Also, evaluation of one version of the CFS in which the convective parameterization is changed to the revised simplified Arakawa-Schubert (RSAS) scheme was carried out; and in another CFS version (CFSR) with a more physically based cloud scheme (WRF Single-Moment 6-Class microphysics scheme; WSM6), comparisons were made with the default CFSv2 (CTRL) and RSAS. Only very few models, such as the MPI-ESM-LR, MRI, HadGEM, and NorESM models from among the 26 CMIP5 suites, and CFSCR from among the CFS suites, showed some fidelity in capturing the low-level clouds over the SIO. This highlights that significant improvement is needed in climate models to improve the representation of the MBL over the SIO. [***Roy K, Mukhopadhyay P, Krishna R.P.M., Ganai M., Mahakur M.,*** *Rao T. N., Nair Anish Kumar M., Ramakrishna S.S.V.S., Assessment of climate models in relation to the low-level clouds over the southern Indian Ocean,* ***Quarterly Journal of Royal Meteorological Society****, 146, October 2020 Part A, 3306-3325, DOI:10.1002/qj.3847*]

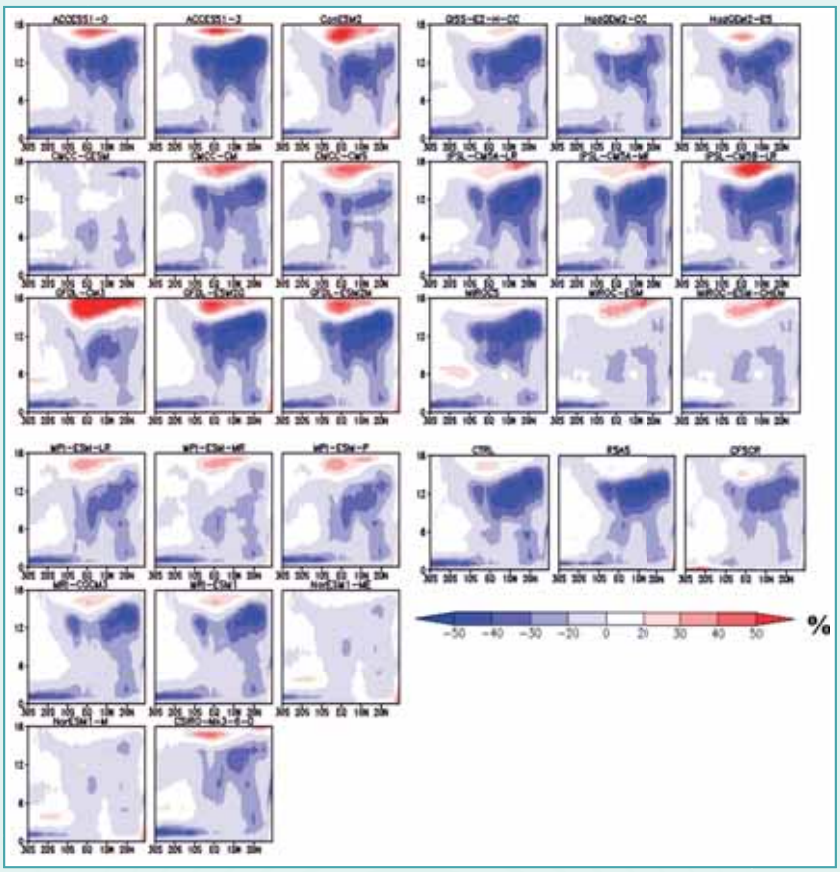


Fig. 3.20: *Differences between the simulated average seasonal mean (June-September) latitude-altitude cross-section of the frequency of occurrence of clouds (FALT, expressed as a percentage) during Asian Summer Monsoon (ASM) averaged over 80-100°E by the 26 CMIP5 models and three different versions of CFSv2 T126 (CTRL, RSAS and CFSCR), respectively, from CloudSat-CALIPSO observations.*

3.3.6. An assessment of radiative flux biases in the climate forecast system model CFSv2

The radiative flux biases in the Climate Forecast System Model Version 2 (CFSv2) were extensively analysed. Annual mean and seasonal variations of biases at the surface and top of the atmosphere (TOA) were reported in the global domain. Large regional biases in shortwave (SW) and longwave (LW) radiation were observed over convectively active zones in the tropics. The relative contribution of various processes responsible for the reported biases was quantified. The poor simulation of clouds (**Fig. 3.21**) and inadequate representation of surface properties seem to be major contributors. Over certain regions, errors due to different processes added up, whereas, over other regions, errors tended to nullify each other. Surface and atmospheric variables taken as input parameters in the radiative transfer modules were compared with satellite-based observations. The maximum biases in SW and LW radiation were observed over the regions of persistent low clouds. The magnitude of the SW and LW biases at the TOA was in phase with the biases in cloud fraction by and large. However, the error in the radiative fluxes due to errors in surface radiative properties was of equal importance. The cold bias in near-surface air temperature reported in other studies may partly be attributed to an underestimation in the net SW radiation at the surface. A plausible prescription is provided to correct the source of these biases. [***Kumar S., Phani R., Mukhopadhyay P., Balaji C.***, *An assessment of radiative flux biases in the climate forecast system model CFSv2,* ***Climate Dynamics****, 56, March 2021, 1541–1569, DOI: 10.1007/s00382-020-05546-2*]

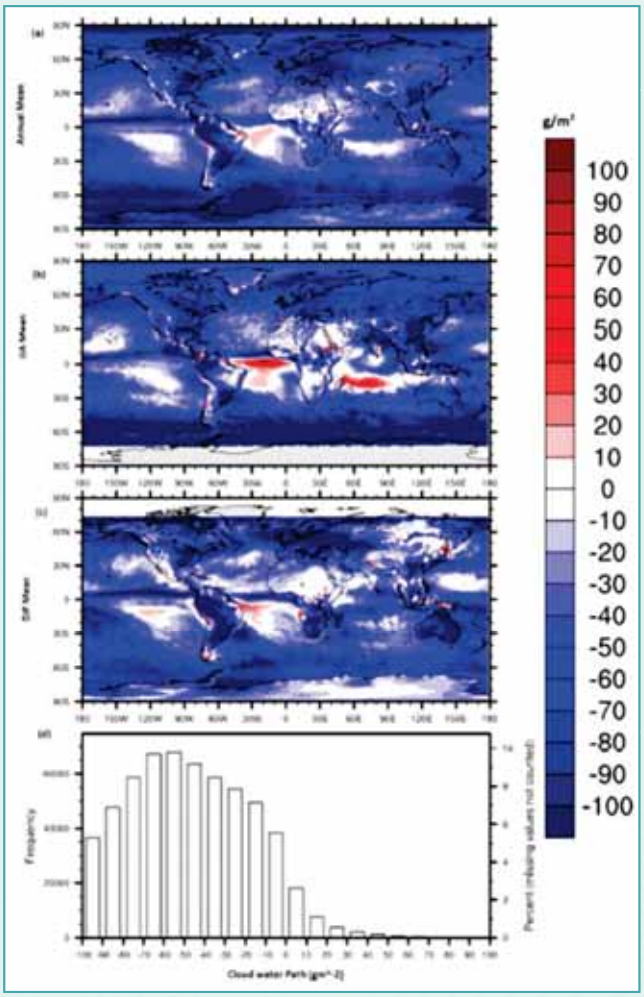


Fig. 3.21: *Bias in annual mean cloud water path (g/m^2).*

3.3.7. Evaluation of convective parameterization schemes in simulation of tropical cyclones by Climate Forecast System model: Version 2

Recently, a high resolution atmospheric general circulation model, *i.e.,* Global Forecast System has been operationalized for 10 days weather forecast over the Indian region. However, for extreme weather systems such as cyclones, different physical processes and their interactions with atmosphere and ocean play an important role in cyclone intensity, track, etc. Keeping this in view, Coupled Forecast System model version 2 has been used to evaluate the simulation for three severe cyclones (Phailin, Viyaru, and Lehar) of 2013. In addition to the already existing mass-Cux cumulus parameterization schemes [Simplified Arakawa-Schubert (SAS) and revised SAS (RSAS)], an additional convective adjustment scheme – Betts-Miller-Janjic (BMJ) – was implemented and its performance was evaluated for the Indian Ocean cyclones. The experiments were conducted with three cumulus schemes at three different resolutions (T126, T382, and T574). Both SAS and RSAS overestimated convective rain, whereas BMJ

scheme produced convective rain comparable with the observation due to the fact that BMJ produces deeper convection and does not trigger the convection too often. BMJ sustains the instability and deep convection longer thereby impacting the cyclone intensity and heavy rainfall associated with it. It is also noted that BMJ is efficient in producing rain than the SAS and RSAS. From the analyses of OLR and rain rate, BMJ is found to simulate a much realistic relation of cloud and precipitation. It is argued that compared to available SAS and RSAS, BMJ scheme realistically produces heavy precipitation (**Fig. 3.22**) associated with the tropical cyclone over the Indian region in a coupled model. [***Kanase R.D., Deshpande M.S., Krishna R.P.M., Mukhopadhyay P.***, *Evaluation of convective parameterization schemes in simulation of tropical cyclones by Climate Forecast System model: Version 2,* ***Journal of Earth System Science****, 129: 168, August 2020, DOI: 10.1007/s12040-020-01433-w*]

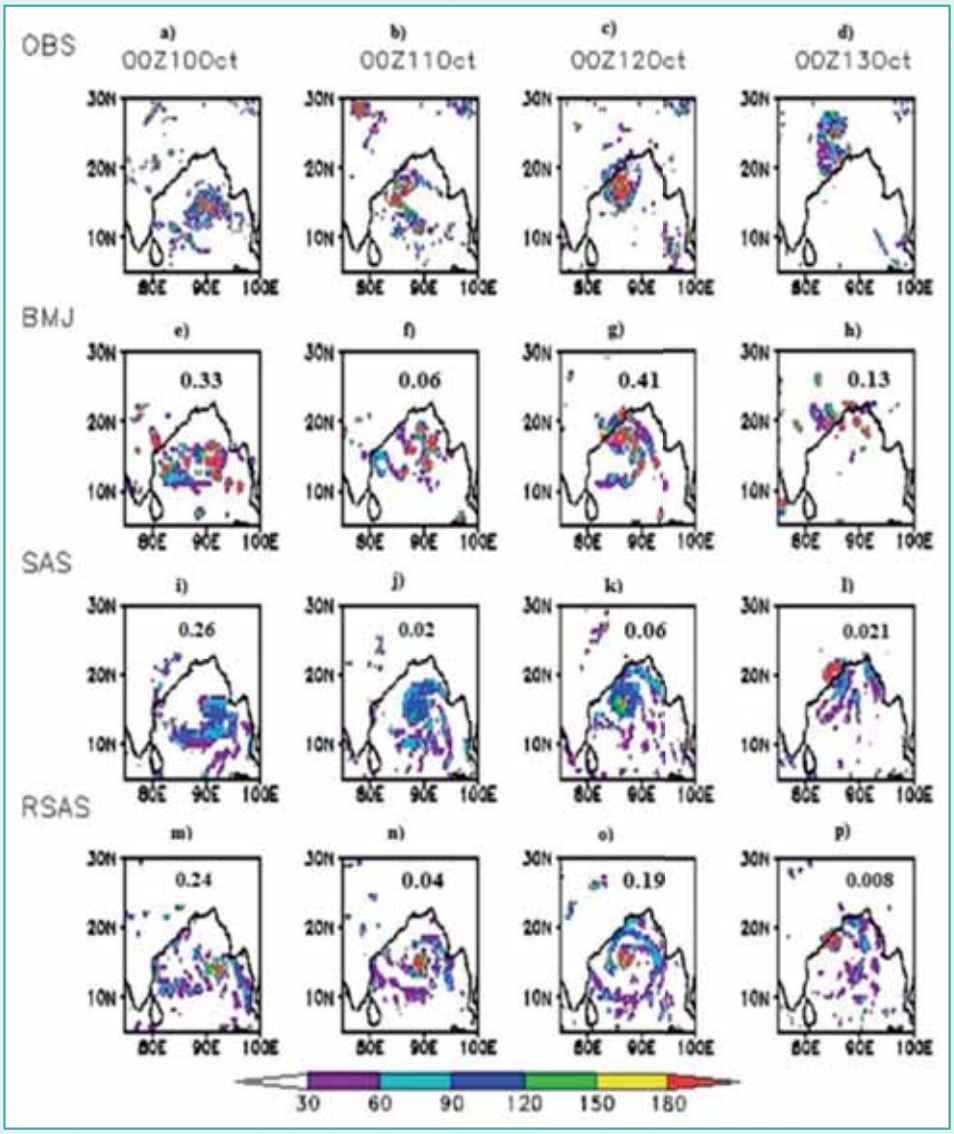


Fig. 3.22: *Total precipitation in mm/day for cyclone Phailin of 2013 at 00Z10Oct, 00Z11Oct, 00Z12Oct, and 00Z13Oct respectively in columns from left to right. Rows: (**a-d**) Observations, (**e-h**) BMJ, (**i-l**) SAS, and (**m-p**) RSAS. The number in each figure block (**a-p**) shows the spatial correlation coefficient (cc) between observations and model forecast.*

Chapter 4
Physics and Dynamics of Tropical Clouds

Project Directors: Dr. Thara Prabhakaran, Dr. G. Pandithurai, Dr. S.D. Pawar

Objectives

- To conduct Cloud Aerosol Interaction and Precipitation Enhancement Experiment, a cloud seeding science experiment and formulate protocols for cloud seeding and rain enhancement.
- To conduct physical (documenting changes in cloud before and after seeding and tracking precipitation development) and statistical evaluation (through randomization) of cloud seeding.
- To generate high quality observations of cloud and precipitation related processes in natural and seeded clouds over the rain shadow region.
- To better understand orographic convection precipitation processes and microphysical processes of cloud and precipitation using radar and satellite remote sensing.
- To develop spatial distribution of rainfall from radar data sets and to retrieve cloud micro/macro physical parameters using X and Ka-band radar.
- To utilize satellite remote sensing data for better understanding on aerosol-cloud-precipitation interactions.
- To understand the micro physical and dynamical processes involved in aerosol-cloud-precipitation interactions using in-situ and remote sensing measurements over a high-altitude site.
- To understand the role of aerosol size, chemical constituents and hygeroscopicity in cloud activation processes.
- To develop parameterization schemes for CCN, ice nuceli, warm rain processes to implement in CFS/ESM models.
- To study the dynamical, microphysical and electrical characteristics of thunderstorms, and their interactions with each other over the Indian region (which can help in improving their prediction).
- To study the interaction of thunderclouds with environmental conditions.
- To understand the effect of electrical forces on microphysical characteristics of thunderstorm.

Highlights of Major Achievements:

►Research from continuous aerosol and CCN measurements carried out at the ground observational facility in the rain-shadow region of the Indian subcontinent are presented. ►Characteristics of CCN activation and cloud microphysics over the east coast of India during the Northeast Monsoon onset are discussed. ►An investigation provides a new understanding of the connection between flow organization and flux generation mechanisms, two cornerstones of turbulence research. ►Implications of different aerosol species to direct radiative forcing and atmospheric heating rate are discussed. ► Asymptotic scaling of drag in flat-plate turbulent boundary layers investigated. ►Efforts were made to continue CAIPEEX observations at the Solapur and Tuljapur sites even during the CONVID-19 situation. ►An ice nucleation parameterization as a function of temperature and aerosol concentration developed for the first time over Indian region using collocated measurements at HACPL, Mahabaleshwar. ► Civil and electrical infrastructure works initiated at Atmospheric Research Testbed site in Central India. ►Role of droplet size classes on the cloud droplet spectral dispersion over the Western Ghats is investigated. ►First results from the Doppler weather radar observations over Mumbai during 2018 monsoon are discussed. ►A new attenuation correction procedure improves the reflectivity measurement in ground-based radars which can improve the quantitative application of reflectivity data. ►Mumbai Mesonet with Automatic Rain Gauges has been established. ►A new study suggests inductive charging mechanism can contribute to thunderstorm electrification in the dissipation stage of thunderstorm. ►A new relationship is proposed that the lightning flash rate (LFR) is proportional to a product of the Bowen ratio and the sum of precipitation and evaporation rates. ► A map of lightning prone areas has been prepared and shared with National Disaster Management Authority (NDMA). ►An observatory is being established at Sanjay Ghodawat University (SGU), Kolhapur to study atmospheric electricity along with micrometeorological parameters. ►Features of the first observations of atmospheric electric field at Kashmir valley are discussed.

Sub-Projects

- Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)
- High-Altitude Cloud Physics Laboratory (HACPL)
- Radar and Satellite Meteorology
- Thunderstorm Dynamics

4.1. Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)

Basic Research

4.1.1. Cloud condensation nuclei characteristics during the Indian summer monsoon over a rain-shadow region

Continuous aerosol and cloud condensation nuclei (CCN) measurements were carried out at the ground observational facility situated in the rain-shadow region of the Indian subcontinent and major findings are presented. These observations were part of the Cloud Aerosol Interaction Precipitation Enhancement Experiment (CAIPEEX) during the Indian summer monsoon season (June to September) of 2018. Observations are classified as dry-continental (monsoon break) and wet-marine (monsoon active) according to the air mass history. CCN concentrations measured for a range of supersaturations (0.2% – 1.2%) are parameterized using Twomey's empirical relationship. CCN concentrations at low (0.2%) supersaturation (SS) were high (>1000 cm^{-3}) during continental conditions and observed together with high black carbon (BC ~ 2000 ng m^{-3}) and columnar aerosol loading. During the marine air mass conditions, CCN concentrations diminished to ~350 cm^{-3} at 0.3% SS and low aerosol loading persisted (Bc ~ 800 ng m^{-3}). High CCN activation fraction (AF) of ≅0.55 (at 0.3% SS) was observed before the monsoon rainfall, which reduced to ≅0.15 during the marine air mass and enhanced to ≅0.32 after that. There was mostly monomodal aerosol number size distribution (NSD) with a mean geometric mean diameter (GMD) of ≅85 nm, with least (≅9%) contribution from nucleation mode (<30 nm) particles persisted before the monsoon, while multimode NSD with ≅19 % of nucleation mode particles was found during the marine air mass. Critical activation diameters ($^{3}dcri$) for 0.3% SS were found to be about 72, 169, and 121 nm prior to, during, and after the marine conditions, respectively. The better association of CCN with aerosol absorption, and the concurrent accumulation mode particles during continental conditions, points to the possibility of aged (oxygenated) carbonaceous aerosols enhancing the CCN activity prior to the marine conditions. An enhancement in CCN concentrations and *k* values during the daytime along with absorption Ångström exponent was observed during the marine conditions. Best closure obtained using measured critical diameter and ammonium sulfate composition during continental conditions emphasizes the role of aged aerosols contributing to the accumulation mode, enhancing the CCN efficiency. The overestimation of CCN and less hygroscopicity of accumulation mode aerosols during the marine air mass indicate the role of size-dependent aerosol composition in CCN activity during the period. (**Fig. 4.1**) [***Jayachandran V.N., Varghese M., Murugavel P., Todekar K.S., Bankar S.P., Malap N., Dinesh G., Safai P.D., Rao J., Konwar M., Dixit S., and Prabha T.V.,*** *Cloud condensation nuclei characteristics during the Indian summer monsoon over a rain-shadow region,* ***Atmospheric Chemistry and Physics****, 20, June 2020, 7307–7334, DOI:10.5194/acp-20-7307-2020*]

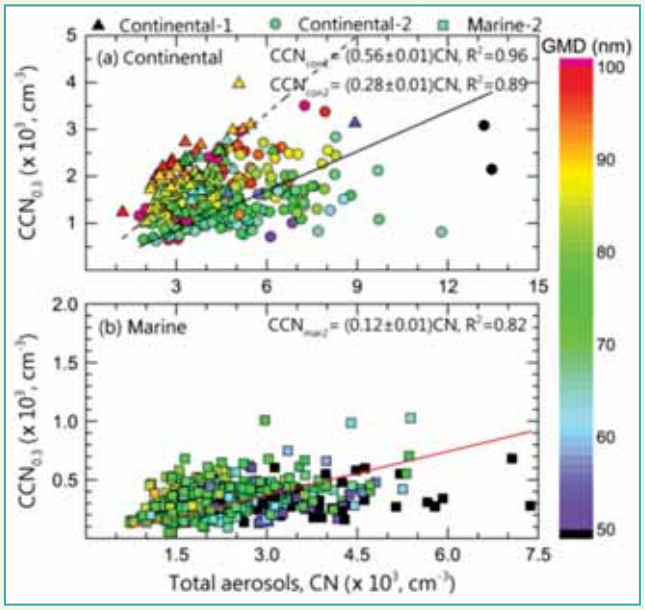


Fig. 4.1: *Association between CCN (at 0.3 % SS) and CN concentrations segregated to (**a**) continental and (**b**) marine conditions. The color of the scatter indicates the concurrent geometrical mean diameter of the aerosol system. The least-square linear fit is also shown along with the fit parameters.*

4.1.2. Characteristics of CCN activation and cloud microphysics over the east coast of India during the Northeast Monsoon onset

Airborne observations conducted during the Northeast Monsoon onset as part of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX 2011) are used to link the activation properties of aerosols with the observed cloud microphysics from the cloud base to cloud top. The significant spatial variability in the aerosol spectrum, cloud condensation nuclei (CCN) activation characteristics, and the cloud droplet spectral properties over a coastal and an inland location is illustrated. High concentrations of Aitken mode and black carbon aerosols were observed in the free troposphere and are attributed to the convectively transported smoke and aerosols from the coastal boundary layer. The assumption of an internally mixed organic and inorganic aerosol composition provided a better CCN closure over assumptions of either purely organic or purely inorganic aerosols. The coastal clouds were equally polluted as the inland clouds with high droplet number concentrations near the cloud base. The vertical distribution of droplet spectral characteristics was similar in both coastal and inland clouds. An increase in droplet number concentration up to 2 km above the cloud base indicated a prominent influence of submicron particles on the cloud microphysical parameters. Evidence for an enhanced concentration of supercooled drops above the freezing level up to temperatures below −12°C is documented. The secondary ice production was evident through observations of graupel and snow particles. Heavy loading of aerosols near the cloud base leads to enhanced mixed-phase processes in these clouds. **(Fig. 4.2)** [***Varghese M., Thara V.P., Patade S., Kulkarni G., Safai P.D.***, *Axisa D., Characteristics of CCN activation and cloud microphysics over the east coast of India during the Northeast Monsoon onset,* ***Atmospheric Research****, online, March 2021, DOI: 10.1016/j.atmosres.2021.105589*]

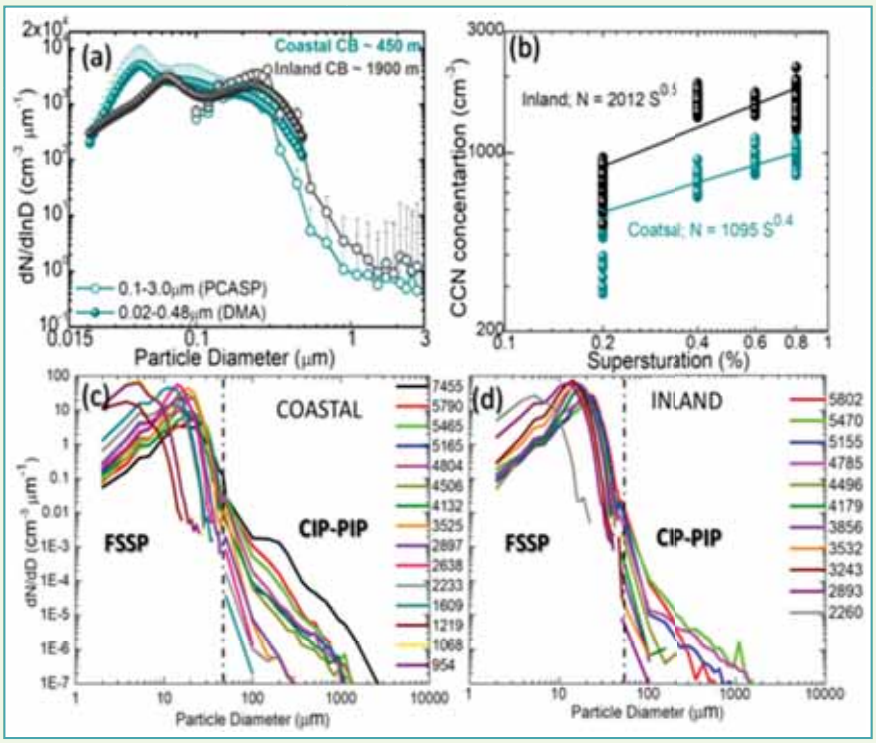


*Fig. 4.2: (**a**) Coastal (dark cyan) and Inland (grey) cloud base (CB) aerosol size spectra from DMA (spheres) and PCASP (open circle) measurements, the vertical error bars denote the standard deviation in each bin (**b**) CCN supersaturation spectra at the cloud base of coastal and inland clouds, (**c**) the cloud particle size distribution of the deep coastal cloud and (**d**) the cloud droplet size spectra of inland clouds. Both (**c**) and (**d**) are colored based on the altitude of observation (m). The dotted vertical line separates the FSSP and CIP-PIP measurements.*

4.1.3. Persistence behaviour of heat and momentum fluxes in convective surface layer turbulence

The characterization of heat and momentum fluxes in wall-bounded turbulence is of paramount importance for a plethora of applications ranging from engineering to Earth sciences. Nevertheless, how the turbulent structures associated with velocity and temperature fluctuations interact to produce the emergent flux signatures has not been evident until now. This fundamental issue is investigated by studying the switching patterns of intermittently occurring turbulent fluctuations from one state to another, a phenomenon called persistence. It is found that the persistence patterns for heat and momentum fluxes are widely different. Moreover, power-law scaling and length scales of turbulent motions that cause this behavior are uncovered. Furthermore, by separating the phases and amplitudes of flux events, the origin and differences between heat and momentum transfer efficiencies in convective turbulence are explained. The findings provide a new understanding of the connection between flow organization and flux generation mechanisms, two cornerstones of turbulence research. (**Fig. 4.3**) [***Chowdhuri S., Prabhakaran Thara****, Banerjee T., Persistence behavior of heat and momentum fluxes in convective surface layer turbulence,* ***Physics of Fluids****, 32: 115107, November 2020, DOI:10.1063/5.0027168*]

4.1.4. Implications of different aerosol species to direct radiative forcing and atmospheric heating rate

The optical and radiative characteristics of water-soluble and carbonaceous aerosol species in the $PM_{2.5}$ samples were examined for a representative megacity over the Indo-Gangetic Basin (IGB). Aerosol optical and radiative transfer models were used for extracting sulphate (SO_4), nitrate (NO_3), organic (OC) and elemental carbon (EC) from the observations in 2012. Initial results suggest that the mass concentration of OC was dominating over other species, but impacts on optical characteristics were mostly due to the SO_4aerosols.

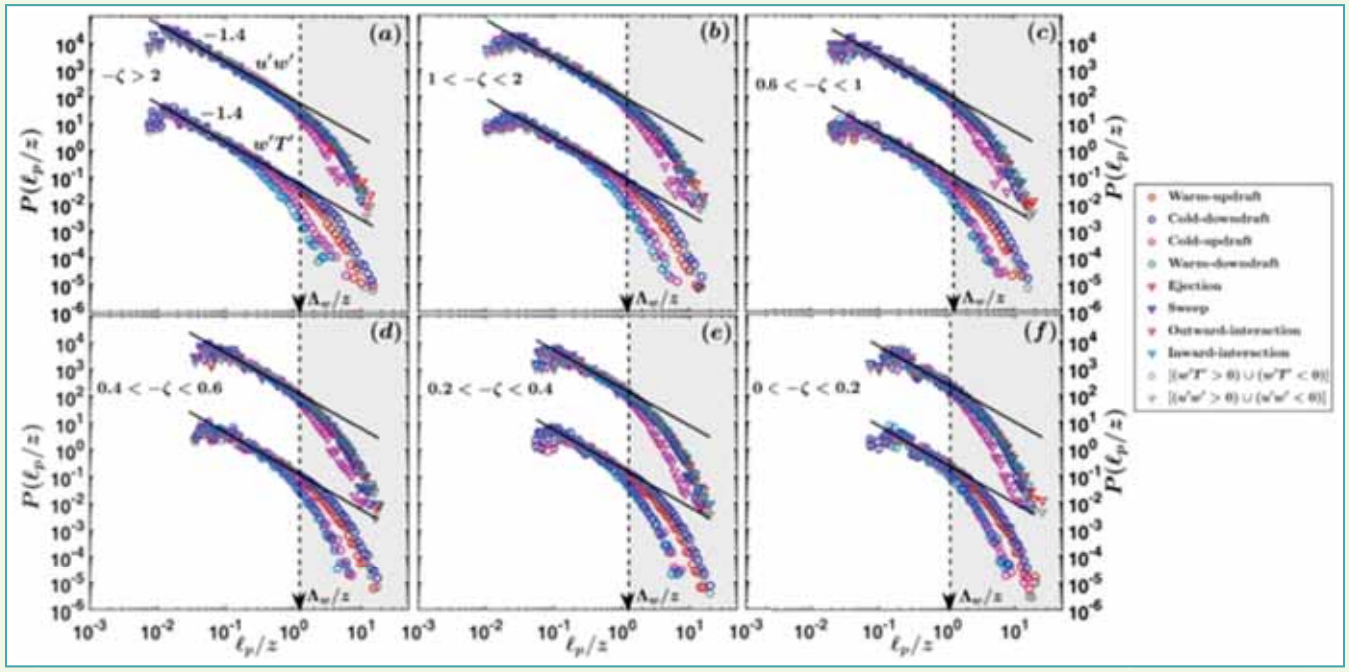


Fig. 4.3: The persistence PDFs of heat and momentum fluxes (w'T' and u'w') are shown for the six different stability classes from a convective atmospheric surface layer flow. For visualization purposes, the persistence PDFs of u'w' signals associated with all the four quadrants are shifted vertically upwards by three decades. The grey inverted triangles and circles denote the u'w' and w'T' persistence PDFs, computed after considering both the positive and negative values together. See the legend for description of the different markers.

Further, EC shows relatively large impact on radiative forcing. The aerosol optical depth (AOD) at 500 nm for SO_4, NO_3, EC and OC was found to be contributed ~36%, 20%, 27% and 9%, respectively in the total AOD value (0.61±0.18) during the entire study period. The single scattering albedo (SSA) for SO_4 and NO_3 was high and suggested their scattering nature; however, being the highly absorbing species, EC was found to show the lowest values of SSA during the study period. SSA for OC was, however, ~0.70, which was found to show the second highest warming species in the atmosphere with contribution of ~10%, after EC, which caused the highest warming (~70%), to the total atmospheric warming. (**Fig. 4.4**) [***Srivastava A.K.**, Mehrotra B.J., Singh A., Singh V., **Bisht D.S., Tiwari S.**, Srivastava M.K., Implications of different aerosol species to direct radiative forcing and atmospheric heating rate, **Atmospheric Environment**, 241: 117820, November 2020, DOI:10.1016/j.atmosenv.2020.117820*]

4.1.5. Asymptotic scaling of drag in flat-plate turbulent boundary layers

A new asymptotic −1/2 power-law scaling is derived from the momentum integral equation for the drag in flat-plate turbulent boundary layers. In the limit of infinite Reynolds number, the appropriate velocity scale for drag is found to be M/v, where M is the boundary layer kinematic momentum rate and v is the fluid kinematic viscosity. Data covering a wide range of Reynolds numbers remarkably collapse to a universal drag curve in the new variables. Two models, discrete and continuous, are proposed for this universal drag curve, and a robust drag estimation method, based on these models, is also presented (**Fig. 4.5**). [***Dixit S.A., Gupta A., Choudhary H.**, Singh A.K., **Prabhakaran Thara**, Asymptotic scaling of drag in flat-plate turbulent boundary layers, **Physics of Fluids**, 32:041702, April 2020, DOI:10.1063/5.0004464*]

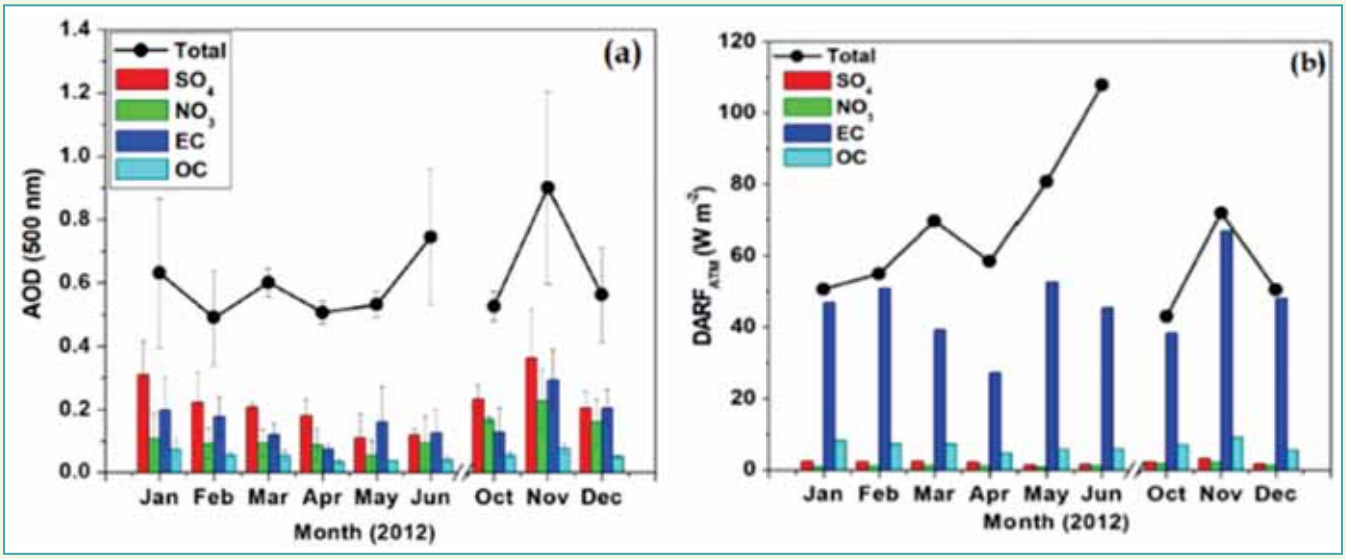


Fig. 4.4: *(**a**) Monthly variability of OPAC-derived AOD (at 500 nm) for the total aerosols along with different aerosol species (SO_4, NO_3, OC and EC) (**b**) Monthly variability of direct aerosol radiative forcing for total and individual aerosol species during the study period.*

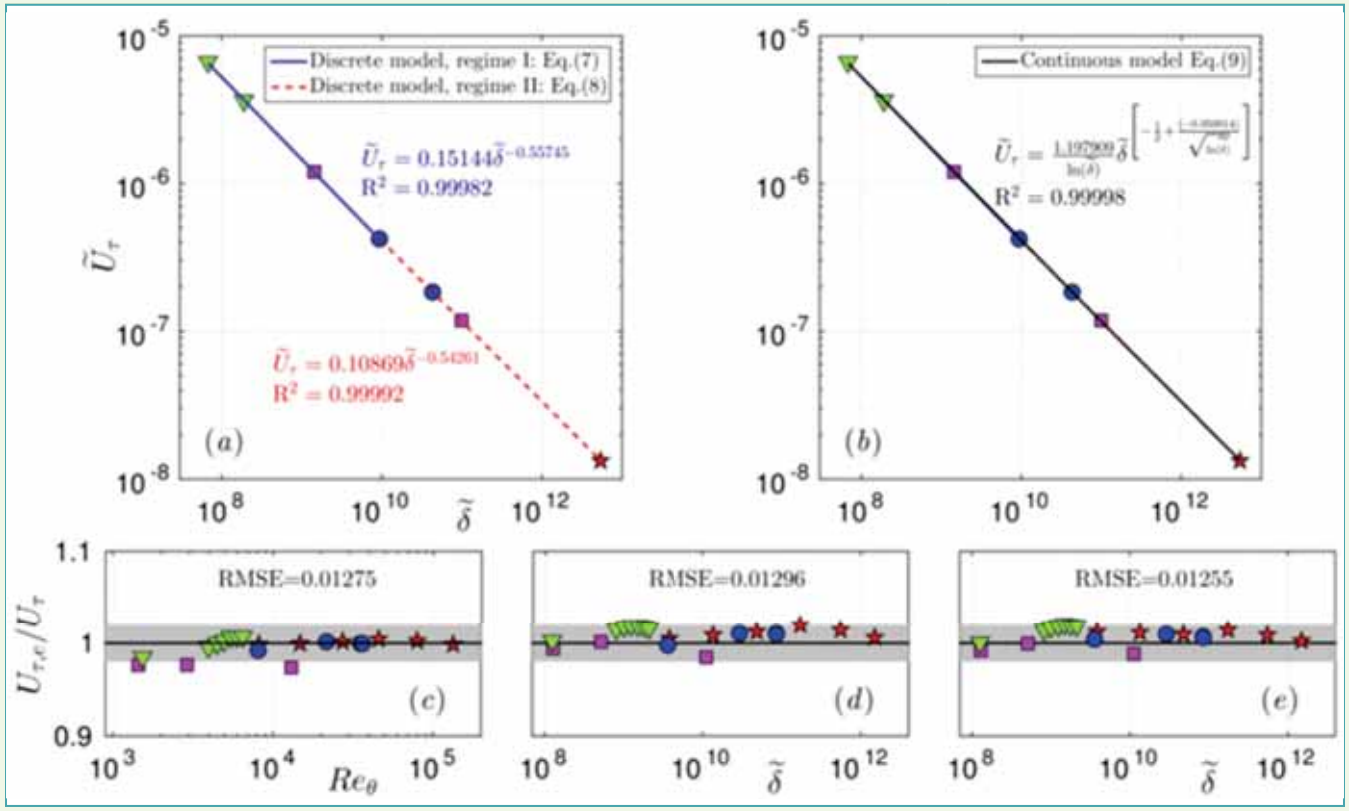


Fig. 4.5: *A new universal model for the drag in ZPG turbulent boundary layers.*

Developmental Activities

4.1.6. CAIPEEX Phase-IV at Solapur and Tuljapur Sites

Observations at the Solapur and Tuljapur sites were continued in March 2020 as it was a requirement to have long term observations over the cloud seeding study area. Solapur and Tuljapur sites were operational during the lockdown with minimum instrumentation. Several instruments in the laboratory were shut down due to the lockdown conditions and the Solapur College being converted into a quarantine centre for COVID-19 patients. Some instruments (wind profiler, radiometer and tower based measurements of meteorological parameters, ceilometer, etc.) were running and collecting valuable data during this period. Solapur radar was not operational due to austerity measures and lack of CAMC.

4.1.7. Fluid Dynamics Laboratory (FDL): FDL wall jet PIV experiments phases- I and II are completed and data are being analyzed. Novel methods are developed to post process PIV fields for removing tapshift artefacts and field stitching for wide FOV PIV.

4.2. High Altitude Cloud Physics Laboratory, Mahabaleshwar

Basic Research

4.2.1. Atmospheric ice nucleating particle measurements and parameterization representative for Indian region

Atmospheric ice nucleating particle (INP) concentration measurements over the Indian region are very sparse; hence more observations are required to represent heterogeneous ice nucleation processes in the regional cloud models for better accuracy. Ice nucleation experiments were conducted at temperatures between -25 and -34°C and water supersaturation conditions up to 102%. The mean INP concentrations varied from 1.1 to 9.5 L^{-1} and correlated well with coarse mode aerosol particle concentration (> 1 µm). Higher INP concentrations were observed when the aerosol loading was influenced by the regions such as Mumbai metro city, Gujarat, Thar Desert region, and the Arabian Sea region close to the Oman Coast. An empirical equation was formulated to represent the INP concentrations using supercooled temperature and coarse mode aerosol particle concentration. The sensitivity of new heterogeneous ice nucleation parameterization was tested against literature INP parameterizations using Weather Research and Forecasting (WRF) model. The model results showed that the new parameterization helped to simulate the rainfall amount better as compared to the old formulations. Better reproduction of convection and possible reduction of biases in the formation of cloud ice in the cloud-resolving model improved the model accuracy. These results show the importance of implementing new INP parameterization in a real-time forecast model to improve the regional climate model forecasting. (**Fig. 4.6**) [***Anil Kumar V., Hazra A., Pandithurai G.***, *Kulkarni G.*, ***Mohan G.M., Mukherjee S., Leena P.P., Patil R.D.***, *Prasad D.S.V.V.D., Atmospheric ice nucleating particle measurements and parameterization representative for Indian region,* ***Atmospheric Research****, Online, January 2021, DOI:10.1016/j.atmosres.2021.105487*]

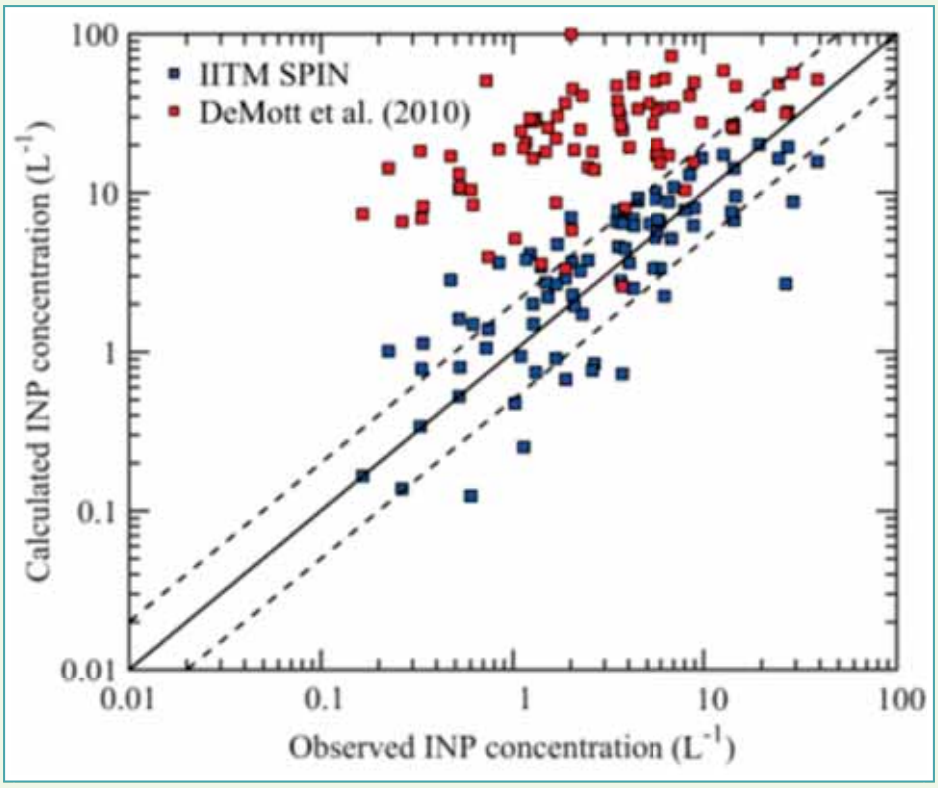


Fig. 4.6: *Comparison of observed vs. calculated INP concentration. INP was calculated using eq. 2 (IITM_SPIN) and eq. 1(DeMott et al. 2010). The black line shows the 1:1 line and the dotted lines outline a range of 'a' factor of 2.*

4.2.2. Role of droplet size classes on the cloud droplet spectral dispersion as observed over the Western Ghats

The aerosol indirect e ects (AIE) on cloud microphysical properties were studied using ground-based *in-situ* measurements. Aerosol and cloud microphysical properties were collected from a high altitude site in the Western Ghats region of India, where clouds pass over the surface during the South West monsoon. The AIE was estimated using cloud droplet number concentration (AIE_n) and cloud droplet e ective radius (AIE_s) at di erent fixed liquid water content (LWC) bins. The AIE varied in the range 0.01-0.13 for LWC between 0.04 g m^{-3} and 0.26 g m^{-3}. The maximum AIE_n and AIE_s (0.125 and 0.119) were observed at the lower LWC bin (0.06-0.07 g m^{-3}). An overestimation in AIE_n is due to the dispersion e ect. The o set was reduced and AIE_n became close to AIEs after dispersion correction. Hence for the correct estimation of AIE using cloud droplet number concentration (N_c), dispersion correction should be considered. At the same time, the AIE estimate obtained using R_e does not need correction as the dispersion e ect is implicitly included. Relative dispersion can be viewed not only as the combined e ects of σ and R_m, but also as the combined e ects of cloud droplets of di erent sizes. Further, for the first time in India, the relative contribution by the smaller and medium size droplets to the total dispersion of cloud droplet size distribution (CDSD) at lower and higher LWC bins were studied. In lower LWC, the smaller size droplets are contributing maximum (71%) to the total N_c, whereas the medium size droplets are contributing maximum (61%) to the total dispersion. At higher LWC, the contribution to total N_c by the smaller size droplets was reduced by 20%, however contribution by the medium size droplets increased by 17%, compared to the lower LWC case. Hence, at higher LWC, both smaller (42%) and medium (55%) size droplets have a significant role in the total dispersion of CDSD. [*Ansari K.*, ***Pandithurai G., Anil Kumar V.***, *Role of droplet size classes on the cloud droplet spectral dispersion as observed over the Western Ghats,* ***Atmospheric Research****, 246: 105104, December 2020, DOI:10.1016/j.atmosres.2020.105104*]

4.2.3. Sub-micron aerosol variability and its ageing process at a high altitude site in India: impact of meteorological conditions

The effect of relative humidity and temperature on the sub-micron aerosol variability and its ageing process was studied over a high altitude site, Mahabaleshwar in the south-west India. The mass composition of non-refractory particulate matter of 1 µm ($NR\text{-}PM_1$) size was obtained using Time of Flight Aerosol Chemical Speciation Monitor (ToF-ACSM) along with the measurements on a few trace gases during winter and summer season. Sulfate exhibited strong dependence on the relative humidity (RH) as its mass fraction increased with the increase in RH. The Sulfate oxidation ratio (SOR) calculated during summer season also showed an increasing trend with RH indicating the influence of aqueous phase oxidation on sulfate fraction. On the other hand, OOA showed remarkable enhancement in its mass fraction with the increase in temperature along with the corresponding increase in f_{44} and tropospheric ozone. OOA, ozone and f_{44} ratio increased 14-34%, 8-26% and 25-43% respectively with the increase in temperature. This is indicative of the dominance of photochemical ageing processes during high temperature conditions. The extent of photochemical ageing was found to be higher during summer season as compared to winter season. The nitrate diurnal was majorly governed by gas to particle partitioning process during winter season, whereas the summertime nitrate diurnal was influenced primarily by its formation rate. The non-parametric wind regression analysis revealed that the mass concentration during winter was majorly contributed by distant sources from north east direction while during summer the local sources were more dominant. (**Fig. 4.7**) [***Mukherjee S.****, Singla V.,* ***Meena G.S., Aslam M.Y., Safai P.D., Buchunde P., Vasudevan A.K., Jena C.K., Ghude S.D., Dani K.K., Pandithurai G.****, Sub micron aerosol variability and its ageing process at a high*

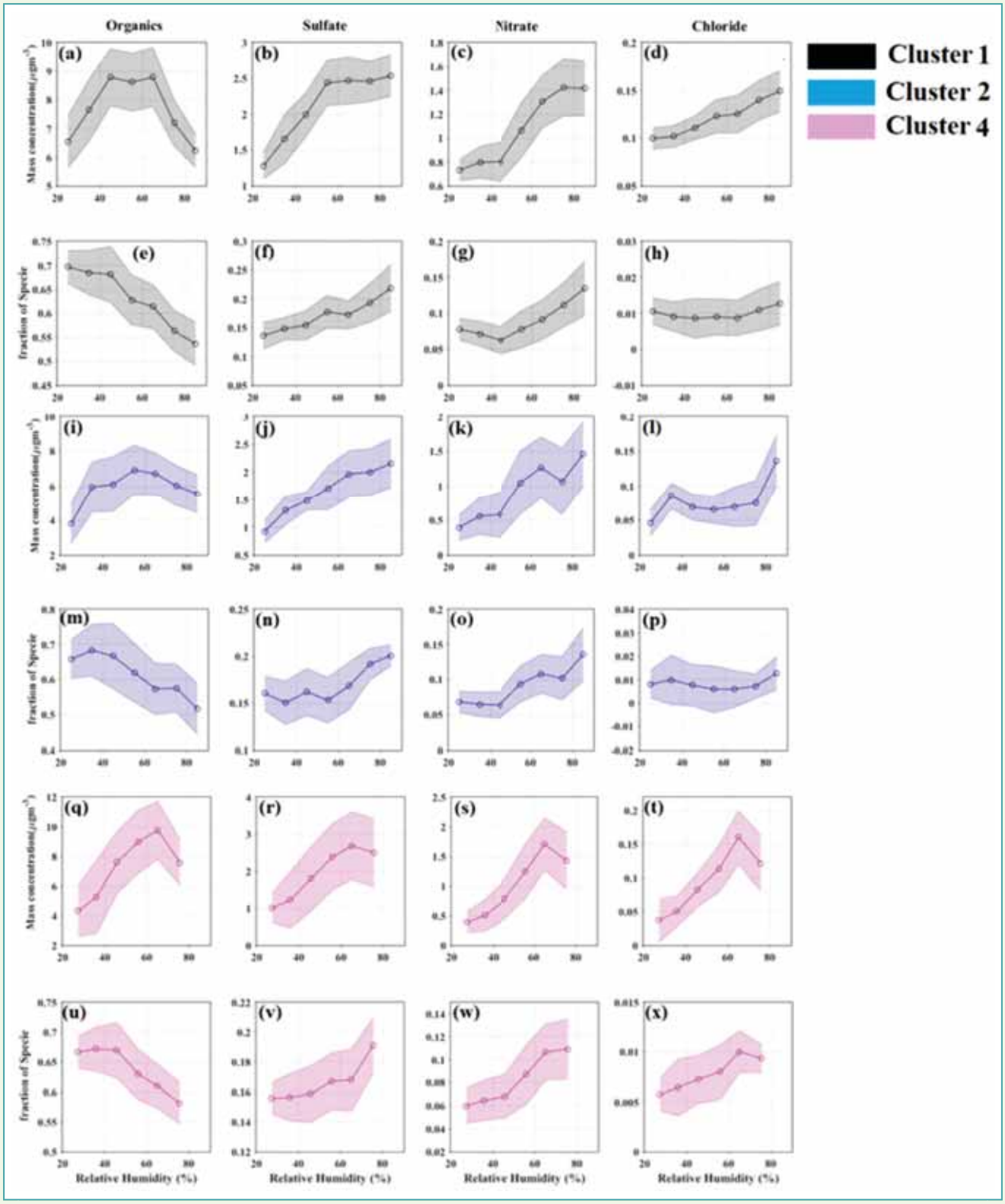


Fig. 4.7: *The cluster wise variation of mass and fraction of NR-PM1 aerosol components, namely organic, sulfate, nitrate and chloride with RH during winter season. (**a**) to (**h**) represent cluster1 (black), (**i**) to (**p**) represent cluster 2 (blue), and (**q**) to (**x**) represents cluster 4 (magenta).*

altitude site in India: Impact of meteorological conditions, ***Environmental Pollution****, 265: 115019, October 2020, DOI:10.1016/j.envpol.2020.115019*]

Development Activities

4.2.4. Ice Nucleating Particle Observations: Atmospheric ice nucleating particle (INP) concentration measurements over the Indian region are very sparse and there is no exclusive parameterization developed by utilizing observations from India which is a function of both temperature and aerosol concentration. These observations at wide temperature range are required to represent heterogeneous ice nucleation processes in the regional cloud models for better accuracy. For the first time in India, INP concentrations are parameterized using observations from HACPL and tested in numerical models.

4.2.5. CCN Activation Experiments: CCN activation mainly depends on aerosol size and its hygroscopicity (chemical composition). To better understand the CCN activation for different emissions, experiments were designed and conducted to understand the CCN activation processes from different emissions such as bio-fuel, fossil fuel, etc. Efforts are underway to parameterize the CCN activation process using hygroscopicty measurements.

4.3. Radar and Satellite Meteorology

Basic Research

4.3.1. First results from the Doppler weather radar observations over Mumbai urban region during the inter-seasonal phases of 2018 monsoon

First of its kind, an effort is made to clearly portray the inter-seasonal relationship between the morphology of clouds, microphysics of precipitation and the occurrences of lightning by synergetic use of the data from S-band Doppler weather radar, Disdrometer and Maharashtra Lightning Detection Network in an urban coastal megacity like Mumbai, which experiences severe rainfall spells in the pre-monsoon and monsoon months. In this effort, one of the important findings is the presence of a distinct diurnal variation of rainfall occurrences with three peaks for the pre-monsoon period which are not visible during the monsoon months. The rainfall peaks correspond to an intense meso-convective environment as observed from the S-band doppler radar along with larger raindrops and severe lightning flashes (**Fig. 4.8**). It has been observed that the monsoon clouds over Mumbai, which are maritime in nature and accompanied by large moisture, yield widespread rainfall over the city during the month of June - September. As such, the surface remains cool during most of the time in this period with respect to the pre-monsoon months (March – May). Hence, the rate of evaporation and the tendency of upward movement of warm air parcels occur more during the pre-monsoon period with respect to the monsoon months. This builds up the higher potential for convective environment which ultimately results in these scattered regions of higher rainfall occurrences with larger drops during the pre-monsoon period with respect to the monsoon month over Mumbai. The prominent role of the urban environment on the pre-monsoon convection and the interaction of the offshore moisture over the city during the monsoon months is one of the contributing factors for this contrasting diurnal behaviour of rainfall for the inter-seasonal phases of monsoon over Mumbai. These findings and observations will be helpful to aid the heavy rainfall research over the urban coastal cities, particularly in the Indian monsoon regions, to advance science in the benefit of the society. [***Chakravarty K.***, *Gayathridevi S., Mohmmad J., Hosalikar K.S.,* ***Pandithurai G.****, Niyogi D., First results from the Doppler Weather Radar observations over Mumbai urban region during the inter seasonal phases of 2018 monsoon,* ***Natural Hazards****, Online, March 2021, DOI:10.1007/s11069-021-04637-5*]

4.3.2. Assessment of ground-based X-band radar reflectivity: Attenuation correction and its comparison with space-borne radars over the Western Ghats

Reflectivity measurements from X-band ground-based radar (GR) are assessed using observations from the Ku-band space-borne radars (SRs) onboard the Tropical Rainfall Measuring Mission and Global Precipitation Measurement satellites as a reference. The GR is at Mandhardev (18.04ºN, 73.86ºE) in the Western Ghats region, and the evaluation period is from June to September of 2014 and 2018. At X-band, the rainfall-induced attenuation leads to significant signal loss. The rain attenuation correction of GR is performed based on the relationship between specific attenuation and reflectivity. Using T-matrix scattering simulations, the specific attenuation and reflectivity are derived from the disdrometer data. Further, the systematic differences between reflectivity measured by GR and SR are minimized by performing the frequency scaling using scattering simulation. The comparison between corrected reflectivities of GR and SR is achieved by matching the resolution volumes and viewing geometry of both radars. The evaluation between corrected reflectivities of GR and SR shows reasonable agreement between them, indicating that the attenuation correction performs reasonably for GR. In rain regions, the GR bias lies between -2.6 and -1.8 dB for stratiform cases, while for convective samples, the GR bias varies from -2.4 to -0.7 dB relative to SR observations. The GR shows smaller reflectivity compared to SR at all heights. Attenuation

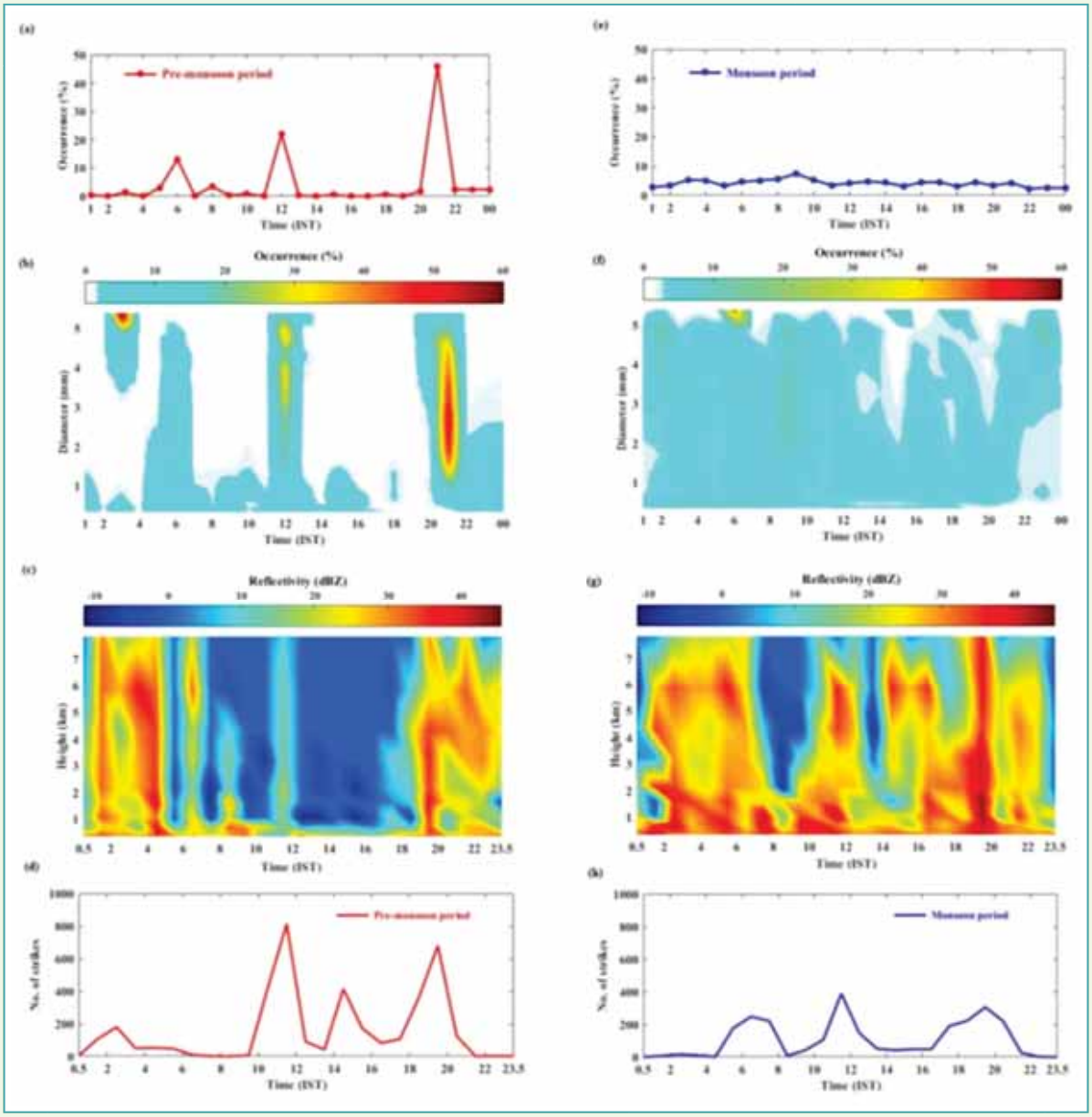


Fig. 4.8: *(**a**) Diurnal variation of rainfall, (**b**) raindrop size distribution, (**c**) vertical profile of radar reflectivity, and (**d**) lightning occurrences during the pre-monsoon period. The same parameters for the monsoon months are obtained in (**e**) to (**h**) respectively. The x-axis represents Local Time in IST, that is Indian standard time (= GMT + 5:30 h).*

correction is implemented to long-term X-band radar data available in the Western Ghats region to study the orographic precipitation and convective system during monsoon. The proposed attenuation correction procedure could improve the GR reflectivity measurement and can recover much of the reflectivity information that is lost due to attenuation of radar beam. The accuracy of the GR reflectivity measurements is assessed. The corrected GR reflectivity can improve the quantitative application of reflectivity data to determine the precipitation product, separation of precipitation into different types, storm structure analysis, storm top-height, severe weather

monitoring and nowcasting, and assimilation in numerical weather prediction models. (**Fig. 4.9**) [***Das S.K., Murali Krishna U.V., Kolte Y.K., Deshpande S.M., Pandithurai G.***, *Assessment of ground-based X-Brand Radar Reflectivity: attenuation correction and its comparison with space-borne radars over the Western Ghats, India,* ***Earth and Space Sciences****, 7: e2019EA000861, November 2020, DOI:10.1029/2019EA000861*]

Development Activities

4.3.3. Mumbai Mesonet with Automatic Rain Gauges (about 40 Nos) has been established. It also collates data from other projects / agencies (SAFAR-Mumbai, IMD, MCGM) into a common web based data portal (mumbairain.tropmet.res.in). Also, these real-time datasets were provided through mobile application (Mumbai Weather Live). These datasets were being used for NCCR's Integrated Flood Warning System (iFLOWS) and NCMRWF's validation efforts for model simulation. The above datasets are also being used for nowcasting efforts of IMD.

4.3.4. Atmospheric Research Testbed facility in the core monsoon zone (Central India) is being established. Work for establishing civil infrastructure is initiated and in progress. A dual-polarimetric C-band Doppler Weather Radar is being installed and will be operational in Monsoon-2021.

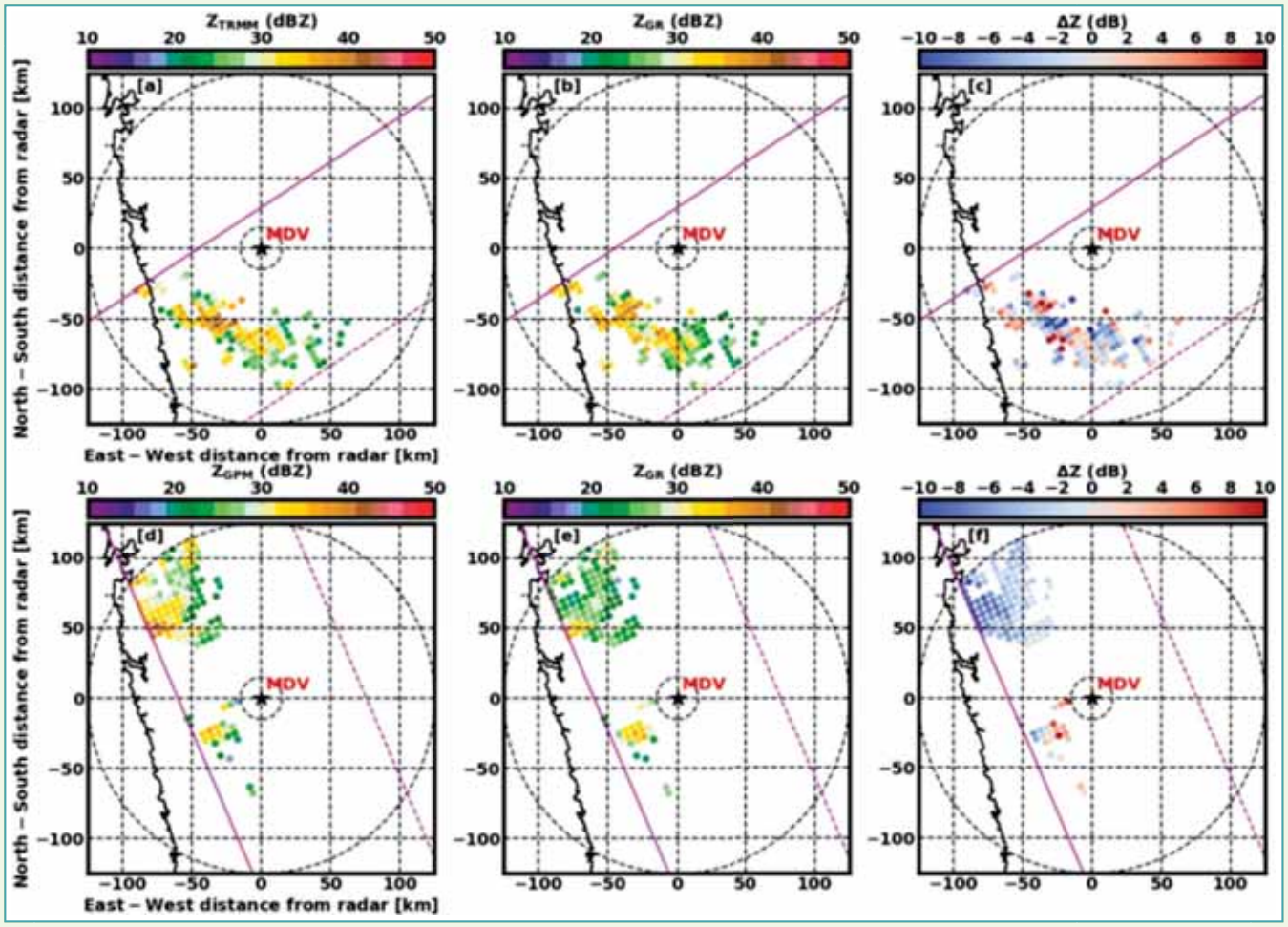


Fig. 4.9: *Volume matched sample of radar reflectivity distributions at 0.5° elevation from (**a**) TRMM, (**b**) GR, and (**c**) their difference. (**d**)-(**f**): same as (**a**)-(**c**), but for GPM on June 24, 2018. The dotted circles represent the minimum (15 km) and maximum (125 km) ranges of the X-band radar measurements taken for the analysis. The solid black line represents the coastline. The dashed and solid line in magenta represents the central axis and edge of the TRMM/GPM ground track, respectively.*

4.4. Thunderstorm Dynamics

Basic Research

4.4.1. Charging processes during the dissipation stage of thunderstorms

The significance of inductive charging mechanism to thunderstorm electrification is not clearly understood and many laboratory studies suggest that the inductive charging mechanism may be playing contributory role in the thunderstorm electrification. Charging processes occurring during dissipation stage of thunderstorms are examined by using measurements of electric field and Maxwell current density below thunderstorms (**Fig. 4.10**). These observations suggest that during the dissipation stage of thunderstorm, different charging processes contribute to the cloud electrification depending on the type of thunderstorms. Observations suggest that updraft may not be sufficient to activate charging mechanism inside cloud during the dissipation stage in small thunderstorms. However, in big thunderstorms, non-inductive charging mechanism may be active during the dissipation stage. From the observed pattern of recovery curves of electric field and Maxwell current density measured during dissipation stage of inverted polarity thunderstorms, it is suggested that inductive charging mechanism can contribute to the thunderstorm electrification in the dissipation stage of thunderstorm. [***Gopalakrishnan V., Pawar S.D. and Domkawale M.A.***, *Charging processes during the dissipation stage of thunderstorms,* ***Meteorology and Atmospheric Physics****, Online, September 2020.* DOI: 10.1007/s00703-020-00755-0]

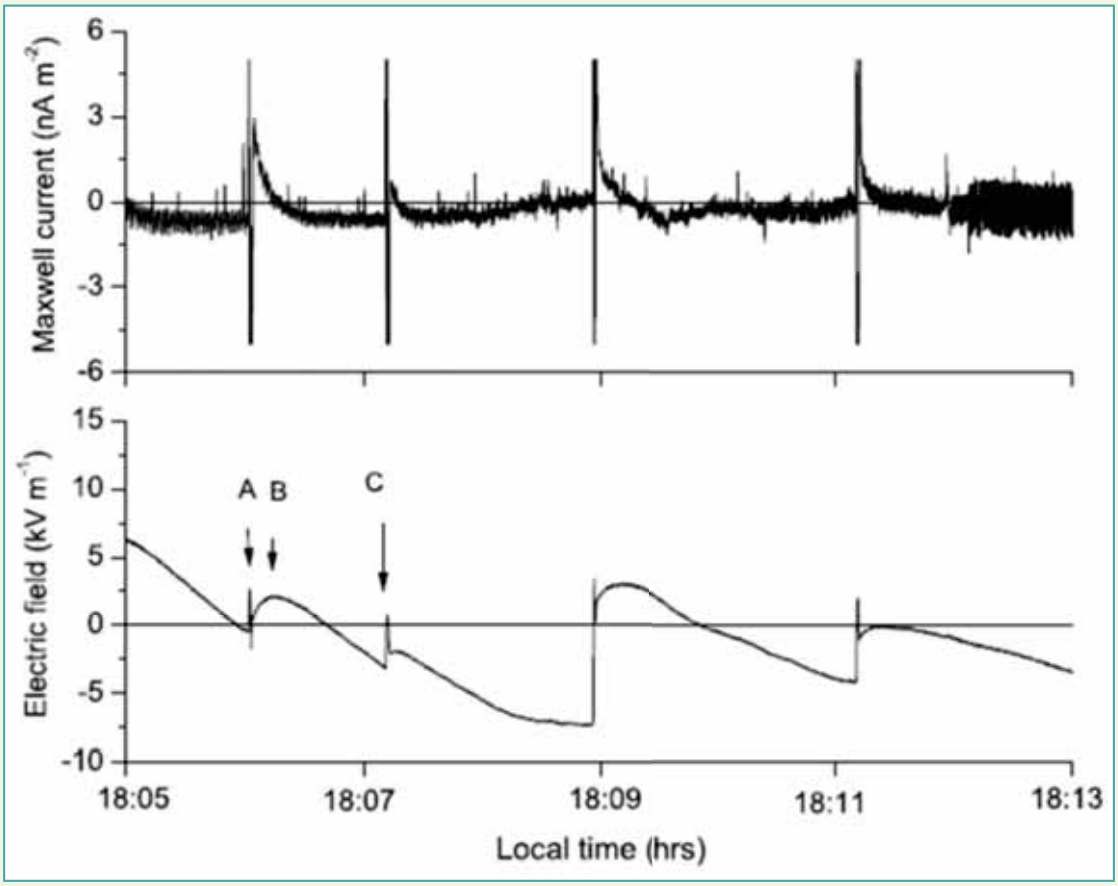


Fig. 4.10: *Records of bipolar recovery curves and Maxwell current density plotted on extended time scale during dissipation stage of thunderstorm on May 3, 2002.*

4.4.2. Lightning activity over south/southeast Asia: Modulation by thermodynamics of lower atmosphere

Simulation of lightning and its prediction by weather or climate models has remained a challenging problem mainly due to the complex interactions of large number of thermodynamic, micro-physical, dynamical and electrical processes which cause the clouds to get electrified and produce lightning in them. Hence, a parameterization or proxy has often been used to explain the spatio-temporal variance of the lightning and its forecast. Nine different proxies based on thermodynamic variables of the lower atmosphere *viz*. surface air temperature, convective available potential energy (CAPE), precipitation rate (Pr), CAPE × Pr, evaporation rate (Er) + Pr, CAPE (Er + Pr), CAPE × Bowen ratio (BR), BR × Pr, and BR (Pr + Er) were considered and analyzed. Correlations and spatial distributions of these proxies were compared with those of the lightning flash rate (LFR). Based on their performances and correlations with the total (cloud-to-cloud (CC) + cloud-to-ground (CG)) lightning flash rate obtained from the satellite data over south and southeast Asia for the period of 1995-2013, it is proposed that the lightning flash rate (LFR) is proportional to a product of the Bowen ratio and the sum of precipitation and evaporation rates. The proposed relationship is justified on the basis of the conversion of the kinetic energy of charging hydrometeors to the energy of flash discharges. This product explains 90% of the variance in the monthly-averaged time series of the total LFR over the study area of 0°N - 40°N and 60°E - 120°E including south/southeast Asia and some part of southern China. The conversion efficiency is maximum in the pre-monsoon season and minimum in the winter season. The total heat flux best accounts for the seasonal variation of the LFR. (**Fig. 4.11**) [***Chandra S., Siingh D., Victor N.J.*** *and* ***Kamra A.K.****, Lightning activity over South/Southeast Asia: Modulation by thermodynamics of lower atmosphere,* ***Atmospheric Research****, 250, March 2021, 105378*]

4.4.3. Features of the first observation of atmospheric electric field in the Kashmir valley

Influence of the local meteorological parameters and pollution on atmospheric electric field is examined by using measurements carried out in Srinagar (J&K) situated in the valley of Himalayan range. Diurnal variation of fair-weather electric field (potential gradient) shows a maxima during early morning hours followed by a maxima around 1000 LT and a secondary maxima around 1900 UT. The first maxima is absent in Carnegie curve, which is attributed to upward lifting surface air caused by surface heating and convecting space charges and aerosols. Morning hours increase of potential gradient (PG) is also attributed to the "Sunrise" effect. The timing of the second peak seems to be associated with the period of daily maximum lightning occurrences over African region. Diurnal variation compasses well with those measured at different continental stations. The variations in amplitude could be due to different local conditions like aerosol concentration, meteorological parameters, radioactivity, topography etc. The seasonal variation of PG is maximum during winter and autumn whereas it is low during summer and spring. Diurnal variation of monthly mean value shows temporal shift which clearly follows change in sunrise time and local boundary layer mixing.

The change in amplitude of primary maxima during winter is corroborated with increased aerosol due to increased use of fossil fuel in winters; lower lying boundary layer, westerly winds bring huge amounts of dust, etc. Aerosol concentration substantially depends upon the height of mixing layer along with the upslope valley winds. During summer months, fossil fuel usage decreases along with an increase in mixing layer height, thus decreasing aerosol concentration. PG is found to be highly influenced by $PM_{2.5}$ rather than PM_{10}, which may be due to the high suspension duration of $PM_{2.5}$ in the ambient air. Diurnal variation of fair weather fields remains higher than the all-weather field except around 0300 LT. Further, all-weather field has many peaks. This deviation is due to the extensive thunderstorm activity at/near the site of measurements.

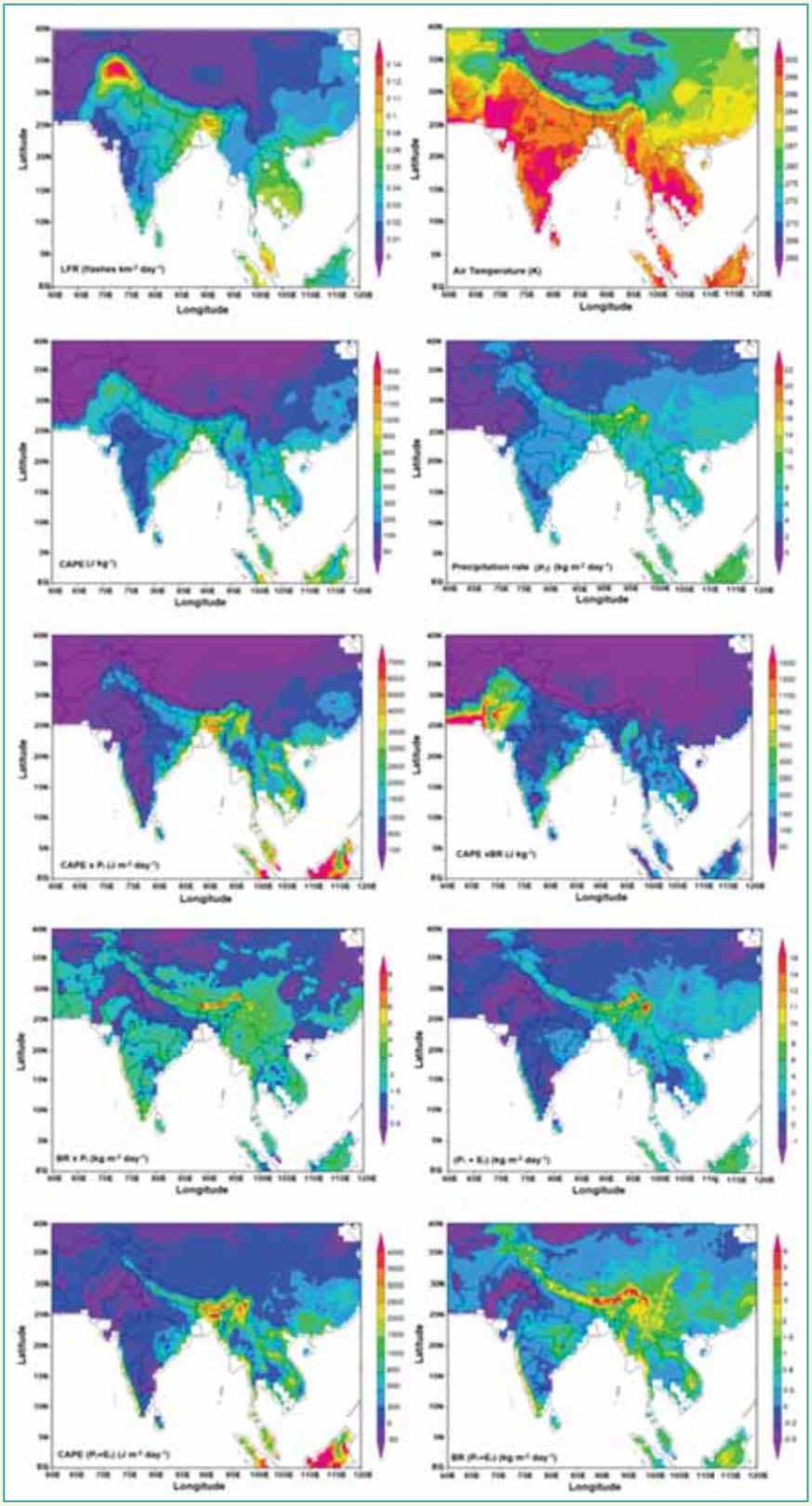


Fig. 4.11: *Annually averaged spatial distributions of LFR and the proxies for the period of 1995-2013 over South/South East Asia.*

Comparison of observed PG with global values suggested to the temporal dependency of the local and global signals on the diurnal and monthly scale. (**Fig. 4.12**) [*Afreen S., **Victor N.J.**, Bashir G., **Chandra S.**, Ahmed N., **Siingh D.**, Singh R.P, First observation of atmospheric electric field at Kashmir valley North Western Himalayas, Srinagar (India), **Journal of Atmospheric and Solar Terrestrial Physics**, 211:105481, December 2020, DOI:10.1016/j.jastp.2020.105481*]

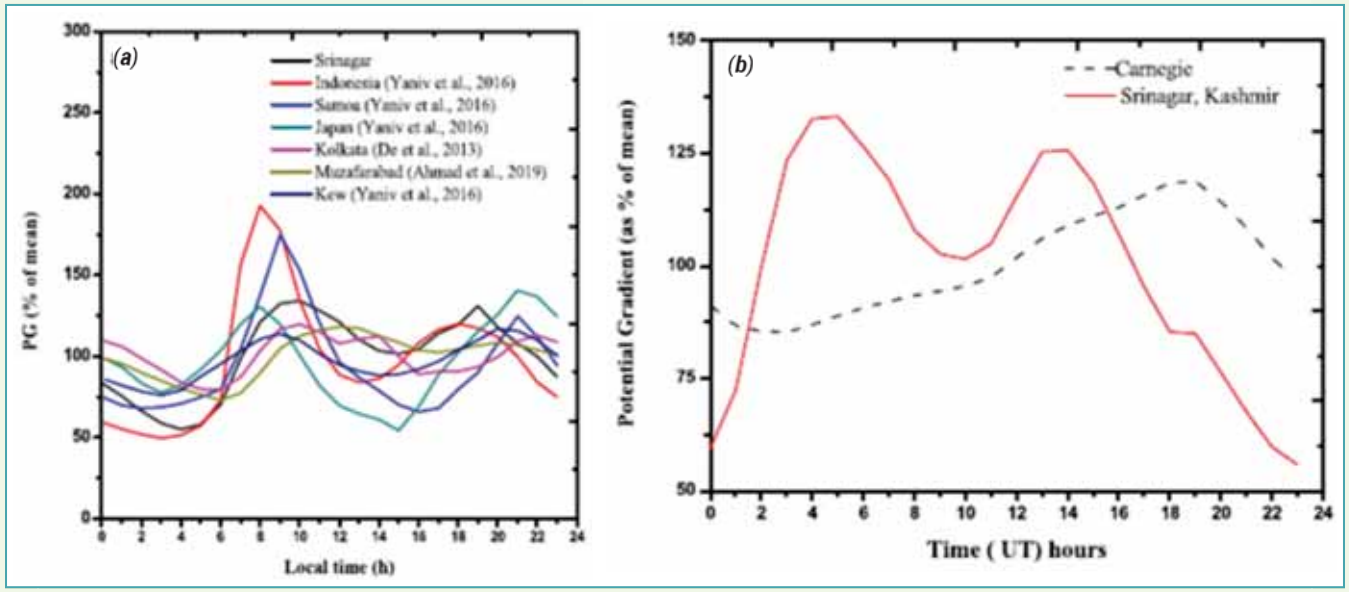


Fig. 4.12: *Comparison of fair-weather (PG) at Srinagar with (**a**) global values of different landsite and (**b**) Carnegie curve.*

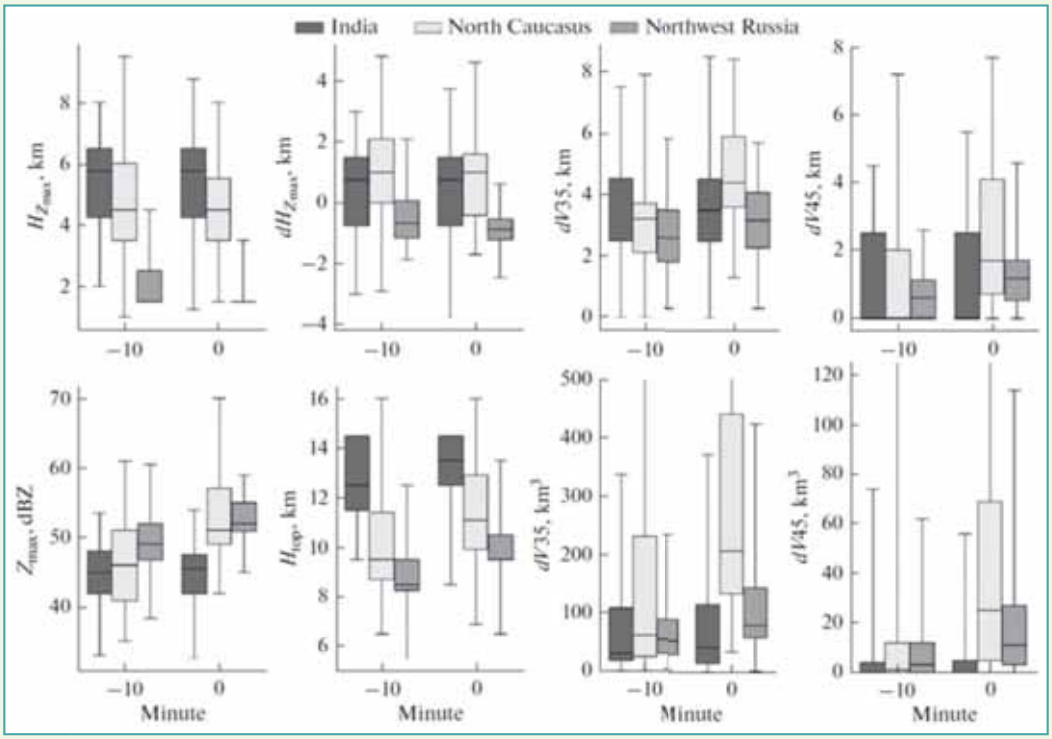


Fig. 4.13: *Box-whisker diagram of samples of radar characteristics for two radar scans made at the time of a discharge (0 min) and 10 min before the discharge (−10 min); a box shows the 25% and 75% quintiles, the line inside a box is the median, whiskers are the minimum and maximum in a sample.*

4.4.4. Radar Characteristics of Convective Clouds during Transition to the Cumulonimbus Stage in Different Regions of the World

The comparative analysis of radar characteristics of clouds transforming in the Cumulo-nimbus (Cb) clouds phase has been carried out for three regions of the world viz., India, the North Caucasus, and northwestern Russia. The only parameter which increases in all the regions is the altitude of the cloud top. It is maximal in India (the median is 13.5 km) and minimal in northwestern Russia (median is 9.5 km). In the Russian regions, the maximal reflectivity Z_{max} of clouds increases when transiting to the thunderstorm phase; no difference in the Z_{max} is observed for clouds in India. The reflectivity maximum at the instant of first discharges turned out to be the highest for clouds in northwestern Russia; this is associated with an increase in the reflectivity in the melting zone of ice particles. The volumes of the supercooled part of the clouds with high reflectivity increase when the first discharges appear for the Russian regions under study. The corresponding parameters in India are significantly lower and weakly change during the transition to the Cb stage. The different behavior of these parameters is apparently due to the difference in the conditions for formation of large ice particles, which are much fewer in clouds in India. (**Fig. 4.13**) [*Sin'kevich A. A., Popov V.B., Abshaev A.M., Boe B.A.,* ***Pawar S.D.****, Mikhailovskii Yu. P., Toropova M.L.,* ***Gopalakrishnan V.****, Gekkieva Zh. M, Radar Characteristics of Convective Clouds during Transition to the Cumulonimbus Stage in Different Regions of the World,* ***Atmospheric and Oceanic Optics****, 34, March 2021, 135-140*]

Developmental Activities

4.4.5. Map of lightning prone areas: A map of lightning prone areas has been prepared and shared with National Disaster Management Authority (NDMA).

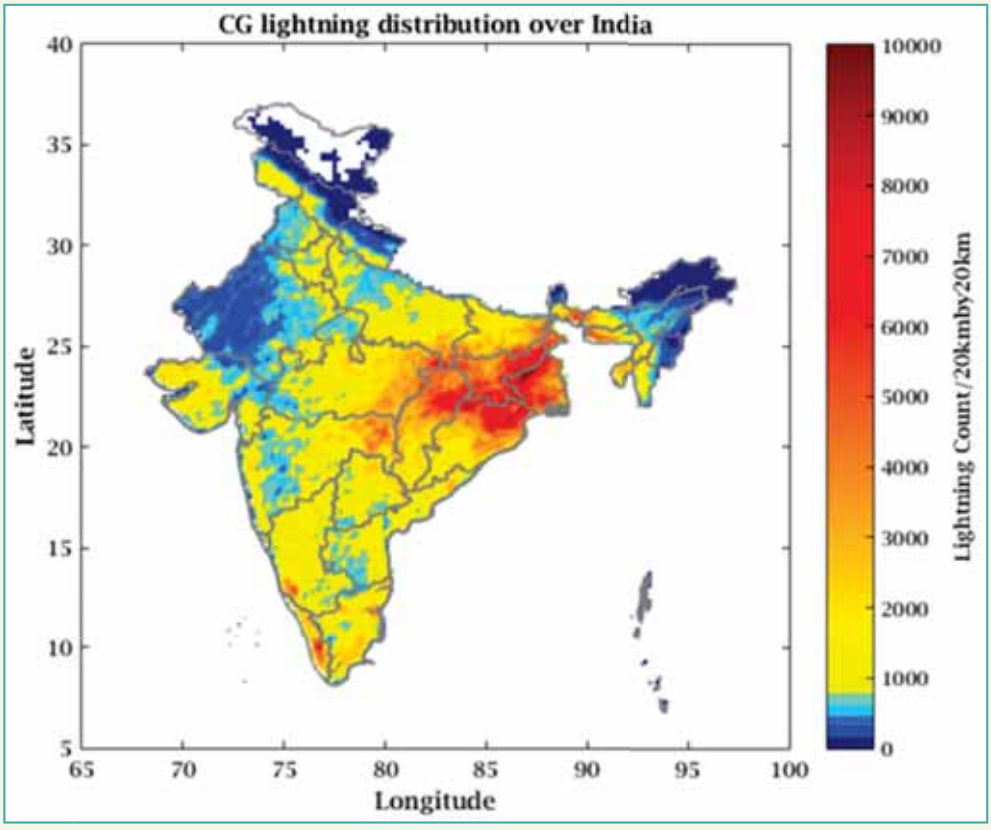


Fig. 4.14: *A map of lightning prone areas over India.*

4.4.6. Lightning causalities: The pattern of huge lightning deaths that occurred in Bihar and Uttar Pradesh during May 2020 has been analysed. Results show that the lightning causalities were mainly related to time of occurrence of lightning and people's work style. The diurnal variation of CG lightning which shows lightning activity in this region increases very early at about 12 hrs LT and remains high upto 18 hrs LT. Analysis of causality data reveals that as many as 80% of deaths are reported from rural areas. In rural areas, most of the people work in fields during this period and are exposed to the perils of lightning. Therefore, early start of lightning activity can be one of the reasons for more number of deaths due to lightning in this region compared to other regions of the country. Records reveal that very few fatalities are reported for people who take proper shelter (i.e., inside buildings/homes).

4.4.7. Observatory in Kolhapur: Under an MoU signed with Sanjay Ghodawat University (SGU), Kolhapur, an observatory is being established to study atmospheric electricity along with micrometeorological parameters. All micrometeorological parameters, such as temperature, humidity, wind direction and speed, pressure and rainfall are being measured at 2 m height. A phased array Doppler SODAR has been installed at the observatory and is made operational since July 2020 to study thermodynamical structure during thunderstorm and other periods. An electric field-mill and a sensor of Lightning Location Network are also installed at the SGU campus.

4.4.8. New sensors for meteorological tower: A 3-axis sonic anemometer on 11 m tower (height of the sensor 12 m) for study of turbulence structure of atmospheric surface layer, and a 6 level soil moisture and temperature sensor to study the energy exchange between sub-surface and surface have been installed at IITM campus.



Fig. 4.15: *Doppler SODAR installed at the observatory in Kolhapur.*

Chapter 5

National Facility for Airborne Research (NFAR)

Project Director : Dr. B. Padmakumari

Objectives

The project envisages the establishment of an airborne research facility for the nation to cater the scientific needs of research community in the country for the advancement of atmospheric process studies. The broad objectives of NFAR are:

- Procurement of an Instrumented Aircraft System (IAS) as a national facility for airborne atmospheric research.
- To facilitate cloud microphysics and aerosol observations during different seasons using the instrumented airborne platform for studying cloud aerosol interactions over different parts of the country.
- To facilitate observations for understanding the interactions between clouds and large-scale environment, which may be used in developing physical parameterization schemes useful in numerical models used for monsoon prediction.
- To use Unmanned Aerial Systems (UAS) for lower atmospheric research and boundary layer process studies.

Highlights of Major Achievements :

- Lower Atmospheric Research using Unmanned Aerial System Facility (LARUS) has been established at IITM.
- Unique identity numbers from DGCA have also been obtained for IITM's UAV systems.
- Standard Operating Procedures for UAV operations in India for atmospheric research submitted to DGCA for vetting/concurrence.
- INSAT-3D Fog data was used to study the evolution, spatial and temporal variability of fog over the Indo-Gangetic Basin for the winter months of December 2016 and January 2017 in conjunction with surface measurements.
- Cloud fraction time series for 24 hours over a complex terrain of the Western Ghats using a TIR Sky Imager was constructed. CF Diurnal cycle (24 hours) over the Western Ghats showed huge variability in all seasons except in monsoon.

Due to paucity of funds, aircraft procurement could not be achieved in 2020-21, and NFAR project is temporarily suspended. Henceforth, UAV activities will be carried out under Ministry's newly approved 'Atmospheric Research Test-bed (ART)' sub-project of Monsoon Convection, Clouds and Climate Change (MC4) under ACROSS programme.

Developmental activities

5.1. Lower Atmospheric Research using Unmanned Aerial System Facility (LARUS)

The Unmanned Aerial System (UAS) Laboratory named as 'Lower Atmospheric Research using Unmanned Aerial System Facility – LARUS' has been established at IITM with basic infrastructure to take up various R&D activities with Unmanned Aerial Vehicle (UAV) systems for lower atmospheric process studies. IITM's UAV systems have been listed in the digital sky platform of DGCA, and unique identity numbers (UIN) from DGCA have also been obtained for the same. IITM is the first government organization in the country to obtain UIN for UAVs. Standard Operating Procedures (SOP) for UAV operations in India for atmospheric research submitted to DGCA for vetting/ concurrence are under consideration. Miniaturized multichannel data logger, and the state-of-the-art mini meteorological data reception equipment at ground were designed and developed in-house for utilization during UAS operations.

Basic Research

5.2. Spatiotemporal variability and evolution of day and night winter Fog over the entire IGB using INSAT-3D and comparison with surface Visibility

Every year during the peak winter months (December-January), dense and prolonged fog envelops the Indo-Gangetic Basin (IGB) over the Indian sub-continent leading to economic loss. Many efforts are being made to understand its characteristics to improve forecasting skills. Fog data available at every 30 minutes interval throughout the day and night, retrieved from a geostationary satellite INSAT-3D, was used to study the evolution, spatial and temporal variability of fog for the winter months of December 2016 and January 2017 in conjunction with surface measurements. The important findings of the study are highlighted. Spatiotemporal evolution of fog is depicted by INSAT-3D for continuous day and night hours. INSAT-3D captured fog very well for visibility ranging from 0 to 500 m representing very dense, dense, and moderate fog, while the shallow fog with visibility > 600 m was captured occasionally. INSAT-3D fog and surface visibility exhibited a good relationship. Widespread fog enveloped IGB for long duration at midnight and early morning hours. Fog onset was triggered by high pollution levels and stable atmosphere in winter. The central and west IGB was most vulnerable to frequent and dense fog events. (**Fig. 5.1**) [*Banerjee S.,* ***Padmakumari B.****, Spatiotemporal variability and evolution of day and night winter fog over the Indo Gangetic Basin using INSAT-3D and comparison with surface visibility and aerosol optical depth,* ***Science of the Total Environment****, 745: 140962, November 2020, DOI:10.1016/j.scitotenv.2020.140962*]

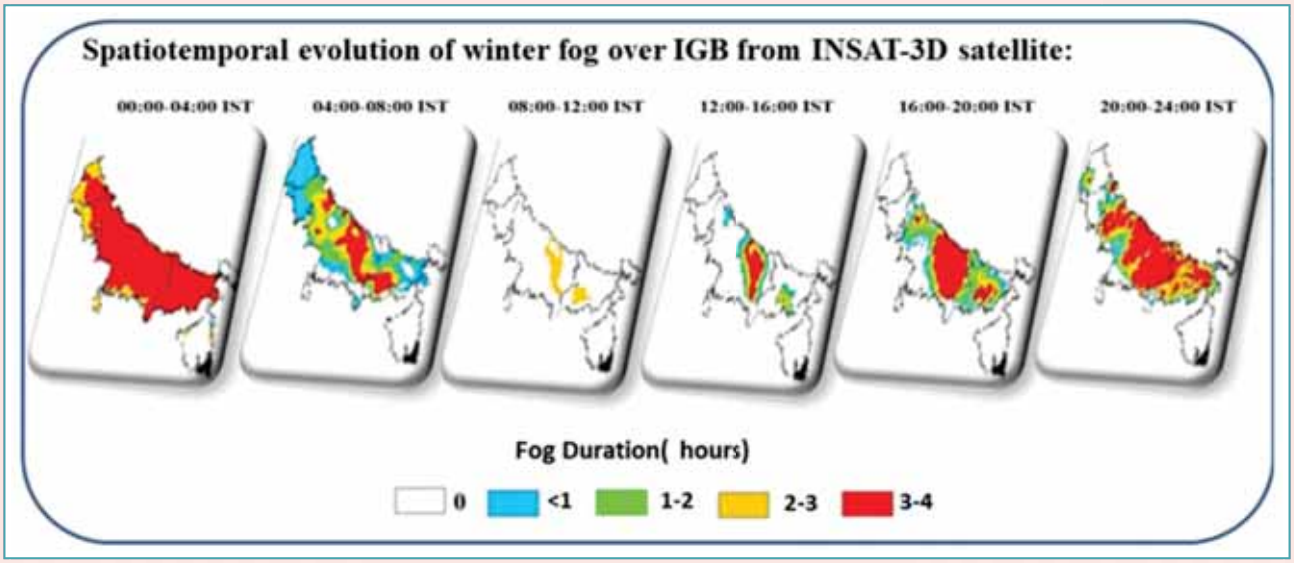


Fig. 5.1: *Spatiotemporal evolution of winter fog over IGB from INSAT-2D satellite.*

5.3. Diurnal (24 hours) cycle and Seasonal variability of Cloud Fraction retrieved from a Whole Sky Imager over a complex terrain in the Western Ghats and comparison with satellite

Continuous monitoring of cloud fraction (CF) using a Whole Sky Imager (WSI) equipped with a thermal infrared (TIR) camera play a crucial role in validating satellite data and numerical models. WSI was operated at a high altitude station located in the complex terrain of the Western Ghats of the peninsular India during December 2016 to May 2019. CF is retrieved continuously for 24 hours at a high temporal resolution (5 minutes) and a unique time series is constructed for thick, thin and total cloud cover. Some important findings of the study are highlighted here. The CF time series for 24 hours over a complex terrain of the Western Ghats using a TIR Sky Imager was constructed. CF Diurnal cycle (24 hours) over the Western Ghats showed huge variability in all seasons except in monsoon. Day CF was higher than night CF in post-monsoon and winter, while almost similar in other seasons. JJAS showed continuous 100% CF during day as well as night. The retrieved CF is compared with MODIS (Aqua and Terra satellites) CF during the overpass times over the study area. Good correlation is observed, however, more bias is observed during broken/partial clouds. The study inferred that cloud events/characteristics observed on a temporal scale gets averaged out on diurnal, monthly and seasonal scales. When compared with MODIS diurnal and seasonal variability, large biases were observed on a regional scale due to high CF variability, and more importantly, fewer satellite observations representing the day average. (**Fig. 5.2**) [***Sneha Sunil, Padmakumari B., Pandithurai G., Patil R.D.***, *Naidu C.V., Diurnal (24 h) cycle and seasonal variability of cloud fraction retrieved from a Whole Sky Imager over a complex terrain in the Western Ghats and comparison with MODIS,* ***Atmospheric Research****, 248: 105180, January 2021, DOI:10.1016/j.atmosres.2020.105180*]

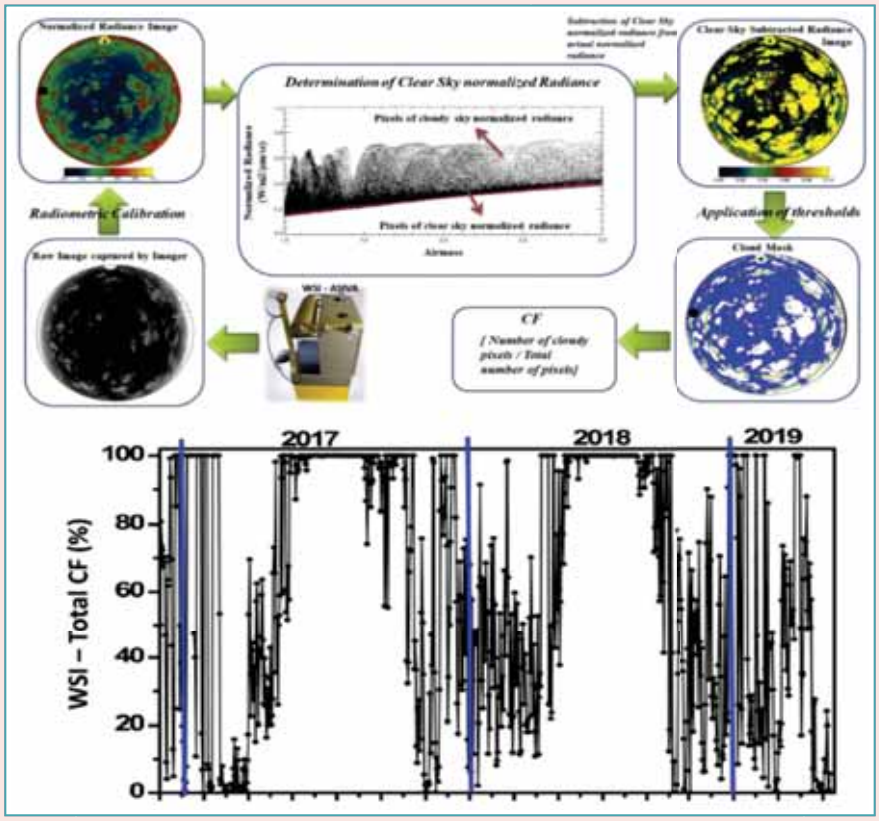


Fig. 5.2: *Top panel shows the schematic of the new methodology used for remote sensing of clouds from ground-based sky imager. Bottom panel shows the time series of cloud fraction over a high altitude region in the Western Ghats.*

Chapter 6

High Performance Computing System (HPCS)

Objectives

- Establishing a multi-petaflops scale computing facility for the MoES institutes to meet the requirement of numerical modeling for weather and climate forecasting, basic research, and observations.
- To make available computational resources to the academic and other R&D community to work on the operational forecasting system and to improve forecast skill.
- To build a robust computational and visualization environment to deliver state-of-the-art Big Data Analytics and AI/ML Application in the Earth Science issues domain.
- To establish and maintain an MoES Atmospheric Research Data Center, and provide researchers with easy access to data.
- Basic research in cloud-microphysics using small-scale simulations.
- Promote research on weather/climate applications and AI/ML.

Developmental Activities

6.1. Uses and achievements of HPC

- An atmosphere research data center has been established on the HPC.
- Being under essential services both HPC Pratyush and HPC Aaditya have been operational even during the lockdown period with the desired uptime.
- Small scale simulation code such as DNS and scaled-up DNS runs on HPC.
- AI/ML models development for weather and climate applications are being done on HPC systems.
- HPC provides facilities for researchers at IITM, institutes under MoES, and universities.
- Lightning activity for the complete Maharashtra state is monitored and networked through HPC.
- Air quality forecast models are run on HPC.
- Seasonal and extended range forecasts are carried by using the HPC facility at IITM.
- High-resolution IITM short-range deterministic forecast is done with the GFS model at T1534 (12 km grid).

6.2. Support to HPC System

Storage and compute quotas for each specific group have been designed and assigned as per the recommendations from the HPC Committee of MoES for both the systems. The storage of both the systems has been designed to be secure yet flexible so that the data can be shared freely among research and operational groups. The compute queues function in such a way that the operational jobs get the highest and immediate priority while research jobs also get their fair share.

Adequate efforts were taken by the HPC support during lockdown time during the last year to maintain uptime, resolving the issues of users within the stipulated time frame. User support was made available through email and a web-based system as a one-stop solution. Emergency services were kept on in lockdown time. The majority of the user issues were dealt with within an acceptable time frame and symbiotic co-operation from the support team and end-users. In urgent and extreme cases, the support was also made available over the phone.

6.3. HPC System Utilization

The utilization of both HPC systems (Aaditya and Pratyush) during the last year are provided in figures 6.1 and 6.2 respectively.

6.4. Upgrades in HPC systems

The Institute has procured the following software for MoES HPC systems installed at IITM, Pune (Pratyush), and NCMRWF Noida (Mihir) for the use of various HPC users. The procurements were the latest programming tools that are being used by

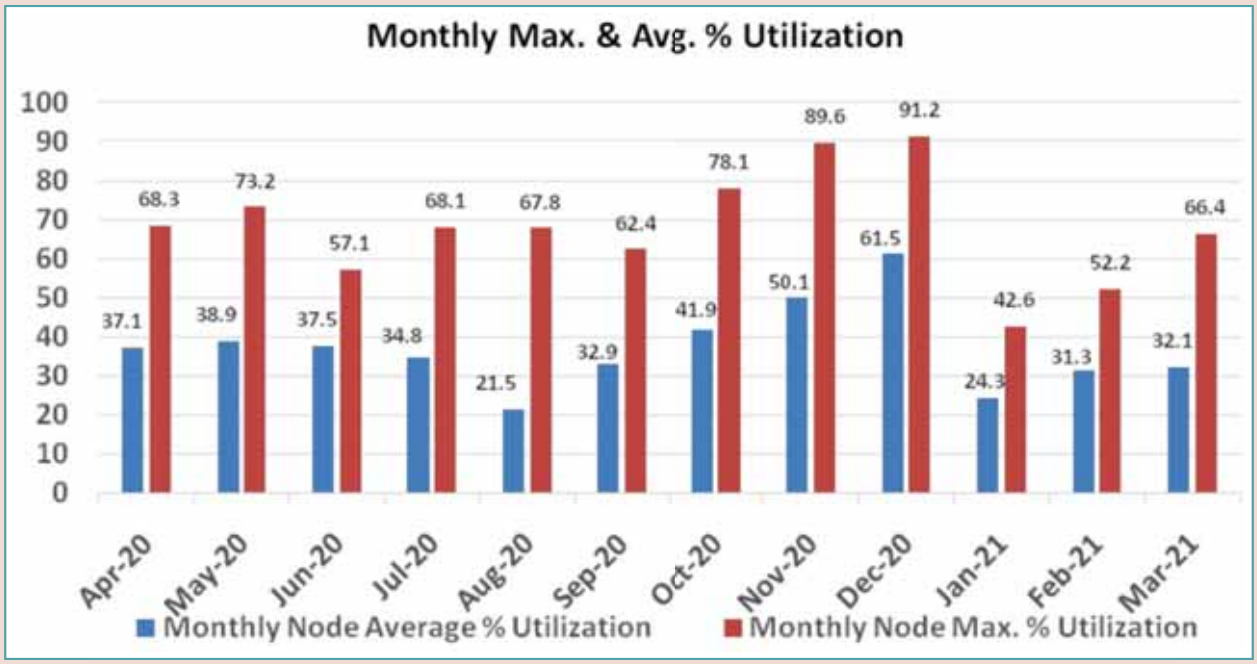


Fig. 6.1: *Utilization (%) for HPC Aaditya.*

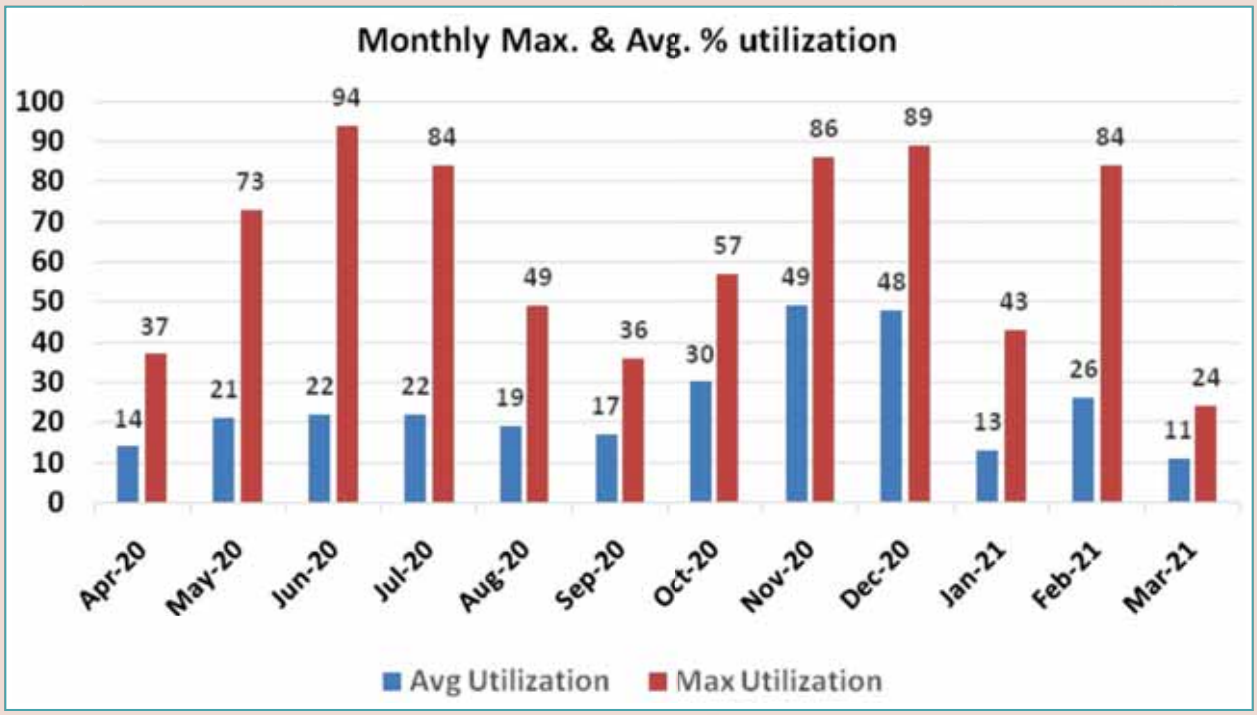


Fig. 6.2: *Utilization (%) for HPC Pratyush.*

various scientists for their models. The installation of these software was completed successfully and handed over to the users. Details of the newly procured software are given below:

No.	Description	License for Pratyush HPC System	License for Mihir HPC System
1	Intel Parallel Studio XE Software	07 Users	07 Users
2	Matlab 2019b	10 Users	10 Users
3	IDL 8.7	05 Users	05 Users

The Institute has procured an additional new layer of the disk storage system with a high storage capacity and low throughput which will be the disk archival layer before the tape archival. Installation and acceptance of disk archival storage along with HPSS at both the sites of MoES (17 PB at IITM, Pune and 10 PB at NCMRWF, Noida) and 5 PB HPSS tape archival each at both the sites was completed. Apart from this augmentation, following points to be noted for upgradation:

- Integration of Cray tape libraries under HPSS is under progress. Data migration from Cray tape archival to HPSS storage will be completed shortly.
- Various modelling and observational datasets were included in Atmospheric research data centre (https://ardc.tropmet.res.in/las/UI.vm).

Several changes made in system, including installation/reinstallation of applications (latest versions) and software upgrades/updates, on HPC Pratyush and HPC Aadtiya are provided in **Appendix-1**.

Basic Research

6.5. Statistical data downscaling using AI techniques

The data downscaling is used to generate high-resolution observational data to validate the climate model forecast or monitor rainfall at the micro-regional level operationally. The models for dynamical and statistical downscaling are often used to get information at high-resolution gridded data over larger domains. As rainfall variability is dependent on the complex spatio-temporal process leading to non-linear or chaotic spatio-temporal variations, no single downscaling method can be considered efficient enough. The deep learning based methods provide an efficient solution in downscaling rainfall data for regional climate forecasting and real-time rainfall observation data at high spatial resolutions. Three deep learning based models, namely, SRCNN, Stacked.SRCNN and DeepSD, were employed on summer monsoon season data from India Meteorological Department (IMD) and the tropical rainfall measuring mission (TRMM) data set and downscaled them to the higher resolution. The high-resolution data derived from deep learning based models provided better results than linear interpolation for up to 4 times higher resolution. In particular, the DeepSD method found to be the best among the three methods. Also, these methods were applied for model data post-processing, in particular, ERA5 reanalysis data. Downscaled ERA5 rainfall data showed a much better distribution of spatial covariance and temporal variance when compared with observation. This study is the first step towards developing deep learning based weather data downscaling model for Indian summer monsoon rainfall data. **Fig 6.3** represents an overview of the deep learning methods, based on Super-Resolution Convolutional Neural Network (SRCNN) technique, that were used in the study. [***Kumar B., Chattopadhyay R., Singh M.,*** *Chaudhari N., Kodari K. and Barve A., Deep-learning based down-scaling of summer monsoon rainfall data over Indian region,* ***Theoretical and Applied Climatology****, 143, January 2021, 1145-1156,* DOI: 10.1007/s00704-020-03489-6]

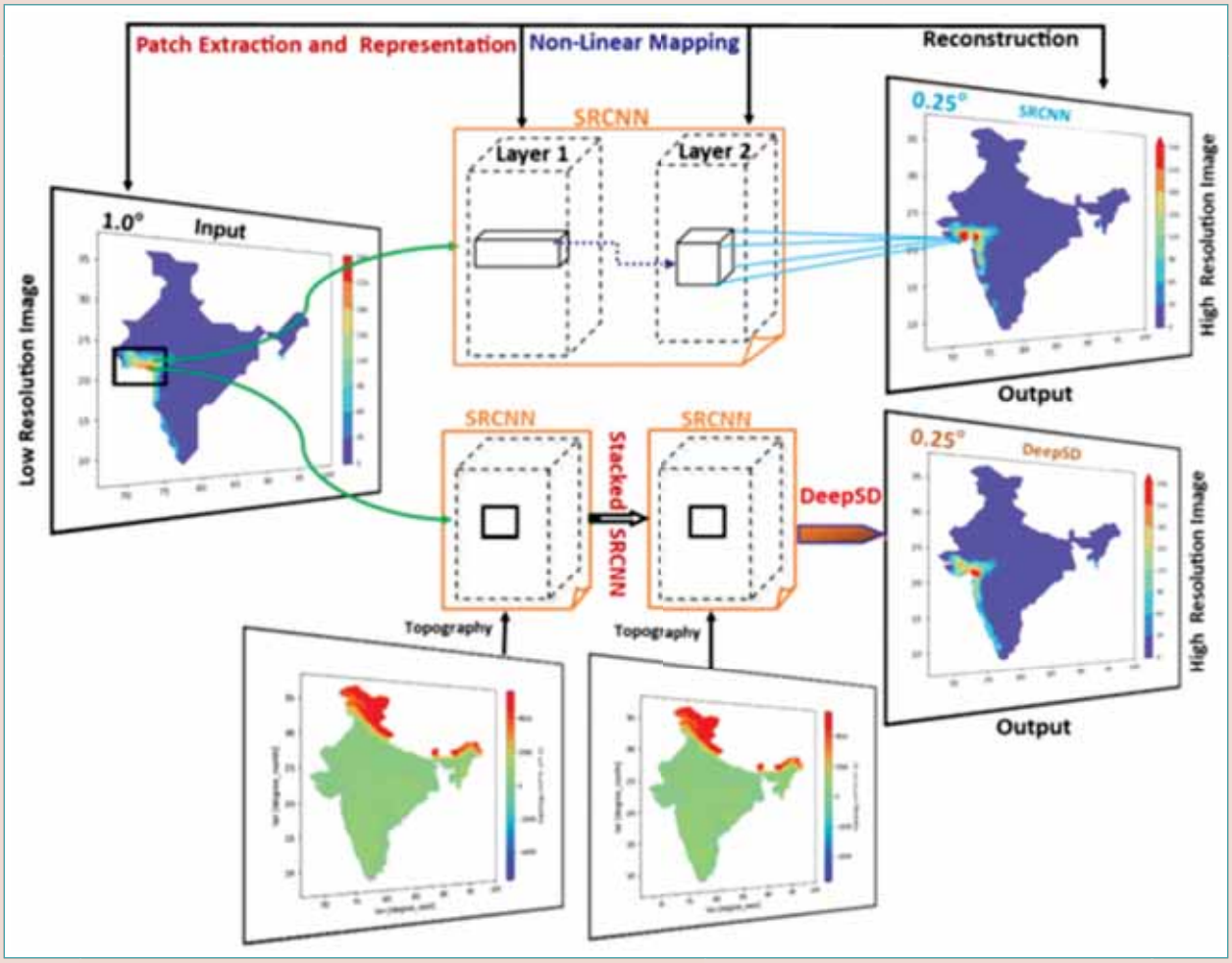


***Fig. 6.3**: An overview of deep learning based methods, namely, SRCNN, Stacked-SRCNN and DeepSD method. These methods were used to downscale the IMD and TRMM data for ISMR.*

6.6. Scaled-up DNS

The excessive computational cost limits the range of scales that can be simulated in the traditional DNS. Resolving all the scales involved, that is, from the scale of largest eddy in the domain to the Kolmogorov dissipative scales, and following every single droplet contributes to this cost. A new approach called 'scaled-up DNS' was devised. It effectively reduced the computational cost but allowed simulations up to Large Eddy Simulation (LES) scales (up to the domain size (64^3 m^3). The two important steps of scaling up are: a) scaling up of Turbulent Kinetic Energy (TKE) by increasing domain length as well as grid size, and b) using super-droplets instead of real droplets. The key is to ensure proper dissipation of TKE and scalar variance at small scales by appropriately increasing molecular coefficients corresponding to the length scales. To address the massive task of following billions of real droplets in a scaled-up DNS, these were replaced with super-droplets, where each super-droplet represented a group of identical real-droplets. Scaled-up DNS simulations were conducted for several domains with the largest being 64^3 m^3 volume using a $(256)^3$ grid point DNS. The scaled-up DNS generated energy spectra and

TKE values for the larger domains as expected from the theory. The increases in supersaturation fluctuations as well as the spectral width with domain size were also demonstrated. **Fig 6.4** represents a comparison of energy spectra for real and scaled-up DNS taken from this publication.

[***Thomas L.***, *Grabowski W.W.*, ***Kumar B.***, *Diffusional growth of cloud droplets in homogeneous isotropic turbulence: DNS, scaled-up DNS, and stochastic model,* ***Atmospheric Chemistry and Physics****, 20, July 2020, 9087-9100, DOI: 10.5194/acp-20-9087-2020*]

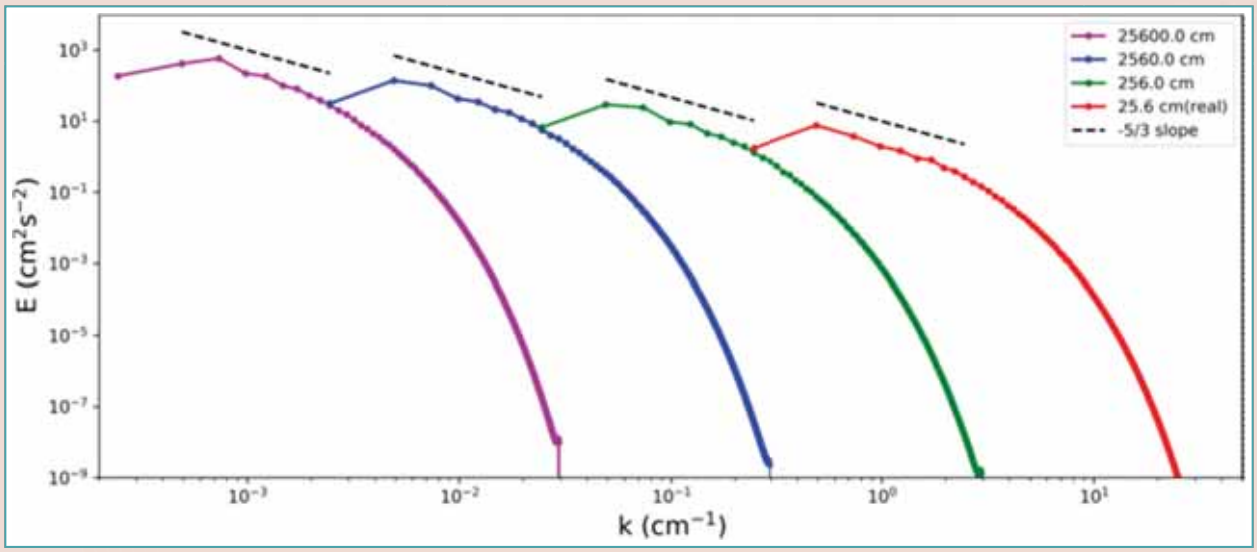


Fig. 6.4*: Comparison of energy spectra for real and scaled-up DNS.*

Chapter 7

Metropolitan Air Quality and Weather Services (MAQWS)

Project Director : Dr. B.S. Murthy

Objectives

- Advance research on Atmospheric Processes governing atmospheric chemical composition and air pollutants through modeling and observational network.
- Development of gridded emission inventory of air pollutants for India and updating to High-resolution Inventories for SAFAR cities to help mitigation planning.
- Establishment of national MAPAN (Modeling Air Pollution And Networking) network for atmospheric chemical parameters and chemical characterization.
- Investigating the role of carbonaceous species (black carbon, organic carbon, brown carbon, etc.), particularly in Himalayan region.
- Development of research based integrated Multi- Hazard Early Warning System for Air Quality, Weather and Health to predict environmental emergencies with air-health advisory services for Indian SAFAR Mega cities.

Highlights of Major Achievements:

- Ceilometer observations during lockdown in Delhi suggest the propagation of cloud bases from lower to higher levels due to large reduction (47%) in cloud condensation nuclei (CCN). Cloud base height is found to have an inverse correlation with CCN and NO_2/NH_3 concentrations.
- Observations through 34 stations in Delhi during lockdown provided an opportunity to assess the minimum level of pollution in Delhi achieved by almost nullifying the emission from transport and industrial sectors.
- Covid-19 lockdown induced base level PM2.5 and mortality rate per million is found to be highly correlated (> 0.8) as per the evaluation over 4 SAFAR cities and metropolis Chennai and Kolkata.
- Air quality observations during the nationwide lockdown suggest a dramatic decline in major sources of emissions, except for household cooking, over Delhi and Mumbai.
- Laboratory experiment reveals that carbonaceous aerosols emitted from biomass (Cow dung) burning get completely activated to CCN at lower super-saturation than those emitted from fossil fuel.
- During lockdown, over Mumbai and Pune, surface Ozone generation tends to be controlled by volatile organic compounds (VOCs), suggesting that air pollution mitigation strategies should target VOC reduction under low vehicular emission scenario.
- A study based on biomass emission inventory, model and satellite observations proposes that if the crop residue burning period is preponed by about a month having higher atmospheric dispersive capacity from mid-September to mid-October could avoid extreme air pollution events over Delhi.

Basic Research

7.1. Impact of Covid-19 Lockdown on Clouds

Aerosol-cloud interactions and feedbacks play an important role in modulating cloud development, microphysical and optical properties thus enhancing or reducing precipitation over polluted/pristine regions. The lockdown enforced on account of Covid-19 pandemic is a unique opportunity to verify the influence of drastic reduction in aerosols on cloud development and its vertical distribution embedded in identical synoptic conditions. Cloud bases measured by ceilometer in Delhi are observed to propagate from lower to higher levels as the lockdown progresses. It is explained in terms of trends in temporal variation of cloud condensation nuclei (CCN) and precursor gases to secondary hygroscopic aerosols. The large reduction (47%) in CCN estimated from aerosol extinction coefficient during the lockdown results in upward shift of cloud bases. Low clouds with bases located below 3 km are found to have reduced significantly from 63% (of total clouds distributed in the vertical) during pre-lockdown to 12% in lockdown period (less polluted). Cloud base height is found to have an inverse correlation with CCN (r=−0.64) and NO_2/NH_3 concentrations (r=−0.7). The role of meteorology and CCN in modulating the cloud vertical profiles is discussed in terms of anomalies of various controlling factors like lifting condensation level (LCL), precipitable water content (PWC) and mixing layer height (MLH). (**Fig. 7.1**) [***Latha R., Murthy B.S., Sandeepan B.S.,*** *Bhanage V.,* ***Rathod Aditi,*** *Tiwari Arpit,* ***Beig G.****, Singh S., Propagation of cloud base to higher levels during Covid-19-Lockdown,* ***Science of the Total Environment****, 759:144299, March 2021, DOI:10.1016/j.scitotenv.2020.144299*]

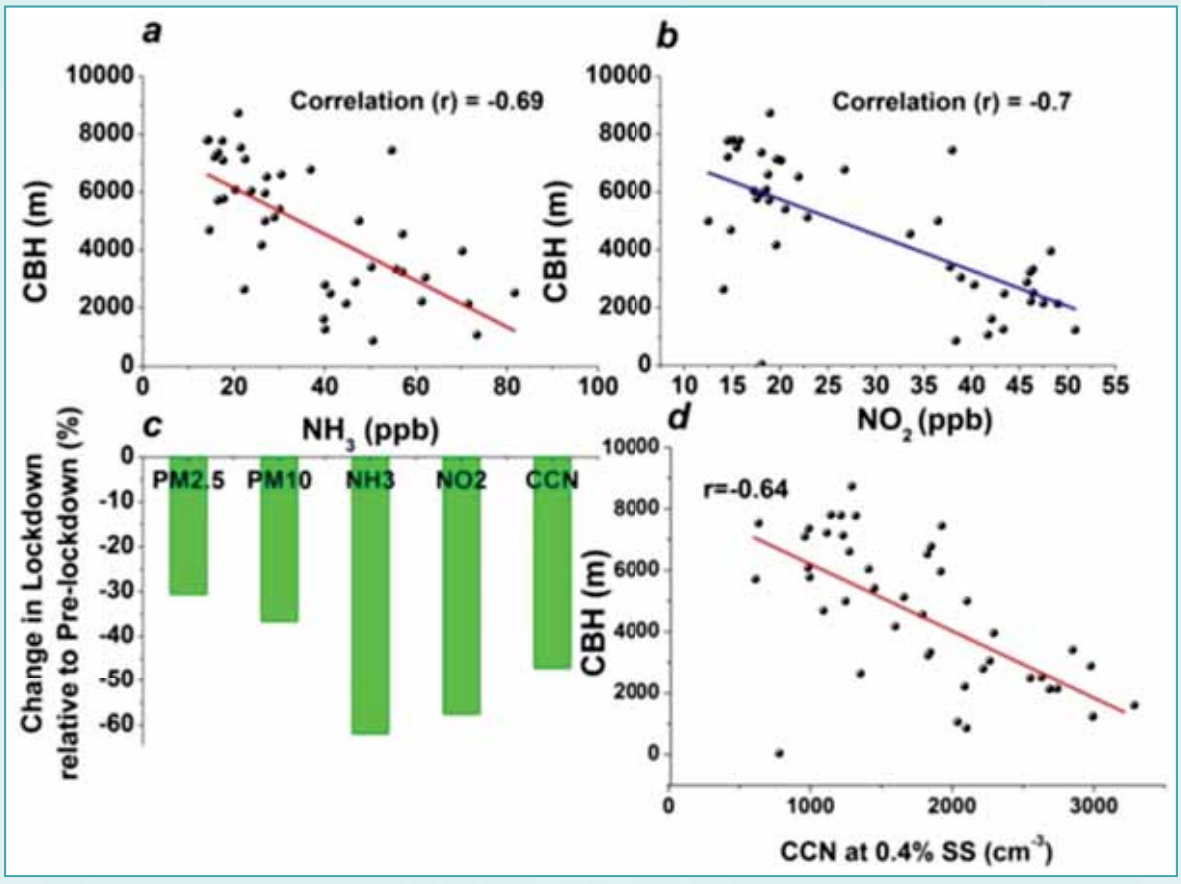


Fig. 7.1: *Scatter plot of (**a**) Cloud Base Heights (CBH) and NH_3 and (**b**) CBH and NO_2, (**c**) Percentage change in $PM_{2.5}$, PM_{10}, NO_2, NH_3, and CCN during the lockdown period with respect to the pre-lockdown period, and (d) Scatter plot between CBH and CCN at 0.4% super-saturation.*

7.2. Impact of Covid-19 on air quality and mortality

The lockdown provided an opportunity to assess the minimum level of pollution in Delhi achievable by almost decimating the emissions from transport and industrial sectors based on the observations through 34 stations. This level could be considered as a base level for policy makers in various fronts. Lockdown evolved base level and mortality rate per million is found to be highly correlated (> 0.8) as per the evaluation over four SAFAR cities and in addition metropolis Chennai and Kolkata. This preliminary study revealed that $PM_{2.5}$ baseline levels and total mortality also correlate well. (**Fig. 7.2**) [***Beig G.,*** *George M.P., Sahu S.K.,* ***Rathod A.,*** *Singh S.,* ***Dole S., Murthy B.S., Latha R., Tikle S., Shinde R.,*** *Towards baseline air pollution under COVID-19: implication for chronic health and policy research for Delhi, India,* ***Current Science****, 119, October 2020, DOI: 10.18520/cs/v119/17/1178-1184, 1178-1184* and ***Beig G., Bano S.****, Sahu S.K.,* ***Anand V., Rathod A., Yadav R.****, Mangaraj P.,* ***Murthy B.S.****, Singh S.,* ***Latha R., Shinde R.****, COVID-19 and environmental -weather markers: Unfolding baseline levels and veracity of linkages in tropical India,* ***Environmental Research****, 191: 110121, December 2020, DOI:10.1016/j.envres.2020.110121*]

7.3. Impact of bio-fuel emissions during Covid-19 lockdown in Indian Metros

While local anthropogenic emission sources contribute largely to deteriorate metro air quality, long range transport can also play a significant role in influencing levels of pollutants, particularly carbon monoxide (CO) that has a relatively long life span. A nationwide lockdown of two months imposed across India amid COVID-19 led to a dramatic decline in major sources of emissions except for household, mainly from cooking. This initially led to declined levels of CO in two of the largest megacities of India, Delhi and Mumbai under stable weather conditions, followed by a distinctly different variability under the influence of prevailing mesoscale circulation. The sources of CO were traced from local emissions to transport pathways and the observed variability in CO is interpreted by using the interactive WRF-Chem model and back trajectory analysis. For this purpose, COVID-19 emission inventory of CO was estimated. Model results indicate a significant contribution from externally generated CO in Delhi from surrounding regions and an unusual peak on 17th May 2020 amid lockdown due to long range transport from the

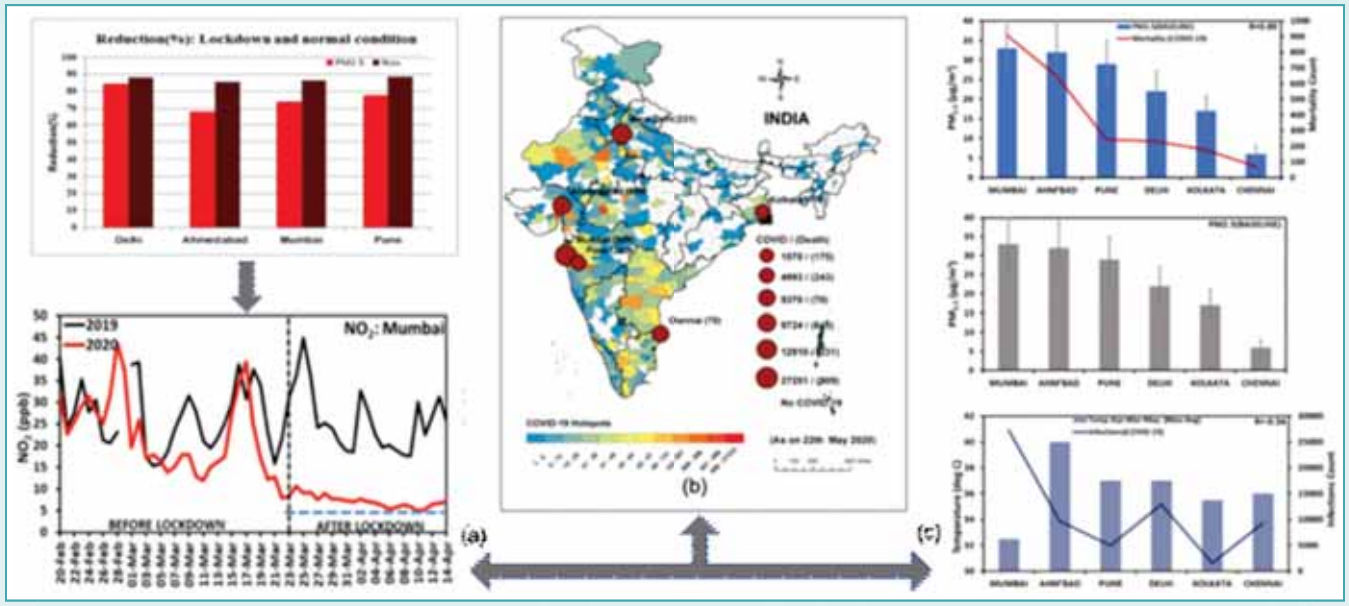


*Fig. 7.2: The six mega city COVID-19 study: (**a**) Reduction in PM2.5 and NO_x during COVID-19 lockdown, (**b**) Infection counts in bracket as on 22 May 2020, (**c**) correlation of baseline $PM_{2.5}$ with mortality; $PM_{2.5}$ baseline levels and correlation of infection with temperature.*

source region of biofuel emissions in central India. However, the oceanic winds played a larger role in keeping CO levels in check in a coastal megacity Mumbai which otherwise has high CO emissions from household sources due to a larger share of urban slums. Keeping track of evolving carbon-intensive pathways can help inform government responses to the COVID-19 pandemic to prioritize controls of emissions sources. (**Fig. 7.3**) [***Beig G., Korhale N., Rathod A., Maji S.,*** *Sahu S.K.,* ***Dole S., Latha R., Murthy B.S.****, On modelling growing menace of household emissions under COVID-19 in Indian metros,* ***Environmental Pollution****, 272:115993, March 2021, DOI:10.1016/j.envpol.2020.115993*]

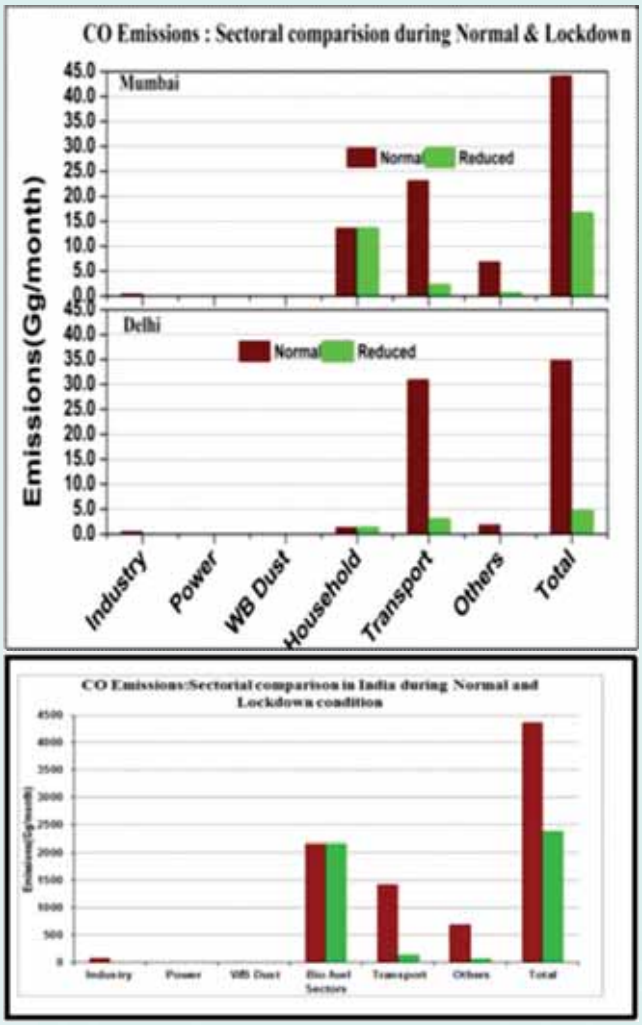


Fig. 7.3: *Impact of bio-fuel emissions during lockdown.*

7.4. CCN Activation of Carbon aerosols from various combustion sources

A laboratory-based experiment was carried out to understand the cloud condensation nuclei (CCN) activation of carbonaceous aerosols from various sources of emissions such as combustion of wood, cow dung cake, wood-coal burning and diesel generator (DG). The aerosol particles from DG exhaust were found to get activated completely to cloud condensation nuclei (CCN) at a higher super-saturation (SS) of 0.9% (100.9% RH). However, the CCN activation was faster in carbonaceous aerosol emission from combustion of cow dung cake, where complete CCN activation of particles was observed at 0.3% SS. Wood burning also showed a faster activation at 0.4% SS, whereas for wood-coal burning, the CCN activation occurred at 0.7% SS. Organic carbon (OC) was found to be the dominant carbon component in all four emission sources compared to elemental carbon (EC) and black carbon (BC). Among all the four combustion emissions, wood-burning had the highest OC/EC ratio (8.35) and the lowest was for DG emissions (2.03). BC mass concentration was higher in DG emissions compared to other emissions for the same number of aerosol particles. The non-refractory aerosol chemical composition analysis showed that organic species dominate inorganic species in all the emissions. The study indicates that the carbonaceous aerosols originating from direct emission sources have the potential to get activated as CCN at high super-saturation. (**Fig. 7.4**) [***Panicker A.S., AnilKumar V., Raju M.P., Pandithurai G., Safai P.D., Beig G.****, Das S., CCN activation of carbonaceous aerosols from different combustion emissions sources: A laboratory study,* ***Atmospheric Research****, 248: 105252, January 2021, DOI:10.1016/j.atmosres.2020.105252*]

7.5. Disparity in Ozone trends in nearby costal and hillocky cities during lockdown

The behaviour of surface ozone (O_3) concentrations and its precursors, oxides of nitrogen (NO_x), carbon monoxide (CO), and volatile organic compounds

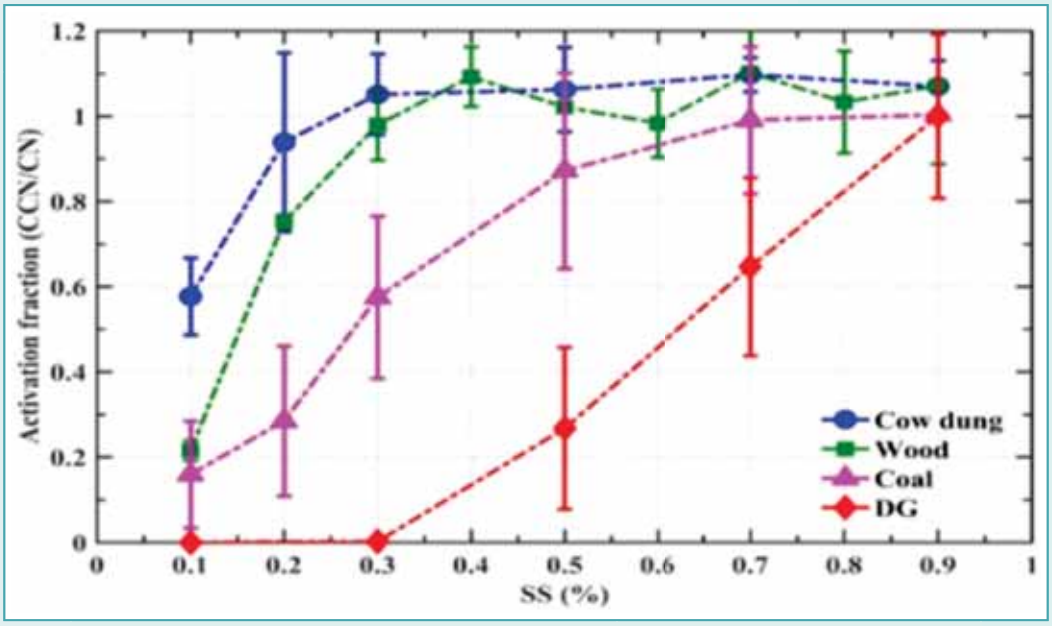


Fig. 7.4: CCN activation spectra from different sources of emissions (Cow dung cake, Wood, Coal, and DG).

(VOC) at two Indian megacities namely Mumbai and Pune, closely located yet vastly differing in meteorology due to their locations, was studied. Although levels of CO, NO_2 and VOC declined sharply after the lockdown in both the cities, with NO_2 showing the highest reduction, ozone concentration in Pune remained unaffected, whereas Mumbai exhibited a mixed trend, touching even a maximum in between the lockdown. On a diurnal scale, the magnitude of O_3 levels during the lockdown period is higher at almost all hours in Mumbai; and in Pune, it is almost identical except during night hours when it is marginally higher in the lockdown period as compared to the normal period. The coastal city Mumbai shows less reduction in NO_2 and VOC as compared to Pune. It is observed that VOC played a major role in controlling the ozone behaviour during lockdown, underlining the fact that the air pollution mitigation strategies should be targeted more towards controlling the emission sources of VOCs. (**Fig. 7.5**) [***Korhale N., Anand V., Beig G.***, *Disparity in ozone trends under COVID-19 lockdown in a closely located coastal and hillocky metropolis of India.* ***Air Quality Atmosphere and Health***, *Online, October 2020, DOI: 10.1007/s11869-020-00958-9*]

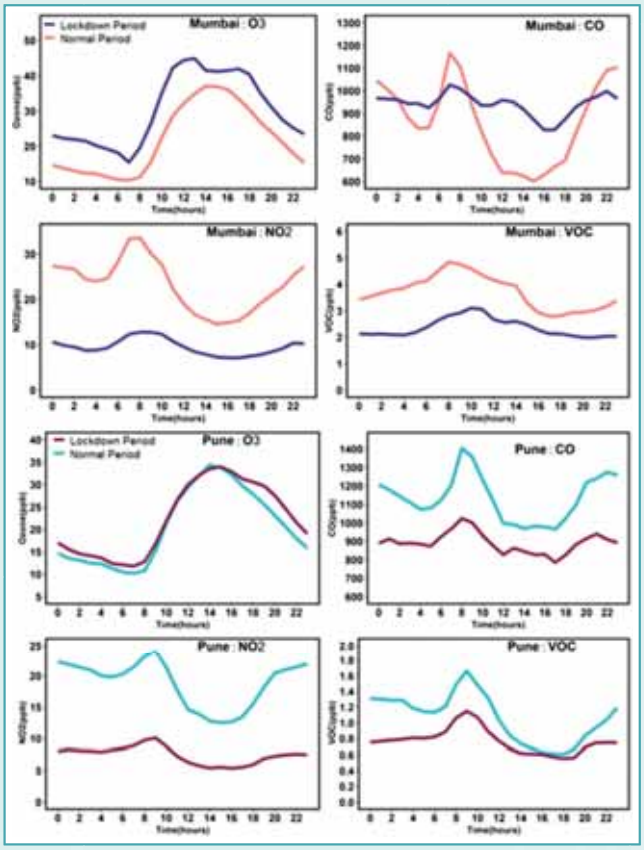


Fig. 7.5: *Diurnal variability of O_3, CO, NO_2, and VOC at Mumbai and Pune during the two periods: normal period and lockdown period.*

7.6. Role of meteorological regime in mitigating biomass induced extreme air pollution events

The Kharif crop stubble burning starts around the first week of October and lasts up to the end of November. It is proposed that if the burning period is advanced backward by about a month then the severity of its impact in deteriorating the air quality of Delhi would be significantly reduced due to less hostile meteorological regime. The current work is based on 2018 and generalization of current findings would require a much more comprehensive simulation and protocols. In the present work, an interactive high resolution WRF-Chem model forced with newly developed synergized gridded stubble burning emission inventory of PM2.5 for 2018 was used along with normal emissions. Results indicate that emergency episodes significantly reduced from 12 to nil, under proposed scenario that may help minimizing adverse health impacts. Such an effort, however, requires a feasibility study and policy level intervention. (**Fig. 7.6**) [***Beig G.***, *Sahu S.K.*, ***Rathod A.***, ***Tikle S.***, *Singh V.*, ***Sandeepan B.S.***, *Role of meteorological regime in mitigating biomass induced extreme air pollution events,* ***Urban Climate****, 35: 100756, January 2021, DOI: 10.1016/j.uclim.2020. 100756*]

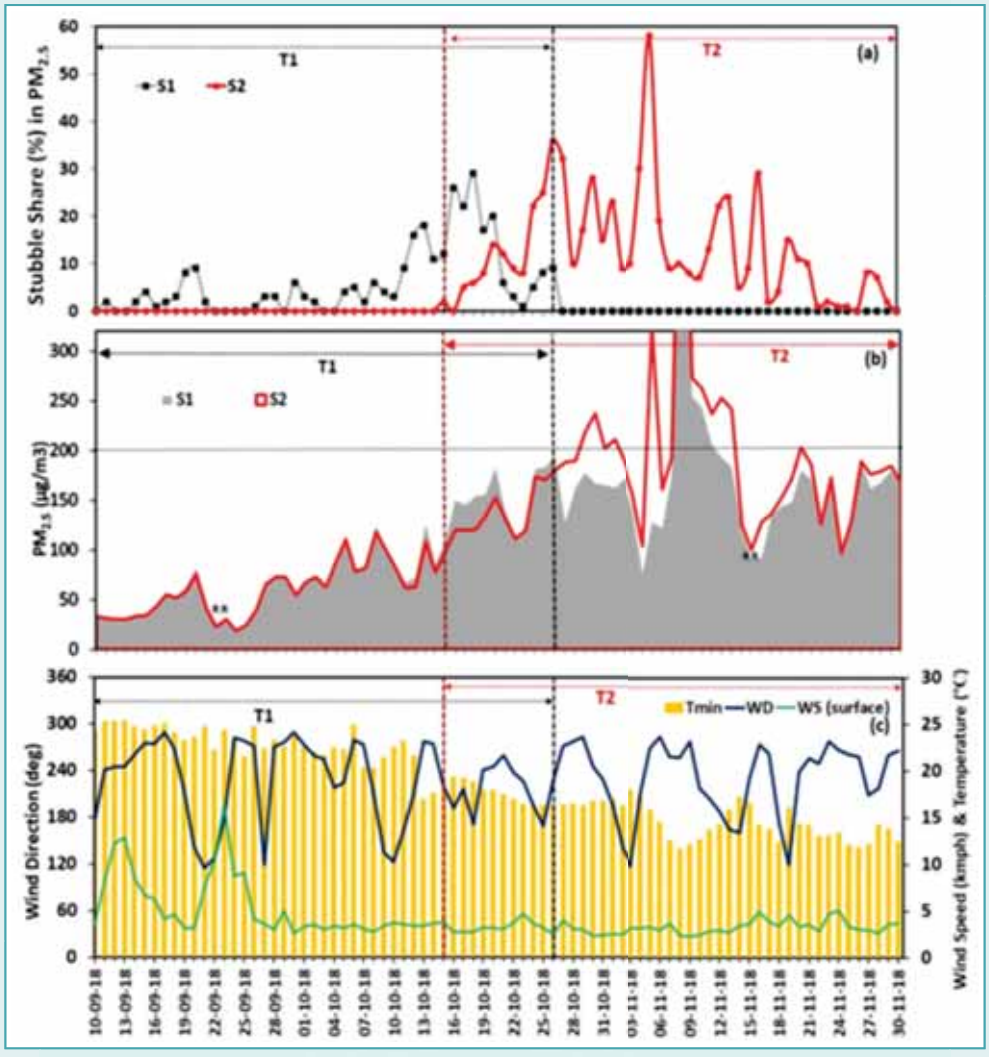


Fig. 7.6: *The time series for the study period 10 September to 30 November 2018 for: (a) Percent contribution of PM2.5 attributed to stubble burning for proposed alternative scenario S1 and baseline scenario S2; (b) Daily averaged PM2.5 mass concentration (µg/m^3) for both the scenario S1 and S2; and (c) Temperature, wind speed and wind direction. Two time frames T1 and T2 considered in this work for sensitivity study are also marked.*

Developmental Activities

7.7. Installation of microwave radiometer in Delhi: A microwave radiometer has been recently installed in Rajendra Nagar, New Delhi to study thermodynamic evolution in the lower troposphere. It provides vertical profiles of temperature and humidity. Initial field testing is in progress.

7.8. Sharing air quality information with CPCB: The hourly air quality information about SAFAR cities is shared with the Central Pollution Control Board (CPCB) in real time. The same information is displayed in CPCB's continuous air quality monitoring data portal for India.

7.9. Stubble burning transport through Ceilometer images: Ceilometer measures profiles of aerosol back scatter coefficient which depends on the magnitude of aerosol concentration. In the month of November, Delhi is largely affected by agricultural residue burning from the neighboring states. **Fig. 7.7** shows elevated level transport from outside Delhi as a result of stubble burning; marked with an ellipse.

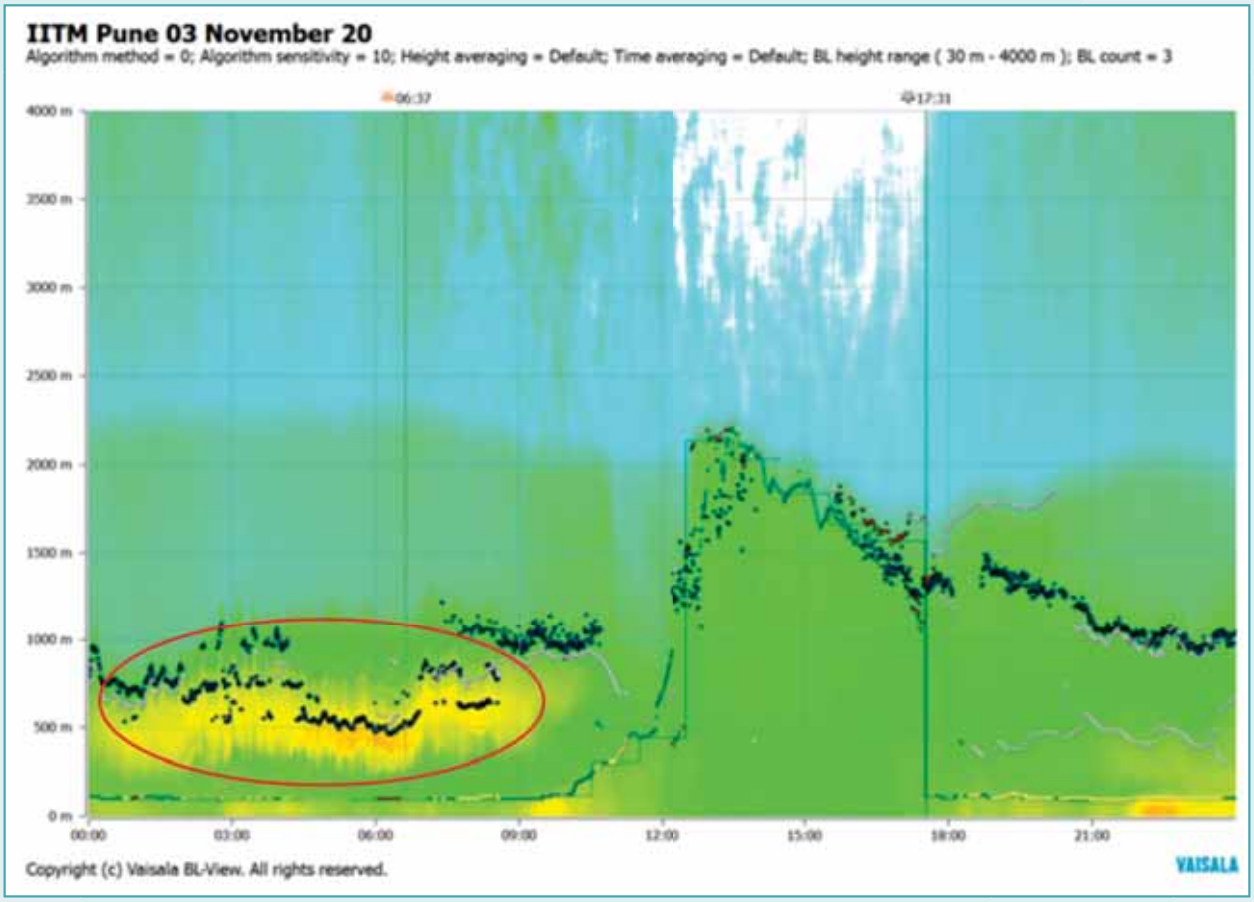


Fig. 7.7: Elevated level transport from outside Delhi as a result of stubble burning; marked with an ellipse.



Chapter 8
India UK Water Centre (IUKWC)

The India-UK Water Centre (IUKWC) was a virtual joint centre established in 2016 and funded by the Indian Ministry of Earth Sciences (MoES) and the UK's Natural Environment Research Council (NERC). The India-UK Water Centre aimed to promote cooperation and collaboration between NERC-MoES water security research to establish a platform for, and legacy of, long-term partnerships and dialogue between Indian and UK water researchers, water policy-makers and water businesses.

This aim was achieved by fulfilling five objectives as follows:

- Engaging the community;
- Facilitating partnerships and building capacity;
- Enhancing knowledge exchange;
- Supporting future India-UK collaboration; and
- Developing effective communication platforms.

These objectives, in turn, were achieved by undertaking a series of activities during the lifespan of the Centre. The activities included:

(1) Establishment and maintenance of an Open Network of Water Researchers, which was hosted on the IUKWC website (iukwc.org), with the aim to promote engagement;

(2) Facilitation of community-led Science Workshops and Researcher Exchange scheme that facilitated partnerships and built capacity;

(3) Delivery of User Engagement Initiatives (UEIs) and

(4) Grassroots Field Exposure Sessions (GFES), which enhanced knowledge exchange between scientists, water professionals, and other stakeholders, as well as promoting co-design and co-development of new research;

(5) Commissioning of Pump Priming Projects (PPPs) to promote and support future India-UK collaborations; and

(6) Developing and maintaining efficient and varied communication methods, ranging from an active website and social media accounts, to regular updates using mailing lists, disseminating information to IUKWC members and the wider public.

The Centre's activities were guided by five key cross-sectoral themes.

(1) Developing hydro-climatic services to support water security

(2) Building cross-sectoral collaborations to understand the dynamic interactions across the water-energy-food nexus

(3) Using new scientific knowledge to help stakeholders set objectives for freshwater management

(4) Improving freshwater monitoring frameworks and data for research and management

(5) Transforming science into catchment management solutions

Webinar Series 2020

During the period 28th May to 16th September 2020, the IUKWC held its Webinar Series to showcase the breadth of Indo-UK water research/practice and its impacts, as well as outputs and learnings from IUKWC activities. Webinar topics were gathered from both invitations to project leads of IUKWC activities and open calls to the Open Network membership. A total of 9 webinars on a variety of topics were held using the GotoWebinar© platform. The webinars were always well attended, normally ranging between 80 and 110 attendees on average, though the highest attendee number peaked at 525 for the fourth webinar. Attendees were mostly from academic institutions (researchers and students), however businesses including consultancies and industry, as well as government departments from both countries, also attended.

Details of the webinars are provided in chapter15 on Seminars under section 15.7.

Publications

The Centre has published a range of Water Briefs, authored by Open Network members, exploring the state of science in a field, and opportunities for knowledge exchange and capacity development. The Briefs confirm the complementary scientific expertise that exists in India and the UK across many components of water science, and offer significant collaboration opportunities to improve water resource management. The development of a SMART rivers concept, improvement of catchment planning and management through incorporation of ecosystem services assessments, and enhancement of water quality improvement strategies and monitoring networks, were identified as just some of the areas where Indo-UK collaborative science could pave the way. These Water Brief publications along with other IUKWC outputs can be found on the IUKWC website. In addition to IUKWC publications, a number of Open Network Members have co-authored peer-reviewed papers stemming from Centre activities.

Due to the maturity of the India-UK research partnership, the IUKWC at IITM has now been closed w.e.f. 30 September 2020.

Over the space of four years, IUKWC has built an active community of over 1000 water scientists and stakeholders from both countries through its Open Network, and has engaged directly with water resource managers across India to promote Indo-UK freshwater research. The Centre's activities and publications have underlined the complementarity in expertise, significant enthusiasm for collaboration, and breadth of ideas that exist between the two countries in the field of water science.

The IUKWC has provided opportunities for networking between scientists through workshops and research exchanges, as well as supporting pilot-level projects exploring new ideas for future collaborative research. The Centre's Open Network, which currently has 1060 members across India, the UK and a few other countries, has enabled scientists to find and interact with others who have similar research interests. Scientific workshops, on topics including freshwater earth observations and Himalayan hydro-climatology, have enabled the sharing of research outputs and the building of collaborative relationships and project ideas primed for future funding. On the back of IUKWC events, a number of members have submitted Indo-UK joint proposals, including bids to Global Challenges Research Fund and other similar initiatives. Activities focused on early-career researchers, such as the IUKWC's Researcher Exchange Scheme, have helped participants establish wider networks in both countries with which they can progress their careers.

As well as strengthening links across the Indian and UK water science communities, the Centre has helped researchers connect with policymakers, implementation agencies, and the end-users of water science through its User Engagement and Grassroots initiatives. Designed to promote the outputs of recent research projects and enhance the co-design of future science, these initiatives have included events focused on water availability and quality in West Bengal, freshwater monitoring in Kerala, and water resources management in Madhya Pradesh. Participants were able to gain a better understanding of the needs of these stakeholders and the opportunities for future high impact research in the area of water. The Grassroots events in West Bengal took this co-design a step further, by advancing understanding of surface and groundwater supply in the Sundarbans through two pilot projects. These IUKWC-supported projects were developed through collaborations between UK and Indian scientists, NGOs, and water users.

More details about the activities and publications of the Centre are available at www.iukwc.org.

Chapter 9
Winter Fog Campaign (WIFEX) and Air Quality Early Warning System for Delhi

9.1. Air Quality Early Warning System (AQEWS)

Air pollution has been identified as one of the most critical environmental challenges facing Indian megacities due to its adverse effects on human health. Thus, improving air quality and protecting public health by enforcing policy-driven emissions, mitigation measures have emerged as a top priority. A Graded Response Action Plan (GRAP) designed for the National Capital Region that allows pollution control authorities to reduce the magnitude of predicted air pollution for different air quality index (AQI) categories by imposing temporary control measures. Activation of different GRAP measures requires information of forthcoming extreme air pollution episodes so that effective temporary control measures can be identified early and implemented in advance. Among various initiatives, MoES has mandated IITM to develop air quality early warning systems (AQEWS) to timely alert the public of forthcoming air pollution episodes.

In response to this mandate, IITM has developed a unique integrated technology for Air Quality Early Warning System (AQEWS) for the country under the Smart Cities Mission (NP15) that is contributing to the Sustainable Development Goals (SDGs) laid down by the NITI Aayog. This program is designed to enable and provide air quality forecasting and information services at a very high spatial resolution (400 m) in a globally harmonized and standardized way, tailored to the needs of society and policy makers. Stressing the importance of the need of the day-to-day air quality information for society, an information dissemination system has also been developed that provides real-time and future air quality information to the public via website (https://ews.tropmet.res.in). This website disseminates air quality forecasts to the public and decision-makers, and provides near real-time observations of air quality for Delhi, Bengaluru, Pune, Mumbai, Hyderabad, Lakhnow, Kolkata and Ahmadabad, and warning messages, alerts, and bulletins. This website displays animations of the spatial distribution of $PM_{2.5}$ in the northern Indian subcontinent at 10 km resolution and 400 m resolution in Delhi (**Fig. 9.1 left**), and quick overview of operational air quality forecasting setup for Delhi at 400 m resolution and a 72-h outlook for Delhi, and a recent 3-month window of near-real time verification of $PM_{2.5}$ and PM_{10} forecasts in Bengaluru (**Fig. 9.1 right**). These efforts have made Indian

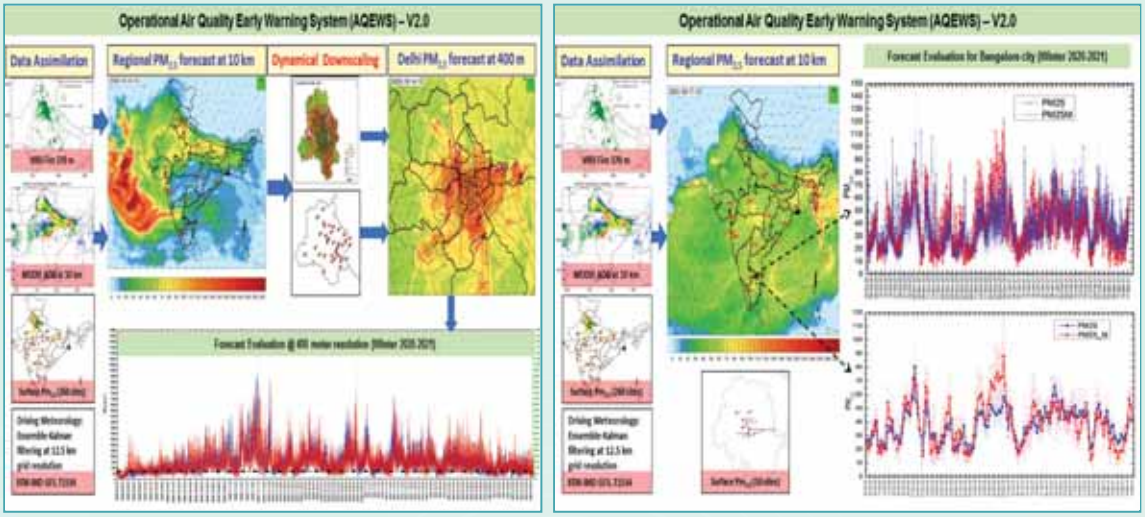


*Fig. 9.1: **(Left)** Quick Overview of operational air quality forecasting setup for Delhi at 400 m resolution. **(Right)** Quick Overview of operational air quality forecasting setup for South Asia and example of hourly forecast verification for Bengaluru city for Winter (Blue: mean $PM_{2.5}$ from air quality monitoring stations, Red: forecast with AOD and surface data assimilation).*

agencies rank ahead of any other operational agency across the globe that makes such air-quality forecasts.

9.2. Winter Fog Campaign (WIFEX)

Winter Fog Campaign (WIFEX): The 6th phase of winter fog experiment was conducted in New Delhi (IGI Airport) and Hissar during November 2020 – March 2021. New visibility instruments were installed at the new ATC tower at IGI Airport. Additionally, Hissar measurement site was made operational by installing visibility meter, soil sensors, automatic weather sensors and net radiation sensors on 10 meter flux tower. All the sensors were connected to Pune server through GSM modem so that real-time data can be accessed at IITM, Pune. Empirical relations for predicting visibility based on microphysical data based on WIFEX campaign (NC, LWC, visibility) have been developed and incorporated in the operational forecasting system. Fog forecasting system based on physics ensemble was developed for Delhi (2 km and 400 m resolution) and northern region of India (4 km resolution) and forecast was generated for both visibility and LWC. A dedicated website (https://ews.tropmet.res.in/fog_forecast.php) has been developed to present now-casting and forecasting information for IGI Airport, New Delhi and visibility forecast for Varanasi, Lakhnow, Amritsar and Jaipur airports.

New 21 Member Ensemble fog forecast: The ensemble forecasts give a clear idea about different weather phenomena which may occur at a particular time. The fog forecast has been produced using 21 members during the 2020-2021 WIFEX campaign (**Fig. 9.2**). Based on their final products, the 21 member ensemble probability forecast of visibility is generated spatially and statistically for the Indo-Gangetic Plain (IGP) region and the IGI Airport, New Delhi with different CATegory fog (CAT2, CAT3A, CAT3B, and CAT3C). The spatial probability forecast of visibility for the IGP region is processed for 36 hours.

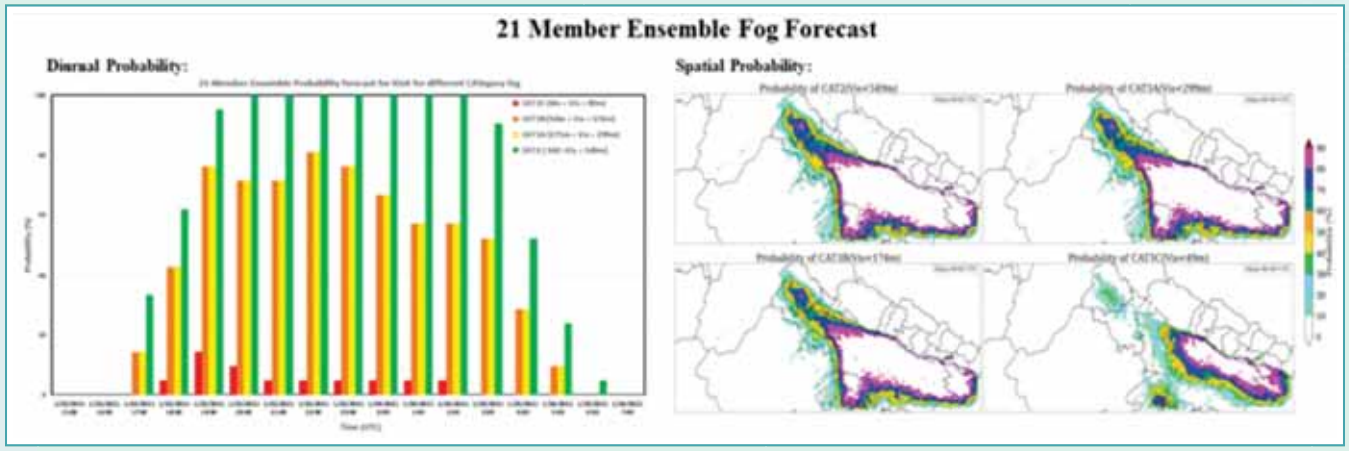


Fig. 9.2: *(**left**) 21-member ensemble hourly probability fog forecast based on different visibility category at IGI Airport, New Delhi. (**right**) 21-member ensemble mean visibility forecast over northern region of India for different hours.*

OVERVIEW

Chapter 10
International CLIVAR Monsoons Project Office (ICMPO)

Executive Director : Dr. Rupa Kumar Kolli

10.1. Objectives

- To implement the agreement between IITM and the World Climate Research Programme, (WCRP) endorsed by the Union Cabinet, and host the ICMPO to function as a node of International CLIVAR Project Office (ICPO).

10.2. ICMPO responsibilities

One of the key responsibilities of the ICMPO is to support the CLIVAR/GEWEX (Climate Variability and predictability/ Global Energy and Water Exchanges) Monsoons Panel, which was established to take a more global view of monsoon activities and better coordinate monsoon research between the World Climate Research Programme (WCRP) core projects GEWEX and CLIVAR. The Monsoons Panel has established a structure of three Regional Working Groups to support its work, focusing on the Asian-Australian, American, and African monsoons. More details about the Monsoons Panel membership and additional links are available at: https://icmpo.tropmet.res.in/mp-members.html. Other responsibilities of the ICMPO include support to the Indian Ocean Region Panel (IORP), liaison with all WCRP and other international monsoon-related activities including support to the International CLIVAR Global Project Office (ICGPO), China.

10.3. Developmental activities and major achievements

As one of the International Project Offices (IPOs) supporting WCRP activities, ICMPO has closely liaised with the ICGPO (China), the International GEWEX Project Office (IGPO, USA) as well as the WCRP Secretariat (Switzerland). ICMPO being one of the nodes of the ICPO, much of the interaction and support has been directed towards the ICGPO. ICMPO has also interacted with the WMO Secretariat on monsoon-relevant matters of the World Weather Research Programme (WWRP) and the WCRP Coordination Office for Regional Activities (CORA).

ICMPO has provided full editorial coordination and production support to the following publications focused on monsoons:

10.3.1. CLIVAR Exchanges No. 79, November 2020, Special Issue on 'India's Monsoon Mission': Recognizing the broader interest of the Monsoon Mission activities to the WCRP community, the CLIVAR/GEWEX Monsoons Panel has coordinated a special issue of CLIVAR Exchanges on India's Monsoon Mission, with Dr. M. Rajeevan, Secretary, MoES, as the Guest Editor. This issue showcases 12 articles, many of these contributed by IITM scientists, highlighting the results achieved so far under Monsoon Mission. The special issue can be accessed here: https://www.clivar.org/sites/default/files/documents/CLIVAR%20Exchanges%2079%20Monsoon%20Mission%20Final_1231.pdf.

10.3.2. GEWEX Quarterly, Vol. 30, No. 4, Quarter 4, 2020, Special Issue on 'Monsoons of the World: Addressing Global Challenges in Monsoon Research': The topics covered in this issue include monsoon rainfall metrics, diurnal precipitation simulation in the global monsoon system, North and South American Monsoons, West African Monsoon and the intersection between global monsoon regions and GEWEX's Regional Hydroclimate Projects. The special issue can be accessed here: https://www.gewex.org/gewex-content/uploads/2020/12/Q42020.pdf.

10.4. Support to CLIVAR/GEWEX Monsoons Panel

- ICMPO coordinated with Monsoons Panel Co-Chairs for preparation of annual report (2020) of the Monsoons Panel and its submission to the CLIVAR and GEWEX SSG (Scientific Steering Group) annual meetings.
- ICMPO supported membership revision proposal package as per the applicable norms,

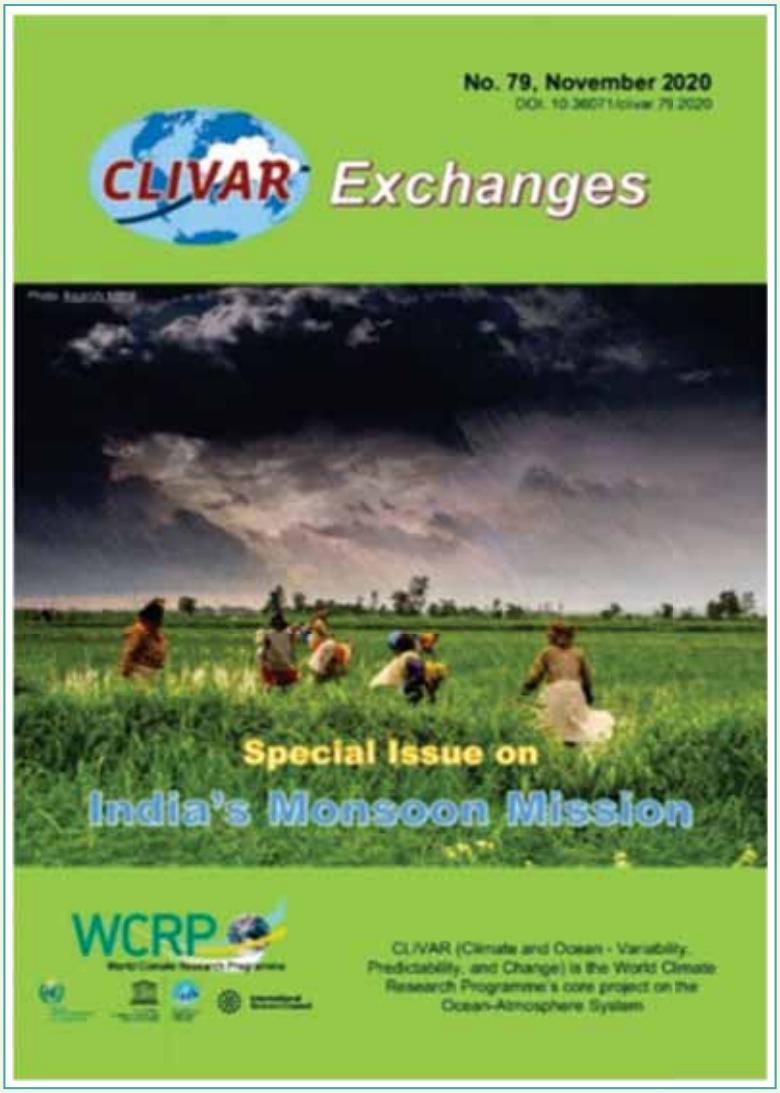


Fig. 10.1: *Cover of the CLIVAR Exchanges No. 79, November 2020, Special Issue on India's Monsoon Mission.*

submitted it to both ICGPO and IGPO for further action to seek the approval of CLIVAR and GEWEX SSGs. The final recommendations of the SSGs are awaited, and the current list of the membership continuing from 2020 is available at: https://icmpo.tropmet.res.in/mp-members.html.

10.5. New Initiatives: ICMPO has actively supported discussions on the development of a new implementation plan for WCRP, to identify and prioritize the critical research activities needed over the next decade to address the challenges and to take advantage of the opportunities of a changing climate. In particular, ICMPO was involved in the consultations for the formation of a new WCRP core project 'Regional climate Information for Societies', and a new series of regionally-based WCRP Climate Research Forums (CRFs; https://www.wcrp-climate.org/climate-research-forums). The CRFs will provide a chance to exchange ideas, discuss new activities and opportunities being developed by WCRP, and explore ways that the community of climate scientists, partner programmes, funders and end-users of climate science can engage. ICMPO has been identified as the logistic support for the CRF for Southern Asia in close coordination

with the concerned WCRP Regional Focal Points (RFPs). Dr. Roxy Mathew Koll, Scientist-E, has been nominated as one of the four RFPs for CRF-Southern Asia.

10.6. Outreach Activities

- Regular teleconferences are found to be quite useful for effective communications between personnel of ICGPO China and ICMPO India, as well as the members of the CLIVAR/GEWEX Monsoons Panel, to which ICMPO has actively contributed including coordinating several of them. ICMPO has also coordinated regular ICMPO contributions to the monthly CLIVAR Bulletin issued by ICGPO, which are available at http://www.clivar.org/clivar-bulletin.
- The web pages of ICMPO have been integrated with IITM web portal (https://icmpo.tropmet.res.in/), and efforts are underway to revamp its contents. Eventually, this website is envisaged to be a repository of information on global monsoons research.
- ICMPO has actively contributed to the preparation of WMO El Niño/La Niña Updates issued in February, May, August, and October 2020. ICMPO has been acknowledged as a contributing partner for this widely recognized WMO product (https://community.wmo.int/activity-areas/climate/wmo-el-ninola-nina-updates).
- ICMPO is also supporting the Institute's longstanding "Monsoon On Line" portal (http://mol.tropmet.res.in/).

10.7. Important Events and Meetings: ICMPO organized many events and meetings online, details of which are provided in **Appendix-2**.

10.8. Collaborative Programmes

The WCRP Joint Scientific Committee and the WWRP Scientific Steering Committee have formally endorsed the proposal for ICMPO to move towards a more holistic support facility for monsoon research coordination spanning the entire WCRP and WWRP. ICMPO is now working with the secretariats of WCRP and WWRP as well as the MoES to prepare a revised draft agreement between IITM and WMO. The name of the office is also proposed to be revised as International Monsoon Project Office (IMPO). Subject to approvals by the concerned higher authorities on both the sides, efforts are underway to have the process completed by the end of May 2021. The current IITM-WCRP agreement for the hosting of ICMPO has been extended up to the end of May 2021 through exchange of letters.

ICMPO is actively involved in working with the national coordinators as well as Monsoons Panel in organizing the Seventh International Workshop on Monsoons (IWM-7), which is expected to be hosted in India as soon as the pandemic situation subsides, possibly in early 2022. Dr. Rupa Kumar Kolli, Executive Director of ICMPO, has been nominated as a member of the National Organizing Committee to support the preparatory work and organizational matters of IWM-7.

Chapter 11
Development of Skilled Man power in Earth System Sciences (DESK)

Project Director : Dr. V. Valsala

Objectives

DESK is a major training project under REACHOUT programme of the MoES with following objectives:

- To implement JRF/SRF programme for the Ministry and their *ab-initio* training in DESK of one-to-two semester duration – part of human resources development (called as MRFP).
- To organize courses of short and medium duration on specific or targeted areas for skilled manpower development within and outside MoES by conducting short-term schools and workshops of 1 week to 10 day duration.
- To strengthen research and educational support for science of the climate and climate change and to establish linkages amongst the education, research and operational organizations in the country.

11.1. MoES Research Fellow Programme (MRFP)

The MRFP was successfully implemented with the recruitment of the first batch of 21 JRFs after following a through selection process including written examination and interviews. The programme was given wide publicity through nationwide advertisements. The *ab-initio* training of the selected JRFs for four months was conducted at DESK with the following subjects:

- Introduction to Earth System Sciences
- Research Methodology and Computer programming.
- Mathematics and Statistics

IITM scientists acted as faculty for the above training.

All the 21 students completed the course work successfully and were recruited to the following MoES institutes as JRF to pursue PhD programme:

Institutes at which MRFP JRFs are recruited to:	Number of JRFs
INCOIS	2
NCCR	3*
NCPOR	3
NIOT	2
NCMRWF	3
CMLRE	4*
NCESS	3
NCS	1*
*One person each discontinued.	

The work done by these JRFs during their first year was evaluated in an interview in November 2020.

Further, advertisement for the second batch of MRFP was processed and a shortlist of candidates was made.

11.2. Short-term Trainings Organized

- DESK organized a 9 session virtual lecture series on **'Introduction to OpenMP'** from 17 August 2020 onwards. This series is led by Mr. Mandar Gurav from IIT Mumbai. The lectures are held on every Monday, Wednesday, and Friday. The lectures were attended by 30 participants.
- **VAIBHAV Summit** organized by the Government of India, 2-31 October 2020.
- A 3-day online training programme on **'Assessment of Climate Change and its impacts over the Indian region- RCP 4.5 Scenario'** with Farmbridge Foundation, Bharuch, Gujarat was conducted during 19-21 January 2021.

11.3. MoES Webinar Series on 'Earth Sciences Popular Lectures'

During the lock-down, DESK conducted an MoES Webinar series on 'Earth Sciences Popular Lectures'. A total of 38 talks were conducted by eminent national speakers with an average of 1000 views per talk. The activity was conducted in coordination with MoES and MoES institutions, also with active support of Computer Division, and Library, Information and Publication Division. Many webinars were arranged. Details are provided in the chapter 15 on Seminars under the section 15.8.

OVERVIEW

Chapter 12
Academic Cell

Coordinator : Dr. V. Valsala

12.1. Objectives

- To conduct and continue PhD, M.Tech. and M.Sc. courses in Atmospheric Sciences in collaboration with S.P. Pune University and other academic institutions.
- To generate a trained pool of human resources in the field by attracting young talent and by encouraging IITM scientists to opt for higher studies.

12.2. M.Tech. (Atmospheric and Space Sciences) programme

M.Tech. (Atmospheric and Space Sciences) is a joint academic programme of IITM and the Department of Atmospheric and Space Sciences (DASS) of S.P. Pune University (SPPU), Pune. Ten (10) students were admitted in this programme for the academic session 2020-22. The 1st semester classes were started from 28 January 2021 at DASS, SPPU. The 2nd year students (07) of the M.Tech. 2019-21 batch are doing their project work at IITM and DASS, SPPU.

12.3. M.Sc. (Atmospheric and Space Sciences) programme

Under this IITM and Department of Atmospheric and Space Science (DASS) of S.P. Pune University (SPPU), Pune collaborative M.Sc. (Atmospheric Science) Programme, 10 students were admitted for the academic session 2020-22. The M.Sc. second year students (08) of the batch 2019-21 are doing their project work at IITM and DASS, SPPU.

12.4. PhD Degree Awarded during 2020-21:

S.No.	Student	Guide	Co-guide	Name of University	Thesis Title
1.	Ms. Ananya Karmakar	Dr. A. Parekh	Dr. C. Gnanaseelan	S.P. Pune University, Pune	Study of the Role of Physics and Resolution on the Interannual Variability of Indo-Pacific Ocean using Ocean Model
2.	Mr. Malay Ganai	Dr. P. Mukhopadhyay	Ravuri Phani Murali Krishna	S.P. Pune University, Pune	Study of Rainfall Variability and Associated Convective Processes at Different Spatio-Temporal Scales During Indian Monsoon
3.	Ms. Sukanya Patra	Dr. M.C.R. Kalapureddy	-	S.P. Pune University, Pune	Investigation of Vertical Structure of Tropical Clouds over Western Ghats using Ka-Band Rader
4	Mr. Bhowmik Utsav	Dr. G. Pandithurai	Dr. Sachin Deshpande	S.P. Pune University, Pune	Study of Spatio-Temporal Variability of Convection over the Western Ghats based on Doppler Weather Radar

12.4. PhD Degree Awarded during 2020-21: (Contd.)

S.No.	Student	Guide	Co-guide	Name of University	Thesis Title
5	Ms. Ganesh S. Saranya	Dr. S. Abhilash	Dr. A. K. Sahai and Dr. Susmita Joseph	S.P. Pune University, Pune	Development of Prediction System for Genesis, Track and Intensity of North Indian Ocean Tropical Cyclones in a Multi-Model Ensemble Framework
6	Ms. Rohini P.	Dr. M. Rajeevan	Dr. P. Mukhopadhyay	S.P. Pune University, Pune	Observational and Modelling Aspects of Heat Waves Over India
7	Mr. Pithani RDS Prakasa Rao	Dr. Sachin Ghude (Internal Guide at IITM)	Prof. C. V. Naidu (External Guide at Andhra University)	Andhra University	Observational aspects and Numerical modeling of Fog over the Indo-Gangetic Plain

12.5. PhD Thesis submitted during 2020-21:

S. No.	Student	Guide	Co-guide	Name of University	Thesis Title
1	Mr. Dipjyoti Mudiar	Dr. S.D. Pawar (External Supervisor) and Dr. Anupam Hazra and Dr. D.M. Lal (External Co-Supervisors)	Dr. M.K. Srivastava, BHU, Varanasi (Internal Supervisor)	Banaras Hindu University (BHU), Varanasi	Effects of Electric Forces on Rain Formation Processes in Tropical Clouds
2	Mr. Anil Kumar V.	Dr. G. Pandithurai	Prof. D.S.V.V.D. Prasad	Andhra University	On the Influence of Atmospheric Aerosols in Ice Nuclei Characteristics and its Parameterization
3	Ms. Jyoti Jadhav	Dr. Swapna Panickal and Dr. R. Krishnan	Prof. C. V. Naidu	Andhra University	Multi-decadal sea level variability in the Indian Ocean and its possible driving mechanism in a changing climate.

12.6. Research guidance to students for project work

IITM is committed to offer its expertise in Weather and Climate Sciences and extend its state-of-the-art facilities to aspirants seeking knowledge or a career and hands-on experience in these areas of expertise. Therefore, IITM generously admits meritorious under-graduate (UG) and post-graduate (PG) students for their internship/course work. During the year 2020-21, about 31 students of different UG/PG courses in science and engineering from various colleges, universities and institutions from across the country have completed or are working for their short-term project/internship under the guidance of IITM scientists through remote/online mode only.

Chapter 13
Important Events and Activities

13.1. Important Events

13.1.1. DAMINI Lightning Alert Mobile App: A total of 75 sensors of Lightning Location Network (LLN) are installed across the country. Based on the LLN, this mobile app provides lightning alert. The Parliamentary Standing Committee has expressed to make this mobile app available for mac users also. Accordingly, the iPhone version of the mobile app for lightning alert 'DAMINI Lightning Alert' was released on 31 May 2020 and is now available on iPhone apps store for download.

13.1.2. World Environment Day 2020 Celebrations: IITM-ENVIS Centre on Atmospheric Pollution & Climate Change celebrated the World Environment Day 2020 by organizing various online competitions to spread awareness on various pressing environmental and climate issues. Students from across the country participated and showed keen interest about the effect of 'COVID-19 and the Air that they are breathing'. On this occasion, two live talks on YouTube were arranged on 5 June 2020. Dr. M. Rajeevan, Secretary, MoES delivered the IMS Webinar on the topic 'COVID-19 and Meteorology', which covered two aspects: (i) Changes in the environment due to COVID-19 lockdown, and (ii) The impact of lockdown on meteorological observations and forecasts. The second talk on 'COVID-19 and Air you breathe: Positivity of Mind' was delivered by Dr. Gufran Beig, Scientist-G and IITM-ENVIS Coordinator. The names of the winners of competitions were announced during the online talk (https://youtu.be/3hyF8ufbdj0) and they were awarded with attractive prizes and certificates from IITM-ENVIS on 5 June 2020.

13.1.3. Integrated Flood Warning System for Mumbai (iFLOWS-Mumbai): Flood Warning System for Mumbai was launched by Shri Uddhavji Balasaheb Thackeray Honourable Chief Minister, Government of Maharashtra and Dr. Harsh Vardhan, Honourable Union Minister for Health & Family Welfare, Science & Technology and Earth Sciences, Govt. of India on 12 June 2020. This system is jointly developed by India Meteorological Department (IMD), National Centre for Coastal Research (NCCR), Indian Institute of Tropical Meteorology (IITM), and National Centre for Medium Range Weather Forecasting (NCMRWF) for Municipal Corporation of Greater Mumbai (MCGM) under the guidance of the Ministry of Earth Sciences (MoES).

13.1.4. Mausam Mobile App for IMD: IITM contributed in developing this app for IMD to enhance dissemination activity of weather forecast and warning services.

13.1.5. USER Education Sessions on Information Resources: LIP Division conducted a series of user education webinars for IITM in coordination with MoES and service providers on following products: Web Of science WebEx Series (April-May 2020), MAGZTER - Digital newsstand for IITM, EndNote, MoES-KRCNet Portal, JGATE, SCOPUS and InCites.

13.1.6. Launch of MoES Knowledge Resource Centre Network (KRCNet) Portal: Library, Information and Publication (LIP) Division at IITM has contributed in developing the MoES KRCNet portal (single platform for all kind of MoES eResources) and enriched it with addition of IITM eResources (research articles, Video Lectures, Annual Reports, Research Reports, Photo-galleries, Events, News-clippings) for wider visibility. The MoES KRCNet project is listed in the Best of Tech Report 2021 published on 18 July 2020 by Coeus Age (a research led initiative to keep a track of technology evolution in the government sector). The report is available at: https://issuu.com/kapildevsingh/docs/best_of_tech_2021_final_report. The portal along with the Mausam mobile app for IMD was launched by the Hon'ble Union Minister for Earth Sciences, Dr. Harsh Vardhan on MoES Foundation Day, 27 July 2020.

S. No.	Date	Speaker	Topic and video link
1	8 July 2020	**Dr. Pravakar Mishra**, Scientist - F, National Centre for Coastal Research, Chennai	Special Live Talk of the MoES Webinar Series on 'Clean Sea campaign: Citizen Science'. https://youtu.be/WhdQTHPksxk
2	10 July 2020	**Dr. M. Mujumdar**, Scientist-E, IITM Pune	स्वच्छता अभियान 2020 – कोरोना महामारी की पृष्ठभूमिमें सामाजिक उत्तरदायित्व के अनुपालन का महत्व. https://youtu.be/Deh_Wgpiu_s
3	10 July 2020	**Dr. O.N. Shukla**, Hindi Officer, IITM Pune	शरीर और मन पर योग का प्रभाव. https://youtu.be/Deh_Wgpiu_s
4	10 July 2020	**Dr. Ojaswini Valsangkar**, Medical Consultant, IITM Dispensary	कोविड-19 महामारी की स्थिति में स्वच्छता का महत्व (Importance of Swachhata in COVID-19 pandemic situation). https://youtu.be/RtSEnpJPPyU
5	10 July 2020	**Dr. Smitha B R**, Scientist-D, CMLRE, Kochi	Litters in the Marine Systems: Pathways, Hotspots and Ecosystem Impacts. https://youtu.be/VfhsBHqGuR0
6	16 July 2020	**Dr. K. Anoop Krishnan**, Scientist D, Hydrological Processes Group, NCESS, Trivandrum	Need for integrated monitoring and mitigation practices in containing pollution - The NCESS initiative. https://youtu.be/JPw6dBYRY4A

13.1.7. Swachchta Pakhwada Celebrations: As per the guidelines received from the Ministry of Earth Sciences (MoES), and the Department of Drinking Water & Sanitation, Ministry of Jal Shakti, Govt. of India, IITM observed Swachhata Pakhwada 2020 during 1-15 July 2020. As a part of the celebrations at IITM, above webinars on theme 'Swachchta' were organised:

13.1.8. Celebration of World Ozone Day : The World Ozone Day was celebrated at IITM by conducting innovative outreach and awareness events with action-based activities towards environment protection. In view of COVID-19 situation, IITM-ENVIS Centre and TERRE Policy Centre, Pune jointly organized national level online competitions for students and common people to raise awareness about protecting the Ozone Layer. The results of the competition were declared in the open interactive webinar on 16 September 2020. Two online enlightening talks by eminent scientists were also organized: i) 'Parameters of Success of the Montreal Protocol-Past and Future' by Dr. Gilbert Bankobeza, Chief, Legal Affairs and Compliance, Ozone Secretariat, UNEP, Kenya, UN; and ii) 'World Avoided -How Science Leads to Global Success Story' by Dr. Paul Newman, Chief Scientists, Earth Sciences, NASA/GSFC, Maryland, USA.

13.1.9. Celebration of 150th birth anniversary of Mahatma Gandhi: As part of the commemoration of 150th birth anniversary of Mahatma Gandhi, a webinar on "राष्ट्रपिता महात्मा गांधी की 150 वीं जयंती के उपलक्ष्य में गांधी – दर्शन व्याख्यानमाला" (The Relevance of Gandhian Philosophy in the Present Context) by Dr. R.K. Paliwal, Principal Chief Commissioner of Income Tax, Hyderabad was organised on 16 September 2020.

13.1.10. Surface Ocean - Lower Atmosphere Study (SOLAS) Indian Ocean Meeting was held online on 30 September 2020. The aim of the meeting was to present and discuss current, ongoing, and planned SOLAS research and initiatives taking place in the Indian Ocean and help forge collaborations. In addition to this meeting about SOLAS science in the Indian Ocean, there was also a meeting about the SOLAS community in India. The meeting brought together scientists from around the world working on surface ocean lower atmosphere exchange studies. This online meeting was conducted through website https://solas.tropmet.res.in/ and IITM YouTube link: https://youtu.be/u708x-rWvCA.



IMPORTANT EVENTS AND ACTIVITIES

Online registration was done through aforesaid website. The event observed overwhelming response with the participation of about 360 researchers.

13.1.11. Earth Sciences Vertical of Vaishvik Bhartiya Vaigyanik (VAIBHAV) Summit: The VAIBHAV Summit – a global virtual summit of overseas Indian researchers and academicians – was organized during 2-31 October 2020. The summit was digitally inaugurated by the Hon'ble Prime Minister of India Shri Narendra Modi on 2nd October 2020 in the virtual presence of academia and researchers of Indian origin from across the world via https://pmindiawebcast.nic.in and https://pmevents.ncog.gov.in. The event involved multiple levels of interactions among the overseas experts and Indian counterparts over a month-long series of webinars, video conferences etc. Over 1500 panelists from 40 countries and a large number of participants of Indian origin, 200 leading Indian R&D and academic institutions virtually deliberated in 18 different areas and 80 sub-areas in more than 200 deliberation sessions. The event was concluded on 31st October 2020. DESK at IITM coordinated the Earth Sciences Vertical of the VAIBHAV Summit. IITM coordinated with MoES and MoES Institutes for organizing the Earth Sciences Vertical wherein following sessions were organized:

- Atmospheric Sciences session AS-01 on 'Monsoon Variability, Prediction and its Applications' on 14 October 2020. Dr. Suryachandra Rao, Dr. Vinu Valsala and Ms Shikha Singh coordinated the event.
- Atmospheric Sciences session AS-02 on 'Atmospheric Observations' on 15 October 2020. Dr. G. Pandithurai, Dr. Thara Prabhakaran and Mr. Subrato Mukherjee coordinated the event.
- Atmospheric Sciences session AS-03 on 'Climate Variability and Change (V13H1S3)' on 19 October 2020. Dr. R. Krishnan coordinated this event.
- Atmospheric Sciences session AS-04 on 'Atmospheric Chemistry and Modeling (V13H1S4)' on 20 October 2020. Dr. Sachin Ghude coordinated the event.

Prof. Ravi S. Nanjundiah, Director IITM presented the outcome of VAIBHAV Summit for the Earth Science Vertical before the review committee during the Advisory Council meeting of VAIBHAV (30-31 October 2020).

13.1.12. Activities under Vigilance Awareness Week 2020: IITM observed the week during 27 October – 02 November 2020. As part of the celebrations, IITM employees took the e-pledge on 27 October 2020. As a part of the Week, slogan and essay writing competitions were held on the theme "Satark Bharat, Samriddh Bharat (Vigilant India, Prosperous India)" for IITM employees and the winners were felicitated with prizes. To spread awareness about vigilance, following webinars were also organized: 1) webinar on Vigilance Awareness Week by Dr. P.K. Dhakephalkar, Director, Agharkar Research Institute was arranged on 29 October 2020 (https://youtu.be/E1yombmnijU); 2) Vigilance Mechanism – an overview by Mr. Akhtarul Hanif, Deputy Secretary, Ministry of Road Transport and Highways, 5 November 2020 (https://youtu.be/ sfYq32kuZtw); and 3) Procedure to deal with complaints and how to conduct vigilance Inquiry by Mr. T.P. Sharma, Officer on special Duty (OSD), Central Vigilance Commission, 19 November 2020 (https://youtu.be/ sd0DwCAyzPw)

13.1.13. IITM Foundation Day Celebrations: IITM celebrated its 59th Foundation Day on 17 November 2020. Keeping in view COVID-19 pandemic situation, it was celebrated virtually this time (https://www.youtube.com/watch?v=fKofEf8dd5I) . On this occasion, Dr. Shailesh Nayak, Director, National Institute of Advanced Studies (NIAS), Bengaluru and Former Secretary, Ministry of Earth Sciences was the Chief Guest. The celebrations included the presentation of various awards for the year 2019 viz. Biennial Golden Jubilee Award,

Annual Sliver Jubilee Award, Best Student Research Paper Award, Excellent Performance Awards for Scientific Support, Administrative, Technical and Multi-Tasking Staff, Prof. R. Ananthakrishnan Best Thesis Award and IITM Junior Research Fellow Best Student Awards. The winners of the Biennial Golden Jubilee Award, Silver Jubilee Award, Prof. R. Ananthakrishnan Best Thesis Award and Best Student Research Paper Award also delivered lectures on their respective research achievements.

- Prof. Ravi S. Nanjundiah, Director, IITM briefed about the Institutes' achievements and activities during the year 2020.
- A special IITM Foundation Day Lecture on the topic 'Remote Sensing for National Development: The legacy of Dr. Vikram Sarabhai' by the Chief Guest Dr. Shailesh Nayak.
- Presentation of the 5th biennial IITM Golden Jubilee Award for the year 2020 to Dr. P. Mukhopadhyay for his outstanding contribution in the field of Atmosphere, Weather and Climate Science.
- Presentation of the 32nd annual IITM Silver Jubilee Award for the year 2019 to the paper 'The Tropical Indian Ocean decadal sea level response to the Pacific Decadal Oscillation forcing' by J.S. Deepa, C. Gnanaseelan, Sandeep Mohapatra, J.S. Chowdary, A. Karmakar, Rashmi Kakatkar and Anant Parekh published in Climate Dynamics, 52, April 2019, 5045-5058, DOI: 10.1007/s00382-018-4431-9.
- Presentation of the annual IITM Excellent Performance Award for the year 2019 to Mrs. S. R. Inamdar and Mrs. M.V. Deshpande for the Scientific Support, and Administrative Staff categories respectively.
- Presentation of the Annual Prof. Ananthakrishnan Best Thesis Award for the year 2019 to Dr. Gangiredla Srinivas for his PhD thesis 'Impact of Pacific and Atlantic modes on the Indian Summer Monsoon Variability and Indian Ocean Climate'.
- Presentation of the Annual Best Student Research Paper Award for the year 2019 to the paper 'Effects of a multilayer snow scheme on the global teleconnections of the Indian summer monsoon' by K. Sujith, Subodh Kumar Saha, Archana Rai, Samir Pokhrel, Hemantkumar S. Chaudhari, Anupam Hazra, Raghu Murtugudde and B.N. Goswami published in Quarterly Journal of Royal Meteorological Society, 145, April 2019, 1102-1117, DOI:10.1002/qj.3480.
- IITM Pre-PhD Coursework Award for the year 2020 carrying a citation and a reward of relevant books worth Rs.7500/- to two research fellows Mr. Sumit Kumar Mukherjee and Mr. Rakesh S.
- Hindi Rajbhasha Puraskar for 2020 to Dr. A.K. Sahai and Dr Kaushar Ali.
- Outstanding Performance Award for the year 2020 to General Administration Section, Workshop, and Computer Division.

13.1.14. National Pollution Control Day 2020: IITM-ENVIS Centre observed the National Pollution Control Day 2020 to commemorate the people who lost their lives in the unfortunate incident of Bhopal Gas Tragedy that occurred on this day in 1984. On this occasion, a webinar on 'Bhopal Gas Tragedy: An Eye Opener for Chemical Pollution' by Dr. Rajnarayan R Tiwari, Director, ICMR-National Institute for Research in Environmental Health, Bhopal was arranged online (https://youtu.be/2rsH9eQMPv4) on 2 December 2020. National level online essay and photography competitions were conducted. Also, an awareness campaign on 'Climate Change and Atmospheric Pollution' was initiated, and as part of it, an E-Pledge was posted on IITM-ENVIS website which could be taken by anytime throughout the year, with the participants getting an e-certificate as 'Climate Change Warrior'.

13.1.15. 6th India International Science Festival (IISF-2020): As part of IISF-2020, IITM organised a virtual Curtain Raiser Ceremony for High-Altitude Cloud Physics Laboratory, Mahabaleshwar and the Clean Air Event on 18 December 2020.



IMPORTANT EVENTS AND ACTIVITIES

Dr. Harsh Vardhan, Union Minister for Health and Family Welfare, Science and Technology, and Earth Sciences, digitally inaugurated the event. In the series of activities, IITM in association with Vijnana Bharati, Pune unit showcased scientific activities through webinars, panel discussions, and film shows under the online IISF Mega Science Expo. The event was given wide publicity through various digital modes.

Also as a curtain raiser event, a webinar on 'Clean Air Management for Public Welfare' by Dr. K.J. Ramesh, Former DG, IMD on 27 November 2020 was arranged (https://youtu.be/ylOhnmntFu4) and an online Vigyan Yatra event was organised on 3 December 2020 where IITM R&D activities were screened for Public.

13.1.16. Online Training in AI/ML for Atmosphere-Ocean Applications for Beginners: A 5-day Online Training in AI/ML for Atmosphere-Ocean Applications for Beginners was conducted during 15-19 February 2021. The training was aimed at students and young scientists in MoES institutes and other academic institutions across the country. A total of 107 participants (shortlisted from 264 applicants) including IITM scientists attended the training. Eleven experts from IITM, IIT Gandhinagar, IIT Chennai and IISER Pune took 19 sessions during the training. Certificates of participation were issued. Videos of the training are made available at: https://www.youtube.com/channel/UC_K_3pxWrgRCJ-RMF82lBJw.

13.1.17. National Science Day 2021 Celebrations: Due to COVID-19 pandemic, the Institute celebrated the National Science Day on 28 February 2021 virtually by organising an online symposium on 'science of weather and climate'. As part of this symposium, following four popular science talks on different aspects of weather and climate science by IITM young scientists were arranged: 1.) From observations to predicting Weather and climate by Dr Phani Murali Krishna R.; 2.) Clouds and turbulence in weather and climate by Mr. Subharthi Chowdhuri; 3.) Understanding Climate Change by Dr. Ayantika Dey Choudhury; and 4.) The Indian Ocean sea level rise: An oceanic response to the climate change by Dr Deepa J.S. The event was coordinated and moderated by Mr. Abhay S.D. Rajput. The symposium was organized live online and was made open for all through the YouTube link: https://youtu.be/pdpUiQInHTs.

Also, as part of the National Science Day 2021 celebrations, an educational webinar and online quiz competition were organized by IITM-ENVIS Centre on 26 February 2021. The Online Quiz Competition was based on the educational webinar on 'Our Atmosphere, Air Pollution and Ozone Hole' delivered by Dr. Ravi Yadav, Scientist, INDO-UK Air Pollution & Human Health, IITM, Pune.

13.1.18. World Meteorological Day 2021 Celebrations: IITM celebrated the World Meteorological Day 2021 on 23 March 2021 by organizing a Special Lecture (online) on "Societal Benefits of Ocean Information Services" by Dr. T. Srinivasa Kumar, Director, INCOIS, Hyderabad. The lecture was in lines with the theme of World Meteorological Day 2021 'the ocean, our climate and weather.' The event was coordinated and moderated by Mr. Abhay S.D. Rajput. The online lecture was made open for all at the YouTube link: https://youtu.be/zutJsBVgwCY.

13.1.19. International Conference on Future Directions of Subseasonal to Seasonal Prediction over South Asia: IITM, Pune and the WWRP/WCRP Subseasonal-to-Seasonal (S2S) Prediction Project of WMO jointly organised a Virtual International Conference on 'Future Directions of Subseasonal to Seasonal Prediction over South Asia' during 29-31 March 2021 at IITM, Pune. The conference focused on the subseasonal to seasonal activities over South Asia. Dr. M. Rajeevan, Secretary, MoES inaugurated the conference and also delivered the inaugural address. Several invited speakers of great repute delivered online talks. The meeting aimed to review the current abilities to make skillful predictions on S2S scale and to identify new initiatives, collaborations, and emerging science

questions. At the end of the conference, Dr. A.K. Sahai, Scientist-G & Project Director of Monsoon Mission at IITM, who superannuated on 31 March 2021, was felicitated for his significant contributions in climate science through research on operational prediction of weather parameters at different time scales focusing over the Indian Region. For more details about the conference, please visit: https://www.tropmet.res.in/erpas/s2s/index.php.

13.2. Important Meetings/Events Held at IITM

- Monsoon Mission Phase-II review meeting was held online on 29 June 2020.
- Monsoon Mission Phase-II 8th SRMC meeting was held online on 17 September 2020.
- The 9th SRMC meeting for Monsoon Mission Phase-II was held online on 26 October 2020.
- The 6th Scientific Steering Committee (SSC) meeting of the Monsoon Mission Phase-II was held virtually on 10 March 2021.
- The 5th Steering Group Meeting of the IUKWC was held online on 18 September 2020.
- The S2S Steering Group-Liaison Group meeting was held online on 22-24 September 2020.
- **Meeting on NE India Observational Network (NEION):** A meeting to discuss the Detailed Project Report (DPR) for the NE India Observational Network (NEION) was held via Skype on 12 May 2020. The meeting was attended by IITM Director, IMD DG, and several scientists from IITM and IMD. A summary of planned activities for NEION was presented by Dr. Thara Prabhakaran in the review meeting by MoES on 22 February 2021.

13.3. Observational Programmes/Field Campaigns

13.3.1. Field campaign in Indo-Gangetic region (Gorakhpur): An assessment of air quality in different regions of Gorakhpur (indo-Gangetic region) has been conducted for the first time in collaboration with Disaster Management Department of Government of Uttar Pradesh.

13.3.2. Lightning Location network: New sensors for the Lightning Location network have been installed at remote locations Aizawl, Leh and Port Blair and integrated with central processor at IITM, Pune.

13.3.3. Online monitoring of instrument performance, data acquisition & trouble shooting: The instruments such as Radiometers and Sky imagers operated at IITM, Pune and HACPL, Mahabaleshwar are being regularly monitored online through and the issues arising were attempted through online procedures. Hence, data continuity is maintained. The data is also being calibrated and processed regularly.

13.3.4. Twilight photometry observations are being carried out at IITM, Pune during evening twilight and occasionally during morning twilight for vertical aerosol distribution in the UTLS region.

13.3.5. Sun Photometer is being operated at IITM, Pune since December 2020 for continuous measurements of aerosol optical depth and water vapor.

13.3.6. For the first time, two test flights were conducted successfully using a quad-copter at Police Grounds in Pune for testing the in-house designed ground equipment for operating a meteorological sensor on UAV for temperature, relative humidity and wind measurements.

13.3.7. In-house built portable sensor 'Visible Sky Imager' for cloud detection is successfully tested and is being operated at IITM, Pune for continuous measurements of sky cover during day hours.

13.4. Collaborative Programmes

13.4.1. For observations under MAPAN network, MoUs have been made with different institutions under SAFAR and MAPAN networks.

13.4.2. An MoU and a Non-Disclosure Agreement (NDA) were signed between IITM and WRLDC, POSOCO (Power System Operation Corporation Limited, a government of India Enterprise, Ministry of Power) for sharing of weather forecasting data on 19 August 2020.



13.4.3. An MoU between IITM and Cotton University, Guwahati was signed for work related to thunderstorm and lightning research on 8 January 2021.

13.4.4. An MoU between IITM, Pune and Commissioner of Disaster Management, Govt of Tamil Nadu was signed for work related to lightning and thunderstorm research and data sharing on 8 January 2021.

13.5. Special Days/Weeks Observed

- **Anti-Terrorism Day,** 21 May 2021.
- **International Day of Yoga**, 21 June 2020.
- **Swachhata Pakhwada**, 1-15 July 2020.
- **Sadbhavana Diwas**, 20 August 2020.
- **Independence Day**, 15 August 2020.
- **Vigilance Awareness Week**, 27 October – 02 November 2020.
- **National Unity Day** (Rashtriya Ekta Diwas) was observed on 31 October 2020. On this day, a pledge was administered to all IITM employees.
- **PM's Jan Andolan Campaign on COVID-19:** As part of the campaign on prevention of COVID-19, IITM employees took E pledge (https://pledge.mygov.in/janandolan-covid/).
- **71st Constitution Day (Samvidhan Divas)**, 26 November 2020.
- **National Voters Day**, 25 January 2021.
- **72nd Republic Day**, 26 January 2021 was celebrated with great zeal and enthusiasm by all the employees of IITM, Pune. Prof. Ravi S. Nanjundiah, Director, IITM, Pune hoisted the national flag in the presence of a limited officials as per the COVID-19 guidelines. He addressed the employees online.

13.6. Infrastructure Development

Completed work

- The underground sump (2 lakh litre capacity) at IITM Colony Campus Pashan Pune was made operational in January 2021.
- Completed the work for revamping of institute network including upgrading all the institute switches and core chasses, and installing the campus wide Wi-Fi network along with CCTV.
- Various new applications, websites, mobile apps like mausam.tropmet.res.in, Meghdoot Mobile App. etc. were installed in the new Consolidated Server Infrastructure.
- IITM Online Video Conferencing – Institute has installed Jitsi (an open source Video Conferencing System) for conducting virtual meetings, workshops, seminars, etc. during the lockdowns and COVID-19 pandemic situations.

Work under progress

- Construction work of the Utility Building to accommodate workshop, canteen and recreation hall facility at IITM, Pashan, Pune is under progress. The work is being executed by CPWD, Pune.
- Work for setting up the Atmospheric Research Test-Bed, Central India (ART-CI) near Bhopal is initiated and civil work is being executed through CPWD, Bhopal.
- Construction of 20 meter tower for C- band Doppler Weather Radar for ART-CI Project is at the verge of completion.

13.7. Library, Information and Publication Services

The Library, Information and Publication Division serves as the National Information System in Meteorology and Atmospheric Sciences. The information resources have been strengthened by adding a good number of international scientific journals in Meteorology and Oceanography with online access and purchasing latest books.

IITM subscribed to 196 journals (188 foreign and 08 Indian) (including 154 journals collection package on Earth and Environment Science by Springer) with online access to 188 foreign and 6 Indian journals for the year 2020 (costing approx. Rs.93.91 lakhs). Subscription to 193 journals (188 foreign and 05 Indian) (including 154 journals collection package

on Earth and Environment Science by Springer) with online access to 188 foreign and 03 Indian journals for the year 2021 (costing approx. Rs.91.97 lakhs) has been processed. In addition to this, access to 132 foreign journals and the 'Web of Science' database and writing support tool software 'Grammarly Premium' is available under the MoES Consortium "DERCON". Access to 27 journals (12 Indian and 15 foreign) is available either complimentary/free online or against life membership. Online IP based institutional access to the Earth and Environment Sciences Package of the E-book resources of Springer for the copyright years 2005-13 is working satisfactorily. Online IP based institutional access to 56 titles of Cambridge eBooks is available. Five (5) books covering majority of the Institute's research areas (costing approx. Rs. 38.5 thousand) were purchased. Payments for paper publications charges/page charges/article processing charges/excess length fee for eleven (11) papers of the Institute scientists were approx. Rs.8.13 lakhs. Open access charges (approx.12.27 Lakhs) for India's first report on Assessment of Climate Change over the Indian Region published by Springer were paid by IITM for making the book free to access as e-book globally. Also, 100 hard copies of this book (bulk order) were purchased for wide distribution (costing approx. Rs.2.47 Lakhs).

A good number of scientific and technical reports of leading institutions from various countries have also been received on exchange and gratis basis.

The division is tracking news-clippings on the Institute and archiving the same in an institutional repository for news-clippings. During the period, user education sessions were conducted for Grammarly software, Urkund (plagiarism software) in collaboration with service providers. IITM Library, being one of the important component of DIAP (constituted in 2019 by SPPU), is involved in plagiarism checking mechanism for the researchers' PhD Theses and research articles/papers leading to educational degrees (viz., PhD degree) by the SPPU.

LIP Division is contributing to the development of MoES Knowledge Resource Centre and MoES KRC portal. IITM e-resources are being uploaded on the portal.

LIP Division is managing the contents of digital platforms for the Institute: IITM website and social media handles on Facebook, Twitter and YouTube. Videos/Lectures are being archived at IITM YouTube channel. The division is also involved in the documentation and compilation of various reports including the annual reports.

Notifications of awards, seminars, symposia, conferences, etc. received from other organizations were provided to the scientists of the Institute. Centralised technical services like photocopying, photography, video recording, printing and binding are also being provided to the Institute.

The division arranges programmes for popularisation of Meteorology and Atmospheric Sciences among students and the public by organising open days, scientific exhibition depicting research activities of the Institute, scientific film shows and popular science lectures by experts on the occasion of important events such as National Science Day, Earth Day and World Meteorological Day. The Division also arranged Institute's participation in scientific exhibitions of other organisations.

13.8. Management

13.8.1. Governing Council

As per the Notification No. O.M. No. 25/10/2006 dated 19 July 2006 from the President of India, the Indian Institute of Tropical Meteorology (IITM), Pune has been transferred from the Department of Science and Technology (Ministry of Science and Technology) to the Ministry of Earth Sciences, Government of India with effect from 12 July 2006. The management of the Institute vests with its Governing Council (GC) at the apex level. Consequent upon the reconstitution of the GC of IITM by the Ministry of Earth Sciences, Govt. of India vide Order No. MoES/27/01/2017-Estt dated 17

IMPORTANT EVENTS AND ACTIVITIES

May 2017, now Secretary, MoES is the Chairman (Ex-Officio) and Director, IITM is the Member Secretary. As Secretary, MoES, Dr. M. Rajeevan is the Chairman of GC w.e.f. 17 May 2017. Details of all the members of the GC are given in the starting pages of this report. The Governing Council meets twice a year. During the year 2020-21, the Governing Council had its 101st and 102nd meetings on 30 September 2020 and 22 March 2021 respectively.

The Institute maintains close collaboration and interaction with other organisations working in the field of Meteorology, particularly with the India Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF), Indian Space Research Organisation (ISRO), Indian Institutes of Technology, universities and other scientific organisations associated with academic and research work in Atmospheric and Oceanic Sciences.

13.8.2. Research Advisory Committee

The Governing Council at its 69th meeting held on 26 December 2003 formed a Research Advisory Committee (RAC) for the Institute which consists of four scientists from various disciplines of meteorology and atmospheric sciences, one of whom will be one of the scientist members of the Governing Council. The Chairman is nominated by the Governing Council. The senior most scientist of the Institute is the Member Secretary. The roles and functions of the Research Advisory Committee are (i) to advice and recommend thrust areas and research programs of the Institute and to monitor and evaluate its programs from time to time, (ii) to recommend in general the allocation of funds to various activities of the Institute to enable it to achieve academic excellence, (iii) to recommend new areas of research to be undertaken by the Institute, and (iv) to advice upon and recommend the creation of posts for priority areas of research. The 15th meeting of the Research Advisory Committee was held during 10-11 February 2021 under the Chairmanship of Prof. J. Srinivasan. Director, IITM presented about the scientific activities of the Institute and scientific presentations on topical scientific issues were also made. RAC members also interacted with scientists and students over poster sessions.

13.9. Administration

The Administration provides support for the personnel management, finance, purchase, stores, capital works and maintenance of buildings and campus.

13.9.1. Personnel Profile as on 31 March 2021:

Category	No. of Posts
Research	135
Scientific Support Staff	14
Technical Support Staff	3
Administrative Support Staff	37
Multi-Tasking Staff	10
Total	**199**

13.9.2. Staff Changes

Appointments: Administrative Staff

- Mrs. Jyoti Waghole, Upper Division Clerk, 01 January 2021.

Retirement on Superannuation

- Dr. M.D. Chipade, Scientist-C, 31 May 2020.
- Dr. S.S. Nandargi, Scientist-E, 31 May 2020.
- Mr. G.R. Chinthalu, Scientist-D, 31 July 2020.
- Mrs. U.S. Iyer, Scientist-C, 31 August 2020.
- Dr. J.V. Revadekar, Scientist-E, 30 September 2020.
- Mrs. A.A. Desai, Assistant Manager, 31 December 2020.
- Mr. S.P. Ghanekar, Scientist-D, 28 February 2021.
- Mr. R.A. Paradkar, Technician Grade-E, 28 February 2021.

Resignation

- Mr. Kalyan Khetre, Upper Division Clerk, 09 December 2020.

Deputation Related

- Mr. R.U. Khapale, Accounts Officer (on deputation) relieved to his parent office w.e.f. 03 August 2020.
- Dr. R. Chattopadhyay, Scientist-E on deputation to IMD w.r.f. 01 January 2021.

13.9.3. Status of SC/ST/OBC/ Reservation as on 31 March 2020:

Category	SC	ST	OBC	Total
Research	11	6	22	39
Scientific Support Staff	3	5	1	9
Technical Support Staff	3	0	0	3
Isolated Staff	0	0	0	0
Administrative Support Staff	4	3	6	13
MTS	2	2	2	6
Total	**23**	**16**	**31**	**70**

13.9.3. Employment of Ex-servicemen

Reservation for Ex-servicemen is made at 10% in Group-C and MTS posts of the Institute. The percentage of Ex-servicemen at the Institute via-a-vis total number of employees in group of 'A', 'B', 'C' and MTS is: Nil, Nil, 33% and 10% respectively.

13.10. Finance

13.10.1. Finance Committee

Finance Committee (FC) constituted by the Governing Council meets twice in a year and reviews the financial performance of the Institute and provides guidance for improvement of the performance. Consequent upon the reconstitution of the FC of IITM by the Ministry of Earth Sciences, Govt. of India vide Order No. MoES/27/01/2017-Estt dated 17 May 2017, Additional Secretary & Financial Adviser/Joint Secretary & Financial Adviser, MoES is now the Chairman (Ex-Officio) of the FC. The Finance Committee held its 39th and 40th meetings on 29 September 2020 and 19 March 2021 respectively.

13.10.2. Budget

The grant received and the actual expenditure incurred for the period 2020-21 are as follows (in Crores):

Sr. No.	Schemes	Opening Balance	Other Receipt	Funds received	Total Funds	Cash Expenditure	Amount surrendered to MoES	Closing Balance
A	**ACROSS**							
1	Monsoon Convection Clouds & Climate Change (MC4)	2.15	0.00	24.62	26.77	23.56	4.81	-1.60
2	High Performance Computer System	12.17	0.00	12.41	24.58	15.19	4.52	4.87
3	Monsoon Mission Phase II	1.96	0.00	14.11	16.07	15.44	0.00	0.63
4	National Facility for Airborne Research (NFAR)	4.45	0.37	-3.33	1.49	0.18	0.00	1.31
	TOTAL (A)	**20.73**	**0.37**	**47.81**	**68.91**	**54.37**	**9.33**	**5.21**
B	**REACHOUT**							
1	DESK	4.40	0.00	0.00	4.40	5.81	0.00	-1.41
	TOTAL (B)	**4.40**	**0.00**	**0.00**	**4.40**	**5.81**	**0.00**	**-1.41**
C	**ASSISTANCE TO AUTONOMOUS BODIES**							
1	IITM Operations & Maintenance	0.17	0.00	83.42	83.59	79.33	0.00	4.26
	TOTAL (C)	**0.17**	**0.00**	**83.42**	**83.59**	**79.33**	**0.00**	**4.26**
D	**SPONSORED PROJECT**	2.14	0.00	1.01	3.15	1.75	0.00	1.40
	TOTAL (D)	**2.14**	**0.00**	**1.01**	**3.15**	**1.75**	**0.00**	**1.40**
	TOTAL (A+B+C+D)	**27.44**	**0.37**	**132.24**	**160.05**	**141.26**	**9.33**	**9.46**

IMPORTANT EVENTS AND ACTIVITIES

The Auditors appointed by the Governing Council M/s C.R. SAGDEO & Co., Pune conducted the audit for the year 2020-21. The abstract of the report is enclosed at the end of this report.

13.11. Purchase and Stores

The Institute acquired scientific equipment and accessories, data acquisition and storage systems, personal computers, work stations, enhancing systems and accessories to the existing computer systems and office furniture items.

During the period, the following purchases were made:

	Institute Funds (in ₹)	Project Funds (in ₹)	Total (in ₹)
Non-Consumables-Equipment	2,72,29,215.74	0.00	2,72,29,215.74
Dead Stock	25,76,257.58	0.00	25,76,257.58
Consumables	10,46,935.29	0.00	10,46,935.29
Total	**3,08,52,408.62**	**0.00**	**3,08,52,408.61**

13.12. Official Language Implementation

- Continuous efforts are being made to comply with the Official Language Policy of the Union.
- All documents covered under Official Language Act 1963 Section 3(3) are issued in bilingual form.
- Official Language Implementation Committee meetings were held on 03 July 2020, 07 September 2020, 30 December 2020 and 28 January 2021 respectively. Due to the COVID-19 pandemic, all the meetings were conducted online.
- Department of Official Language, Ministry of Home Affairs, Government of India has entrusted the responsibility of Town Official Language Implementation Committee-2, Pune to IITM. The Director of the institute is Chairperson and Hindi Officer is the Member-Secretary of NARAKAS-II, Pune. Eighty five (85) Central Government offices located at Pune are the members of this committee. It is the responsibility of the Institute to review the work related to the official language and organize two meetings in a year. Two half-yearly meetings of the Town Official Language Implementation Committee (Ka-2), Pune were organized through video conferencing on 03 September 2020 and 29 January 2021 respectively.
- Quarterly reports and the annual progress report regarding the progressive use of Hindi in the institute were prepared and sent to the Ministry of Earth Sciences and Department of Official Language.
- **Hindi week Celebrations:** IITM celebrated Hindi week during 14-21 September 2020. Various competitions such as essay writing, noting and drafting, solo songs, poetry recitation, extempore speech etc. were organized during the week. All these competitions were organized online in which many officers and employees of IITM participated enthusiastically. The prizes for the winners of these competitions were announced by the Director of the Institute during the closing ceremony held on 21 September 2020
- **Gandhian Philosophy lecture series:** Under the aegis of the Ministry of Earth Sciences, two webinars on Gandhian Philosophy were organized by the institute on 16 September 2020 and 1 October 2020 respectively to commemorate the 150th birth anniversary of Mahatma Gandhi. In the first webinar, the Chief Principal Commissioner of Income Tax of Andhra Pradesh and Telangana, Dr. R.K. Paliwal was the guest speaker who presented his views

on the topic 'Importance of Gandhi Philosophy in the present context'. In the second webinar, former Vice Chancellor of Mahatma Gandhi International Hindi University, Wardha, Prof. (Dr.) Girishwar Mishra delivered a lecture on the topic 'Social Vision of Mahatma Gandhi'.

- **Jan-Jan ke liye vigyan webinar series:** Under the aegis of the Ministry of Earth Sciences, IITM organized six online scientific lectures to make scientific subjects easily accessible to the public in Hindi language. The details of these lectures are as follows:

S.No.	Date	Topic (Hindi)	Name of the Guest Speaker
1.	20 October 2020	गंगोत्री ग्लेशियरों के माध्यम से जलवायु परिवर्तन	Prof. Dhruvsen Singh, Lucknow University
2.	23 October 2020	समुद्री पुरातत्वविज्ञान	Dr. Rajeev Nigam, NIO
3.	06 November 2020	देश में भूभौतिकीय यंत्रों के क्षेत्र में पृथ्वीविज्ञान मंत्रालय की भूमिका	Dr. O.P. Mishra, NCS
4.	20 November 2020	तटीय प्रबंधन	Dr. R.S. Kankra, NCCR
5.	24 November 2020	भाषाविज्ञान बनाम राजभाषा : दशा और दिशा	Dr. Sumeet Jairath, Secretary, Department Official Language
6.	04 December 2020	बाढ़ और सूखा : बुनियादी विज्ञान और प्रबंधन में पृथ्वी विज्ञान मंत्रालय की भूमिका	Dr. A.K. Sahai, IITM

- For the financial year 2019-20, Hindi books worth Rs 40,000/- were to be purchased which could not be purchased due to COVID-19 pandemic and lockdown. With the permission of the Director, Hindi books worth Rs. 20000/- have been purchased this year.

- **Akhil Bharteey Kavi Sammelan:** Under the aegis of the Ministry of Earth Sciences, a Akhil Bharteey Kavi Sammelan was organized under the programme series 'Azadi Ka Amrit Mahotsav' in which the famous poets of the country Mr. Gajendra Solanki, Ms. Sarita Gupta and Mr. Vineet Pandey along with Dr. Kausar Ali, Scientist-F recited their poems. This Kavi Sammelan was organized through video conferencing and was also broadcast through Institute's YouTube channel. Apart from IITM, officers and employees of seven other autonomous institutes under the Ministry of Earth Sciences also enjoyed the Kavi Sammelan.
- Hindi library is being maintained regularly and books are being issued to employees.
- Daily translation and correspondence work is being done.

Chapter 14
Honours and Awards

Dr. R. Krishnan

- Member, Scientific Advisory Committee of National Atmospheric Research Laboratory (SAC-NARL).
- Expert Member, Working Group on Climate Research (WG-CR), Mega Science Vision-2035 (MSV-2035) Exercise for India.
- Nominated as Focal Point for the 53rd BIS Session of the IPCC.

Dr. G. Beig

- Member, Scientific Steering Group (SSG), SPARC, World Climate Research Program, WMO, Geneva.
- Member, Project Assessment and Monitoring Committee for DST-NPDF-Earth & Atmospheric Sciences fresh proposals.
- Panel Member, discussion on "Changes in Air Quality and Climate during COVID-19" organized by National Resources Defense Council (NRDC) in collaboration with Indian Institute of Public Health, Gandhinagar (IIPH-G), 15 October 2020.
- Eminent Speaker, Plenary session 9: 'Climate Change, Poverty & Pandemic: Is it time to recalibrate SDGs?' 4-day International Conference (online) of 'Eradication of Biological and Chemical Weapon', organized by Maharashtra Institute of Technology World Peace University (MIT-WPU), Pune, 26 June 2020.
- Panel Member, discussion on 'Changes in Air Quality and Climate during COVID-19' organized by NRDC Resources Defense Council (NRDC) in collaboration with Indian Institute of Public Health, Gandhinagar (IIPH-G), 15 October 2020.

Dr. A.K. Sahai

- Co-chaired a Session on 'Extreme Weather Events' at the Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' jointly organized by MoES, IMD, IITM, NCMRWF, SPPU, and IMS during 19-21 January 2021.

Dr. S.D. Pawar

- Member, Expert Group to implement the Action Plan on Thunderstorm & Lightning by National Disaster Management Agency (NDMA).
- Chaired a technical session on Lightning Physics and forecasting at the TROPMET 2020 held at NESAC, Shillong.
- Member of Board of Studies in Department of Physics by the Sanjay Godhawat University, Kolhapur.
- Member, National Disaster Management Authority's (a) Working Group for formulation of Guidelines on preparation of Action Plan for prevention and management of Cold Wave; and (b) Working Group to formulate policy for resettlement of displaced people affected by River and Coastal Erosion.
- Expert Member of Board of Studies (Physics) of Sanjay Godhawat University, Kolhapur.

Dr. Thara Prabhakaran

- Member, New Programme Advisory and Monitoring Committee (PAMC/MoES).
- Panelist for 'Atmospheric Observations', Vaishvik Bhartiya Vaigyanik (VAIBHAV) Summit.
- Indian Representative, WMO-Expert team meeting of weather modification.
- Focal Point for Cloud Seeding Techniques for the MoU signed between the Ministry of Earth Science (MoES) and the National Centre of Meteorology (NCM), United Arab Emirates (UAE) Asia regarding the Scientific and Technical Collaboration between NCM & MoES.

Dr. S. Chakraborty

- Associate Editor, Frontiers in Water and Climate.

Dr. G. Pandithurai

- Chaired Committee meeting to review the need of TDMA ERS, 17 November 2020.
- Panelist, Atmospheric Observations, VAIBHAV Summit.
- Member, Review Committee by Centre for High Energy Systems and Sciences, DRDO lab, Hyderabad for their project 'Atmospheric Parameters affecting the laser propagation and characterization of turbulence effects on long range laser propagation'.

Dr. Ashwini Kulkarni

- Chief Guest and Keynote Speaker at AICTE sponsored short term training program on Disaster Mitigation and Management organised at KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, 12 October 2020.
- Member, Empirical Statistical Downscaling Group-Asia.
- Member, Upper Indus Basin – Network.

Dr. J. Sanjay

- Resource person in the National Training Programme on "Audit of Climate Change and Disaster Management" organised by the International Centre for Environment Audit and Sustainable Development (iCED) Jaipur, through Video Conference on 3 August 2020.
- Member of the Expert Network of the new WMO Technical Commissions: INFCOM and SERCOM.
- Resource Person, training workshop on "Regional climate change projections: Climate change analysis using CORDEX regional climate models over South Asia" organised online by ICIMOD and UK Met Office as a key activity of the institutional capacity building programme of the CARISSA-ARRCC project during 12-14 October, and 19-21 October 2020.
- Member, World Climate Research Program (WCRP) Coordinated Regional climate Downscaling Experiment (CORDEX) Science Advisory Team (SAT) (term extended for two years up to 31 December 2021).

Mr. V. Gopalakrishnan

- Served as a member of the Expert Committee set up by Commissioner of Revenue Administration, Govt. of Tamil Nadu to discuss 'Setting up of Telemetric Rain Gauge (ARG) Automatic Weather Stations (AWS) & Automatic Water Level Recorders (AWLR) & Lightning Alert System over Tamil Nadu'.

Dr. Suvarna Fadnavis

- Member, Scientific Steering Committee, Chemistry Climate Modelling Initiative jointly sponsored by Stratosphere-troposphere Processes and their Role in Climate (SPARC) and the International Global Atmospheric Chemistry (IGAC) programs.

Dr. P. Mukhopadhyay

- Associate Editor, 'Journal of Earth System Science', Indian Academy of Sciences, Bengaluru for the period July 2020 to July 2024.
- Nominated as TIGGE panel member for GEFS forecast at TIGGE Archive since 1 July 2020.
- Guest Editor, Special issue of MAUSAM (January 2021) on the theme "Tropical cyclones over north Indian Ocean: Recent advances in monitoring, understanding and prediction".

Mr. S. Mahapatra

- First Prize, Pune City level online Hindi essay completion, on a topic related to COVID-19 pandemic from CSIR-NCL Pune (during Hindi Week Celebration by NCL).
- Resource Person, International e-Conference on "Possibilities & Prospects of Climate

HONOURS AND AWARDS

Research & Studies in the Contemporary Era", South Asian Institute for Advanced Research & Development (SAIARD), Centre for Climate Research and Studies (CCRAS), 12 December 2020.

Dr. Devendraa Siingh

- Member of COSPAR-URSI-SCOSTEP- National committee for International Science Council-INSA, New Delhi.
- Recognized as Ph.D. guide in Physics by Hemvati Nandan Bahuguna Garhwal University (A Central University), Srinagar (Garhwal), Uttarakhand.

Dr. Anoop Mahajan

- Chair, Committee to highlight Indian science achievements through the Indian National Young Academy of Sciences (INYAS).

Dr. Sachin D. Ghude

- MoES Certificate of Merit for the year 2020 for his outstanding contribution in the field of Atmospheric Science and Technology.

Dr. Milind Mujumdar

- Member, Advisory Committee and presented a lead talk in International Conference on Meteorology and Climate Science-2020 (ICMCS-2020), 11-12 December 2020, Department of Meteorology, University of Dhaka, Bangladesh.

Mrs. Shompa Das

- Invited Member, MoES Knowlege Resource Center Network Portal Committee.
- Member, DERCON.

Dr. M.C.R. Kalapureddy

- Best Presentation Award, TROPMET- 2020, 15 December 2020.

Dr. Swapna Panickal

- Member, SPARC Science Task Team, World Climate Research Program (WCRP) for the period 2020-2025.
- Member, Drafting Group on Climate Research, Mega Science Vision-2035 (MSV-2035) Exercise for India.

Dr. Roxy Mathew Koll

- Member, Research Foci Group on Tropical Basin Interactions (TBI), announced by CLIVAR.
- Associate Editor for the journals: 'Progress in Oceanography' and 'Frontiers in Climate'.
- Chaired (i) CLIVAR/IOC/GOOS Indian Ocean Region Panel in the e-meeting with the Global Oceans on employing an Atmospheric Instrumentation Suite (AIS) in the Indian Ocean, 21 April 2020, and (ii) Quarterly meetings of the CLIVAR/IOC/GOOS Indian Ocean Region Panel on 21 September and 02 November 2020.
- Chair of the 2019-2020 Annual Report of the Indian Ocean Region Panel (IORP).
- Represented the Indian Ocean Region Panel at the quarterly session of the Indian Ocean Observing System (IndOOS) Resource Forum (IRF-11), organized by NOAA, 19 August 2020.
- Chaired sessions on (i) WG3: observations at the WCRP-CLIVAR Workshop on Climate Interactions among the Tropical Basins, 24-26 February 2021; and (ii) Climate Change Hazards in the Himalayas organized by the National Mission on Biodiversity and Human Well-Being, 25 February 2021.

Dr. Hamza Varikoden

- Secretary, Ocean Society of India Pune Chapter for the period 2021-23.

Dr. Yogesh K. Tiwari

- Member for the Integrated Global Greenhouse Gas Information System (IG3IS) Steering Committee by WMO - Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC-SSC). Initial period of appointment is for 2 years.

Dr. Subrata Kumar Das

- Chaired a session titled 'Wind Profiling Radars' during 4th National conference on India Radar

Meteorology (iRAD-2020), IIT, Chennai, 5-7 February 2020.

Dr. J.S. Chowdary

- Invited as Review Editor on the Editorial Board of Predictions and Projections, Frontiers in Climate from February 2021.

Dr. N.R. Deshpande

- Member, Expert Committee by the Govt. of Maharashtra to 'Study reasons of occurrence of 2019 Floods in Bhima & Krishna basin & propose technical measures to be undertaken in future'.

Dr. Atul Kumar Srivastava

- Member, Scientific Organizing Committee (SOC) and Co-chair for a session, International Conference on Aerosol Air Quality, Climate Change and Impact on Water Resources and Livelihoods in the Greater Himalayas, ARIES, Nainital, 14-16 September 2020.
- Member, Panel Discussion on 'Recent Developments and Way Forward in Measurements and Modeling of Health and Climate Change', Amity Innovation Week 2020, Amity University Haryana (AUH), Gurugram, 25 September 2020.
- Panelist, Vaibhav Summit: V11-Environmental Sciences, H1: Air quality management, S5: Air pollution management, 12 October 2020.
- Panelist, Citizen's Forum India (CFI) for Discussion on 'Curbing Air Pollution Amidst COVID-19', 21 November 2020.
- Theme Coordinator, Young Scientist Conference (YSC) in India International Science Festival (IISF-2020) under the Theme: Frontier Areas of Sciences-Environment during 22-24 December 202 and he conducted a Plenary and Oral Session on 23 December 2020.
- Resource Person for online Refresher Course on 'Environmental Science', Utkal University, Bhubaneswar, Orisha, 17 March 2021.

Dr. H.N. Singh

- Nominated as an Editor of e-Journal of Geohydrology published by Indian National Chapter of International Association of Hydrogeologists (IAH).

Mr. Raju Mandal

- Best Paper Presentation Award under the theme 'Climate Change Impacts' in the National E-Symposium on 'Cloud and Precipitation Processes', organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Mr. Sahadat Sarkar

- Best Paper Presentation Award under the theme 'Extreme-Weather-Events' in the National E-Symposium on 'Cloud and Precipitation Processes', organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Ms. Aditi Modi

- Core Committee Member, International Indian Ocean Expedition (IIOE-2) Early Career Scientist Network.

Mr. Parmit Deb Burman

- External reviewer of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Draft Scoping Report on the Underlying Causes of Biodiversity Loss and the Determinants of Transformative Change and Options for Achieving the 2050 Vision for Biodiversity (Transformative Change Assessment).
- Resource Person (i) Student and Faculty Development Program on Earth System Science for Society, PES Institute of Technology and Management, Shivamogga, Karnataka during 30 November - 5 December 2020, and (ii) AICTE Sponsored Online Short-Term Training Program on Applications of GIS & Remote Sensing in Civil Engineering, Sri Siddhartha Institute of Technology, Tumakuru, Karnataka, 14-19 December 2020.

HONOURS AND AWARDS

- Awarded the Top 10 Project Award for their project titled 'No Haze' for the ENVRI Community Hackathon: Hack the Arctic organised by Environmental Research Infrastructure (ENVRI), Institute for Atmospheric and Earth Systems Research (INAR) Finland, and Integrated Carbon Observation System (ICOS), 12-14 February 2021.

Mrs. A.A. Desai, Mr. Sandip S. Kulkarni and Mr. Vikas V. Bamble

- MoES Annual Awards for Best Employees for the year 2020 under the category 'Group B Gazetted', 'Group B Non-Gazetted' and 'Multi-Tasking Staff' respectively.

Dr. Rupa Kumar Kolli

- Member, Standing Committee on Climate Services (SC-CLI), WMO services Commission and Co-Lead of the Expert Team on Climate Services Information System Operations (ET-CSISO), under SC-CLI.
- Member, International Organizing Committee for ICCS-6
- One of the founding members of the Steering Committee of the Global Heat-Health Information Network (GHHIN).
- Invited as a member of the Vulnerability, Impacts, Adaptation and Climate Services (VIACS) Advisory Board for the Coupled Model Intercomparison Project Phase 6 (CMIP6).
- Invited by the Working Group on Tropical Meteorology Research (WG-TMR) of WWRP as one of the Co-chair of the International Organizing Committee (IOC) for the upcoming Virtual International Training Workshop on S2S Prediction in Monsoon Regions.

Mr. Abhishek Jha

- Young Scientist Award in 33rd General Assembly and Scientific Symposium in the International Union of Radio Science (URSI-2020), Rome, Italy.

Mr. Sandip Ingle and **Dr. R. Mahesh**

- Resource Persons, Training Workshop on 'Regional climate change projections: Climate change analysis using CORDEX regional climate models over South Asia' organised online by ICIMOD and UK Met Office as a key activity of the institutional capacity building programme of the CARISSA-ARRCC project during 12-14 October, and 19-21 October 2020.

Dr. Gayatry Kalita

- Editorial Board Member, International Journal of Atmospheric and Oceanic Sciences, 9 October 2020 to 9 October 2022.

Ms. Swaleha Inamdar

- Best Presentation Award in the Frontier Areas of Research - Environmental Sciences category during the Young Scientists' Conference (YSC-2020), India International Science Festival, 22-25 December 2020.

Mr. Hrudya P.H.

- Best Poster Presentation Award in the Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Dr. Sukanya Patra

- Best Presentation Award in the Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Ms. Meenu R. Nair

- INSPIRE Fellowship under INSPIRE Program of DST from 25 January 2021.

Mr. Ushnanshu Dutta

- Best Paper Presentation Award in the Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Dr. Ila Agnihotri

- Prize in Oral Technical Presentation on 'Modelling Surface Runoff in West Flowing River Basin of Kutch, Saurashtra and Marwar during contrasting monsoons' in the Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' organized by India Meteorological Society, Pune Chapter, 19-20 January 2021.

Swachhata Pakhwada Award 2020: As part of Swachh Bharat initiative, MoES appreciated & awarded their autonomous & attached offices for their efforts and innovative initiatives towards cleanliness during Swachhta Pakhwada (1-15 July 2020). Among MoES institutes, IITM has bagged 2nd prize under Swachhata Pakhwada Award 2020 coordinated by Ministry of Drinking Water and Sanitation, Government of India.

Chapter 15
Seminars

15.1. Monsoon Discussion Forum

Dr. A.K. Sahai

- Extended Range Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2020', 16 June 2020.

Dr. Suryachandra A. Rao

- Seasonal Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2020', 16 June 2020.

Dr. C. Gnanaseelan

- Oceanic Conditions, 1st Seminar: focus on 'Onset and LRF of monsoon 2020', 16 June 2020.

Dr. P. Mukhopadhyay

- Short Range Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2020', 16 June 2020.

Dr. Susmitha Joseph

- Extended Range Prediction, 2nd Seminar: focus on 'Advance of monsoon 2020', 16 July 2020.

Dr. Medha Despande

- Short Range Prediction, 2nd Seminar: focus on 'Advance of monsoon 2020', 16 July 2020.

Mr. Ankur Srivastava

- Ocenaic conditions and seasonal prediction, 2nd Seminar: focus on 'Advance of monsoon 2020', 16 July 2020.

Mr. Tanmoy Goswami

- Short Range Prediction, 3rd Seminar: focus on 'Progress of monsoon and future evolution', 21 August 2020.

Mr. Maheshwar Pradhan

- Oceanic conditions and Seasonal Prediction, 3rd Seminar: focus on 'Progress of monsoon and future evolution', 21 August 2020.

Mr. Avijit De

- Extended Range Prediction, 3rd Seminar: focus on 'Progress of monsoon and future evolution', 21 August 2020.

Dr. Prasanth Pillai

- Oceanic conditions and Seasonal Prediction perspective, 4th Seminar: focus on 'Withdrawal of monsoon', 21 September 2020.

Dr. Rajib Chattopadhyay

- Extended Range Prediction, 4th Seminar: focus on 'Withdrawal of monsoon', 21 September 2020.

Dr. Malay Ganai

- Short Range Prediction, 4th Seminar: focus on 'Withdrawal of monsoon', 21 September 2020.

15.2. Prof. R. Ananthakrishnan Seminars/ Colloquium

Dr. S.A. Dixit

- Scaling mean velocity in wall jets and drag in boundary layers: Recent laboratory studies from IITM, 19 August 2020.

Dr. Suvarna Fadnavis

- Chemical-Dynamical feedback of the Asian Summer monsoon circulation, 9 September 2020.

Dr. Anoop S. Mahajan

- Reactive trace gases in the Indian Ocean, Southern Ocean and Antarctica and why we need to change them, 23 September 2020.

Mr. Manmeet Singh

- Fingerprint of volcanic forcing on the ENSO–Indian monsoon coupling, 30 September 2020.

Dr. Vinu Valsala

- The IOD Impacts on the Indian Ocean Carbon Cycle, 14 October 2020.

Dr. Nils P. Wedi, Principal Scientist & Head, Earth System Modelling, ECMWF, Reading, **UK**

- A baseline for global weather and climate simulations at 1 km resolution, 11 November 2020.

Dr. Milind Mujumdar

- A study of field-scale soil moisture variability using the COsmic ray Soil Moisture Observation System (COSMOS), 24 February 2021.

15.3. Seminar on PhD Proposal

Mr. Sreeraj P.

- Mean and Extreme Sea-level Response of the Indian Ocean to Climate Change, 10 July 2020.

Ms. Chandrima Mallick

- Prediction of Lightning over India using dynamical model, 18 September 2020.

Ms. Pratibha Gautam

- Understanding the role of Land Surface Process in the Prediction of Monsoon Low-Frequency Variability, 14 October 2020.

Mr. Prashant L. Chavan

- Variability of aerosols in the upper troposphere and stratosphere over the Asian summer monsoon region, 21 October 2020.

Mr. Gokul T.

- Low-level clouds in the Mascarene High environment and links to the Indian monsoon in a changing climate, 23 October 2020.

Mr. Avishek Ray

- Study of aerosol hygroscopicity and its role on CCN activation based on measurements over Mahabaleshwar, Western Ghats and modelling, 28 October 2020.

Ms. Mercy Varghese

- Study of cloud base aerosol activation during monsoon using observations and numerical modeling experiments, 4 November 2020.

Ms. Rituparna Sarkar

- Development of lightning prediction system using Global Forecast System and machine learning model over India, 6 November 2020.

Mr. Subrata Mukherjee

- Study of volatile organic compounds (VOCs) and its implications to secondary organic aerosol (SOA) formation over a high-altitude site in Western Ghats, 11 November 2020.

Ms. Supriya M. Ovhal

- Subsurface Oceanic impact on tropical atmospheric convection, 23 December 2020.

Mrs. Archana Rai

- Investigating the Role of Vegetation Processes on the Indian Summer Monsoon Variability and Predictability, 30 December 2020.

Mr. Ashish Dhakate

- Study on the seasonal extremes of Indian summer monsoon rainfall: Mechanism and Predictability, 30 December 2020.

Mrs. Anika Arora

- Biennial Variability of rainfall over Western Ghats and governing mechanisms, 13 January 2021.

15.4. Seminar on PhD Synopsis

Miss. Jyoti A Jadhav

- Multi-decadal sea-level variability in the Indian Ocean and its possible driving mechanism in a changing climate, 3 July 2020.

Mr. Dipjyoti Mudiar

- Effects of Electric Forces on Rain Formation Processes in Tropical Clouds, 17 July 2020.

Mr. Anil Kumar

- On the influence of atmospheric aerosols in ice nuclei characteristics and its parameterization, 23 September 2020.

Mr. Pramit Kumar Deb Burman

- Carbon Sequestration Studies in Forest Ecosystems using Tower-based Observations and GPP-NEE Modelling, 9 October 2020.

Mr. Rahul Pai

- Understanding the variability of Shallow Meridional Overturning Circulation and its impact on the Indian Ocean temperature, 16 October 2020.



SEMINARS

15.5. Invited Lectures / Talks Delivered Outside at Academic Institutions

Prof. Ravi S. Nanjundiah

- Understanding and Predicting the Monsoons, GRSS Bangalore Chapter: Bhoo-Mandal Talk Series, IISc, Bengaluru, 14 August 2020.
- Use of AI and ML for Weather and Climate Tropmet Conference Shillong, 15 December 2020.
- Variability of Monsoons at Different scales, PRL colloquium, 05 January 2021.

Dr. R. Krishnan

- Climate Science and Earth System Modelling, MoES Webinar Series, 12 July 2020.

Dr. G. Beig

- Exposure to UV Radiations – Key role of environmental factors, Baerlocher India R&D Pvt. Ltd., 02 July 2020.
- Do you care for Air you Breathe? MIT-ADT University, Pune, 15 July 2020.
- Sustainable development, MIT-ADT University, Pune, 12 September 2020.
- Frontier of Science and Research in IITM (in Hindi), Marathi Vigyan Parishad, Pune, 7 August 2020.

Dr. C. Gnanaseelan

- Decadal Climate Variability, Predictability and Prediction, Indian Institute of Space Science and Technology, Thiruvananthapuram, 24 March 2021.
- Crop weather relationship, El Nino, IOD and their linkages with monsoon and climate', in One-week online training programme on "Advanced Agrometeorological Techniques for Climate Smart Agriculture" held during 29 June to 03 July, 2020 organized by Mahatma Phule Krishi Vidyapeeth, Rahuri.
- Physical and dynamical oceanography (online lectures) to the participants of 'UGC-HRDC refresher course on Earth Sciences-Exo meteorology' during 11-13 January 2021.
- Indian Ocean Warming on a Changing Climate, WMO Day, Amity University, 23 March 2021.

Dr. S. Chakraborty

- Quantifying biosphere-atmosphere carbon transfer processes in natural ecosystems using the eddy-covariance technique, Refresher Course in Earth System and Exo-Meteorology, UGC-HRDC, Osmania University, Hyderabad, 17-29 August 2020.
- Quantifying biosphere-atmosphere carbon transfer processes at a semi-deciduous forest in northeast India, National Institute of Oceanography, Goa, 26 November 2020.
- Study of carbon-water linkage using the meteorological and isotopic techniques, Department of Environmental Science, University of Calcutta, 4 February 2021.
- Environmental influence on GHGs distribution in the urban environment, Refresher Course in Environmental Studies, University of Calcutta, 18 March 2021.

Dr. G. Pandithurai

- Atmospheric aerosols and their role in climate, Department of Physics, Kamaraj College, Thoothukudi, Tamil Nadu, 10 July 2020.

Dr. Ashwini Kulkarni

- Climate change and natural hazards, AICTE sponsored short term training program on Disaster Mitigation and Management at KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, 12 October 2020.

Dr. J. Sanjay

- Assessment of Climate Change over the Indian Region (lectures) officers of Indian Audit & Accounts Department through Video Conference, 3 August 2020.

Dr. Suvarna Fadnavis

- Ozone for life-35 years of ozone protection layer, Patangrao Kadam, Mahavidhyalaya, Sangili, World Ozone Day, 16 September 2020.

Dr. P. Mukhopadhyay

- Probabilistic forecast of extreme precipitation events of August 2018 and 2019 during monsoon over Kerala, India, Department of Physics, Oxford University, UK, 20 April 2020.
- Is it possible to break the cloud-convection parameterization deadlock in climate model? New Insights, International Centre for Theoretical Sciences, TIFR, Bengaluru, 15 December 2020.
- Numerical weather prediction: the current status in India and the future pathways, Indian Meteorological Society, Kolkata chapter, 13 February 2021.

Dr. Anoop Mahajan

- Oceanic emissions of reactive trace gases, and their impact on the atmosphere, PRL, Ahmedabad, 15 March 2021.

Dr. Roxy Mathew Koll

- Extreme weather events in a changing climate, Amity University, 12 June 2020.
- Extreme weather events over India, under a climate change - COVID scenario, Faculty Development Program, Savitribai Phule Pune University, 12 July 2020.
- Climate Change: Extreme Weather Events over India and Impacts on Biodiversity, Nilgiri Natural History Society (NNHS), Ooty, Tamila Nadu, 5 September 2020.
- Rapid ocean warming and extreme weather events, Department of Physics, Assam University, 11 September 2020.
- Climate change, extreme weather events and India, Department of Communication, Shiv Nadar University, Noida, 10 November 2020.
- Indian Ocean warming and extreme weather and climate events, Refresher Course on Earth Sciences-Exo Meteorology, Savitribai Phule Pune University and UGC Human Resources Development Centre, 15 January 2021.
- The role of forests and trees in mitigating the impacts of climate change over India, Oakridge School, Hyderabad, 5 February 2021.
- Climate change and extreme weather and extreme weather events over India, Refresher Course, Kerala University and UGC Human Resources Development Centre, 16 February 2021.
- Climate change and extreme weather events over India, National Science Day, CMS College and the Academy of Physics Teachers, Kerala, 27 February 2021.

Dr. Bipin Kumar

- Application of Deep-Learning methods in data downscaling and weather forecasting, IMD, Pune, 25 February 2021.
- Application of AI/ML algorithms in atmospheric science, IISER Pune, 21 February 2021.

Dr. Hamza Varikoden

- Physics of climate change under the topic 'ocean and atmospheric systems': A physics perspective, National Science Day 2021, Sree Krishna College Guruvayoor, Kerala, 12 February 2021.

Dr. Yogesh K. Tiwari

- Carbon emissions reduction during Covid-19 pandemic and its impact on the climate, National webinar, Gandhi Institute for Education and Technology (GIET), Bhubaneswar, Orissa, 23 May 2020.

Dr. J.S. Chowdary

- Recent developments and challenges in weather and climate-Indian Perspective, National Webinar Series, Department of Meteorology and Ocenography, Andhra University, Visakhapatnam 10-25 August 2020.
- STTP on Disaster Mitigation and Management, Webinar, Department of Civil Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, 14-19 September 2020.

Dr. Rajib Chattopadhyay

- Monsoon variability and its seamless forecasting for agromet services, web-based

training course on'Advanced Agro-meteorological Techniques for Climate Smart Agriculture', Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, 29 June 2020.

Dr. Atul Kumar Srivastava

- Atmospheric aerosols: Measurements, monitoring, and its impact assessment, online Refresher Course on 'Environmental Science', Utkal University, Bhubaneswar, Orisha, 17 March 2021.

Dr. Ayantika Dey Choudhury

- South Asian Monsoon, UGC-HRDC Refresher Course on Earth Sciences Exo-meteorology, Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, 4-17 January 2021.

Mr. Bhupendra Bahadur Singh

- Indian Summer Monsoon variability and interactions with extratropical circulation in Himalayan extreme rainfall, Faculty Development Programme on Climate Change and Hydrologic Extremes, Department of Civil Engineering and Water Institute, Karunya Institute of Technology and Science, India, 20 July 2020.
- Indian Summer Monsoon variability, interactions with extratropical circulation and aspects of climate change over India, Student Development Program (SDP) and Faculty Development Program (FDP), Department of Civil Engineering, PES Trust Shivamogga, Karnataka, 4 December 2020.
- Application of satellite data in climatic studies, Online STTP program, Department of Civil Engineering, Sri Siddhartha Institute of Technology, Tumakuru, Karnataka, 18 December 2020.

Mr. Pramit Kumar Deb Burman

- Climate change, carbon cycle and water cycle, Department of Environmental Science, University of Calcutta, Kolkata, 29 December 2020.
- Data analytics in earth science and climate studies, Indian Statistical Institute (ISI), Bangalore (to the Master of Science in Quality Management Science faculty and students).
- Ecophysiology and Ecohydrology of Terrestrial Ecosystems using in situ Measurements and Satellite Observations, AICTE Sponsored Online Short Term Training Program on Applications of GIS & Remote Sensing in Civil Engineering, Sri Siddhartha Institute of Technology, Tumakuru, Karnataka, 14-19 December 2020.
- Forest-Atmosphere Interaction in the Context of Climate Change, Student and Faculty Development Program on Earth System Science for Society, PES Institute of Technology and Management, Shivamogga, Karnataka, 30 November to 5 December 2020.

Dr. C. Dhara

- Energy budgets, radiative forcing and climate change, Part-1 and Part-2, UGC-HRDC Teacher Refresher Course, Department of Atmospheric and Space Sciences, S.P. Pune University, 9-11 January 2021.

15.6. Invited Talks at conferences, workshops, important meetings, etc.

Dr. R. Krishan

- Climate change projections and monsoon variability, Virtual International Conference on the 'Future Directions of Subseasonal to Seasonal Prediction over South Asia', 29-31 March 2021.
- Role of oceans on future changes in the regional monsoons, National E-Symposium on 'The Ocean, Our Climate and Weather' held on the World Meteorological Day, 23-March 2021.

Dr. A.K. Sahai

- भारतवर्ष में कृषिजलवायु सेवाओं की बेहतरी हेतु पृथ्वी विज्ञान मंत्रालय की पहल और COVID19 आपदा से निपटने में इसकी भूमिका, National Webinar: Survival Strategies for Post COVID-19 Era: Perspectives from

Science, Technology and Social Science, Department of Physics, Ewing Christian College, Prayagraj, 20-26 May 2020 (on 25 May 2020).

- Challenges and Mathematical Complexities in Providing Climate Services in Changing Climate, W3APACM 2020, Department of Applied Mathematics, Gautam Buddha University, Greater Noida, 13 June 2020.
- Analysing climate disease linkages for development of disease early warning system, Webinar on Emerging scenarios related to zoonoses in a warming environment, KBCAOS, University of Allahabad, 19-20 June 2020 (on 19 June 2020).
- Hydroclimatic Extremes and Geospatial Techniques, Roles of spatial intelligence during post covid hydro-meteorological extreme, International Webinar on Spatial Intelligence for Real World Solutions, Symbiosis Institute of Geoinformatics, Pune, 16 September 2020.
- Challenges in the Extended Range Preiction: Where do we stand? National Webinar: Aryabhatta Research Institute of Observational Sciences, Nainital, 9 December 2020.
- New extended range modelling strategy, Brain Storming Workshop on Monsoon 2020 Jointly Organised by Ministry of Earth Sciences (MoES), India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM), National Centre for Medium Range Weather Forecasting (NCMRWF), and Indian Meteorological Society (IMS) on 18 January 2021.
- Towards the development of an efficient extended range prediction system for societal applications over South Asia, Virtual International Conference on the 'Future Directions of Subseasonal to Seasonal Prediction over South Asia,' jointly organised by WWRP/WCRP and IITM at IITM, Pune during 29-31 March 2021.

Dr. Suryachandra Rao

- Impact of Pacific Ocean SST bias on simulation and prediction of Indian summer monsoon in coupled models, Virtual International Conference on the 'Future Directions of Subseasonal to Seasonal Prediction over South Asia', jointly organised by WWRP/WCRP and IITM at IITM, Pune during 29-31 March 2021.

Dr. C. Gnanaseelan

- Towards development of a decadal prediction system for India, IMSP webinar felicitating Dr. A.K. Sahai, 26 March 2021.

Dr. S.D. Pawar

- Effect of climate change on lightning activity, International Symposium on Advanced Research in Physics, Department of Physics of Bangalore University, Bengaluru, 27-31 2020 (on 28 July 2020).
- Lightning activity over India during pre-monsoon and monsoon, IMS Patna Chapter, 18 August 2020.
- Spatial and temporal change in lightning activity over India, TROPMET 2020, NESAC, 14-17 December 2020.
- Effect of drop size distribution on charging process inside thundercloud, National E-Symposium on “Cloud and Precipitation Processes”, Jointly organized by IMSP, SPPU & IITM, 19-20 January 2021.

Dr. Thara Prabhakaran

- Mixed phase cloud processes, National E-symposium the Annual Monsoon Workshop 2019-2020 with special session “Cloud and Precipitation Processes”, 18–20 January 2021.

Dr. G. Pandithurai

- Cloud observations by in-situ and radar remote sensing techniques, virtual workshop on 'Atmospheric Observational Techniques', South Asian Meteorological Association (SAMA) and SRM University, 12 December 2020.



SEMINARS

- Aerosol-cloud interactions: Glimpses from High-Altitude Cloud Physics Laboratory, Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' hosted by IMS, Pune Chapter, Pune, 18-20 January 2021.

Dr. Ashwini Kulkarni

- Climate Change and Natural Hazards (Keynote Speaker), AICTE sponsored short term training program on Disaster Mitigation and Management, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, 12 October 2020.

Dr. P. Mukhopadhyay

- Application of Probabilistic forecast for issuing QPF over river sub basin, Training Workshop of Officials of Flood Meteorological Offices and other Forecasting Offices of IMD, 2 July 2020.
- GFS based medium range ensemble prediction system (GEFS), Online Workshop cum Training on 'Use of Ensemble Model Forecast Products for Weather/Climate', BIMSTEC Centre for Weather and Climate (BCWC), 25 March 2021.
- Recent developments in GFS T1534 (12 km) for improving the forecast, Online MoES NWP Review meeting, 25 February 2021.
- NWP Model development for improved operational forecast, MoES Brain Storming Workshop on Monsoon 2020, 18 January 2021.
- GEFS based ensemble products in medium range, Workshop on Use of Products from Ensemble Prediction Systems, NCMRWF, 21 January 2021.
- Lessons learnt from weather scale forecast to improve fidelity of S2S, Virtual International Conference on the 'Future Directions of Subseasonal to Seasonal Prediction over South Asia', jointly organised by WWRP/WCRP and IITM at IITM, Pune, 29-31 March 2021.

Mr. S. Mahapatra

- The Earth's Climate System and Basics of Climate Modelling, One-day International e-Conference on Possibilities & Prospects of Climate Research & Studies in the Contemporary Era, South Asian Institute for Advanced Research & Development (SAIARD), Centre for Climate Research And Studies (CCRAS), 12 December 2020.

Dr. Devendraa Siingh

- COVID- 19 and meteorological parameter, International webinar on "Air quality, climate change and environmental effects referring to the Pandemic Covid-19 lockdown", HNB Garhwal University, Srinagar and Govt. P. G. College, Gopeshwar, Agra, 2-3 May 2020.
- Lightning Discharges in the Atmosphere, International Workshop on Joint Modernistic and Innovative Technology, Physics Department, Seth Jai Parkash Mukand Lal Institute of Engineering & Technology, Radaur (Yamunanagar) UP, 4 August 2020.

Dr. Milind Mujumdar

- Ventilation and healthy indoor environment in the tribal houses, Geomedical Health Hazards and Environmental Problems in Tribal Areas: Issues, Challenges and Opportunities, Kaviyatri Bahinabai Chaudhari - North Maharashtra University (KBC-NMU), Jalgaon (MS), 17 September 2020.
- Droughts over India: Present and Future, International Conference on Meteorology and Climate Science-2020 (ICMCS-2020), Department of Meteorology, University of Dhaka, Bangladesh, 11-12 December 2020.
- आई. आई. टी. एम्. पुणे साईट पर स्थित अत्याधुनिक तकनीक (कॉसमॉस) कॉस्मिक-रे मृदा नमी अवलोकन प्रणाली द्वारा क्षेत्रिय पैमाने पर मिट्टी की नमी की परिवर्तनशीलता का अध्ययन, हिंदी वैज्ञानिक संगोष्ठी - आज़ादी का अमृत महोत्सव, राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केन्द्र (एन सी एम् आर डब्लू एफ), 23 मार्च 2021.

Dr. Swapna Panickal

- Mean state and variability in IITM-ESM CMIP6 simulations, WCSSP-India IND4 STIMULATE, University of Reading, UK and Met Office, UK, 14-15 May 2020.
- Climate change and regional sea level rise; an Indian Ocean perspective, SOLAS Indian Ocean meeting, 30 September 2020.

Dr. Roxy Mathew Koll

- Rising ocean temperatures, marine heatwaves and impact on the marine biodiversity, Times of India, World Environment Day 2020 Conclave, 7 June 2020.
- Extreme weather events over India in a changing climate, National webinar on Recent Developments and Challenges in Weather and Climate - Indian Perspective, Department of Meteorology and Oceanography, Andhra University, 13 August 2020.
- Climate change and river-rain water monitoring, Meenachil River Protection Council, Kottayam, Kerala, 27 September 2020.
- Indian Ocean warming and monsoon extremes, Surface Ocean - Lower Atmosphere Study (SOLAS) Meeting, IITM, 30 September 2020.
- Climate change and extreme weather events in the SAARC region, SAARC webinar on Enhancing Preparedness for Responding to COVID19 and Extreme Weather Events, SAARC Disaster Management Centre (SDMC), Ahmedabad, 4 November 2020.
- Climate change in the Indian Ocean and its impacts, Science Webinar-Climate Change Edition, Young Earth System Scientists (YESS) Community, 5 November 2020.
- Climate change and extreme weather events in the Indian Ocean region, Annual Monsoon E-Workshop and National E-Symposium on Cloud and Precipitation Processes, Indian Meteorological Society (IMS), 20 January 2021.
- Indo-Pacific warming and its impacts on the MJO and global rainfall patterns, Workshop on Indian Ocean Variability and Teleconnections, International Centre for Theoretical Physics (ICTP), 16 March 2021.
- Cyclones in the Indian Ocean, Virtual Conference on Disaster Risk Reduction, National Institute of Technology Karnataka and the Asian Disaster Reduction and Response Network, 17 March 2021.

Dr. Ramesh Kumar Yadav

- Swapping of the Pacific and Atlantic Niño influences on north central India summer monsoon, TROPMET-2020: National Virtual Symposium on Weather and Climate Services over Mountainous Regions, North Eastern Space Applications Centre (NESAC), Umiam and India Meteorological Society (IMS)-Shillong Chapter, Shillong, Meghalaya, 14-17 December 2020.

Dr. Yogesh K. Tiwari

- Carbon emissions reductions during COVID-19 pandemic and its impact on the climate, National Webinar Series, Gandhi Institute for Education and Technology (GIET) Bhubaneswar, Orissa, 23 May 2020.

Dr. J.S. Chowdary

- Interdecadal modulations of ENSO-ISM rainfall regional teleconnection patterns, Annual Monsoon E-Workshop and National E-Symposium on 'Cloud and Precipitation Processes' hosted by IMS, Pune Chapter, Pune, 18-20 January 2021.

Dr. Sabin T.P.

- Climate change and climate modelling: are we heading towards an annual affair of floods and extremes? PHYTECH 2020, Mar Thoma College, Chungathara, Kerala, 18 September 2020.
- Assessment of Himalayan climate: the need for high-resolution climate modelling



strategies, International Conference on Himalayan Cryosphere-2020, Indian Institute of Science, Bengaluru, 9-23 October 2020.

Mr. Abhay SD Rajput

- Toward integrating science communication training in STEM education, One-Day National Multidisciplinary e-Conference on "Research in Science and Technology for Sustainable Development" organized by Rajarshee Shahu Science College, Chandur Railway, Dist. Amravati (MS) in collaboration with Indian Science Congress Association, Amravati Chapter, 23 March 2021.

Dr. Atul Kumar Srivastava

- Assessment of near-surface air pollutants over the Indo-Gangetic Basin: Inference to the lockdown caused by COVID-19 pandemic, International Webinar on Air Quality, Climate Change and the environment effect referring to the Pandemic COVID-19 Lockdown, HNB Garhwal University, Srinagar, Uttarakhand, 2-3 May 2020 (on 03 May 2020).
- Invited Talk for an on-line educational program, Geo-Varta, conducted by the Department of Geophysics, Banaras Hindu University, Varanasi, 07 July 2020.

Dr. H.N. Singh

- Weakening Asia-India monsoon on the face of global warming – A climate change research for science and society, 2nd International Conference (Virtual) on Science & Technology for Society, Manipur Technical University, Imphal & KKT, Imphal, 9-11 September 2020.

Mr. Bhupendra Bahadur Singh

- Statistical tools in scientific research, Online Workshop on Holistic approach towards Research in Pandemic, Department of Genetics, Maharshi Dayanand University, Rohtak and SHoDH Haryana, 1 July 2020.

Dr. Rupa Kumar Kolli

- Climate Services, Andhra University National Webinar Series on 'Recent Developments and Challenges in Weather and Climate – Indian Perspective', 11 August 2020.
- CSIS Implementation: Recent Developments, North Eurasian Climate Outlook Forum (NEACOF) coordinated by Russian Federation, 17 November 2020.
- Keynote lecture on 'Climate Change over South Asia: A Few Glimpses into the Pioneering work of Dr. G.B. Pant', National Webinar on An Overview of Climate Change over South Asia: Observational and Modeling Perspective, ARIES, Nainital 9 December 2020.
- G.B. Pant Memorial Lecture on 'Understanding Climate and Climate Change over the Himalayas: Dr. G.B. Pant's Legacy', TROPMET-2020, 15 December 2020.
- Enabling S2S Prediction Applications: WMO Climate Services Information System Operations, IITM/WWRP/WCRP Virtual International Conference on Future directions of Sub-seasonal to Seasonal Prediction over South Asia', IITM, Pune, 29-31 March 2021 (on 31 March 2021).

15.7. Webinars under IUKWC Webinar Series 2020

Dr. Akanksha Singh Kachhawaha, Gujarat Forensic Sciences University

- Occurrence of pharmaceuticals and personal care products in the aqueous environment and a comparative estimation of pharmaceutical contamination in India and the United Kingdom, 25 May 2020.

Dr. Chadra Rupa Rajulapathi, Centre for Hydrology, University of Saskatchewan, Canada

- The latest phase of global climate models for end user-how confident are we in using them for risk analysis and decision support, 11 June 2020.

Dr. Rajendra Pandey, National Institute of Hydrology, India & **Dr. Simon Parry** and **Mr Thomas Chitson**, UK Centre for Ecology & Hydrology

- Developing an interactive web-application to aid drought decision making in Maharashtra State, 25 June 2020.

Prof. Ramkar Jha, National Institute of Technology, Patna

- Understanding River System and Pollution Management: A case study of Water Quality of the Ganga River around Patna due to Lockdown, a natural remedy?, 9 July 2020.

Dr. Andrea Momblanch Cranfield Water Science Institute, Cranfield University, UK & **Dr. Sumit Sen,** Indian Institute of Technology, Roorkee,

- Informing catchment management decisions based on ecosystem services modelling in the Himalayas, 23 July 2020.

Dr. David Jenkins, University of Plymouth, UK, & **Dr. Shivaraju Puttaiah**, JSS Academy of Higher Education& Research (JSSAHER)

- Sustainable provision and access to drinking and irrigation water in rural communities, even during times of pandemic – such as with Covid-19, and the effect of lockdown, 6 August 2020.

Dr. Ajay Bhave, Newcastle University, UK, & **Prof. Suraje Dssai,** University of Leeds, UK

- Water Resource Planning Under Future Climate & Socioeconomic Uncertainty in the Cauvery River Basin in Karnataka, India , 19 August 2020.

Dr. Priyanka Jamwal, Ashoka Trust for Research in Ecology and the Environment (ATREE), India, & **Prof. Laurence Carvalho**, UK Centre for Ecology & Hydrology

- Approaches Towards Restoration of Urban Lakes: A case study from Bangalore, India, 16 September 2020.

Dr. Shubha Sathyendranath, Plymouth Marine Laboratory

- Threats to Human Health from Water-Associated Diseases: How Can Remote Sensing Help?, 02 September 2020.

15.8. MoES Webinar Series on 'Earth Sciences Popular Lectures'

Dr. M.A. Atmanand, Director, NIOT, Chennai

- Oceans - the give and take, 08 May 2020 (https://youtu.be/zxu176d2x2Y).

Prof. (Dr.) Gufran Beig, Scientist-G, IITM, Pune

- Air Pollution and Covid-19, 12 May 2020 (http://youtu.be/9AtLnKdyBF8).

Dr. S.C. Shenoi, Director, INCOIS, Hyderabad

- Tsunami - Basics and Warning System, 14 May 2020 (youtu.be/J5X61CbTd-g).

Dr. R. Venkatesan, Head, OOS Group, NIOT, Chennai

- Sustaining the Ocean Observations, 19 May 2020 (youtu.be/j2v_FcVd86Q).

Prof. Ravi S. Nanjundiah, Director, IITM, Pune

- Basics of Monsoon, 21 May 2020 (https://youtu.be/NlYRiVz8qA0).

Dr. G.A. Ramadass, Scientist-G &Head, Deep Sea Technologies Group, NIOT, Chennai

- Technology Development for the exploration and harvesting of deep ocean minerals, 26 May 2020 (https://youtu.be/ZERaHzHatNk).

Dr. Thamban Meloth, Scientist-F & Group Director (Polar Sciences), NCPOR, Goa

- Himalayan glaciers in a changing climate, 28 May 2020 (https://youtu.be/oI5kqI2CdLc).

Dr. Rahul Mohan, Scientist-F and Group Director, International Cooperation and Outreach, NCPOR, Goa

- Antarctica- Past and Present, 02 June 2020 (https://youtu.be/t5ZnAQNPL3E).

Dr. G. Pandithurai, Scientist-F and Project Director, PDTC, IITM, Pune

- Cloud Physics: How Clouds Form, 04 June 2020 (https://youtu.be/sfZAIKEnzdM).

SEMINARS

Dr. M.V. Ramana Murthy, Director, NCCR, Chennai; Director in-Charge, CMLRE, Kochi, and Project Director, NIOT, Chennai

- Enhancing Resilience to Erosion and Flooding in Coastal Areas, 09 June 2020 (https://youtu.be/DS4BEjkZ9vM).

Dr. Somenath Dutta, Scientist-F, IMD, Pune

- Basics of Weather Forecasting Including Observation, 11 June 2020 (https://youtu.be/S5LXq2j48kk).

Dr. Mrutyunjay Mohapatra, Director General of Meteorology, IMD, New Delhi

- Tropical Cyclone-Basics Dynamics and Prediction, 16 June 2020 (https://youtu.be/Rfk1GyQW2nE).

Dr. V. Nandakumar, Director, NCESS, Thiruvananthapuram

- Geoscience-Basics, 18 June 2020 (https://youtu.be/N6jexqtX2Ls).

Dr. C. Gnanaseelan, Scientist-F & Project Director (Short Term Climate Variability & Prediction), IITM, Pune

- Monsoon Variability, Teleconnection and Prediction, 23 June 2020 (https://youtu.be/vYItvR4PfMs).

Dr. Thara Prabhakaran, Scientist-F and Project Director, PDTC, IITM, Pune

- Physics of Precipitation, How rain occurs, 25 June 2020 (https://youtu.be/8Ua4B0xMJuQ).

Dr. Soma Sen Roy, Scientist-F, IMD, New Delhi

- Thunderstorms, Dust Storms and Lightning, 30 June 2020 (https://youtu.be/Oc2iGnUpDrI).

Dr. D.S. Pai, Scientist-F & Head, Climate Research & Services, IMD, Pune

- Climate Services for Society, 02 July 2020 (https://youtu.be/XIXbUJNErnE).

Dr. T.M. Balakrishnan Nair, Director (I/c), INCOIS, Hyderabad

- Ocean Information Services to Society and Industry, 07 July 2020 (https://youtu.be/BiUweOT6d2Q).

Dr. Purnima Jalihal, Scientist-G & Head Energy and Fresh Water, NIOT, Chennai

- Ocean Thermal Desalination - A Success Story, 09 July 2020 (https://youtu.be/BZWB7FwWqek).

Dr. D.S. Suresh Babu, Scientist-F, NCESS, MoES, Thiruvananthapuram

- Ground Water Science and Societal implications, 14 July 2020 (https://youtu.be/HrtdKWwY_1w).

Dr. M. Ravichandran, Director, NCPOR, Goa

- Indian Arctic Program, 21 July 2020 (https://youtu.be/KtOvYM7DcZQ).

Dr. G.V.M. Gupta, Scientist-F, CMLRE, Kochi

- Marine Ecosystems and Living Resources in India, 23 July 2020 (https://youtu.be/WRTJuaUcUZs).

Dr. Abhijit Sarkar, Scientist-E, NCMRWF, Noida

- Basics of Numerical Weather Prediction and Data Assimilation, 28 July 2020 (https://youtu.be/IqAjt0hG3rw).

Dr A.K. Sahai, Scientist-G & Project Director, Monsoon Mission, IITM, Pune

- Floods and Droughts: Basic Science and Predictions, 30 July 2020 (https://youtu.be/pZPbTmdo4LQ).

Dr. Kamaljit Ray, Advisor/Scientist-G, MoES, New Delhi

- 50 Years of Agro Advisory Services of IMD: In Support of Farmers, 04 August 2020 (https://youtu.be/UfEz-ErmEvg).

Dr. A.P. Singh, Scientist-E, National Centre for Seismology, New Delhi

- Understanding the basic concept of Seismology, Awareness regarding the techniques and Institutional Mechanism setup for monitoring of Seismic Activities of the Country, 06 August 2020 (https://youtu.be/_ePDV0n5XqY).

Dr. Supriyo Chakraborty, Scientist-F, IITM, Pune

- Paleoclimatic study of the Indian summer monsoon variability, 11 August 2020 (https://youtu.be/mVCaIhZzSDg).

Prof. Ashok Sahni, Emeritus Professor, Panjab University, Chandigarh

- Modern Indian Biodiversity: The Geological Past, 18 August 2020 (https://youtu.be/jLGqj0Ordoc).

Dr. V.V.S.S. Sarma, Senior Principal Scientist and Professor, CSIR-NIO, Regional Centre, Vishakhapattnam

- Human impact on modification of biogeochemical processes in the seas around India, 20 August 2020 (https://youtu.be/zbgHIL42pJA).

Prof. N.V. Chalapathi Rao, Professor, Department of Geology, Institute of Science, Banaras Hindu University, Varanasi

- Kimberlites, related rocks, and diamonds: Mysteries of the Earth's Mantle, 25 August 2020 (https://youtu.be/eoAkM2g6bko).

Dr. M. Ravichandran, Director, NCPOR, Goa

- Ocean observations by India: a brief history, present status and future directions, 27 August 2020 (https://youtu.be/tenOdC2FD6g).

Dr. S. Suresh Babu, Head, Aerosols Trace Gases and Radiative Forcing Branch, Space Physics Laboratory, VSSC, ISRO, Thiruvananthapuram

- Aerosol Radiative Forcing over India, 01 September 2020.

Dr. Lidita Khandeparker, Principal Scientist, Biological Oceanography Division, CSIR-NIO, Goa

- Marine Microbial Diversity: Implications for population connectivity and ecosystem functioning, 03 September 2020.

Dr. Indra Sekhar Sen, Assistant Professor, IIT, Kanpur

- Surface Impurities in The Himalayan Glacier: Its sources, pathways, and spatial variation, 08 September 2020.

Dr. M.A. Atmanand, Director, NIOT Chennai

- Growth of Ocean Technology in India, 10 September 2020.

Dr. Arvind Singh, Associate Professor, PRL, Ahmedabad

- Nitrogen Cycling in the Northern Indian Ocean, 15 September 2020.

Dr. John P. George, Dr. V. S. Prasad and **Mr. T. Arulalan,** Scientists at NCMRWF, Noida

- IMDAA Regional Reanalysis, NGFS Global Reanalysis and Reanalysis Data Services at NCMRWF, 15 October 2020 (https://youtu.be/yWWrqyMwguY).

Dr. Jothiram Vivekanandan, Senior Scientist, Earth Observing Laboratory, NCAR, USA

- A Technique For Estimating Liquid Droplet Diameter & Liquid Water Content in Stratocumulus Clouds Using Radar & Lidar Measurements, 24 November 2020.

Chapter 16
Deputation Abroad

Ms. Chaitri Roy

- Selected for the Fulbright-Kalam Climate Fellowship for the 2020-2021 academic year to undertake research in Chemistry, Colorado State University - Graduate School, Fort Collins, USA, 04 January to 03 October 2021.

Mr. Manmeet Singh

- As a Visiting Student Researcher under the Fulbright-Kalam Climate Fellowship for doctoral Research 2020-2021 Programme, Austin, Texas, USA and National Centre for Atmospheric Research, Boulder, USA, 01 February to 31 October 2021.

Chapter 17

Regular Staff (as on 31 March 2021)

Research Category
Director
Prof. R.S. Nanjundiah
Scientist-G
Dr. R. Krishnan
Dr. Gufran Beig
Dr. A.K. Sahai
Dr. A. Suryachandra Rao
Dr. C. Gnanaseelan
Scientist-F
Dr. S.D. Pawar
Dr. Thara Prabhakaran
Dr. S. Chakraborty
Dr. G. Pandithurai
Dr. A.A. Kulkarni
Dr. Kaushar Ali
Dr. Anupam Hazra
Dr. B.S. Murthy
Dr. Sanjay J.
Dr. P.D.Safai
Mr. V. Gopalkrishnan
Dr. Suresh Tiwari
Dr. Suvarna S. Fadnavis
Dr. P. Mukhopadhyay
Dr.Vinu Valsala
Dr. Ramesh Vellore
Dr. Subodh Kumar Saha
Scientist-E
Mr. S. Mahapatra
Dr. H. S. Chaudhari
Dr. Devendraa Siingh
Dr. Padma Kumari
Mr. P. Murugvel
Mr. S.M.D. Jeelani (Comp. Engg.)
Dr. Anoop Mahajan
Dr. Shivsai Dixit
Dr. M.N.Patil
Mr. K.K. Dani
Dr. Sachin D. Ghude
Dr. Milind Mujumdar
Dr. G.S. Meena
Mrs. Shompa Das
Dr. S.G. Narkhedkar
Dr. Susmitha Joseph
Dr. Sreenivas Pentakota
Dr. K.M.C. Reddy
Dr. Swapna P.
Dr. Roxy Mathew Koll
Dr. Samir Pokhrel
Dr. A.B. Parekh
Dr. Bipin Kumar
Dr. A.A. Deo
Dr. Hamza Varikoden
Dr. S.M. Deshpande
Dr. Preethi Bhaskar
Dr. Ramesh K. Yadav
Dr. K. Chakravarty
Dr. Y.K. Tiwari
Dr. Saikat Sengupta
Dr.Subrata Kumar Das
Dr. Jasti Sriranga Chowdhary
Dr. Prasanth A. Pillai
Dr. Naveen Gandhi
Dr. Rajib Chattopadhyay.
Dr. Abhilash S. Panicker
Mr. Mahesh Dharua (Mech. Engg.)
Dr. Phani Murali Krishna
Dr. Sabin T.P
Dr. Amita Ajay Prabhu
Mr. Prem Singh
Dr. Latha R.
Dr. Deen Mani Lal
Mr. R.M.Bankar (Mech. Engg.)
Mr. A.K.Saxena (Civil Engg.)
Dr. M.S. Deshpande
Dr. K.P. Sooraj
Dr. Mahen Konwar
Mr. Siddharth Kumar
Mr. Libin T.R.
Scientist-D
Dr. S.K. Patwardhan
Dr. N.R. Deshpande
Dr. T. Dharmaraj
Dr. Y. Jaya Rao

REGULAR STAFF

Dr. S.K. Mandke
Mr. S. De
Dr. P.R.C. Reddy
Mr. N.K. Agarwal
Mr. D.K. Trivedi
Mr. Abhay S.D. Rajput
Mr. Mata Mahakur
Mrs. M.N. Kulkarni
Mrs. R.V. Bhalvankar
Mr. Jnanesh S.P (Electrical Engg.)
Dr. A.K. Srivastava
Dr. M.I.R. Tinmaker
Mr. S.M. Sonbawne
Dr. H.N. Singh
Mrs. Anika Arora
Dr. Ayantika Dey Choudhury
Mr. Somaru Ram
Mr. Bhupendra Bahadur Singh
Mr. Balaji B.
Mrs. Mercy Varghese
Dr. Leena P.P.
Mr. S.K. Saha
Mr. Subharthi Chowdhuri
Mr. Prajeesh A. G.
Ms. Latika N.
Dr. Appala Ramu Dandi
Mr. Pottapinjara Vijay
Mr. Malay Ganai
Mr. Sudarsan Bera
Mr. Vivek Singh
Mr. Sandeep Narayanasetti
Mr. Maheswar Pradhan
Mr. Ankur Srivastava
Mr. Mriganka Sekhar Biswas
Scientist-C
Mrs. Sompriti Deb Roy
Mrs. Renu Subrata Das
Mr. Tanmoy Goswami
Mrs. Archana Rai
Ms. Snehlata Tirkey
Ms. Rashmi Arun Kakatkar
Mr. Raju Mandal
Mr. Avijit Dey
Ms. Chaitri Roy

Mrs. Shikha Singh
Mr. Sahadat Sarkar
Mrs. Shilpa Malviya
Mrs. Deepa J.S.
Ms. Aditi Modi
Mr. Manmeet Singh
Mrs. Smrati Gupta
Mr. Subrata Mukherjee
Mr. Pramit Kumar Deb Burman
Mr. Sujit Maji
Mr. Ambuj Kumar Jha
Mrs. Sayanti Bardhan
Mr. Srinivasu Upparapalli
Scientific Support Staff Category
Scientific Officer Grade-II
Mrs. S.U. Athale
Mrs. S.S. Naik
Mrs. D.W. Ganer
Mr.V.R. Mali
Mrs. S.R. Inamdar
Mr. V.H. Sasane
Scientific Officer Grade-I
Mrs. S.B. Patankar
Scientific Assistant Grade-C
Mr. A.R. Dhakate
Mr.R.S.K. Singh
Junior Scientific Officer
Dr. Deewan Singh Bisht
Scientific Assistant Grade-B
Mr.V. Vasudevan
Mr. R.T. Waghmare
Mr. K.D. Salunke
Scientific Assistant Grade-A
Mrs. P.J. Padwal
Technical Support Staff Category
Technician Grade-F
Mr. H.K. Trimbake
Mr. S.M. Thorat
Technician Grade-E
Vacant
Technician Grade-C
Mr. S.P. Hasnale

Administrative Staff Category
Administrative Officer
Mr. Ajit Prasad P.
Accounts Officer
Vacant
Hindi Officer
Dr. Omkar Nath Shukla
Deputy Manager
Mrs. Y.V. Kad
Mrs. R. S. Salunke
Ms. M.M. Lakra
Mrs. R.S. Ovhal
Assistant Manager
Mr. Y.S. Belgude
Mrs. Sheetal Deshmukh
Mr. M.V. Kale
Mrs. S.S. Kharbanda
Mrs. Y.J. Pawar
Mrs. A.S. Bhandari
Junior Translator
Mrs. Deepak Pandey
Senior Executive
Mrs. B.N. Naik
Mr. Niraj Kumar Jha
Mr. I.A. Pathan
Mr. D. E. Shinde
Mrs. S.H. Otari
Mr. S.S. Kulkarni
Mr. R.P. Dhanak
Mrs. Kavita Bharati
Mr. S.B. Ghoman
Mr. S.B. Gaikwad
Mr. Shafi S. Sayyed

Junior Executive
Mrs. M. V. Deshpande
Mr. B.T. Pawar
Mr. G.R. Handrale
Upper Division Clerk
Mr. Prabhudatta Biswal
Mr. Bhausaheb Kolhe
Mr. Kunal Yemul
Mr. Swaraj Kulkarni
Mrs. Jyoti Waghole
Coordinating Staff
Coordinator Grade - V
Ms. S.R. Kamble
Mr. K.D. Barne
Mrs. S.P. Iyer
Coordinator Grade-IV
Coordinator Grade- III
Mr. R.D. Nair
Mr. R.K. Nandanwar
Multi-Tasking Staff Category
Mr. V.V.Bamble
Mr. S.V.Raut
Mr. P.P.Vyawahare
Mr. D. D. Takawale
Mr. G. E. Dhongade
Mr. Rakesh Bhandari
Mr. T.L. Mundhe
Mrs. K.Y.Chavan
Mr. M.S.Waghela
Mr. I.R. Mhetre

* This list is not as per the seniority.

Chapter 18
Publications

Peer-reviewed Research Publications

1. **Acharja P., Ali K., Trivedi D.K., Safai P.D., Ghude S., Prabhakaran Thara**, Rajeevan M., Characterization of atmospheric trace gases and water soluble inorganic chemical ions of PM1 and PM2.5 at Indira Gandhi International Airport, New Delhi during 2017-18 winter, **Science of the Total Environment**, 729:138800, August 2020, DOI:10.1016/j.scitotenv.2020.138800, 1-13 **(Impact Factor 5.589)**
2. Afreen S., **Victor N.J.**, Bashir G., **Chandra S.**, Ahmed N., **Siingh D.**, Singh R.P, First observation of atmospheric electric field at Kashmir valley North Western Himalayas, Srinagar (India), **Journal of Atmospheric and Solar Terrestrial Physics**, 211: 105481, December 2020, DOI:10.1016/j.jastp.2020.105481, 1-14 **(Impact Factor 1.790)**
3. **Agnihotri I.**, Punia M.P., Sharma J.R., Spatiotemporal Analysis of Maximum and Minimum Temperature within a Basin: A Case Study of West-Flowing River Basin of Kutch, Saurashtra and Marwar, India, **Journal of the Indian Society of Remote Sensing**, Online, March 2021, DOI: 10.1007/s12524-021-01340-7, 1-8 **(Impact Factor 0.997)**
4. **Anil Kumar V., Pandithurai G.**, Kulkarni G., **Hazra A., Patil S.S., Dudhambe S.D., Patil R.D.**, Chen J-P, Niranjan K., Atmospheric ice nuclei concentration measurements over a high altitude-station in the Western Ghats, India, **Atmospheric Research**, 235:104795, May 2020, DOI:10.1016/j.atmosres.2019.104795, 1-12 **(Impact Factor 4.114)**
5. **Anju M., Sreeush M.G, Valsala V.**, Smitha B.R., **Hamza F.**, Bharathi G., Naidu C.V., Understanding the role of nutrient limitation on plankton biomass over Arabian Sea via 1-D coupled biogeochemical model and Bio-Argo observations, **Journal of Geophysical Research: Oceans**, 125: e2019JC015502, June 2020, DOI:10.1029/2019JC015502, 1-28 **(Impact Factor 3.235)**
6. Ansari K., **Pandithurai G., Anil Kumar V.,** Role of droplet size classes on the cloud droplet spectral dispersion as observed over the Western Ghats, **Atmospheric Research**, 246: 105104, December 2020, DOI:10.1016/j.atmosres.2020.105104, 1-10 **(Impact Factor 4.114)**
7. Arushi P.V., Chakraborty A., **Nanjundiah R.S.**, Recent weakening in MJO-related convective activity over the equatorial Indian Ocean and Maritime Continent, **Theoretical and Applied Climatology**, 143, January 2021, DOI:10.1007/s00704-020-03423-w, 267-278 **(Impact Factor 2.882)**
8. **Aslam M.Y., Mukherjee S., Anil Kumar V., Patil R.D., Patil S.S., Dudhambe S.D., Saha Sanjay Kumar, Pandithurai G.**, Seasonal characteristics of boundary layer over a high-altitude rural site in Western India: implications on dispersal of particulate matter, **Environmental Science and Pollution Research**, Online, March 2021, https://doi.org/10.1007/s11356-021-13163-7, 1-12 **(Impact Factor 3.056)**
9. Aswini M.A., Kumar Ashwini, **Das S.K.**, Quantification of long-range transported aeolian dust towards the Indian peninsular region using satellite and ground-based data - A case study during a dust storm over the Arabian Sea, **Atmospheric Research**, 239:104910, July 2020, DOI:10.1016/j.atmosres.2020.104910, 1-11 **(Impact Factor 4.114)**
10. **Ayantika D.C., Krishnan R., Singh M., Swapna P., Sandeep N., Prajeesh A.G.**, Vellore R., Understanding the combined effects of global warming and anthropogenic aerosol forcing on the South Asian monsoon, **Climate Dynamics**, 56, March 2021, DOI:10.1007/s00382-020-05551-5, 1643–1662 **(Impact Factor 4.486)**
11. Baburaj P.P., **Abhilash S.**, Mohankumar K., **Sahai A.K.,** On the Epochal Variability in the

Frequency of Cyclones during the Pre-Onset and Onset Phases of the Monsoon over the North Indian Ocean, **Advances in Atmospheric Sciences**, 37, June 2020, DOI:10.1007/s00376-020-9070-5, 634–651 **(Impact Factor 1.140)**

12. Banerjee S., **Padmakumari B.**, Spatiotemporal variability and evolution of day and night winter fog over the Indo Gangetic Basin using INSAT-3D and comparison with surface visibility and aerosol optical depth, **Science of the Total Environment**, 745: 140962, November 2020, DOI:10.1016/j.scitotenv.2020.140962, 1-13 **(Impact Factor 5.589)**
13. Beal L.M., Vialard J., **Roxy M.K.**, … et al., A roadmap to IndOOS-2: Better observations of the rapidly-warming Indian Ocean, **Bulletin of the American Meteorological Society**, 101, November 2020, DOI:10.1175/BAMS-D-19-0209.1, E1891-E1913 **(Impact Factor 8.166)**
14. **Beig G., Bano S.,** Sahu S.K., **Anand V., Rathod A., Yadav R.,** Mangaraj P., **Murthy B.S.,** Singh S., **Latha R., Shinde R.**, COVID-19 and environmental -weather markers: Unfolding baseline levels and veracity of linkages in tropical India, **Environmental Research**, 191: 110121, December 2020, DOI:10.1016/j.envres.2020.110121 **(Impact Factor 5.715)**
15. **Beig G.**, Clearing smog's particulate problem, **Nature Geoscience**, 14, February 2021, DOI:10.1038/s41561-021-00687-3, 59–60 **(Impact Factor 13.566)**
16. **Beig G.,** George M.P., Sahu S.K., Rathod A., **Singh S., Dole S., Murthy B.S., Latha R., Tikle S., Shinde R.**, Towards baseline air pollution under COVID-19: implication for chronic health and policy research for Delhi, India, **Current Science**, 119, October 2020, DOI: 10.18520/cs/v119/17/1178-1184, 1178-1184 **(Impact Factor 0.756)**
17. **Beig G., Korhale N., Rathod A., Maji S.**, Sahu S.K., **Dole S., Latha R., Murthy B.S.**, On modelling growing menace of household emissions under COVID-19 in Indian metros, **Environmental Pollution**, 272:115993, March 2021, DOI:10.1016/j.envpol.2020.115993, 1-11 **(Impact Factor 6.792)**
18. **Beig G.**, Sahu S.K., **Rathod A., Tikle S.**, Singh V., Sandeepan B.S., Role of meteorological regime in mitigating biomass induced extreme air pollution events, **Urban Climate**, 35: 100756, January 2021, DOI:10.1016/j.uclim.2020.100756, 1-9 **(Impact Factor 3.834)**
19. **Bera S.**, Droplet spectral dispersion by lateral mixing process in continental deep cumulus clouds, **Journal of Atmospheric and Solar Terrestrial Physics**, 214: 105550, March 2021, DOI:10.1016/j.jastp.2021.105550, 1-9 **(Impact Factor 1.503)**
20. Bhat M.A., Romshoo S.A., **Beig G.**, Measurement and Modelling of Particulate Pollution over Kashmir Himalaya, India, **Water, Air, & Soil Pollution**, 232: 120, March 2021, DOI:10.1007/s11270-021-05062-x,1-22 **(Impact Factor 1.900)**
21. **Biswas M.S., Ayantika D.C.**, Impact of COVID-19 control measures on trace gases (NO2, HCHO and SO2) and aerosols over India during pre-monsoon of 2020, **Aerosol and Air Quality Research**, 21: 200306 Sp. Issue, January 2021, DOI:10.4209/aaqr.2020.06.0306, 1-20 **(Impact Factor 3.337)**
22. **Biswas M.S., Pandithurai G., Aslam M.Y., Patil R.D., Anilkumar V., Dudhambe S.D.**, Lerot C., De Smedt I., Van Roozendael M., **Mahajan A.S.**, Effect of Boundary Layer Evolution on Nitrogen Dioxide (NO2) and Formaldehyde (HCHO) Concentrations at a High-altitude Observatory in Western India, **Aerosol and Air Quality Research**, 21: 200193, March 2021, DOI:10.4209/aaqr.2020.05.0193, 1-21 **(Impact Factor 3.337)**
23. Budhavant K.B., **Gawhane R.D., Rao P.S.P.**, Nair H.R.C.R., **Safai P.D.,** Physico-chemical characterization and sink mechanism of atmospheric aerosols over South-west India, **Journal of Atmospheric Chemistry**, 77, June

PUBLICATIONS

2020, DOI:10.1007/s10874-020-09400-x, 17-33 **(Impact Factor 1.783)**

24. Carpenter L.J., Chance R.J., Sherwen T., Adams T.J., Ball S.M., Evans M.J., Hepach H., Hollis L.D.J., Hughes C., Jickells T.D., **Mahajan A.**, ... et al., Marine iodine emissions in a changing world, **Proceedings of The Royal Society A-Mathematical Physical and Engineering Sciences**, 477: 20200824, March 2021, DOI:10.1098/rspa.2020.0824, 1-17 **(Impact Factor 2.741)**
25. **Chakraborty S.,** Potential of reef building corals to study the past Indian monsoon rainfall variability, **Current Science**, 119, July 2020, DOI:10.18520/cs/v119/i2/273-281, 273-281 **(Impact Factor 0.756)**
26. **Chakravarty K.**, Bhangale R., Das S., **Yadav P.**, Kannan B.A.M., **Pandithurai G.**, Unraveling the characteristics of precipitation microphysics in summer and winter monsoon over Mumbai and Chennai – the two urban-coastal cities of Indian sub-continent, **Atmospheric Research**, 249: 105313, January 2021, DOI:10.1016/j.atmosres.2020.105313, 1-14 **(Impact Factor 4.676)**
27. **Chakravarty K., Murugavel P.,** Christy A.A., Singh V., **Pandithurai G**., Impact of electrified and non-electrified clouds on the inter-seasonal characteristics of surface-based precipitation, **Journal of Earth System Science**, 129:169, August 2020, DOI:10.1007/s12040-020-01432-x, 1-11 **(Impact Factor 1.104)**
28. **Chaluvadi R., Varikoden H., Mujumdar M., Ingle S.T.**, Variability of West Pacific subtropical high and its potential importance to the Indian summer monsoon rainfall, **International Journal of Climatology**, Online, February 2021, DOI: 10.1002/joc.7057, 1-14 **(Impact Factor 3.928)**
29. Chance R., Liselotte T., Sarkar A., Sinha A.K., **Mahajan A.S.,** Chacko R., Sabu P., Roy R., Jickells T.D., Stevens D., Wadley M., Carpenter L.C., Surface Inorganic Iodine Speciation in the Indian and Southern Oceans From 12°N to 70°S, **Frontiers in Marine Science**, 7: 621, August 2020, DOI:10.3389/fmars.2020.00621, 1-16 **(Impact Factor 3.086)**
30. **Chandra S., Siingh D., Victor N.J. Kamra A.K.**, Lightning activity over South/Southeast Asia: Modulation by thermodynamics of lower atmosphere, **Atmospheric Research**, 250: 105378, March 2021, DOI:10.1016/j.atmosres.2020.105378, 1-10 **(Impact Factor 4.676)**
31. Chen Y., **Beig G.**, Archer-Nicholls S., Drysdale W., Acton,W.J.F., Lowe D., Nelson B., Lee J., ... et al., Avoiding high ozone pollution in Delhi, India, **Faraday Discussions**, 226, March 2021, DOI: 10.1039/d0fd00079e, 502-514 **(Impact Factor 3.797)**
32. **Chowdhuri S.,** Kalmár-Nagy T., Banerjee T., Persistence analysis of velocity and temperature fluctuations in convective surface layer turbulence, **Physics of Fluids**, 32: 076601, July 2020, DOI:10.1063/5.0013911, 1-17 **(Impact Factor 2.627)**
33. **Chowdhuri S., Prabhakaran Thara,** Banerjee T., Persistence behavior of heat and momentum fluxes in convective surface layer turbulence, **Physics of Fluids**, 32: 115107, November 2020, DOI:10.1063/5.0027168, 1-16 **(Impact Factor 2.627)**
34. **Chowdhuri S., Siddharth Kumar,** Banerjee T., Revisiting the role of intermittent heat transport towards Reynolds stress anisotropy in convective turbulence, **Journal of Fluid Mechanics**, 899: A26, September 2020, DOI:10.1017/jfm.2020.471, 1-41 **(Impact Factor 3.137)**
35. **Chowdhuri S., Todekar K., Murugavel P.**, Karipot A., **Prabhakaran Thara**, Unravelling the turbulent structures of temperature variations during a gust front event: a case study, **Environmental Fluid Mechanics**, 21, February 2021, DOI:10.1007/s10652-020-09769-z, 263-281 **(Impact Factor 1.512)**
36. Collins M., Barreiro M., Frölicher T., Kang S.M., Ashok K., **Roxy M.K.,** Singh D., Tedeschi R.G.,

Wang G., Wilcox L., Wu B., Frontiers in climate predictions and projections, **Frontiers in Climate**, 2: 571245, October 2020, DOI:10.3389/fclim.2020.571245, 1-3 **(Impact Factor 0.000)**

37. **Dandi A.R., Pillai P.A., Chowdary J.S., Srinivas D., Srinivas G., Koteswara Rao K.**, Nageswararao M.M., Inter-annual variability and skill of tropical rainfall and SST in APCC seasonal forecast models, **Climate Dynamics**, 56, January 2021, DOI:10.1007/s00382-020-05487-w, 439-456 **(Impact Factor 4.486)**
38. Das B.K., **Anandh T.S.**, Kuttippurath J., Chakraborty A., Influence of river discharge and tides on the summertime discontinuity of western boundary current in the Bay of Bengal, **Journal of Physical Oceanography**, 50, December 2020, DOI:10.1175/JPO-D-20-0133.1, 3513-3528 **(Impact Factor 3.389)**
39. **Das Subrata Kumar, Murali Krishna U.V., Kolte Y.K., Deshpande S.M., Pandithurai G.,** Assessment of ground-based X-Band Radar Reflectivity: attenuation correction and its comparison with space-borne radars over the Western Ghats, India, **Earth and Space Sciences**, 7: e2019EA000861, November 2020, DOI:10.1029/2019EA000861, 1-15 **(Impact Factor 2.152)**
40. **Das Subrata Kumar, Hazra A., Deshpande S.M., Murali Krishna U.V., Kolte Y.K.**, Investigation of cloud microphysical features during the passage of a tropical mesoscale convective system: Numerical simulations and X-Band radar observations, **Pure and Applied Geophysics**, 178, January 2021, DOI:10.1007/s00024-020-02622-w, 185–204 **(Impact Factor 1.586)**
41. **Das Subrata Kumar**, Joshi P.P., Kokitkar R.S., **Krishna U.V.M.**, Tanti H.A., Phadake A.C., Detection and validation of cloud top height from scanning ka-band radar measurements using digital image processing technique, **IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing**, 14,January 2021, DOI:10.1109/JSTARS.2020.3042868, 1848-1856 **(Impact Factor 3.827)**
42. **Das Subrata Kumar**, Thatte T., Uma K.N., **Murali Krishna U.V.**, **Saha Sanjoy Kumar**, Characteristics of temperature inversion from radiosonde measurements in the Western Ghats region , **Atmospheric Research**, 250: 105391, March 2021, DOI:10.1016/j.atmosres.2020.105391, 1-11 **(Impact Factor 4.676)**
43. **Dasgupta P., Metya A.,** Naidu C.V., **Singh M., Roxy M.K.**, Exploring the long-term changes in the Madden Julian Oscillation using machine learning, **Scientific Reports**, 10: 18567, October 2020, DOI:10.1038/s41598-020-75508-5, 1-13 **(Impact Factor 4.011)**
44. **De S., Sahai A.K.,** Was the earliest documented account of tornado dynamics published by an Indian scientist in an Indian journal, **Weather**, 75, April 2020, DOI:10.1002/wea.3485, 120-123 **(Impact Factor 1.143)**
45. **Deepa J.S., Gnanaseelan C., Parekh A.**, The sea level variability and its projections over the Indo-Pacifc Ocean in CMIP5 models, **Climate Dynamics**, Online, February 2021, DOI:10.1007/s00382-021-05701-3, 1-21 **(Impact Factor 4.486)**
46. **Deepa J.S., Gnanaseelan C.**, The decadal sea level variability observed in the Indian Ocean tide gauge records and its association with global climate modes, **Global and Planetary Change**, 198: 103427, March 2021, DOI:10.1016/j.gloplacha.2021.103427, 1-13 **(Impact Factor 4.448)**
47. **Deo A.A., Ganer D.W.**, Decadal changes of cyclone tracks in the Bay of Bengal, **Mausam**, 72, January 2021, 199-206 **(Impact Factor 0.370)**
48. **Deshpande Medha, Kanase R., Krishna R.P.M., Tirkey S., Mukhopadhyay P.**, Prasad V.S., Johny C.J., Durai V.R., Devi S., Mohapatra M., Global Ensemble Forecast System (GEFS T1534) evaluation for tropical cyclone prediction over

PUBLICATIONS

the North Indian Ocean, **Mausam**, 72, January 2021, 119-128 **(Impact Factor 0.370)**

49. **Dey Avijit, Chattopadhyay R., Sahai S.K., Mandal R., Joseph S., Phani M.K.,** Pattanaik D.R., MJO Prediction Skill Using IITM Extended Range Prediction System and Comparison with ECMWF S2S, **Pure and Applied Geophysics**, 177, October 2020, DOI: 10.1007/s00024-020-02487-z, 5067–5079 **(Impact Factor 1.466)**

50. **Dhara C.,** Constraining global changes in temperature andprecipitation from observable changesin surface radiative heating, **Geophysical Research Letters**, 47: e2020GL087576, May 2020, DOI:10.1029/2020GL087576, 1-8 **(Impact Factor 4.578)**

51. **Dixit S.A., Gupta A., Choudhary H.,** Singh A.K., **Prabhakaran Thara,** Asymptotic scaling of drag in flat-plate turbulent boundary layers, **Physics of Fluids**, 32:041702, April 2020, DOI:10.1063/5.0004464, 1-8 **(Impact Factor 2.627)**

52. **Dixit S.A., Gupta A., Choudhary H.**, Singh A.K., **Prabhakaran Thara**, A new universal model for friction factor in smooth pipes,, **Physics of Fluids**, 33: 035134, March 2021, DOI:10.1063/5.0041342, 1-13 **(Impact Factor 3.514)**

53. **Dutta U., Chaudhari H.S., Hazra A., Pokhrel S., Saha Subodh Kumar, Veeranjaneyulu C.,** Role of convective and microphysical processes on the simulation of monsoon intraseasonal oscillation, **Climate Dynamics**, 55, November 2020, DOI:10.1007/s00382-020-05387-z, 2377–2403 **(Impact Factor 4.048)**

54. **Fadnavis S.**, Müller R., Chakraborty T., **Sabin T.P.**, Laakso A., Rap A., Griessbach S., Vernier J.V., Tilmes S., The role of tropical volcanic eruptions in exacerbating Indian droughts , **Scientific Reports**, 11: 2714, February 2021, DOI:10.1038/s41598-021-81566-0, 1-13 **(Impact Factor 3.998)**

55. **Fadnavis S.**, Sioris C.E., Wagh N., **Chattopadhyay R.**, Tao M., Chavan P., Chakraborty T., A rising trend of double tropopauses over South Asia in a warming environment: implications for moistening of the lower stratosphere, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6677, E200-E215 **(Impact Factor 3.928)**

56. Francis P.A, Jithin A.K, Effy J.B., Chatterjee A., **Chakraborty K.,** Paul A., Balaji B., Shenoi S.S.C., Biswamoy P., Mukherjee A., **Singh P., … Rao Suryachandra A.,** et al., High-resolution Operational Ocean Forecast and reanalysis System for the Indian Ocean, **Bulletin of the American Meteorological Society**, 101, August 2020, DOI:10.1175/BAMS-D-19-0083.1, E1340–E1356 **(Impact Factor 8.166)**

57. **Ganai M., Tirkey S., Krishna R.P.M., Mukhopadhyay P.**, The impact of modified rate of precipitation conversion parameter in the convective parameterization scheme of operational weather forecast model (GFS T1534) over Indian summer monsoon region, **Atmospheric Research**, 248: 105185, January 2021, DOI:10.1016/j.atmosres.2020.105185, 1-16 **(Impact Factor 4.676)**

58. **Ganesh S.S., Abhilash S., Joseph S., Manpreet Kaur, Dey A., Mandal Raju., Phani R., Chattopadhyay R.,** Pattanaik D.R., **Sahai A.K.**, A review of the development and implementation of a tropical cyclone prediction system for North Indian Ocean in a multi-model ensemble framework, **Mausam**, 72, January 2021, 57-76 **(Impact Factor 0.370)**

59. **Ganesh S.S., Sahai A.K., Abhilash S., Joseph S., Kaur M., Phani R.**, An improved cyclogenesis potential and storm evolution parameter for North Indian Ocean, **Earth and Space Science**, 7: e2020EA001209, October 2020, DOI:10.1029/2020EA001209, 1-10 **(Impact Factor 2.152)**

60. Ganeshi N.G., **Mujumdar M., Krishnan R., Goswami M.,** Understanding the linkage between soil moisture variability and temperature extremes over the Indian region, **Journal of Hydrology**, 589: 125183, October

2020, DOI:10.1016/j.jhydrol.2020.125183, 1-16 **(Impact Factor 4.405)**

61. Gao M., Gao J., Zhu B., Kumar Rajesh, Lu X., Song S., Zhang Y., Ji B., Wang P., **Beig G.,** et al, Ozone pollution over China and India: seasonality and sources, **Atmospheric Chemistry and Physics**, 20, April 2020, DOI: 10.5194/acp-20-4399-2020, 4399-4414 **(Impact Factor 5.668)**
62. Gautam A.S., Dilwaliya N.K., Srivastava A., Kumar S., Bauddh K., **Siingh D.**, Shah M.A., Singh K., Gautam S., Temporary reduction in air pollution due to anthropogenic activity switch-off during COVID-19 lockdown in northern parts of India, **Environment, Development and Sustainability**, Online, September 2020, DOI:10.1007/s10668-020-00994-6, 1-24 **(Impact Factor 1.930)**
63. **Ghude S.D.**, Rajesh Kumar, **Jena C., Debnath S., Kulkarni R.G.**, Alessandrini S., Biswas M., Kulkrani S., **Pithani P., Kelkar S., Sajjan V., Chate D.M.**, Soni V.K., Singh S., **Nanjundiah R.S.**, Rajeevan M., Evaluation of PM2.5 forecast using chemical data assimilation in the WRF-Chem model: A novel initiative under the Ministry of Earth Sciences air quality early warning system for Delhi, **Current Science**, 118, June 2020, DOI:10.18520/cs/v118/i11/, 1-13 **(Impact Factor 0.756)**
64. Girishkumar M.S., Ashin K., McPhaden, M.J., **Balaji B.,** Praveenkumar B., Estimation of vertical heat diffusivity at the base of mixed layer in the Bay of Bengal, **Journal of Geophysical Research: Oceans**, 125, May 2020, DOI:10.1029/2019jc015402 **(Impact Factor 3.235)**
65. Gnanamoorthy P., Selvam V., **Deb Burman P.K.**, **Chakraborty S.,** Karipot A., Nagarajan R., Ramasubramanian R., Song Q., Zhang Y., Grace J., Seasonal variations of net ecosystem (CO2) exchange in the Indian tropical mangrove forest of Pichavaram, **Estuarine Coastal and Shelf Science**, 243: 106828, September 2020, DOI:10.1016/j.ecss.2020.106828, 1-16 **(Impact Factor 2.611)**
66. **Gopalakrishnan V., Pawar S.D., Domkawale M.A.**, Charging processes during the dissipation stage of thunderstorms, **Meteorology and Atmospheric Physics**, Online, September 2020, DOI:10.1007/s00703-020-00755-0, 1-12 **(Impact Factor 1.656)**
67. **Goswami T.,** Goswami B.B., **Krishna R.P.M., Mukhopadhyay P.,** Evaluation of SP-CAM and SP-CCSM in capturing the extremes of summer monsoon rainfall over Indian region, **Journal of Earth System Science**, 129:116, April 2020, DOI:10.1007/s12040-020-1381-5 **(Impact Factor 1.104)**
68. **Goswami T., Mukhopadhyay P., Ganai M., Krishna R.P.M., Mahakur M.,** Han J., How changing cloud water to rain conversion profile impacts on radiation and its linkage to a better Indian summer monsoon rainfall simulation, **Theoretical and Applied Climatology**, 141, August 2020, DOI:10.1007/s00704-020-03222-3, 947–958 **(Impact Factor 2.720)**
69. Grabowski W.W., **Thomas L.**, Cloud droplet diffusional growth in homogeneous isotropic turbulence: bin microphysics versus Lagrangian super-droplet simulations, **Atmospheric Chemistry and Physics**, 21, March 2021, DOI: 10.5194/acp-21-4059-2021, 4059–4077 **(Impact Factor 5.414)**
70. **Guha T.**, Mahata S., Bhattacharya S.K., **Singh B.B.**, Toyoda S., Yoshida N., Liang M.C., Stratospheric incursion as a source of enhancement of the isotopic ratios of atmospheric N_2O at Western Pacific, **Earth and Space Science**, 7: e2020EA001102, November 2020, DOI:10.1029/2020EA001102, 1-13 **(Impact Factor 2.152)**
71. **Gupta A., Choudhary H**, Singh A.K., **Prabhakaran Thara, Dixit S.A**, Scaling mean velocity in two-dimensional turbulent wall jets, **Journal of Fluid Mechanics**, 891: A11, May 2020, DOI:10.1017/jfm.2020.132, 1-33 **(Impact Factor 3.137)**

PUBLICATIONS

72. **Halder S., Parekh A., Chowdary J.S., Gnanaseelan C., Kulkarni Ashwini**, Assessment of CMIP6 models skill for tropical Indian Ocean sea surface temperature variability, **International Journal of Climatology**, 41, March 2021, DOI:10.1002/joc.6975, 1-21, 2568-2588 **(Impact Factor 3.928)**

73. **Hamza F., Valsala V., Mallissery A.**, George G., Climate impacts on the landings of Indian oil sardine over the south-eastern Arabian Sea, **Fish and Fisheries**, 22, January 2021, DOI:10.1111/faf.12513,175-193 **(Impact Factor 6.785)**

74. Hanumanthu S., Vogel B., Müller R., Brunamonti S., **Fadnavis S.**, Li D., Ölsner P., Naja M., **Singh B.B.**, Ravi Kumar K., **Sonbawne S.,** Jauhiainen H., Vömel H., Luo B., Jorge T., Wienhold F.G., Dirkson R., Peter T., Strong day-to-day variability of the Asian Tropopause Aerosol Layer (ATAL) in August 2016 at the Himalayan foothills, **Atmospheric Chemistry and Physics**, 20, November 2020, DOI:10.5194/acp-20-14273-202, 14273-14302 **(Impact Factor 5.668)**

75. **Hari K.B.R.R., Sreenivas P., Rao Suryachandra A., George G., Salunke K., Krishna P.M., Dandi A.R., Rao D.N.**, Impact of horizontal resolution on sea surface temperature bias and air–sea interactions over the tropical Indian Ocean in CFSv2 coupled model, **International Journal of Climatology**, 40, September 2020, DOI:10.1002/joc.6496, 4903-4921 **(Impact Factor 3.601)**

76. Hazra V., Pattnaik S., **De S.**, Vishwakarma V., Segregation of forecast errors in the planetary boundary layer parameterization over the state of Odisha and neighboring regions in India during summer monsoon season, **Pure and Applied Geophysics**, 178, February 2021, DOI:10.1007/s00024-020-02651-5, 583-601 **(Impact Factor 1.586)**

77. Hrudya P.H., **Varikoden H.**, Vishnu R., A review on the Indian summer monsoon rainfall, variability and its association with ENSO and IOD, **Meteorology and Atmospheric Physics**, 133, February 2021, DOI:10.1007/s00703-020-00734-5, 1-14 **(Impact Factor 2.204)**

78. Hrudya P.H., **Varikoden H.,** Vishnu R., Kuttippurath J., Changes in ENSO-monsoon relations from early to recent decades during onset, peak and withdrawal phases of Indian summer monsoon, **Climate Dynamics**, 55, September 2020, DOI:10.1007/s00382-020-05335-x, 1457–1471 **(Impact Factor 4.048)**

79. Hrudya P.P.V.H., **Varikoden H.**, Vishnu R.N., Changes in the relationship between Indian Ocean dipole and Indian summer monsoon rainfall in early and recent multidecadal epochs during different phases of monsoon, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6685, E305-E318 **(Impact Factor 3.928)**

80. **Hulswar S.**, Soni V.K., Sapate J.P., More R.S., **Mahajan A.S.,** 2020, Validation of satellite retrieved ozone profiles using in-situ ozonesonde observations over the Indian Antarctic station, Bharati, Polar Science, 25: 100547, DOI:10.1016/j.polar.2020.100547, 1-8 **(Impact Factor 1.389)**

81. **Inamdar S.,** Tinel L., Chance R., Carpenter L.J., Sabu P., Chacko R., Tripathy S.C., Kerkar A.U., Sinha A.K., Bhaskar P.V., Sarkar A., Roy R., Sherwen T.T., Cuevas C., Saiz-Lopez A., Ram K., **Mahajan A.S.**, Estimation of reactive inorganic iodine fluxes in the Indian and Southern Ocean marine boundary layer, **Atmospheric Chemistry and Physics**, 20, October 2020, DOI:10.5194/acp-20-12093-2020,12093-12114 **(Impact Factor 5.668)**

82. Jahfer S., Vinayachandran P.N., **Nanjundiah R.S.,** The role of Amazon river runoff on the multidecadal variability of the Atlantic ITCZ, **Environmental Research Letters**, 15: 054013, May 2020, DOI:10.1088/1748-9326/ab7c8a, 1-10 **(Impact Factor 6.192)**

83. Janapati J., Seela B.K., Lin P.-L., Wang P.K., Tseng C.-H., Reddy K.K, Hashiguchi H., Feng L., **Das S.K.,** Unnikrishnan C.K., Raindrop size

distribution characteristics of Indian and Pacific Ocean tropical cyclones observed at India and Taiwan sites, **Journal of Meteorological Society of Japan**, 98, April 2020, DOI:10.2151/jmsj.2020-015,299–317 **(Impact Factor 0.000)**

84. **Jayachandran V.N., Varghese M., Murugavel P., Todekar K.S., Bankar S.P., Malap N., Gurnule D., Safai P.D., Jaya Rao, Konwar M., Dixit S., Prabhakaran Thara,** Cloud condensation nuclei characteristics during the Indian summer monsoon over a rain-shadow region, **Atmospheric Chemistry and Physics**, 20, June 2020, DOI:10.5194/acp-20-7307-2020, 7307–7334 **(Impact Factor 5.668)**

85. **Jena C., Ghude S.D.**, Kumar Rajesh, **Debnath S.**, Govardhan G., Soni V.K., Kulkarni S.H., **Beig G., Nanjundiah R.S.**, Rajeevan M., Performance of high resolution (400 m) PM2.5 forecast over Delhi, **Scientific Reports**, 11: 4104, February 2021, DOI:10.1038/s41598-021-83467-8, 1-9 **(Impact Factor 3.998)**

86. Jorge T., Brunamonti S., Poltera Y., Wienhold F.G., Luo B.P., Oelsner P., Hanumanthu S., **Singh B.B.**, Körner S., Dirksen R., Naja M., **Fadnavis S.**, Peter T., Understanding balloon-borne frost point hygrometer measurements after contamination by mixed-phase clouds, **Atmospheric Measurement Techniques**, 14, January 2021, DOI:10.5194/amt-14-239-2021, 239-268 **(Impact Factor 3.668)**

87. Joseph J., Girishkumar M.S., **Varikoden H.**, Thangaprakash V.P., Shivaprasad S., Rama Rao E.P., Observed sub-daily variability of latent and sensible heat fluxes in the Bay of Bengal during the summer, **Climate Dynamics**, 56, February 2021, DOI:10.1007/s00382-020-05512-y, 917-934 **(Impact Factor 4.486)**

88. **Joshi M.K.**, Abid M.A., Kucharski F. , The Role of an Indian Ocean Heating Dipole in the ENSO Teleconnection to the North Atlantic European Region in Early Winter during the Twentieth Century in Reanalysis and CMIP5 Simulations , **Journal of Climate**, 34, February 2021, DOI: 10.1175/JCLI-D-20-0269.1, 1047-1060 **(Impact Factor 5.707)**

89. **Kakatkar R., Gnanaseelan C., Chowdary J.S.,** Asymmetry in the tropical Indian Ocean subsurface temperature variability, **Dynamics of Atmospheres and Oceans**, 90:101142, June 2020, DOI:10.1016/j.dynatmoce.2020.101142, 1-17 **(Impact Factor 1.405)**

90. **Kalita G.,** Kunchala R.K., **Fadnavis S.,** Kaskaoutis D.G., Long term variability of carbonaceous aerosols over Southeast Asia via reanalysis: Association with changes in vegetation cover and biomass burning, **Atmospheric Research**, 245: 105064, November 2020, DOI:10.1016/j.atmosres. 2020.105064, 1-14 **(Impact Factor 4.114)**

91. **Kalshetti M., Chattopadhyay R., Phani R., Joseph S., Sahai A.K.**, Climatological patterns of subseasonal eddy flux transfer based on the co-spectral analysis over the Indian region and the derivation of an index of eddy transfer for operational tracking, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6821, E1906-E1925 **(Impact Factor 3.928)**

92. **Kamra A.K.**, Ramesh Kumar P., Regional variability in lightning activity over South Asia, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6641, 625-646 **(Impact Factor 3.928)**

93. **Kanase R.D., Deshpande M.S., Krishna R.P.M., Mukhopadhyay P.,** Evaluation of convective parameterization schemes in simulation of tropical cyclones by Climate Forecast System model: Version 2, **Journal of Earth System Science**, 129: 168, August 2020, DOI:10.1007/ s12040-020-01433-w, 1-18 **(Impact Factor 1.104)**

94. Kant S., Panda J., Rao Prakash, Sarangi C., **Ghude S.D.**, Study of aerosol-cloud-precipitation-meteorology interaction during a distinct weather event over the Indian region using WRF-Chem, **Atmospheric Research**, 247:

PUBLICATIONS

105144, January 2021, DOI:10.1016/j.atmosres.2020.105144, 1-15 **(Impact Factor 4.676)**

95. **Karmakar A., Parekh A., Chowdary J.S., Gnanaseelan C.,** Sensitivity of subsurface processes of equatorial Pacific Ocean to the heat and momentum fluxes: A case study of 1997-98 El Niño, **Journal of Coastal Research**, SI- 89: Oceanic and Coastal Processes of the Indian Seas, June 2020, DOI:10.2112/SI89-005.1, 26-31 **(Impact Factor 1.053)**

96. **Kaur M., Krishna R.P.M., Joseph S., Dey Avijit, Mandal M., Chattopadhyay R., Sahai A.K., Mukhopadhyay P.,** Abhilash S., Dynamical downscaling of a multimodel ensemble prediction system: Application to tropical cyclones, **Atmospheric Science Letters**, 21: e971, August 2020, DOI:10.1002/asl.971, 1-11 **(Impact Factor 1.796)**

97. Kelkar S.M., **Kulkarni Ashwini, Koteswara Rao K.,** Impact of climate variability and change on crop production in Maharashtra, India, **Current Science**, 118, April 2020, DOI:10.18520/cs/v118/i8/1235-1245, 1235-1245 **(Impact Factor 0.756)**

98. Kolukula S.S., **Balaji B.**, Murty P.L.N., Kumar J.P., Rao E.P.R., Shenoi S.S.C.,Gaps filling in HF radar sea surface current data using complex empirical orthogonal functions, **Pure and Applied Geophysics**, 177, December 2020, DOI:10.1007/s00024-020-02613-x 5969–5992 **(Impact Factor 1.466)**

99. **Koteswara Rao K., Kulkarni Ashwini, Patwardhan S.K.,** Vinodh Kumar B., Lakshmi Kumar T.V., Future changes in precipitation extremes during northeast monsoon over south peninsular India, **Theoretical and Applied Climatology**, 142, October 2020, DOI:10.1007/s00704-020-03308-y, 205–217 **(Impact Factor 2.720)**

100. **Koteswara Rao K.,** Lakshmi Kumar T.V., **Kulkarni Ashwini,** Ho C-H., Mahendranath B., Desamsetti S., **Patwardhan S., Dandi A.R.,** Barbosa H., **Sabade S.**, Projections of heat stress and associated work performance over India in response to global warming, **Scientific Reports**, 10: 16675, October 2020, DOI:10.1038/s41598-020-73245-3,1-14 **(Impact Factor 4.011)**

101. **Krishna U.V.M., Das Subrata Kumar**, Sulochana E.G., **Bhowmik U., Deshpande S.M., Pandithurai G.**, Statistical characteristics of raindrop size distribution over the Western Ghats of India: wet versus dry spells of the Indian summer monsoon, **Atmospheric Chemistry and Physics**, 21, March 2021, DOI:10.5194/acp-21-4741-2021, 4741–4757 **(Impact Factor 5.414)**

102. **Kulkarni Ashwini,** Guhathakurta P., **Patwardhan S.,** Gadgil S., Meteorological sub-divisions of India: Assessment of coherence, homogeneity and recommended redelineation, **Mausam**, 71, October 2020, 585-604 **(Impact Factor 0.238)**

103. **Kumar Bipin, Chattopadhyay R., Singh M.**, Chaudhari N., Kodari K., Barve A., Deep learning-based downscaling of summer monsoon rainfall data over Indian region, **Theoretical and Applied Climatology**, 143, February 2021, DOI:10.1007/s00704-020-03489-6, 1145–1156 **(Impact Factor 2.882)**

104. **Kumar Bipin, Nanjudiah R.S., Bhowmik M.,** Prospective applications of artificial intelligence/machine learning techniques in earth sciences, **Current Science**, 119, August 2020, 424-425 **(Impact Factor 0.756)**

105. Kumar R., **Ghude S.D.,** Biswas M., **Jena C.,** Alessandrini S., **Debnath S.,** Kulkarni S., Sperati S., Soni V.K., **Nanjundiah R.S.,** Rajeevan M., Enhancing accuracy of air quality and temperature forecasts during paddy crop residue burning season in Delhi via chemical data assimilation, **Journal of Geophysical Research: Atmospheres**, 125: e2020JD033019, September 2020, DOI: 10.1029/2020JD033019, 1-16 **(Impact Factor 3.633)**

106. **Kumar Siddharth, Phani R., Mukhopadhyay P.**, Balaji C., An assessment of radiative flux

biases in the climate forecast system model CFSv2, **Climate Dynamics**, 56, March 2021, DOI:10.1007/s00382-020-05546-2,1541-1569 **(Impact Factor 4.486)**

107. Kumar Sunil, **Srivastava A.K.**, Pathak V., Characteristics of near-surface air pollutants at an urban station in the central Indo-Gangetic Basin, **Mausam**, 71, April 2020, 245-254 **(Impact Factor 0.238)**

108. Kumar Vinay, **Sunilkumar K.**, Sinha T., Proportional trends of continuous rainfall in Indian summer monsoon, **Remote Sensing**, 13: 398, January 2021, DOI:10.3390/rs13030398, 1-21 **(Impact Factor 4.509)**

109. Kumari Khushboo, **Deo A.A.**, Effect of Indian ocean cyclone on coastal region using remote sensing and GIS, **International Journal of Big Data Mining for Global Warming**, 2: 2050005, December 2020, DOI:10.1142/S2630534820500059, 1-17 **(Impact Factor 0.000)**

110. Kuttippurath J., Murasingh S., Stott P.A., Sarojini B.B., Jha M.K., Kumar P., Nair P.J., **Varikoden H.**, Raj S., Francis P.A., Pandey P.C., Observed rainfall changes in the past century (1901-2019) over the wettest place on earth, **Environmental Research Letters**, 16: 024018, January 2021, DOI:10.1088/1748-9326/abcf78, 1-15 **(Impact Factor 6.096)**

111. Kuttippurath J., Singh A., Dash S.P., Mallick N., Clerbaux C., Van Damme M., Clarisse L., Coheur P.-F., Raj S., Abbhishek K., **Varikoden H.**, Record high levels of atmospheric ammonia over India: Spatial and temporal analyses, **Science of the Total Environment**, 740: 139986, October 2020, DOI:10.1016/j.scitotenv.2020.139986, 1-11 **(Impact Factor 5.589)**

112. **Latha R., Murthy B.S., Sandeepan B.S.**, Bhanage V., **Rathod Aditi**, Tiwari Arpit, **Beig G.**, Singh S., Propagation of cloud base to higher levels during Covid-19-Lockdown, **Science of the Total Environment**, 759:144299, March 2021, DOI:10.1016/j.scitotenv.2020.144299, 1-9 **(Impact Factor 6.551)**

113. Li Q., Badia A., Fernandez R.P., **Mahajan A.S.**, López-Noreña A.I., Zhang Y., Wang S., Puliafito E., Cuevas C.A., Saiz-Lopez A., Chemical interactions between ship-originated air pollutants and ocean-emitted halogens, **Journal of Geophysical Research: Atmospheres**, 126: ee2020JD034175, February 2021, DOI:10.1029/2020JD034175, 1-17 **(Impact Factor 3.821)**

114. Lone A.M., Achyuthan H., **Chakraborty S., Metya Abirlal, Datye A.**, **Kripalani R.H.,** Fousiya A.A., Controls on the isotopic composition of daily precipitation characterized by dual moisture transport pathways at the monsoonal margin region of NorthWestern India, **Journal of Hydrology**, 588:125106, September 2020, DOI:10.1016/j.jhydrol.2020.125106, 1-10 **(Impact Factor 4.405)**

115. **Mahapatra S.,** Innovating Extension of "Almost Pythagorean Triples" in Prime Numbers and Possible Uses in Science, **International Journal of Science and Research**, 10, February 2021, DOI: 10.21275/SR21220172453, 1230-1234 **(Impact Factor 0.000)**

116. **Mahendra N., Chowdary J.S., Patekar D.**, Sunitha P., **Parekh A., Gnanaseelan C.**, Interdecadal modulation of interannual ENSO-Indian summer monsoon rainfall teleconnections in observations and CMIP6 models: Regional patterns, **International Journal of Climatology**, 41, March 2021, DOI:10.1002/joc.6973, 2528-2552 **(Impact Factor 3.928)**

117. **Mandke S.K., Pillai P.A., Sahai A.K.**, Simulation of monsoon intra-seasonal oscillations in Geophysical Fluid Dynamics Laboratory models from Atmospheric Model Intercomparison Project integrations of Coupled Model Intercomparison Project phase 5, **International Journal of Climatology**, 40, November 2020, DOI: 10.1002/joc.6536, 5574-5589 **(Impact Factor 3.601)**

118. Mathew T.A., **Malap N.**, Manoj M.G., **Jayarao Y., Todekar K.**, Rakesh V., Rebello R., Mohankumar

PUBLICATIONS

K., **Prabhakaran Thara**, Pre-monsoon convective events and thermodynamic features of southwest monsoon onset over Kerala, India – A case study, **Atmospheric Research**, 248: 105218, January 2021, DOI:10.1016/j.atmosres.2020.105218, 1-12 **(Impact Factor 4.676)**

119. McNaughton K.G., **Chowdhuri Subharthi,** Temperature profiles, plumes, and spectra in the surface layer of convective boundary layers, **AIP Advances**, 10: 105306, October 2020, DOI:10.1063/5.0023429, 1-16 **(Impact Factor 1.579)**

120. **Meena G.S., Mukherjee Subrata, Buchunde P., Safai P.D.**, Singla Vyoma, **Aslam M.Y., Sonbawne S.M., Made Raju, Anand V., Dani K.K., Pandithurai G.**, Seasonal variability and source apportionment of black carbon over a rural high-altitude and an urban site in western India, **Atmospheric Pollution Research**, 12, February 2021, DOI:10.1016/j.apr.2020.10.006, 32-45 **(Impact Factor 3.527)**

121. Meenu S., **Kulkarni G., Malap N., Murugavel P., Samanta S., Prabhakaran Thara,** The physics of extreme rainfall event: An investigation with multisatellite observations and numerical simulations, **Journal of Atmospheric and Solar Terrestrial Physics**, 204:105275, August 2020, DOI:10.1016/j.jastp.2020.105275 **(Impact Factor 1.790)**

122. **Metya A., Dagupta P., Halder S., Chakraborty S., Tiwari Y.K.,** COVID-19 Lockdowns improve air quality in the South-East Asian regions, as seen by the remote sensing satellites, **Aerosol and Air Quality Research**, 20, August 2020, DOI:10.4209/aaqr.2020.05.0240, 1772–1782 **(Impact Factor 2.735)**

123. **Metya Abirlal, Datye Amey, Chakraborty Supriyo, Tiwari Y.K.**, Sarma D., Bora A., Gogoi N., Diurnal and seasonal variability of CO2 and CH4 concentration in a semi-urban environment of western India, **Scientific Reports**, 11: 2931, February 2021, DOI:10.1038/s41598-021-82321-1, 1-13 **(Impact Factor 3.998)**

124. **Mohapatra S., Gnanaseelan C., Deepa J.S.,** Multidecadal to decadal variability in the equatorial Indian Ocean subsurface temperature and the forcing mechanisms, **Climate Dynamics**, 54, April 2020, DOI:10.1007/s00382-020-05185-7, 3475–3487 **(Impact Factor 4.048)**

125. Mohapatra S., **Gnanaseelan C.**, Warming trends in the central equatorial Indian Ocean and the associated coupled feedback processes, **Journal of Coastal Research**, SI- 89: Oceanic and Coastal Processes of the Indian Seas, June 2020, DOI:10.2112/SI89-007.1, 39-45 **(Impact Factor 1.053)**

126. Móring A., Hooda S., Raghuram N., Adhya T.K., Ahmad A., Bandyopadhyay S.K., Barsby T., **Beig G.**, Bentley A.R., Bhatia A., Dragosits U., Drewer J., Foulkes John, **Ghude S.D.**, Gupta R., Jain N., Kumar Dinesh, Kumar R.M., Ladha J.K., Mandal P.K., Neeraja C.N., Pandey R., Pathak H., **Pawar Pooja**, … et al., Nitrogen challenges and opportunities for agricultural and environmental science in India, **Frontiers in Sustainable Food Systems**, 5: 505347, February 2021, DOI:10.3389/fsufs.2021.505347, 1-16 **(Impact Factor 0.000)**

127. **Mukherjee S.**, Lohani P., Kumar K., **Chowdhuri S., Prabhakaran Thara,** Karipot A.K., Assessment of new alternative scaling properties of the convective boundary layer: Application to velocity and temperature spectra, **Boundary Layer Meteorology**, 176, May 2020, DOI:10.1007/s10546-020-00525-w, 271-289 **(Impact Factor 3.149)**

128. **Mukherjee S.,** Singla V., **Meena G.S., Aslam M.Y., Safai P.D., Buchunde P., Vasudevan A.K., Jena C.K., Ghude S.D., Dani K.K., Pandithurai G.,** Sub micron aerosol variability and its ageing process at a high altitudesite in India: Impact of meteorological conditions, **Environmental Pollution**, 265: 115019, Pt A,

October 2020, DOI:10.1016/j.envpol. 2020.115019, 1-12 **(Impact Factor 5.714)**

129. **Mukhopadhyay P., Krishnan R., Nanjundiah R.S.,** Mohapatra M., Prediction of Extreme Events: Current status and future pathways against the backdrop of climate change, **Bulletin of the American Meteorological Society**, 101, July 2020, DOI:10.1175/BAMS-D-20-0037.1, E1137–E1141 **(Impact Factor 8.166)**

130. **Mukhopadhyay P., Roy K.,** Evaluation of the convective mass flux profiles associated with cumulus parameterization schemes of CMIP5 models, **Journal of Earth System Science**, 129: 138, June 2020, DOI:10.1007/s12040-020-01400-5, 1-10 **(Impact Factor 1.104)**

131. Murata F., Terao T., **Chakravarty K.**, Syiemlieh H.J., Cajee L., Characteristics of orographic rain drop-size distribution at Cherrapunji, Northeast India, **Atmosphere**, 11:777, August 2020, DOI:10.3390/atmos11080777, 1-18 **(Impact Factor 2.046)**

132. **Murthy B.S., Latha R.**, Tiwari A., **Rathod A.**, Singh S., **Beig G.**, Impact of mixing layer height on air quality in winter, **Journal of Atmospheric and Solar Terrestrial Physics**, 197: 105157, January 2020, DOI:10.1016/j.jastp.2019. 105157, 1-10 **(Impact Factor 1.790)**

133. Nade D.P., Potdar S.S., Pawar R.P., Taori A., Kulkarni G., **Siingh D., Pawar S.D.,** Intra-annual variations of regional total column ozone, aerosol optical depth, and water vapor from ground-based, satellite-based and model-based observations, **Atmospheric Research**, 237, June 2020, DOI:10.1016/j.atmosres.2020. 104860, 1-16 **(Impact Factor 4.114)**

134. Nair P.J., **Varikoden H.**, Francis P.A, Chakraborty A., Pandey P.C., Atmospheric moisture as a proxy for the ISMR variability and associated extreme weather events, **Environmental Research Letters**, 16: 014045, January 2021, DOI:10.1088/1748-9326/ abcfe0, 1-16 **(Impact Factor 6.096)**

135. Nakajima T., Campanelli M., Che H., Estellés V., Irie H., Kim S-W., Kim J., Liu D., Nishizawa T., **Pandithurai G.,** Soni V.K., Thana B., Tugjsurn N-U., Aoki K., Sujung Go, Hashimoto M., Higurashi A., Kazadzis S., Khatri P., Kouremeti N., Kudo R., Marenco F., Momoi M., Ningombam S.S., Ryder C.L., Uchiyama A., Yamazaki A., An overview of and issues with sky radiometer technology and SKYNET, **Atmospheric Measurement Techniques**, 13, August 2020, DOI:10.5194/ amt-13-4195-2020, 4195-4218 **(Impact Factor 3.400)**

136. Pandey A., Brauer M., Cropper M.L., Balakrishnan K., Mathur P., Dey S., Turkgulu B., Kumar G.A., Khare M., **Beig G.**, et.al. India State-Level Disease Burden Initiative Air Pollution Collaborators, Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019, **Lancet**, 5, January 2021, DOI:10.1016/S2542-5196(20)30298-9, E25-E38 **(Impact Factor 60.392)**

137. **Panicker A.S., AnilKumar V., Raju M.P., Pandithurai G., Safai P.D., Beig G., Das S.**, CCN activation of carbonaceous aerosols from different combustion emissions sources: A laboratory study, **Atmospheric Research**, 248: 105252, January 2021, DOI:10.1016/ j.atmosres.2020.105252, 1-6 **(Impact Factor 4.676)**

138. **Parde A.N., Ghude S.D., Pithani P., Dhangar N.G.**, Nivdange S., **Krishna G., Lal D.M.**, Jenamani R., Singh P., **Jena C., Karumuri R., Safai P.D., Chate D.M.**, Estimation of surface particulate matter (PM 2.5 and PM 10) mass concentrations from ceilometer backscattered profiles, **Aerosol and Air Quality Research**, 20, July 2020, DOI:10.4209/aaqr.2019.08.0371, 1640-1650 **(Impact Factor 2.735)**

139. Pathak H.S., Satheesh S.K., Moorthy K.K., **Nanjundiah R.S.**, Assessment of regional aerosol radiative effects under the SWAAMI campaign – Part 2: Clear-sky direct shortwave radiative forcing using multi-year assimilated

PUBLICATIONS

data over the Indian subcontinent, **Atmospheric Chemistry and Physics**, 20, November 2020, DOI:10.5194/acp-20-14237-2020, 14237-14252 **(Impact Factor 5.668)**

140. **Patil M.N., Dharmaraj T., Pawar S.D.**, Influence of Land Surface Characteristics on the Evolution of Convective Boundary Layer over Semi-arid Region, **Journal of Indian Geophysical Union**, 24, May 2020, 49-56 **(Impact Factor 0.000)**

141. Pattanaik D.R., **Sahai A.K., Muralikrishna R.P., Mandal R., Dey A.**, Active-Break transitions of monsoons Over India as predicted by Coupled Model Ensembles, **Pure and Applied Geophysics**, 177, September 2020, DOI: 10.1007/s00024-020-02503-2, 4391–4422 **(Impact Factor 1.466)**

142. Paul B., **Balaji B.**, Paul A., Francis P.A., Shetye S.R., Absence of the annual cycle in shelf current inshore of the East Indian Coastal Current, **Continental Shelf Research**, 215: 104355, February 2021, DOI:10.1016/j.csr.2021.104355, 1-11 **(Impact Factor 2.424)**

143. **Pillai P.A., Ramu D.A., Nair R.C.,** Recent changes in the major modes of Asian summer monsoon rainfall: influence of ENSO-IOD relationship, **Theoretical and Applied Climatology**, 143, February 2021, DOI:10.1007/s00704-020-03454-3, 869-881 **(Impact Factor 2.882)**

144. **Pillai P.A., Rao Suryachandra A., Srivastava Ankur, Dandi R.A., Pradhan M.**, Impact of the tropical Pacific SST biases on the simulation and prediction of Indian summer monsoon rainfall in CFSv2, ECMWF-System4, and NMME models , **Climate Dynamics**, 56, January 2021, DOI:10.1007/s00382-020-05555-1, 1699–1715 **(Impact Factor 4.486)**

145. **Pithani P., Ghude S.D.,** Jenamani R.K., Biswas M., Naidu C.V., **Debnath S., Kulkarni R., Dhangar N.G., Jena C., Hazra A., Phani R., Mukhopadhyay P., Prabhakaran Thara, Nanjundiah R.S.**, Rajeevan M., Real-Time forecast of dense fog events over Delhi: The performance of the WRF model during the WiFEX field campaign, **Weather and Forecasting**, 35, April 2020, DOI:10.1175/WAF-D-19-0104.1, 739-756 **(Impact Factor 2.288)**

146. **Pokhrel S., Dutta U.**, Rahaman H., **Chaudhari H.S., Hazra A., Saha Subodh K., Veeranjaneyulu C.**, Evaluation of different heat flux products over the Tropical Indian Ocean, **Earth and Space Science**, 7: e2019EA000988, June 2020, DOI:10.1029/2019EA000988, 1-22 **(Impact Factor 2.152)**

147. Pottapinjara V., **Roxy M.K.**, Girishkumar M.S., Ashok K., Joseph Sudheer, Ravichandran M., Murtugudde R., Simulation of interannual relationship between the Atlantic zonal mode and Indian summer monsoon in CFSv2, **Climate Dynamics**, Online, March 2021, DOI:10.1007/s00382-021-05712-0, 1-21 **(Impact Factor 4.486)**

148. **Pradhan M., Rao Suryachandra A., Srivastava Ankur**, Factors responsible for consecutive deficit Indian monsoons during 2014 and 2015 , **Theoretical and Applied Climatology**, 143, February 2021, DOI:10.1007/s00704-020-03486-9, 1473–1486 **(Impact Factor 2.882)**

149. **Prasanna K., Chowdary J.S.**, Naidu C.V., **Gnanaseelan C., Parekh A.**, Diversity in ENSO remote connection to northeast monsoon rainfall in observations and CMIP5 models, **Theoretical and Applied Climatology**, 141, August 2020, DOI:10.1007/s00704-020-03208-1, 827–839 **(Impact Factor 2.720)**

150. Prasanna V., **Preethi B.**, Oh J., Kim I., Woo S., Performance of CMIP5 atmospheric general circulation model simulations over the Asian summer monsoon region, **Global and Planetary Change**, 194: 103298, November 2020, DOI:10.1016/j.gloplacha.2020.103298, 1-24 **(Impact Factor 4.100)**

151. **Priya P., Krishnan R., Mujumdar M.**, Uncertainties in river discharge simulations of the upper Indus basin in the Western

Himalayas, **Journal of Earth System Science**, 129: 150, July 2020, DOI:10.1007/s12040-020-01409-w **(Impact Factor 1.104)**

152. Raghav P., Borkotoky S.S., Joseph J., **Chattopadhyay R., Sahai A.K.**, Ghosh S., Revamping extended range forecast of Indian summer monsoon, **Climate Dynamics**, 55, September 2020, DOI:10.1007/s00382-020-05454-5, 3397–3411 **(Impact Factor 4.048)**

153. **Raja B.,** Maheskumar R.S., **Padmakumari B.**, System driven changes in aerosol-cloud interactions and its impact on the life-cycle of a monsoon depression, **Atmospheric Research**, 235:104765, May 2020, DOI:10.1016/j.atmosres.2019.104765, 1-13 **(Impact Factor 4.114)**

154. **Rajput A.S.D.**, Sharma S., India: draft science policy calls public engagement, **Nature**, Online, 30 March 2021, DOI: 10.1038/d41586-021-00861-y (**Impact factor: 42.778)**

155. **Raju M.P., Safai P.D., Sonbawne S.M., Buchunde P.S., Pandithurai G., Dani K.K.**, Black carbon aerosols over a high altitude station, Mahabaleshwar: Radiative forcing and source apportionment, **Atmospheric Pollution Research**, 11, August 2020, DOI:10.1016/j.apr.2020.05.024, 1408-1417 **(Impact Factor 2.918)**

156. Ranalkar M.R., **Chaudhari H.S., Hazra A.**, Microphysical features of unprecedented hailstorms over central region of India during February - March 2014 , **Asia-Pacific Journal of Atmospheric Sciences**, Online, March 2021, DOI:10.1007/s13143-021-00235-4, 1-20 **(Impact Factor 1.833)**

157. **Raut B.A.**, Louf V., **Kulkarni G.U., Murugavel P., Konwar M., Prabhakaran Thara**, A multi-resolution technique for the classification of precipitation echoes in radar data, **IEEE Transactions on Geoscience and Remote Sensing**, 58, August 2020, DOI:10.1109/TGRS.2020.2965649, 1-7 **(Impact Factor 5.630)**

158. **Roy C., Fadnavis S., Sabin T.P.**, The stratospheric ozone rich cold intrusion during El-Niño over the Indian region: implication during the Indian summer monsoon, **International Journal of Climatology**, 41, January 2021, DOI:10.1002/joc.6680, E233-E248 **(Impact Factor 3.928)**

159. **Roy K., Mukhopadhyay P., Krishna R.P.M., Ganai M., Mahakur M.**, Rao T.N., Nair A.K.M., Ramakrishna S.S.V.S., Assessment of climate models in relation to the low-level clouds over the southern Indian Ocean, **Quarterly Journal of Royal Meteorological Society**, 146, October 2020, Pt. A, DOI:10.1002/qj.3847, 3306-3325 **(Impact Factor 3.198)**

160. **Roy Kumar, Mukhopadhyay P., Krishna R.P.M., Ganai M., Mahakur M.**, Rao T.N., Nair A.K.M., Ramakrishna S.S.V.S., Sensitivity of climate models in relation to the "pool of inhibited cloudiness" over South of the Bay of Bengal, **International Journal of Climatology**, 40, June 2020, DOI:10.1002/joc.6423, 3714-3730 **(Impact Factor 3.601)**

161. **Sabin T.P.,** Pauluis O.M., The South Asian monsoon circulation in moist isentropic coordinates, **Journal of Climate**, 33, June 2020, DOI: 10.1175/JCLI-D-19-0637.1, 5253-5270 **(Impact Factor 4.805)**

162. **Saha S.K., Hazra A., Pokhrel S., Chaudhari H.S., Rai A., Sujith K.,** Rahaman H., Goswami B.N., Reply to comment by E. T. Swenson, D. Das, and J. Shukla on "Unraveling the mystery of indian summer monsoon prediction: Improved Estimate of predictability limit", **Journal of Geophysical Research: Atmospheres**, 125: e2020JD033242, November 2020, DOI:0.1029/2020JD033242, 1-9 **(Impact Factor 3.633)**

163. **Saha Subodh Kumar, Konwar M., Pokhrel S., Hazra A., Chaudhari H.S., Rai A.**, Interplay between subseasonal rainfall and global predictors in modulating interannual to multidecadal predictability of the ISMR,

PUBLICATIONS

Geophysical Research Letters, 48: e2020GL091458, January 2021, DOI: 10.1029/2020GL091458, 1-11 **(Impact Factor 4.497)**

164. **Sahai A.K., Mandal R., Joseph S.,** Saha S., Awate P., Dutta S., **Dey Avijit, Chattopadhyay R., Phani R.,** Pattanaik D.R., Despande S., Development of a probabilistic early health warning system based on meteorological parameters, **Scientific Reports**, 10:14741, September 2020, DOI:10.1038/s41598-020-71668-6, 1-13 **(Impact Factor 4.011)**

165. Sahu L.K, Tripathi N., **Yadav R.,** Observations of trace gases in the earth's lower atmosphere: instrumentation and platform, **Current Science**, 118, June 2020, DOI: 10.18520/cs/v118/i12/1893-1902, 1893-1902 **(Impact Factor 0.756)**

166. Sahu S.K., Tyagi B., **Beig G.,** Mangaraj P., Pradhan C., Khuntia S., Singh Vikas, Significant change in air quality parameters during the year 2020 over 1st smart city of India: Bhubaneswar, **SN Applied Sciences**, 2: 1990, November 2020, DOI:10.1007/s42452-020-03831-7, 1-8 **(Impact Factor 0.000)**

167. **Samanta S., Kulkarni G., Murugavel P., Balaji B., Malap N., Jaya Rao Y., Deshpande S.M., Sonbawne S.M.**, Suneetha P., **Prabhakaran Thara**, Case study of a convective cluster over the rain shadow region of Western Ghats using Multi-platform Observations and WRF Model, **Pure and Applied Geophysics**, 177, June 2020, DOI:10.1007/s00024-019-02360-8, 2931-2957 **(Impact Factor 1.466)**

168. Sanap S.D., Mohapatra M., Ali M.M., **Priya P.,** Varaprasad D., On the dynamics of cyclogenesis, rapid intensification and recurvature of the very severe cyclonic storm, Ockhi, **Journal of Earth System Science**, 129: 194, September 2020, DOI:10.1007/s12040-020-01457-2, 1-13 **(Impact Factor 1.104)**

169. **Sandeep K.,** Negi R.S., **Panicker, A.S.,** Gautam A.S., **Bhist D.S., Beig G., Murthy B.S., Latha R.**, Singh S., Das S., Characteristics and variability of carbonaceous aerosols over a semi urban Location in Garhwal Himalayas, **Asia-Pacific Journal of Atmospheric Sciences**, 56, August 2020, DOI:10.1007/s13143-019-00158-1, 455-465 **(Impact Factor 1.772)**

170. **Sandeep N., Swapna P., Krishnan R.,** Farneti R., **Prajeesh A.G., Ayantika D.C., Singh Manmeet,** South Asian monsoon response to weakening of Atlantic meridional overturning circulation in a warming climate, **Climate Dynamics**, 54, April 2020, DOI:10.1007/s00382-020-05180-y, 3507–3524 **(Impact Factor 4.048)**

171. Sandhu S., Sathe V., Chakarborty K.S., **Chakraborty S.**, Chauhan P.R., Carbon and Oxygen Isotope Analysis of Modern Cattle (Bos indicus) Molars from the Central Narmada Valley, India, **Ancient Asia**, 12: 3, March 2021, DOI:10.5334/aa.210, 1-19 **(Impact Factor 0.000)**

172. Sannan M.C., **Nageswararao M.M.**, Mohanty U.C., Performance evaluation of CORDEX-South Asia simulations and future projections of northeast monsoon rainfall over south peninsular India, **Meteorology and Atmospheric Physics**, 132, October 2020, DOI:10.1007/s00703-019-00716-2, 743–770 **(Impact Factor 1.656)**

173. **Sarkar S., Mukhopadhyay P.**, Dutta S., **Krishna R.P.M., Kanase R.**, Prasad V.S., **Deshpande M.S.**, GFS model fidelity in capturing the transition of low pressure area to monsoon depression, **Quarterly Journal of Royal Meteorological Society**, Online, March 2021, DOI:10.1002/qj.4024, 1-35 **(Impact Factor 3.471)**

174. Sen R., Pandey S., **Dandapat Sumit**, Francis P.A., Chakraborty A., A numerical study on seasonal transport variability of the North Indian Ocean boundary currents using Regional Ocean Modeling System (ROMS), **Journal of Operational Oceanography**, Online, November 2020, DOI:10.1080/1755876X.2020.1846266, 1-20 **(Impact Factor 1.717)**

175. **Sengupta S.,** Bhattacharya S.K., **Parekh A.,** Nimya S.S., Yoshimura K., Sarkar A., Signatures

of monsoon intra-seasonal oscillation and stratiform process in rain isotope variability in northern Bay of Bengal and their simulation by isotope enabled general circulation model, **Climate Dynamics**, 55, September 2020, DOI:10.1007/s00382-020-05344-w, 1649–1663 **(Impact Factor 4.048)**

176. Shahi N.K., Rai S., **Sahai A.K.**, The relationship between the daily dominant monsoon modes of South Asia and SST, **Theoretical and Applied Climatology**, 142, June 2020, DOI:10.1007/s00704-020-03304-2, 59–70 **(Impact Factor 2.720)**

177. **Shamal M., Sanjay J.**, An observational equatorial Atlantic Ocean constraint on Indian monsoon precipitation projections, **Climate Dynamics**, Online, February 2021, DOI:10.1007/s00382-021-05703-1, 1-13 **(Impact Factor 4.486)**

178. Sherin V.R., Durand F., Papa F., Islam A.K.M.S., **Gopalakrishna V.V.**, Khaki M., Suneel V., Recent salinity intrusion in the Bengal delta: Observations and possible causes, **Continental Shelf Research**, 202:104142, November 2020, DOI:10.1016/j.csr.2020.104142, 1-10 **(Impact Factor 2.134)**

179. **Singh M., Krishnan R.,** Goswami B., **Choudhury A.D., Swapna P., Vellore R., Prajeesh A.G., Sandeep N.,** Venkataraman C., Donner R.V., Marwan N., Kurths J., Fingerprint of volcanic forcing on the ENSO–Indian monsoon coupling, **Science Advances**, 6: eaba8164, September 2020, DOI:10.1126/sciadv.aba8164 **(Impact Factor 12.804)**

180. **Singh V.K., Roxy M.K., Deshpande M.**, Role of warm ocean conditions and the MJO in the genesis and intensification of extremely severe cyclone Fani, **Scientific Reports**, 11: 3607, February 2021, DOI:10.1038/s41598-021-82680-9, 1-10 **(Impact Factor 3.998)**

181. **Singh Vineet K., Roxy M.K., Deshpande M.,** The unusual long track and rapid intensification of very severe cyclone Ockhi, **Current Science**, 119, September 2020, DOI: 10.18520/cs/v119/i5/771-779, 771-779 **(Impact Factor 0.756)**

182. Singh Vivek, Konduru R.T., **Srivastava A.K.**, Momin I.M., Kumar Sushant, Singh A.K., **Bisht D.S., Tiwari Suresh**, Sinha A.K., Predicting the rapid intensification and dynamics of pre-monsoon extremely severe cyclonic storm 'Fani' (2019) over the Bay of Bengal in a 12-km global model, **Atmospheric Research**, 247: 105222, January 2021, DOI:10.1016/j.atmosres.2020.105222, 1-18 **(Impact Factor 4.676)**

183. **Sinha N., Chakraborty S.,** Isotopic interaction and source moisture control on the isotopic composition of rainfall over the Bay of Bengal, **Atmospheric Research**, 235: 104760, May 2020, DOI:10.1016/j.atmosres.2019.104760, 1-11 **(Impact Factor 4.114)**

184. Sin'kevich A. A., Popov V.B., Abshaev A.M., Boe B.A., **Pawar S.D.**, Mikhailovskii Yu. P., Toropova M.L., **Gopalakrishnan V.**, Gekkieva Zh. M., Radar Characteristics of Convective Clouds during Transition to the Cumulonimbus Stage in Different Regions of the World, **Atmospheric and Oceanic Optics**, 34, March 2021, 135-140 **(Impact Factor 0.870)**

185. **Somaru Ram, Singh H.N., Yadav R.K., Nandargi S.S.**, Srivastava M.K., Reconstruction of potential evapotranspiration over western Himalaya in India based on tree ring-width records, **Quaternary International**, 547, May 2020, DOI:10.1016/j.quaint.2019.05.005, 145-151 **(Impact Factor 1.159)**

186. **Somaru Ram, Singh H.N., Yadav R.K., Varikoden H., Nandargi S.S.,** Srivastava M.K., Variations in vapor pressure and standardized precipitation evapotranspiration index since AD 1861 over the western Himalaya in India: inference from tree ring-width records, **Theoretical and Applied Climatology**, 140, April 2020, DOI:10.1007/s00704-019-03075-5, 157-166 **(Impact Factor 2.720)**

PUBLICATIONS

187. **Somaru Ram, Yadav R.K., Singh H.N.,** Srivastava M.K., Standardized Precipitation Index reconstruction during the last two centuries over western Himalaya, India: deduced by tree ring-width records, **Himalayan Geology**, 41, July 2020, 202-207 **(Impact Factor 0.333)**

188. **Sooraj K.P.,** Terray P., Shilin A., **Mujumdar M.,** Dynamics of rainfall extremes over India: A new perspective, **International Journal of Climatology**, 40, October 2020, DOI: 10.1002/joc.6516, 5223-5245 **(Impact Factor 3.601)**

189. **Sreeush M.G., Valsala V., Santanu H., Sreenivas P.**, Prasad K.V.S.R., Naidu C.V., Murtugudde R., Biological production in the Indian Ocean upwelling zones - Part 2: Data based estimates of variable compensation depth for ocean carbon models via cyclo-stationary Bayesian Inversion, **Deep Sea Research Part II**, 179: 104619, September 2020, DOI:10.1016/j.dsr2.2019.07.007, 1-17 **(Impact Factor 2.430)**

190. **Srivastava A.K.,** Mehrotra B.J., **Singh A., Singh V., Bisht D.S., Tiwari S.,** Srivastava M.K., Implications of different aerosol species to direct radiative forcing and atmospheric heating rate, **Atmospheric Environment**, 241: 117820, November 2020, DOI:10.1016/j.atmosenv.2020.117820 **(Impact Factor 4.012)**

191. Srivastava A.K., **Revadekar J.V.,** Rajeevan M., State of the Climate in 2019: South Asia, **Bulletin of the American Meteorological Society**, 101, August 2020, S394-S397 **(Impact Factor 8.166)**

192. **Srivastava Ankur, Rao Suryachandra A., Pradhan M., Pillai P.A.**, Prasad V.S., Gain of one-month lead time in seasonal prediction of Indian summer monsoon prediction: comparison of initialization strategies, **Theoretical and Applied Climatology**, 143, February 2021, DOI:10.1007/s00704-020-03470-3, 1083–1096 **(Impact Factor 2.882)**

193. **Srivastava Atul K.**, Bhoyar P.D., Kanawade V.P., Devara P.C.S., Thomas A., Soni V.K., Improved air quality during COVID-19 at an urban megacity over the Indo-Gangetic Basin: From stringent to relaxed lockdown phases, **Urban Climate**, 36: 100791, March 2021, DOI: 10.1016/j.uclim.2021.100791, 1-13 **(Impact Factor 3.834)**

194. **Srivastava Atul K.**, Thomas A., Hooda R.K., Kanawade V.P., Hyvärinen A.-P., **Bisht D.S., Tiwari Suresh**, How secondary inorganic aerosols from Delhi influence aerosol optical and radiative properties at a downwind sub-urban site over Indo-Gangetic Basin?, **Atmospheric Environment**, 248: 118246, March 2021, DOI:10.1016/j.atmosenv.2021.118246, 1-10 **(Impact Factor 4.039)**

195. Srivastava G., Chakraborty A., **Nanjundiah R.S.,** Multidecadal variations in ENSO-Indian summer monsoon relationship at sub-seasonal timescales, **Theoretical and Applied Climatology**, 140, May 2020, DOI:10.1007/s00704-020-03122-6, 1299–1314 **(Impact Factor 2.720)**

196. Sudeep kumar B.L, Babu C.A., **Varikoden H.,** Atmospheric boundary layer height and surface parameters: Trends and relationships over the west coast of India, **Atmospheric Research**, 245, November 2020, DOI:10.1016/j.atmosres.2020.105050, 1-15 **(Impact Factor 4.114)**

197. Sudeepkumar B.L., Babu C.A., **Varikoden H.,** Response of atmospheric surface layer parameters to cloudiness over a tropical coastal station, **Journal of Atmospheric and Solar Terrestrial Physics**, 202:105260, June 2020, DOI:10.1016/j.jastp.2020.105260, 1-13 **(Impact Factor 1.790)**

198. **Sukanya P., Kalapureddy M.C.R.**, Cloud radar observations of multi-scale variability of cloud vertical structure associated with Indian summer monsoon over a tropical location, **Climate Dynamics**, 56, February 2021, DOI:10.1007/s00382-020-05520-y, 1055–1081 **(Impact Factor 4.486)**

199. Suneel V., Alex M.J., Antony T.P., Gurumoorthi K., Trinadha Rao V., Harikrishnan S., **Gopalakrishna V.V.**, Rama Rao E.P., Impact of Remote Equatorial Winds and Local Mesoscale Eddies on the Existence of "River in the Sea" Along the East Coast of India Inferred from Satellite SMAP, **Journal of Geophysical Research: Oceans**, 125: e2020JC016866, December 2020, DOI:10.1029/2020JC016866, 1-18 **(Impact Factor 3.235)**

200. **Sunil S., Padmakumari B.,** High temporal variability of wintertime fog, aerosol and Red-Blue-Ratio using ground-based observations of shortwave irradiance and sky imagery over a station in Indo-Gangetic Basin: Optical and Radiative characteristics, **Atmospheric Environment**, 226:117382, April 2020, DOI:10.1016/j.atmosenv.2020.117382 **(Impact Factor 4.012)**

201. **Sunil S., Padmakumari B., Pandithurai G., Patil R.D.**, Naidu C.V., Diurnal (24 h) cycle and seasonal variability of cloud fraction retrieved from a Whole Sky Imager over a complex terrain in the Western Ghats and comparison with MODIS, **Atmospheric Research**, 248: 105180, January 2021, DOI:10.1016/j.atmosres.2020.105180,1-13 **(Impact Factor 4.676)**

202. **Swetha S., Chowdary J.S., Parekh A., Gnanaseelan C.**, Decadal prediction skill for spring and summer surface air-temperature over India and its association with SST patterns in CFSv2 and CNRM coupled models, **Journal of Earth System Science**, 130: 55, March 2021, DOI:10.1007/s12040-021-01563-9, 1-13 **(Impact Factor 1.423)**

203. Tejas D.M., **Gnanaseelan C., Rashmi A.K., Deepa J.S.,** Indian Ocean warming trends and forcing mechanism with emphasis on northeastern tropical Indian Ocean, **Journal of Coastal Research**, SI- 89: Oceanic and Coastal Processes of the Indian Seas, June 2020, DOI:10.2112/SI89-003.1, 15-19 **(Impact Factor 1.053)**

204. Terray P., **Sooraj K.P.**, Masson. S., Prodhomme C., Anatomy of the Indian Summer Monsoon and ENSO relationships in state-of-the-art CGCMs: role of the tropical Indian Ocean, **Climate Dynamics**, 56, January 2021, DOI:10.1007/s00382-020-05484-z, 329-356 **(Impact Factor 4.486)**

205. Thakur M.K., Desamsetti S., Rajesh A.N., **Koteswara Rao K.,** Narayanan M.S., Lakshmi Kumar T.V., Exploring the rainfall data from satellites to monitor rainfall induced landslides - A case study, **Advances in Space Research**, 66, August 2020, DOI:10.1016/j.asr.2020.05.015, 887-894 **(Impact Factor 1.746)**

206. Thakur M.K., Lakshmi Kumar T.V., Narayanan M.S., **Koteswara Rao K.,** Barbosa H., Analytical study of the performance of the IMERG over the Indian landmass, **Meteorological Applications**, 27: e1908, May 2020, DOI: 10.1002/met.1908, 1-11 **(Impact Factor 1.711)**

207. Thomas A., Kanawade V.P., **Chakravarty Kaustav, Srivastava A.K.**, Characterization of raindrop size distributions and its response to cloud microphysical properties, **Atmospheric Research**, 249: 105292, February 2021, DOI:10.1016/j.atmosres.2020.105292, 1-9 **(Impact Factor 4.676)**

208. **Thomas L.**, Grabowski W.W., **Kumar Bipin,** Diffusional growth of cloud droplets in homogeneous isotropic turbulence: DNS, scaled-up DNS, and stochastic model, **Atmospheric Chemistry and Physics**, 20, July 2020, DOI:10.5194/acp-20-9087-2020, 9087–9100 **(Impact Factor 5.668)**

209. Tobler A., Bhattu D., Canonaco F., Lalchandani V., Shukla A., Thamban N.M., Mishra S., **Srivastava A.K., Bisht D.S., Tiwari Suresh**, Singh S., Močnik G., Baltensperger U., Tripathi S.N., Slowik J.G., Prévôt A.S.H., Chemical characterization of PM2.5 and source apportionment of organic aerosol in New Delhi, India, **Science of the Total Environment**, 745: 140924, November 2020, DOI:10.1016/

PUBLICATIONS

j.scitotenv.2020.140924, 1-12 **(Impact Factor 5.589)**

210. **Todekar K.S.**, Hippargi S.S., IoT based distributed environmental monitoring system and weather prediction using machine learning approach, **International Journal of Engineering Research and Applications**, 10, Series-IV, October 2020, DOI:10.9790/9622-1010042024, 20-24 **(Impact Factor 0.000)**

211. **Todekar K.S.**, Shirgan S., Hippargi S., Mule A.D., Dongare S.A., Gadekar A.R., UAV for atmospheric research, **International Journal of Applied Research and Technology**, 5, August 2020, DOI:10.24163/ijart/2017/5(4)96-103, 96-103 **(Impact Factor 0.000)**

212. Tripathi N., Sahu L.K., Singh A., **Yadav Ravi,** Patel A., Patel K., Meenu P., Elevated Levels of Biogenic Nonmethane Hydrocarbons in the Marine Boundary Layer of the Arabian Sea During the Intermonsoon, **Journal of Geophysical Research: Atmospheres,** 125: e2020JD032869, November 2020, DOI:10.1029/2020JD032869, 1-15 **(Impact Factor 3.633)**

213. Uma K.N., Mohan T.S., **Das S.K.,** Role of intra-seasonal variability in the Indian summer monsoon on the hydration and dehydration of the upper troposphere, **Theoretical and Applied Climatology**, 141, July 2020, DOI: 10.1007/s00704-020-03243-y, 747-761 **(Impact Factor 2.720)**

214. Upadhyaya D.B, Evans J., Muddu S., Tomer S.K., Bitar A.A., Yeggina S., Thiyaku S. , Morrison R., Fry M., Tripathi S.N., **Mujumdar M., Goswami M., Ganeshi N.**, Nema M.K., Jain S.K., Angadi S.S., Yenagi B.S., The Indian COSMOS Network (ICON): Validating L-Band remote sensing and modelled soil moisture data products, **Remote Sensing**, 13: 537, February 2021, DOI:10.3390/rs13030537, 1-25 **(Impact Factor 4.509)**

215. **Valsala V., Sreeush M.G.,** Chakraborty K., The IOD impacts on the Indian Ocean carbon cycle, **Journal of Geophysical Research: Oceans**, 125: e2020JC016485, November 2020, DOI: 10.1029/2020JC016485, 1-18 **(Impact Factor 3.235)**

216. **Varghese M., Leena P.P., Murugavel P., Bankar S., Todekar K., Chowdhuri S., Safai P.D., Malap N., Konwar M., Dixit S., Jaya Rao Y., Prabhakaran Thara,** New particle formation observed from a rain shadow region of the Western Ghats, India, **Toxicological & Environmental Chemistry**, 102, July 2020, DOI: 10.1080/02772248.2020.1789134, 305-333 **(Impact Factor 0.971)**

217. **Varikoden H., Roja C., Revadekar J.V., Mujumdar M.,** Rainfall variation in major river basins in India and the association with the Indo-Pacific Oceans, **Journal of Coastal Research**, SI- 89: Oceanic and Coastal Processes of the Indian Seas, June 2020, DOI:10.2112/SI89-001.1, 1-6 **(Impact Factor 1.053)**

218. **Vellore R.K., Bisht J.S., Krishnan R., Umakanth U.**, Di Capua G., Sub-synoptic circulation variability in the Himalayan extreme precipitation event during June 2013, **Meteorology and Atmospheric Physics**, 132, October 2020, DOI:10.1007/s00703-019-00713-5, 631–665 **(Impact Factor 1.656)**

219. **Vibhute A., Halder S., Prem Singh, Parekh A., Chowdary J.S., Gnanaseelan C.**, Decadal variability of tropical Indian Ocean sea surface temperature and its impact on the Indian summer monsoon, **Theoretical and Applied Climatology**, 141, July 2020, DOI:10.1007/s00704-020-03216-1, 551-566 **(Impact Factor 2.720)**

220. Vijayakumar K., Devara P.C.S., **Sonbawne S.M.,** Giles D.M., Holben B.N., Rao S.V.B., Jayasankar C.K., Solar radiometer sensing of multi-year aerosol features over a tropical urban station: direct-Sun and inversion products, **Atmospheric Measurement Techniques**, 13, October 2020, DOI:10.5194/amt-13-5569-2020, 5569–5593 **(Impact Factor 3.400)**

221. **Waghmare V.V., Aslam M.Y., Yang L., Safai P.D., Pandithurai G.**, Inorganic Ionic Composition of Rainwater at a High Altitude Station over the Western Ghats in Peninsular India, **Journal of Atmospheric Chemistry**, 78, February 2021, DOI:10.1007/s10874-021-09416-x, 59–76 **(Impact Factor 1.521)**

222. Wang B., Biasutti M., Byrne M.P., Castro C., Chang C., Cook K., Fu R., Grimm A.M., Ha K., Hendon H., Kitoh A., **Krishnan R.**, Lee J., Li J., Liu J., Moise A., Pascale S., Roxy M.K., Seth A., ... et al., Monsoons climate change assessment, **Bulletin of the American Meteorological Society**, 102, January 2021, DOI:10.1175/BAMS-D-19-0335.1, E1-E19 **(Impact Factor 9.384)**

223. Wing A.A., Stauffer C.L., Becker T., Reed K.A., Ahn M.S., Arnold N.P., ... **Kulkarni G.,** ... **Prabhakaran Thara,** et al., Clouds and Convective Self-Aggregation in a Multimodel Ensemble of Radiative-Convective Equilibrium Simulations, **Journal of Advances in Modeling Earth Systems**, 12: e2020MS002138, September 2020, DOI:10.1029/2020MS002138 **(Impact Factor 3.457)**

224. **Yadav R., Korhale N., Anand V., Rathod A., Bano S., Shinde R., Latha R.,** Sahu S.K., **Murthy B.S., Beig G.,** COVID-19 lockdown and air quality of SAFAR-India metro cities, **Urban Climate**, 34: 100729, December 2020, DOI:10.1016/j.uclim.2020.100729 **(Impact Factor 3.900)**

225. **Yadav R.K.,** Simon Wang S.-Y., Wu C-H., Gillies R.R., Swapping of the Pacific and Atlantic Niño influences on north central India summer monsoon, **Climate Dynamics**, 54, May 2020, DOI:10.1007/s00382-020-05215-4, 4005-4020 **(Impact Factor 4.048)**

226. Yaduvanshi A., **Kulkarni Ashwini,** Bendapudi R., Haldar K., Observed changes in extreme rain indices in semiarid and humid regions of Godavari basin, India: risks and opportunities, **Natural Hazards**, 103, August 2020, DOI:10.1007/s11069-020-04006-8, 685-711 **(Impact Factor 2.319)**

227. Yatagai A., Maeda M., **Sunilkumar K.**, Masuda M., Xie P., End of the Day (EOD) judgment for daily rain-gauge data, **Atmosphere**, 11: 772, July 2020, DOI:10.3390/atmos11080772, 1-15 **(Impact Factor 2.046)**

Other Publications in Books, Reports, Proceesings, Magazines, Newsletters, etc.

1. Annamalai H., Boos W.R., Martin G., Mapes B., Ming Y., **Mukhopadhyay P.,** Koh T.Y., **Rao Suryachandra A.**, Grand Challenges in Asian Summer Monsoon Modeling — Representation of Processes and Sources of Model Error, Chapter 29 in **The Multiscale Global Monsoon System** (4th ed.), Edited by: Chang C.P, Ha K.J., Lau G.N.C., Johnson R.H., February 2021, 367-386.

2. **Kulkarni Ashwini, Koteswara Rao K**., Climate Change Projections for Maharashtra, **State Government report for the preparation of the Departmental Disaster Management Plans**, June 2020.

3. **Kulkarni Ashwini, Patwardhan S.**, ...et al., Projected Changes in Weather and Climate Extremes over India, **India: Preparation of Third National Communication (TNC) and Other New Information to the UNFCCC**, MOEF&CC, March 2017- June 2020, 46.

4. **Chakraborty S.**, Birmal S., Deb Burman P.K., Datye Amey, Mohan P.M., Trivedi N., Trivedi R.K., Statistical Analysis of the Precipitation Isotope Data with Reference to the Indian Subcontinent, Book Chapter in **Hydrology**, Edited by: Hromadka T., Rao P., DOI:10.5772/intechopen.93831, 1-17 (Publisher: IntechOpen).

5. CLIVAR Exchanges: Special Issue on India's Monsoon Mission, **CLIVAR Exchanges**, No. 79, International CLIVAR Project Office (ICPO), ISSN 1026-0471, DOI: 10.36071/clivar.79.2020, November 2020 (newsletter).

6. **Deb Burman P.**, Estimation of Net Primary Productivity: An Introduction to Different Approaches, Book Chapter in **Spatial Modelling**

PUBLICATIONS

in Forest Resources Management, Edited by: Shit P.K., Pourghasemi H.R., Das P., Bhunia G.S., DOI:10.1007/978-3-030-56542-8_2, 33-69 (Springer, Switzerland).

7. **Deshpande M.**, Johny C.J., **Kanase R., Tirkey S., Sarkar S., Goswami T., Roy Kumar, Ganai M., Krishna R.P.M.,** Prasad V.S., **Mukhopadhyay P.,** Durai V.R., **Nanjundiah R.S.,** Rajeevan M., Implementation of Global Ensemble Forecast System (GEFS) at 12km Resolution, August, 2020, ISSN 0252-1075, **IITM Technical Report No.TR-06**, ESSO/IITM/MM/TR/02(2020)/200.
8. Gupta A., Choudhary H., Singh A.K., **Prabhakaran Thara, Dixit S.A.**, Scale-Aware Overlap in Turbulent Wall Jets, In: Venkatakrishnan L., Majumdar S., Subramanian G., Bhat G.S., Dasgupta R., Arakeri J. (eds), **Proceedings of 16th Asian Congress of Fluid Mechanics**, Lecture Notes in Mechanical Engineering, February 2021, https://doi.org/10.1007/978-981-15-5183-3_28, 257-266.
9. **Jena C., Ghude S.**, Kumar R., Debnath S., Soni V.K., **Nanjundiah R.S,** Rajeevan M., 2020, High-resolution (400 m) operational air quality early warning system for Delhi, India, **IGAC News**, 66, 25-26.
10. **Kanase R., Mohan G., Halder M., Deshpande M., Mukhopadhyay P.**, Initiative to Develop a Forecasting System for Wind Energy over a complex terrain in India using Weather Research and Forecasting (WRF) Model, **IITM Research Report**., RR-147, https://www.tropmet.res.in/~lip/Publication/RR-pdf/RR_147.pdf.
11. **Kaur M., Sahai A.K., Phani R., Joseph S.**, Super-Cyclone Amphan (2020): Global versus Regional Ensemble Prediction, **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No.50, WCRP Report No.12/2020, July 2020, WMO, Geneva, 05-09.
12. **Krishnan R., Sanjay J., Gnanaseelan C., Mujumdar M., Kulkarni Ashwini, Chakraborty S.,** Assessment of Climate Change over the Indian Region: - A Report of the Ministry of Earth Sciences (MoES), Government of India, Springer Nature, DOI:10.1007/978-981-15-4327-2, ISBN 978-981-15-4327-2 https://link.springer.com/book/10.1007%2F978-981-15-4327-2.
13. **Kulkarni Ashwini**, Guhathakurta P., **Patwardhan S.**, Gadgil S., Delineation of the meteorological subdivisions of the states of India, **IMD CRS Research Report no. 2/2020**, 2020, 76.
14. **Mahapatra S.**, Some important duties and qualities of a "Rapporteur" for reporting a Scientific event, **Bulletin of IMSP**, 19 (4-6), Special Issue, April - June 2020, 15-19.
15. **Mandke S.K., Prabhu A.**, Future projection of Indian summer monsoon variability under climate change scenario: Results from CMIP5/CCSM4 model simulation, Research activities in Earth system modeling, **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No.50, WCRP Report No.12/2020, July 2020, WMO, Geneva, 7-15.
16. **Marathe Shamal**, Ashok K., The El Nino Modoki, Chapter 4 in **Tropical and Extratropical Air-Sea Interactions**, Edited by: Behera S.K., ISBN: 978-0-12-818156-0, 93-114 (Publisher: Elsevier).
17. Martin G., **Rao Suryachandra A., Chattopadhyay R.**, Moron V., Mitra A., Ashrit R., Overview of Rainfall Metrics for the Assessment of Model Simulations of the Monsoons: Current Status and Future Perspectives, **GEWEX Quarterly**, 30, 4, 5-7.
18. **Mukhopadhyay P., Rao Suryachandra A., Sahai A.K.**, Roadmap for IITM Model Development: Towards Seamless Prediction of Monsoon Weather and Climate - 2020-2029, **IITM Technical Report**, TR-5, February 2020.
19. **Prabhakaran Thara**, Khain A., Water Vapor and Pollutants, Aerosol–Cloud Interactions, Chapter 121 in Maurice P.A. eds, **Encyclopedia of Water: Science, Technology and Society,** 1295-1318, April 2020, ISBN: 978-1-119-30075-5.

20. **Prabhu A., Mandke S.K.**, Relation between Eurasian snow and Indian monsoon in historical simulation of CMIP5 models, **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No.50, WCRP Report No.12/2020, July 2020, WMO, Geneva, 9-05.

21. **Prabhu A., Mandke S.K.**, Spatial features of snow over Eurasia and precipitation over India in the warming scenarios: CCSM4 model projections from CMIP5, Research activities in Earth system modeling, WGNE **Blue Book: Research Activities in Earth System Modelling**, Report No.50, WCRP Report No.12/2020, July 2020, WMO, Geneva, 7-19.

22. Tiwari S., Chen B., Singh S., Singh A.K., and **Srivastava A.K.,** Impact of Black Carbon on Environment and Health in Hussain (Ed.) Book 'Functionalized Nanomaterials based Devices for Environmental Applications', Elsevier Publication, 2020.

23. **Victor N.J.**, Chandra S, **Siingh D.**, Lightning the Global Electric Circuit and Climate, Chapter 8 in **Techniques for Disaster Risk Management and Mitigation**, Ed. by Srivastava P.K., Singh S.K., Mohanty U.C., Murthy T., AGU monograph-Advancing of Earth and Space Science, Willy Publication, ISBN No. 9781119359180, April 2020, https://doi.org/10.1002/9781119359203.ch8, 93-110.

24. **Yadav Ravi**, Trivedi P., Sahu L.K., **Beig G.**, Tripathi N., Air pollution modeling, In: Saxena P., Srivastava A. (eds.), **Air Pollution and Environmental Health**, Environmental Chemistry for a Sustainable World Series., Vol. 20, 2020, DOI:10.1007/978-981-15-3481-2, 37-55.

Summary of Publications during the year 2020-21	
Total No. of papers published in Journals	227
Papers with Impact Factor	217
Papers without Impact Factor	10
Cumulative Impact Factor	835.513
Average Impact Factor	3.681
Other Publications	24

Appendix-1

Details of the various changes made in system on HPC Pratyush and HPC Aaditya.

a) The following applications were installed/reinstalled (latest version) on HPC Pratyush:

Sr. No	Application	Sr. No	Application
1	CLM5	36	GSL
2	GFS-EL	37	Metis
3	ECCODES 2.15.0	38	UCLA-LES
4	SP-CAM (new compset)	39	MET
5	pstswm (user source)	40	NCL on XC50
6	Cloud Resolving Model Radar Simulator	41	User code for cloudmodel
7	UCLALES-SALSA	42	NICAM
8	METv8.0	43	OBSGRID
9	NICAM16.3 with PGI	44	WRF 4.1
10	CFS with PGI	45	WRF 4.2.2
11	NEMOVar	46	WRF 4.2
12	RRTM LW v3.3	47	WRF-CHEM 4.1
13	WRF 4.0 (CRAY)	48	WPS 4.1
14	CFS_LETKF_WCDA(scripted submission)	49	WPS 4.2
15	SURF and JULES	50	WPS 4.0.3
16	CESM 1.2.2.1 with intel 19	51	MODIS 4.3
17	DNS	52	FLEXPART GFS
18	CM1	53	LIS
19	Echam6.2-harm2.3-moz1.0	54	Singularity Application
20	ENS Tracker	55	CDSAPI
21	UM	56	R and R studio
22	HYCOM	57	WRF-CHEM 4.2.2
23	UPPv3.2	58	WPS 4.2.2
24	Ed4 LaRCFuLiou	59	NEPS-R
25	GSDSU Simulator	60	WRF Domain Wizard
26	Afterburner 4.8	61	RegCM
27	GDAL	62	WRF ideal
28	Inland 2.0	63	GFDL Vortex Tracker
29	Biome Bgc 4.2	64	ECHAM6.3-ham2.3-moz1.0
30	Data2gfs	65	Ferret 7.6
31	NCO 4.7.3	66	WRF-CHEM Preprocessing 1.5
32	Pyferret	67	cfs.v2.1.12
33	gifsicle-utility 1.92	68	ARWPOST
34	Sosie	69	MOM6
35	Anaconda python, various libs and frameworks	70	CR-SIM

Sr. No	Application	Sr. No	Application
71	LAS	95	MOM 5.1
72	Hyrax	96	MOM 4
73	XMGRACE and Nedit	97	COAWST
74	GSI	98	GFDL Tracker
75	WRFDA	99	Mothur
76	NCL 6.6.2	100	WRF 4.0
77	GFSNEMSIO2grb 2.5.4	101	WRF 3.9.1 with PGI
78	tsunami-gpu	102	GEOS-CHEM V 13.0.0
79	BUFRLIB 11.3.0	103	ECHAM COCID-19 emission
80	LIS 7.1	104	UM11.5
81	NEMS.x	105	GEFS_T1534
82	Wgrib2 version 2.0.7	106	GFS-SL
83	Ferret 7.5	107	ARDC server installation and publish
84	Nco 4.9.6	108	Tomcat
85	GNUPLOT 5.2.8	109	Xampp server installation
86	EMC_ugcs	110	Login security for ARDC server with email authentication
87	MOM_CM2M		
88	Xgrace	111	QGIS-1.4
89	Ferret 7.6.0 with GNU	112	Spyder-3 , Spyder-4
90	CFSV2 with intel 16	113	tensorflow-gpu-2.2.0 , tensorflow-gpu-1.4 , tensorflow-2.4.0
91	WRF-CHEM 4.0		
92	WRF-SCM	114	Keras-2.1.2
93	WPS 4.0	115	WRF 4.2-CRAY
94	ROMS (CRAY)	116	WRF-4.1-CRAY

APPENDIX

b) Details of various software upgrades/updates on HPC Pratyush:

S.No.	Previous Version	New Version	Remarks
1	CDT 19.08	CDT 20.03	Cray Developer To olkit (CDT) is used to install the Cray Programming Environment software and modules.
2	INTEL & Flexlm Binaries 11.14	INTEL & Flexlm Binaries 11.14	Flexlm Binaries used for management of licenses.
3	INTEL 19.0.5.281	INTEL 19.0.5.281	Intel compilers are used to produce highly optimized code for system CPUs.
4	Urika xc1.2	Urika xc1.2	Urika is an appliance that analyzes the massive amounts of data usually called big data that supercomputers collect.
5	RBH 3.1.5-2	RBH 3.1.5-2	Robinhood Policy Engin e is designed in order to perform all its tasks in parallel, so it is particularly adapted for managing large file systems with millions of entries and petabytes of data.
6	Lustre 2.7.5.11	Lustre 2.7.5.11	Lustre is a type of parallel distributed file system, generally used for large-scale cluster computing.
7	MariaDB 10.2.24	MariaDB 10.2.24	MariaDB is one of the most popular open source relational databases.
8	VSM 1.6.9	VSM 1.6.9	Versity Storage Manager (VSM) has been designed to deliver a powerful data tiering and archive management tool.
9	Cray Connector 3.0.4-3	Cray Connector 3.0.4-3	Cray connector is an intermediate software used for connection between Lustre and VSM.
10	SSA 1.8.0	SSA 1.8.0	The System Snapshot Analyzer (SSA) is support analytics technology. It collects, analyzes, and (if upload is enabled) securely reports product health and configuration or triage information.

c) Details of changes made in system on HPC Pratyush:

S. No.	Upgrades accomplished
1	XC50 from CLE6UP07 to CLE7UP01
2	PBS upgrade to19.2.5 on XC40
3	Patch upgrade in XC40 (SMW 8.0. UP04 PS34 & CLE 6.0. UP04 PS76)
4	NetApp Controller firmware upgrade on XC50 boot raid and DAL storage (Installed FN6060c & FN5977g)
5	Installed IB EDR cards in ma03 and ma04
6	TAS OS Upgrade from CentOS 6.9 to CentOS 7.7 in MA nodes
7	Installed Altair Control version 2020.2 in utility06
8	Generated and Updated BlueScale Software Support key
9	Altair Control 1 year license file updated in utility06
10	Installed Cuda Toolkit 10.2 in XC50.
11	XC50 iDRAC firmware upgrade to 2.75.75.75
12	Installed 8 Arm Nodes in XC50
13	PBS 19.2.5 mom installed on ARM Login node
14	Installed SSA-1.9.3 in xc50
15	Binary Update in all mom nodes

APPENDIX

d) Details of various software upgrades/updates on HPC Aadtiya:

S. No.	Name of Model/Library	Type of Installation
1	HRLDAS installation	New Version of library Installed
2	Reflexible	Newly installed post processing tool
3	graphviz-2.40.1	Newly installed tool
4	CDOv1.9	New Version of tool Installed
5	FFTWv2.1.5	New Version of library Installed
6	SSHPASS	Newly Installed tool
7	Catdoc v0.94.2	Newly Installed tool
8	GNUPLOT v 5.4.0	New Version of tool Installed
9	WRF v4.0	New Version of Model Installed
10	WRFDA v4.0	New Version of Model Installed
11	WRFv4.2.1	New Version of Model Installed
12	NCLv6.6.2	New Version of Library Installed
13	WPSv4.2.1	New Version of pre-processing tool
14	Wgrib2v3.0	New Version of Library Installed
15	SPECFEM3D	New Model Installed
16	WAVEWATCHIII-V6.07	New Version of Model Installed
17	R-packages calibrator, s2dverification, easy Verification, SantanderMetGroup, stormwindmodel	Newly installed R-packages
18	GSI v3.7	New Version of Model Installed
19	GRADSv2.2.1	New Version of tool Installed
20	Curl v7.75.0	New Version of Library Installed

Appendix-2

Details of the important events and meetings organized by ICMPO.

Date	Name of the Event/Meeting
6 April 2020	ICPO/ICMPO Staff meeting
16 April 2020	CLIVAR/GEWEX Monsoons Panel meeting
20-22 April 2020	SASCOF-16 and CSUF
18-22 May 2020	WCRP JSC-41 session
21 May 2020	CLIVAR/GEWEX Monsoons Panel meeting
27 May 2020	WCRP IPOs and JPS Directors meeting
4-5 June 2020	WMO Climate Coordination Panel meeting
23 June 2020	CLIVAR/GEWEX Monsoons Panel meeting
29 June 2020	WCRP IPOs and JPS Directors meeting
6 July 2020	ICPO/ICMPO Staff meeting
23 July 2020	CLIVAR/GEWEX Monsoons Panel meeting
30 July 2020	CLIVAR SSG Co-Chairs and Panel Co-Chairs meeting
7 September 2020	ICPO/ICMPO Staff meeting
9 September 2020	WCRP IPOs and JPS Directors meeting
25 September 2020	CLIVAR/GEWEX Monsoons Panel meeting
23-24 & 28 September 2020	SASCOF-17 and CSUF
16 October 2020	WMO ET-CSISO Introductory meeting
28-29 October 2020	Sixth Arctic Climate Forum (organized by NOAA)
29 October 2020	CLIVAR/GEWEX Monsoons Panel meeting
4-5 November 2020	GHHIN Annual Meeting
6 November 2020	WCRP Task Team on Regional Activities consultation meeting
	on Regional Information for Society (RIfS)
9 November 2020	ICPO/ICMPO Staff meeting
9-10 November 2020	CORDEX-MAIRS FE Meeting
17 November 2020	WCRP Task Team on Regional Activities consultation meeting
	on RIfS
20 November 2020	WCRP Task Team on Regional Activities consultation meeting
	on RIfS
23 November 2020	SASCOF Update session
30 November – 3 December 2020	Extraordinary session of WCRP JSC
7 December 2020	ICPO/ICMPO Staff meeting

APPENDIX

Date	Name of the Event/Meeting
18 December 2020	CLIVAR/GEWEX Monsoons Panel meeting
11 January 2021	ICPO – ICMPO Teleconference Staff meeting
19-20 January 2021	WMO Standing Committee on Climate Services First Meeting
21 January 2021	WCRP IPOs meeting
25 January 2021	CLIVAR Community Conference
26 January 2021	Introductory Workshop on Climate Services Toolkit for Bhutan
10 February 2021	WCRP Climate Research Forum (Oceania)
17-18 February 2021	Arctic Regional Climate Centre (ArcRCC) Network meeting
22 February 2021	VIACS Advisory Board meeting
23 February 2021	WMO Services Commission Side Meeting on Gender Balance
25 February 2021	GHHIN International Steering Committee meeting
01 March 2021	IWM-7 Training Workshop planning meeting
03 March 2021	WCRP IPOs meeting
04 March 2021	GHHIN International Steering Committee meeting
05 March 2021	WCRP RIfS Consultation meeting
08-10 March 2021	CLIVAR SSG-26
23 March 2021	Arctic Climate Forum (ACF) planning meeting
25 March 2021	SASCOF planning meeting
29-31 March 2021	IITM/WWRP/WCRP International Conference on Future directions of Sub-seasonal to Seasonal Prediction over South Asia

C.R. Sagdeo & Co.

4th Floor, "Rainbow", S. No. 110/11/11 & 16, Baner Road, Baner, Pune - 411045
Tel: 020 27295478/79, E-mail: crspune@sagdeo.com
Nagpur Office: Tel: 0712 2424634/2429338/2447757
Mumbai Office: Tel: 022 41272121, Nashik Office: Tel: 0253 2316060
www.sagdeo.com

Independent Auditors' Report

TO

THE DIRECTOR

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

Qualified Opinion

We have audited the standalone financial statements of the Indian Institute of Tropical Meteorology ("the Institute"), which comprise the balance sheet as at March 31, 2021, and the statement of Income and Expenditure, and the notes to the financial statements, including a summary of significant accounting policies and other explanatory information.

In our opinion and to the best of our information and according to the explanations given to us, **except for the possible effects of the matter(s) described in the Basis for Qualified Opinion section**, the aforesaid financial statements give a true and fair view in conformity with the accounting principles generally accepted in India, of the state of affairs of the Institute as at March 31, 2021 and the Statement of Income and Expenditure for the year then ended on that date.

Basis for Qualified Opinion

We conducted our audit in accordance with Standards on Auditing (SAs) specified by the ICAI. Our responsibilities under those Standards are further described in the Auditor's Responsibilities for the Audit of the Financial Statements section of our report. We are independent of "the Institute" in accordance with the Code of Ethics issued by the Institute of Chartered Accountants of India (ICAI) and we have fulfilled our other ethical responsibilities in accordance with these requirements and the ICAI s Code of Ethics. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our qualified opinion.

a) We draw attention to the "Schedule 5 - Fixed Assets of the financial statements regarding the fixed assets held by the Institute. The assets of the Institute are not physically verified by the management as held on March 31, 2021 and hence the report of physical verification was not made available for verification during the course of our audit. Therefore we cannot comment on any damaged and obsolete items, scrap stock and its impact on the financial statements.

However Institute's management has informed us that the physical verification of fixed assets till March 31, 2019 has been completed and approved by the Director.

The verification of fixed assets as on 31st March 2020, and 31st March 2021 is in completion stage, however due to restricted staff because of COVID-19, the work could not be completed in time.

AUDITED STATEMENT OF ACCOUNTS

Emphasis of Matter

We draw attention to the following aspects of the financial statements. Our opinion is not modified in respect of this matter.

There are ledger accounts under both assets and liabilities which are un-reconciled and needs necessary action for proper accounting. The process of passing necessary accounting entries has been initiated during the year and many such ledger accounts have been reconciled on the basis of documents available. However, there are still certain ledger accounts which remaining un-reconciled, and the processing of reconciliation should be continued.

Other Matter

There is an unresolved Land Dispute going on with National Chemical Laboratory (NCL), Pune.

Responsibilities of Management and Those Charged with Governance for the Financial Statements

The Institute's Management is responsible for the preparation of these financial statements that give a true and fair view of the financial position, financial performance and cash flows of the Institute in accordance with the accounting principles generally accepted in India. This responsibility includes the design, implementation and maintenance of internal control relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatement, whether due to fraud or error.

Those charged with governance are responsible for overseeing the Institute's financial reporting process.

Auditor's Responsibility for the Audit of the Financial Statements

Our objectives are to obtain reasonable assurance about whether the financial statements as a whole are free from material misstatement, whether due to fraud or error, and to issue an auditor's report that includes our opinion. Reasonable assurance is a high level of assurance, but is not a guarantee that an audit conducted in accordance with SAs will always detect a material misstatement when it exists.

Misstatements can arise from fraud or error and are considered material if, individually or in the aggregate, they could reasonably be expected to influence the economic decisions of users taken on the basis of these financial statements.

As part of an audit in accordance with SAs, we exercise professional judgment and maintain professional skepticism throughout the audit. We also:

- Identify and assess the risks of material misstatement of the financial statements, whether due to fraud or error, design and perform audit procedures responsive to those risks, and obtain audit evidence that is sufficient and appropriate to provide a basis for our opinion. The risk of not detecting a material misstatement resulting from fraud is higher than for one resulting from error, as fraud may involve collusion, forgery, intentional omissions, misrepresentations, or the override of internal control.
- Obtain an understanding of internal control relevant to the audit in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the Institute's internal control.
- Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by management.

We communicate with those charged with governance regarding, among other matters, the planned scope and timing of the audit and significant audit findings, including any significant deficiencies in internal control that we identify during our audit.

We also provide those charged with governance with a statement that we have complied with relevant ethical requirements regarding independence, and to communicate with them all relationships and other matters that may reasonably be thought to bear on our independence, and where applicable, related safeguards.

For & on behalf of,
C. R. SAGDEO & Co.,
Chartered Accountants
(ICAI FRN.108959W)

(CA Ajay S Joshi)
(Partner, ICAI MN.110708)
(UDIN: 21110708AAAAEV9253)

Pune
July 28, 2021

AUDITED STATEMENT OF ACCOUNTS

COMPLIANCE TO AUDIT OBSERVATIONS

OBSERVATIONS	COMPLIANCE
a) Physical Verification of Assets– Fixed Assets held by the Institute are not physically verified by the management as on March 31, 2021.	The physical verification for the year 2020-2021 is in completion stage.
b) Un-reconciled ledger accounts There are ledger accounts under both assets and liabilities which are un-reconciled and necessary action to be reconciled for proper accounting treatment on an immediate basis.	Action has already been initiated and many un-reconciled ledger accounts have been settled during F.Y. 2020-21. The process of reconciliation of remaining ledgers will be continued.
c) Land dispute with National Chemical Laboratory (NCL), Pune. Land Dispute with National Chemical Laboratory (NCL), Pune, has not been resolved.	Higher level committee has been formed including legal adviser from both the sides and IITM have already requested Sr. Superintending Engineer, CSIR, New Delhi to arrange a meeting in order to address the issue at the earliest. The decision in the matter is still awaited from NCL.

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE-8
BALANCE SHEET AS AT 31-03-2021

1. CORPUS/ CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
CAPITAL FUND	1	9096936661.20	9619468778.27
RESERVES AND SURPLUS (CORPUS)	2	13421245.90	12381866.49
EARMARKED/ ENDOWMENT FUNDS	3	13969427.41	20141657.87
SECURED LOANS AND BORROWINGS			
UNSECURED LOANS AND BORROWINGS			
DEFERRED CREDIT LIABILITIES			
CURRENT LIABILITIES AND PROVISIONS	4	97547980.76	235127781.11
INTEREST	15	47909433.00	81205217.00
2. TOTAL		**9269784748.27**	**9968325300.74**
1. ASSETS			
FIXED ASSETS	5	8499148960.59	8562309939.53
INVESTMENTS - FROM EARMARKED/ ENDOWMENT FUNDS			
INVESTMENTS - OTHERS			
CURRENT ASSETS LOANS ADVANCES ETC.	6	770635787.68	1406015361.21
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)			
3. TOTAL		**9269784748.27**	**9968325300.74**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS		**0.00**	**0.00**

AUDITED STATEMENT OF ACCOUNTS

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE-8
INCOME & EXPENDITURE ACCOUNT FOR THE PERIOD/YEAR ENDED 31-03-2021

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services			
Grants/Subsidiser	7	1292300000.00	1429130000.00
Fees/Subscriptions			
Income from Investments (Income on Invest from earmarked/endow. Funds transferred to Funds)			
Income from Royalty Publication etc.			
Interest Earned			
Other Income	10	3784002.35	10284868.33
Increase/(decrease) in stock of Finished goods and works-in-progress			
TOTAL (A)		**1296084002.35**	**1439414868.33**
EXPENDITURE			
Establishment Expenses	11	436798407.92	411645419.38
Other Administrative Expenses etc.			
Expenditure on Schemes	13	804679363.10	1085784050.29
Interest			
Depreciation during the year	14	503807688.40	483340501.69
TOTAL (B)		**1745285459.42**	**1980769971.36**
TOTAL (C) - Prior Period Expenses	13 B		
Balance being excess of Income over Expenditure (A-[B+C])			
Transfer to Special Reserve (Specify each)			
Transfer to / from General Reserve			
Previous years depreciation			
BALANCE BEING SURPLUS/(DEFICIT) CARRIED TO CORPUS/ CAPITAL FUND		**-449201457.07**	**-541355103.03**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS			

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE - 08
RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31-03-2021

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
I Opening Balances			**I Establishment expenses**		**436798407.92**
a) Cash in hand		**56000.00**	**II Payment made against various project funds**		**17520808.62**
b) Bank Balances			**III Advances to Others than schemes**		**416731.30**
i State Bank of India - Current Account -11099449733		**344976408.49**	**IV Advance to Staff**		**3763679.00**
ii State Bank of India – Vyapar Account -38222234583		**6296919.00**	**V Deposits with**		**0.00**
iii Pujnab National Bank - 0495000100169650 - Saving Account -		**293904319.75**	**VI Overheads**		**0.00**
iv State Bank of India - Project Current Account - 30128441802		**11224786.88**	**VII Funds Retained from suppliers**		**18468306.35**
v State Bank of India ENVIS - 39044342605		**1529912.60**	**VIII Statutory Liability**		**555686112.45**
II II. Grants Received		**1312300000.00**	**IX DESK**		**58086736.00**
1 High Performance Computing (HPC)	124100000.00		Recurring	16181884.00	
2 Monsoon Convection Clouds & Climate Change (Mc4)	212900000.00		Non-Recurring	950776.00	
3 IITM - Operations & Maintenance	834200000.00		Advance	40963720.00	
4 Monsoon Mission	141100000.00		Total	58096380.00	
			Less: Advance adjusted	9644.00	
III Interest Received					
Non-Plan Interest		**19154693.00**	**X IITM Operations & Maintenance**		**356709281.19**
1 CLTD	15460507.00		Recurring	354387017.19	
2 Penal Interest	10319.00		Non-Recurring	1201430.00	
3 Car Interest	12601.00		Advance	3640247.00	
4 HBA Interest	50004.00		Total	359228694.19	
5 Interest (Principle Arreares) Recd. From MSEDCL	3608424.00		Less: Advance adjusted	2519413.00	

AUDITED STATEMENT OF ACCOUNTS

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE - 08
RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31-03-2021

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
6 Computer Interest	12838.00				
			XI Monsoon Mission		**154383213.88**
			Recurring	154235838.88	
			Non-Recurring	152987.00	
			Advance	76287.00	
b Interest - On Schemes		**28754740.00**	Total	154465112.88	
1 High Performance Computer System (HPC)	4403005.00		Less: Advance adjusted	81899.00	
2 Monsoon Convection Clouds & Climate Change (Mc4)	12508776.00				
3 National Facility for Airborne Research (NFAR)	473372.00		**XII HPC**		**151922597.90**
4 Monsoon Mission II	11369587.00		Recurring	121476442.54	
			Non-Recurring	247964588.36	
IV Other Income		**3784002.35**	Advance	294639242.00	
1 Contribution to Pensioners Medical Sch.	1101600.00		Total	664080272.90	
2 Fees from Student	371145.00		Less: Advance adjusted	512157675.00	
3 Guest House charges	763217.00				
4 Licence Fees	1251119.50		**XIII National Facility for Airborne Research**		**1743313.00**
5 Maint of Colony Welfare	43379.00		Recurring	592194.50	
6 Community Hall - Welfare Charges	200.00		Non-Recurring	1187203.00	
7 Community Hall - Licence Fee	11000.00		Advance	963216.50	
8 Misc.Receipts	10024.85		Total	2742614.00	
9 Water charges	73377.00		Less: Advance adjusted	999301.00	
10 TDS refund from Income Tax Department	158940.00				
			XIV Monsoon Convection Clouds & Climate Change (Mc4)		**235642713.92**
V Any other receipts		**525754756.32**	Recurring	157805985.99	
1 Receipts from various project	10118288.16		Non-Recurring	189189725.10	
2 Funds Retained from suppliers	6333262.00		Advance	128758391.93	
3 Claims Receivable	19943131.00		Total	475754103.02	

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE - 08
RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31-03-2021

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
4 Statutory liabilities	473298005.45		Less: Advance adjusted	240111389.10	
5 Deposits with	0.00				
6 Advance to others than schemes	405714.30		**XV Claims Receivable**		**10645330.46**
7 Overheads	1039379.41				
8 Deposits from creditors	10707110.00		**XVI Deposits From Creditors**		**53763759.00**
9 Advance to Staff	3909866.00				
			XVII Interest surrendered to MoES		**79974927.00**
VI Margin money to be surrender to MoES (NFAR)		**3684000.00**			
			XVIII Penalty & Margin Money surrendered to MoES		**93330660.00**
			XIX Closing Balance		
			a Cash in hand		**40000.00**
			b Bank Balances		
			i State Bank of India -11099449733 Current Account -		**90907715.89**
			ii State Bank of India ENVIS - 39044342605		**2684644.60**
			iii State Bank of India – Vyapar Account -38222234583		**257748.00**
			iv Punjab National Bank - 0495000100169650 - Saving Account -		**226274081.75**
			v State Bank of India - Project Current Account - 30128441802		**2399770.16**
TOTAL		**2551420538.39**	**TOTAL**		**2551420538.39**

AUDITED STATEMENT OF ACCOUNTS

SCHEDULE NO. 14 - NOTES TO ACCOUNTS

The accompanying notes form an integral part of the standalone financial statements.

1 Significant accounting policies

1.1 Basis of preparation of financial statements

The Financial Statements are prepared by the Institute on the basis of historical cost convention, unless otherwise stated and on Cash System of accounting.

1.2 Fixed assets

Fixed assets stated in the Balance Sheet are at their cost of acquisition inclusive of freight, octroi and other direct and / or indirect cost in respect thereof less depreciation. Assets acquired for sponsored projects are written off as project cost.

1.3 Depreciation

Depreciation is provided on Straight line method at the following rates-

S No.	Particulars	Rates of Depreciation
1.	Building, Tube walls and Overhead water tank	1.63%
2.	Plant & Machinery, Scientific Equipment and Office Equipment	4.75%
3.	Furniture & fixtures	6.33%
4.	Computers and Workstations, Furniture and Fixtures under Schemes	16.21%
5.	Vehicles	9.50%
6.	Books	100.00%

1.4 Government grants

a) Government grants of the nature of contributions towards capital cost are shown as capital grants in the Balance Sheet.

b) Grants in respect of specific fixed assets acquired are shown as a deduction from the cost of related asset as per "Accounting Standard (AS) 12-Government grants".

c) Government grants received as per the sanction orders from the MOES and other government agencies are accounted on receipt basis.

d) Grants given to other institutions as a part of different schemes and projects are accounted on cash basis.

1.5 Employee benefits

Retirement benefits to the employees comprises of payment of gratuity, superannuation and provident fund under the approved schemes of the trust. Contribution to pension fund is made on monthly basis and accounting for Gratuity and Leave encashment is made following Cash system.

1.6 Previous year's figures have been regrouped, reclassified wherever necessary to confirm current year's classification.

For INDIAN INSTITUTE OF TROPICAL METEOROLOGY

(PROF. RAVI S. NANJUNDIAH)
(Director)
Pune
July 28, 2021

As per our Report on even date
For & on behalf of
C. R. Sagdeo & Co.
Chartered Accountants
(ICAI FRN.108959W)

(AJAY S JOSHI)
(Partner, ICAI MN.110708)
(UDIN: 21110708AAAAEV9253)



Indian Institute of Tropical Meteorology

(An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India)
Dr. Homi Bhabha Road, Pashan, Pune - 411 008, Maharashtra, India

ISSN 0250-6017