ISSN: 0250-6017

भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
Indian Institute of Tropical Meteorology

Annual Report
2021-2022

Azadi Ka Amrit Mahotsav

Top:
Instrumented UAV system for atmosphere and climate studies

Bottom left:
Atmosphere Research Testbed Central India Radar Setup

Bottom right:
View of an oceanographic vessel measuring climatically active trace gases in the Arctic

Annual Report 2021-22

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

SOCIETY

1.	Hon'ble Minister, Ministry of Earth Sciences	Ex-Officio	President
2.	Minister In-charge in the concerned Scientific Ministry, Govt. of Maharashtra	Ex-Officio	Member
3.	Secretary, Ministry of Earth Sciences, Govt. of India	Ex-Officio	Member
4.	Secretary, Department of Space, Govt. of India	Ex-Officio	Member
5.	Secretary, Department of Scientific & Industrial Research, Govt. of India	Ex-Officio	Member
6.	Principle Secretary in-charge of the Department handling MoES or concerned Scientific Ministry, Govt. of Maharashtra	Ex-Officio	Member
7.	Joint Secretary, Ministry of Earth Sciences	Ex-Officio	Member
8.	Financial Advisor, Ministry of Earth Sciences	Ex-Officio	Member
9.	Dr. Harsh K Gupta, Former Secretary, DOD/MoES	Expert	Member
10.	Dr. P.S. Goel, Former Secretary, MoES	Expert	Member
11.	Dr. Shailesh Nayak, Former Secretary, MoES and Director, NIAS, Bengaluru	Expert	Member
12.	Dr. K. Radhakrishnan, Former Chairman, ISRO, Bengaluru	Expert	Member
13.	Dr. Satheesh Reddy, Secretary, Department of Defense R&D	Expert	Member
14.	Dr. K.J. Ramesh, Former Director General, IMD	Expert	Member
15.	Director, IITM	Ex-Officio	Member Secretary

GOVERNING BODY

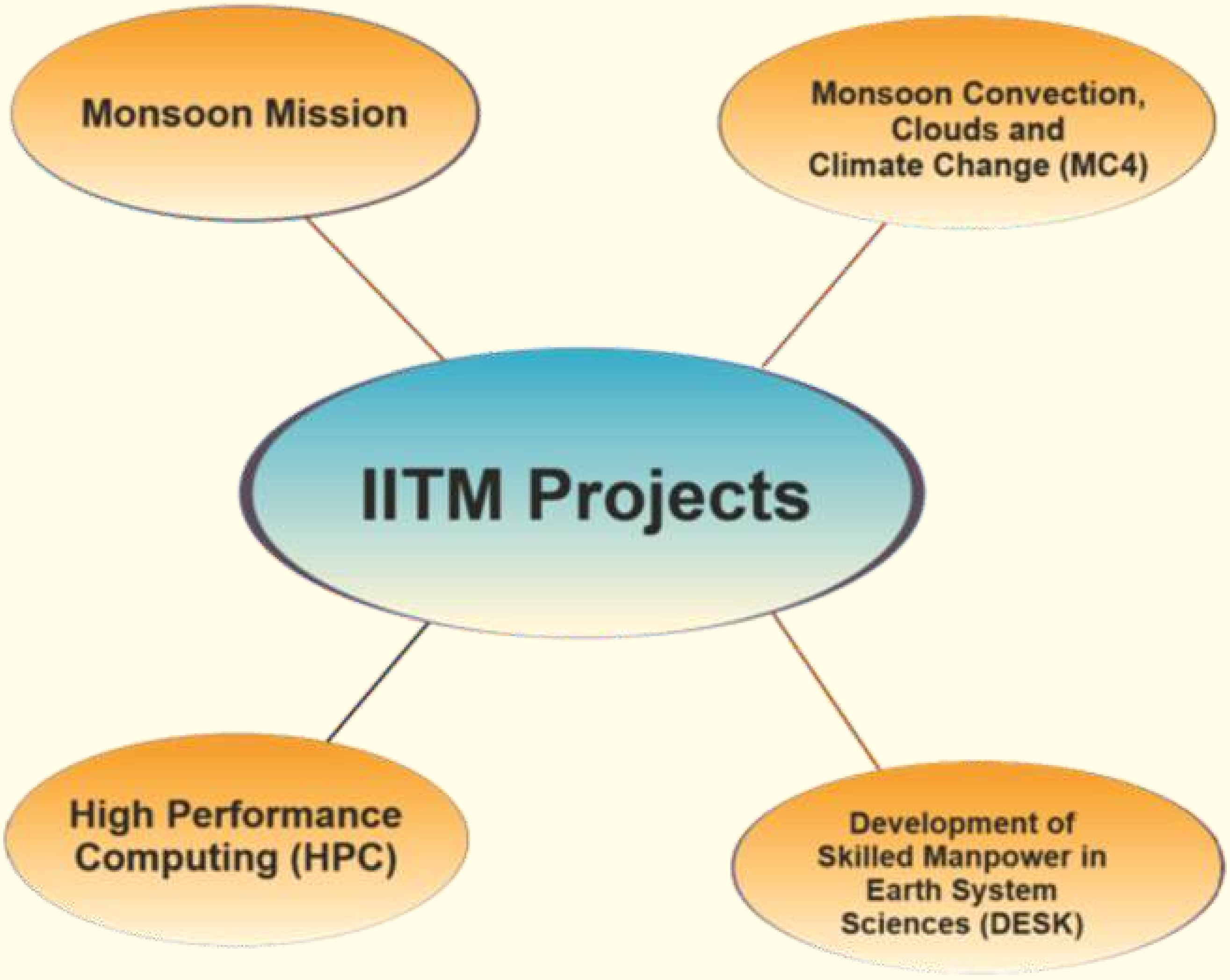
1.	Secretary, Ministry of Earth Sciences, Govt. of India	Ex-Officio	Chairperson
2.	Joint Secretary, MoES	Ex-Officio	Member
3.	Financial Adviser, MoES	Ex-Officio	Member
4.	Chairperson, RAC-IITM	Ex-Officio	Member
5.	Scientist G/H, MoES working as Program Head, IITM	Ex-Officio	Member
6.	Director, IITM	Ex-Officio	Member
7.	Senior-most Scientist, IITM	Ex-Officio	Member
8.	Representative of NITI Aayog looking after the work of MoES	Ex-Officio	Member
9.	Prof G.S. Bhat, CAOS, IISc, Bengaluru	Expert	Member
10.	Dr. M. Mohapatra, DGM, IMD, New Delhi	Expert	Member
11.	Dr. A.K. Mitra, Head, NCMRWF	Expert	Member
12.	Dr. V.K. Dhadwal, Former Director, IIST/ISRO	Expert	Member
13.	Head/In-charge of Administration, IITM	Ex-Officio	Member Secretary

FINANCE COMMITTEE

1.	Financial Adviser, Ministry of Earth Sciences	Ex-Officio	Chairperson
2.	Scientist G/H, MoES working as Program Head, IITM	Ex-Officio	Member
3.	Director, IITM	Ex-Officio	Member
4.	Head/In-charge of Administration, IITM	Ex-Officio	Member
5.	Director, NCPOR	Ex-Officio	Member
6.	Ms. Madhulika Sukul, Former Secretary to Govt. of India & Controller General of Defense Accounts.	Expert	Member
7.	Ms. Neeru Abrol, CA, Former CMD, National Fert. Ltd.	Expert	Member
8.	Senior Finance Officer, IITM	Ex-Officio	Member Secretary

RESEARCH ADVISORY COMMITTEE

1.	Dr. L.S. Rathore, Former DG, IMD	Expert	Chairperson
2.	Scientist G/H, MoES working as Program Head, IITM	Ex-Officio	Member
3.	Director, IITM	Ex-Officio	Member
4.	Prof. G.S. Bhat, CAOS, IISc, Bengaluru	Expert	Member
5.	Dr. M. Mohapatra, DGM, IMD, New Delhi	Expert	Member
6.	Dr. A.K. Mitra, Director, NCMRWF	Expert	Member
7.	Dr. V.K. Dhadwal, Former Director, IIST/ISRO	Expert	Member
8.	Prof. V. Ramaswamy, Director, GFDL, NOAA, USA	Expert	Member
9.	Prof. Rama Govindarajan, (ICTS-TIFR)	Expert	Member
10.	Prof. Anil Kulkarni, Divecha Centre for Climate Change, IISc, Bengaluru	Expert	Member
11.	Dr. Rajeev, Director, SPL-VSSC	Expert	Member
12.	Prof. U.C. Mohanty, IIT-Bhubaneswar	Expert	Member
13.	Senior-most Scientist, IITM	Ex-Officio	Member Secretary

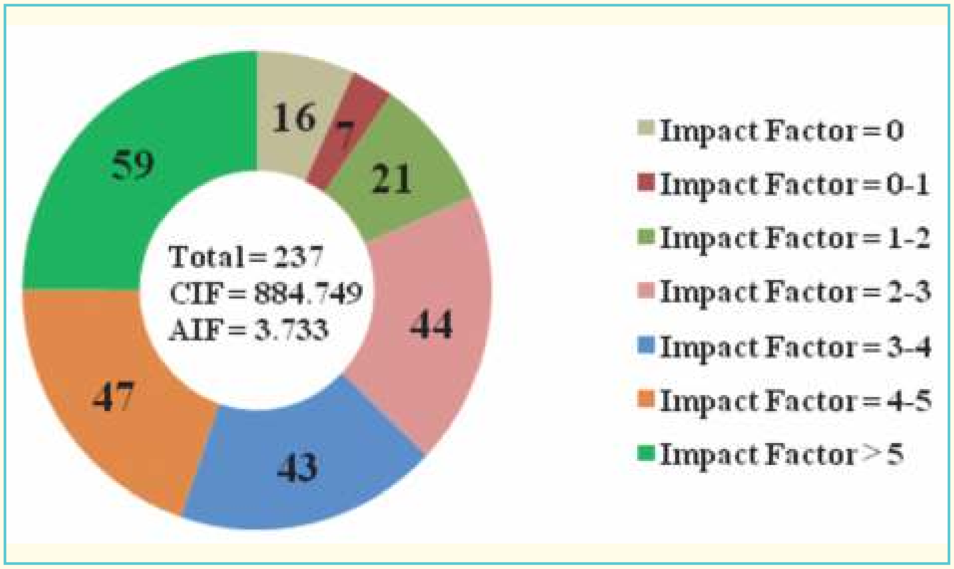


Organisational Flow Chart of R&D Activities

CONTENTS

IITM Publications at a Glance

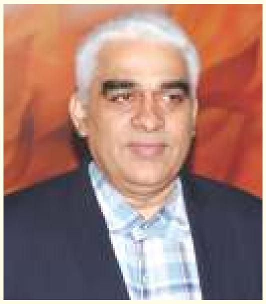
Growth of IITM publications in peer-reviewed journals since 2000



Impact Factor wise distribution of IITM publications during the year 2021-22

Summary of Publications during the year 2020-21	
Total No. of papers published in Journals	237
Papers with Impact Factor	221
Papers without Impact Factor	16
Cumulative Impact Factor	884.749
Average Impact Factor	3.733

Foreword



I am pleased to present the annual progress and activities of the Indian Institute of Tropical Meteorology (IITM), Pune during the financial year 2021-22. With the vision to be a Global Centre of Excellence through basic research and development (R&D) on all aspects of the Tropical Atmosphere-Ocean System required to improve Weather and Climate Forecasts, IITM has constantly strived to enhance India's R&D capabilities to address cutting-edge scientific problems in Tropical Meteorology and Atmospheric Sciences, including the dynamics, variability and predictability of monsoon on different space and time-scales, tropical weather systems and climate related processes, physics and dynamics of tropical and monsoon cloud systems, atmospheric electricity, atmospheric boundary layer processes, aerosol-cloud-precipitation interactions, air-quality research and forecasting, global and regional climate change and also enabled the generation of global climate change projections from India for the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (AR6) which was released in 2021. The roadmap for achieving the vision of IITM has relied on continuously enhancing the following three key components of the Institute ***(a)*** *Focused Science Plan* ***(b)*** *Infrastructure* ***(c)*** *Human Resource Development*.

I am happy to place on record the excellent progress made by IITM during 2021-22, by highlighting below a few significant research outcomes, activities, and accomplishments over the year. The Executive Summary in the Annual Report provides a quick peek into some noteworthy R&D contributions under different projects.

- Publication of 237 research papers in standard National and International journals.
- The Centre for Climate Change Research (CCCR), IITM, Pune successfully developed India's first Earth System Model (IITM-ESM) which participated in the Coupled Model Intercomparison Project – Phase 6 (CMIP6) and contributed to the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) released on 9 August 2021. IITM scientists contributed as Lead Author, Coordinating Lead Author and Chapter Scientist, to the IPCC AR6 WG1 report in *Chapter 4*: *Future Global Climate: Scenario-based projections and near-term information, Chapter 8*: *Water Cycle Changes, and Summary for Policy Makers (SPM).*

- Utilizing the CMIP6 data and IITM-ESM simulations, several high-quality scientific papers were published covering various topics of the science of climate change, such as monsoons, Indian Ocean circulation, temperature and precipitation extremes, floods and droughts, soil moisture, drivers of climate change e.g., greenhouse gases (GHG), aerosols, climatically sensitive trace gases. The IITM-ESM CMIP6 data has been archived on the Earth System Grid Federation (ESGF) portal and has recorded more than two lakh downloads.
- Under the Monsoon Mission, R&D efforts are focussed on improving the forecast of monsoon on different space-time scales, and extreme weather events by enhancing the prediction skill of dynamical models. A multi-physics multi-model ensemble (MPMME) based new extended range prediction system (ERP) has been developed. Preliminary results using the MPMME show improvments in predicting the large-scale low variability signal and weekly mean rainfall up to 3 weeks lead, over its predecessor. For the short and medium scale, the GEFS T1534 based ensemble forecasts provided accurate forecast of ensemble tracks, strike probability, intensity and landfall for the tropical cyclones that were seen over the Arabian Sea and the Bay of Bengal. Efforts are being made to further increase the resolution of GFS/GEFS models to improve the short to medium range prediction skills. The next generation IITM GFS (Tco1534) at ~6 km resolution model has been developed. MoES approved the International Monsoons Project Office (IMPO) at IITM, which will function as a global hub of monsoon research coordination. The IMPO was formally launched by the Honourable Minister of Earth Sciences Dr. Jitendra Singh on 28 February 2022.
- IITM has developed a decadal prediction system (IITM-DPS), which is being further improved by incorporating new tools and strategies.
- IITM has established and manages three Atmosphreric Research Testbeds (ART) across India. Of these three sites, the Orographic-ART at Mahabaleshwar (High Altitude Cloud Physics Laboratory (HACPL)) was established in the past. The Urban-ART focused on the Mumbai Metropolian region, a network of automatic rain gauges (MESONET) is established in collaboration with IMD to assisting the flood warning system in Mumbai. During 2021-22, a new Central India ART facility in Madhya Pradesh was initialised. The facility will provide important observations for better understanding on processes related to convection, clouds and land-atmosphere interactions in the core

monsoon zone region. Physical infrastructure such as civil works (boundary wall and entrance gate), laboratories, and electrical works (HT sub-station) are underway. An observational campaign during monsoon (01 June - 30 September 2021) with the C-band radar was conducted to collect polarimetric data on 3-D structures of convective and microphysical properties in the monsoon core zone for the first time.

- IITM has initiated a new scientific activity - Lower Atmospheric Research using Unmanned aerial System facility (LARUS) to observe the lower atmosphere using unmanned air vehicles (UAVs). After obtaining necessary permissions from Government to operate UAVs, IITM conducted UAV test flights for research purposes for the first time in the country.
- IITM has developed a new Air Quality Early Warning System (AQEWS) for the Delhi NCR region, which was handed over to the India Meteorological Department (IMD) for operational use. A decision support system for air quality management in Delhi has also been developed and operationalised.
- A high-resolution emission inventory mapping the local sources of air pollution in the Pune Metropolitan Region (PMR) for 2019-20 has been published. It maps pollution sources in each 400m x 400m grid of PMR for eight major pollutants, namely, $PM_{2.5}$, PM_{10}, NO_x, CO, SO_2, BC, and HC, from 26 different local sources of air pollution.
- The Institute is actively involved in human resource development and capacity building in weather and climate sciences. Under the DESK programme, continuous efforts are being made to develop trained human resources in Earth System Sciences.
- Seven students graduated with a PhD, while eleven have submitted their doctoral thesis during the year. More than 150 students of different UG/PG courses in science and engineering from various colleges, universities and institutions across the country were provided research guidance and facilities for their short-term project/internship under the guidance of IITM scientists through remote/online or on-campus mode.
- IITM organised several Azadi ka Amrut Mahotsav (AKAM) seminars / events, National and International virtual workshops, conferences, meetings, and short-term training programmes on different aspects of weather and climate sciences during the year. IITM and IISER (Indian Institute of Science Education and Research, Pune) organized

a special Azadi ka Amrut Mahotsav (AKAM) seminar entitled 'Tribute to Professor Syukuro Manabe' to celebrate the ground breaking contributions by Nobel Laureaute Professor Syukuro Manabe in Climate Science. The 2021 Nobel Prize in Physics was shared by Prof. Syukuro Manabe, Prof. Klaus Hasselmann and Prof. Giorgio Parisi. The AKAM seminar talk was delivered by Dr. R. Krishnan.

- IITM hosted the International Commission on Clouds and Precipitation (ICCP) Conference in August 2021 (online mode). The conference was attended by hundreds of experts from around the world and had sessions on various aspects of clouds and precipitation over five days.

All these advances and achievements have resulted due to the collective efforts of our scientific, administrative, technical, and support staff, including PhD students, postdoc researchers and project scientists. I extend my heartiest congratulations and sincerely thank the entire IITM family for the excellent contributions and dedicated efforts.

I express my deep gratitude to the Ministry of Earth Sciences, Government of India, for providing steady financial and advisory support, as well as the Society, Governing Body, Finance Committee, and Research Advisory Committee of the Institute for extending unwavering support and guidance. I would also like to thank the Ministry of Science and Technology, the Ministry of Environment, Forests, and Climate Change, and the Indian Space Research Organisation for continued support and sponsorship of several significant scientific projects. The contributions of our National and International collaborators through scientific and technical cooperation are also gratefully acknowledged.

I firmly believe that IITM will continue to provide strong scientific leadership in Weather and Climate Sciences at the National and Global levels, with enhanced scope, capabilities and expertise, in the years to come.

R. Krishnan
Director

Executive Summary

During the financial year 2021-22, the Indian Institute of Tropical Meteorology (IITM) made considerable research contributions in different areas of atmospheric sciences, meteorology, monsoon – predictions and variability and climate change. During this period, scientists at the Institute published 237 papers in peer-reviewed journals with a Cumulative Impact Factor of 884.749 and the Average Impact Factor of 3.733. Some of the most important research contributions and achievements of the year 2021-22 are summarised below:

Monsoon Convection, Clouds and Climate Change (MC4)

Centre for Climate Change Research (CCCR)

With the help of the latest version of the IITM Earth System Model (IITM-ESM) developed by CCCR scientists at IITM, India has contributed significantly to the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC Ar6) for the first time, which was published on 9 August 2021. IITM scientists contributed to the IPCC AR6 WG1 report in Chapter 4: Future Global Climate: Scenario-based projections and near-term information (Dr. P. Swapna, Lead Author), in Chapter 8: Water Cycle Changes (Dr. R. Krishnan, Coordinating Lead Author and Dr. T.P. Sabin, Chapter Scientist) and Summary for Policy Makers (Dr. R. Krishnan, Drafting Author). Also, CCCR has archived IITM-ESM CMIP6 data on a portal which has recorded more than two lakh downloads by users across the globe. Further efforts are on to develop the next version of IITM-ESM by incorporating an interactive land-ice model and a new spectral dynamical core.

Analysis of 120-year historical records suggested a weakening of the relationship between the South Asian Summer Monsoon (SASM) and the Atlantic Multidecadal Oscillation (AMO) in recent decades. It is found that enhanced Indian Ocean warming and weakened North Atlantic Subtropical High are two prime factors weakening AMO-SASM association. A better understanding of the AMO-SASM teleconnection would help improve the projected warming of the Indian Ocean and the Atlantic in a warming world.

An investigation using IITM-ESM CMIP6 experiments and observed datasets provides a better understanding of the mechanism behind the increasing frequency of extremely severe cyclonic storms (ESCS) in the North Indian Ocean (NIO). It is found that an anomalous increase in potential intensity and ocean heat-content with a higher increase during May and weakening summer monsoon circulation has led to increasing ESCS with peak frequency during May. Also, the projected increase in potential intensity and weakening wind-shear over the 21st century from the ITM-ESM scenario MIP experiment revealed that ESCS may increase further in NIO.

ECHAM6-HAMMOZ model simulations and satellite observations suggested an outflow of Asian biomass burning carbonaceous aerosols into the Upper Troposphere and Lower Stratosphere (UTLS) during the spring season. Model simulations showed that the greatest transport of biomass burning carbonaceous aerosols into the UTLS occurs from the Indochina and East Asia region by deep convection over the Malay Peninsula and Indonesia.

Year-long observations of nitrogen dioxide (NO_2) and formaldehyde (HCHO) over Pune city using the Multi-Axis Differential Absorption Spectroscopy (MAX-DOAS) technique suggested that a lower boundary layer height during October-February leads to higher concentrations of trace gases. Back-trajectory analysis showed that air parcels coming from regions of biomass burning increased the concentrations in Pune. Comparing these observations with previous reports over India revealed that both HCHO and NO_2 concentrations were lower in Pune compared to the other large cities in India.

Studies on carbon sequestration of forest environments were carried out at Kaziranga National Park (KNP) in Assam and Pichavaram Mangrove Forest (PVM) in Tamil Nadu. It is observed that the KNP soils emitted significantly more CO_2, compared to other Indian forests. Also, the KNP ecosystem released more carbon than it absorbed during the observational period from 2016 to 2018. It is also observed that the diurnal pattern of rainfall significantly contributed to the carbon uptake process. A comparison of photosynthetic carbon uptake and evapotranspiration processes at KNP and PVM showed that the PVM ecosystem provided stronger sensible heat flux than latent heat flux to the atmosphere throughout the year and thus behaved like a semi-arid ecosystem.

Potential benefits of atmospheric CO_2 observations and satellite XCO_2 in constraining regional CO_2 fluxes over India were investigated. It was observed that the addition of 17 newly proposed ground-based stations over India into the inversion helped significantly reduce the temperate Eurasian terrestrial flux uncertainty. Combining the data from these newly proposed stations over India with the global observations from select 80 global ground-based CO_2 observation stations could result in a 70% reduction in the annual mean uncertainty for estimating Indian terrestrial fluxes.

Analysis of variations in daily field-scale soil moisture measured using IITM-COSMOS, satellite, reanalysis and model products during 2017-2020 revealed the presence of biweekly and low-frequency intra-seasonal variations in the field-scale soil moisture, which are linked to the dominant modes of Indian summer monsoon sub-seasonal variability.

The precipitation isotopic records from the Andaman Islands were investigated to understand how the precipitation isotopes respond to monsoon rainfall over a varying spatial domain ranging from a local scale to a continental scale. Analysis of moisture transport parameters revealed that the precipitation isotopes are more sensitive to the moisture fluxes than the rainfall amount, and the amount effect was observed to decrease with an increasing spatial domain.

Physics and Dynamics of Tropical Clouds (PDTC)

CAIPEEX Phase-IV ground-based observations were continued at Solapur and Tuljapur sites, except for the C-band radar and radiosonde. Experiments and direct numerical simulations at the Fluid Dynamics Laboratory are being conducted. Direct Numerical Simulations of turbulent boundary layers are also being carried out.

An investigation of characteristics of CCN activation and cloud microphysics during the northeast monsoon onset provided evidence for an enhanced concentration of supercooled drops above the freezing level up to temperatures below −12°C. The secondary ice production was evident through observations of graupel and snow particles. Also, heavy aerosol loading near the cloud base leads to enhanced mixed-phase processes in these clouds.

The performance of different microphysics schemes (WDM6, MORR and SBMF) in simulating various rainfall-types during the lifecycle of a tropical continental mesoscale cloud cluster (observed with Solapur C-band radar) was evaluated. With increasing complexities, the microphysics schemes were found to represent the rainfall-types closer to radar observations. The accumulated rainfall derived from radar observations indicated substantial differences in the observed and simulated rainfall patterns.

A study of surface raindrop size distributions over a rain shadow region showed that rainfall for five dominant clusters has distinct vertical features in polarimetric and micro rain radars.

A visibility network analysis on a field-experimental dataset for exploring convective atmospheric surface layer flows demonstrated that temperature intermittency is related to strong nonlinear dependencies in the temperature signals.

Analysis of the Lightning Location Network data showed a strong association between cloud electrification and precipitation intensity. Further, it is shown for the first time that a larger cloud electric field remains associated with larger raindrops at the Earth's surface. A mathematical framework has also been developed to support the observations. It has also been shown that a cloud electric field can modify the rain rate at the Earth's surface by enhancing the growth of raindrops.

Winter Fog Experiment (WiFEX) – a multidisciplinary/multi-institutional field experiment conducted at IGI Airport, New Delhi – indicates that the formation of optically thin fog before and after the dense spell is modulated tightly by the large mass of water-soluble inorganic ions where these ions hydrate in sub-saturated conditions. One of the important findings from numerical modelling suggested that the WRF model cannot simulate the realistic hydration of the water-soluble inorganic ions in sub-saturated conditions. Therefore, a new 21 ensemble probability forecast system for fog has been developed and operationalised. Also, a new technique has been developed to implement the high-resolution land surface data assimilation to increase the performance of WRF model for improving fog prediction.

In collaboration with NCAR, USA, IITM has developed an integrated technology for Air Quality Early Warning System (AQEWS) for the Delhi NCR region. The frozen version of AQEWS was handed over to IMD in June 2021 for operational use. Further, a decision support system for air quality management in Delhi has also been developed and implemented operationally in October 2021.

Atmospheric Research Testbeds (ART)

IITM is establishing an observational facility Atmospheric Research Testbed (ART) in central India near Bhopal to better understand processes related to convection, clouds and land-atmosphere interactions in the core monsoon zone region. Work is in progress to establish the necessary infrastructure for ART.

A dual polarisation C-band Doppler weather radar was installed and commissioned in June 2021. An observational campaign with the C-band radar was conducted during monsoon 2021 to study 3-D structures of convective and microphysical properties in the monsoon core zone for the first time.

An ice parameterisation scheme is developed using ice nuclei and aerosol measurements carried out over the High-Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar. A chamber experiment was conducted to study the CCN activation fraction of aerosols emitted from different sources. An observational campaign was conducted at HACPL to better understand aerosol-cloud-precipitation interactions.

An automatic rain gauge network (MESONET) is established in collaboration with IMD for collating data from Municipal Corporation for Greater Mumbai (MCGM) to assist the flood warning system. MESONET provides real-time rainfall measurements, which are disseminated through real-time online rainfall data portals and mobile apps. Radio Frequency (RF) noise surveys were conducted for all four radar sites in Mumbai Metropolitan Region as a part of the country's first urban weather radar network.

Diurnal variations of convective storms (CSs) during monsoon season were investigated using ground-based X-band radar and reanalysis data over the complex mountain terrain of the Western Ghats. A prominent bimodal distribution in the CS occurrence is observed along the coastal regions, and a weak bimodal distribution on the mountain peak. The afternoon peak is stronger over high altitude regions, whereas the early morning peak is stronger over coastal regions.

A diagnostic study of the linkages between Eurasian winter snow and the spatial distribution of the following summer monsoon rainfall over India suggested that their association features a tri-polar pattern of significant negative-positive-negative correlations over India's northern, east-central and peninsular regions. Possible pathways for the physical mechanism underlying the snow-monsoon connection are proposed.

The Ministry of Civil Aviation (MoCA) has issued a conditional exemption to IITM for conducting beyond the visual line-of-sight UAV experiments for atmospheric research. IITM is the first institution in the country to obtain such permission for using UAVs for atmospheric research. The Airport Authority of India (AAI) and the Indian Air Force (IAF) have also given necessary permissions in this regard. Installation and demonstration of UAV systems was commissioned, concerned personnel were trained for handling UAVs, field campaigns were conducted at two different locations, and UAV flights for research purposes were executed for the first time in India.

Metropolitan Air Quality and Weather Services (MAQWS)

A high-resolution emission inventory mapping the local sources of air pollution in the Pune Metropolitan Region (PMR) for 2019-20 has been published. It maps pollution sources in each 400 m x 400 m grid of PMR for eight major pollutants, namely, $PM_{2.5}$, PM_{10}, NO_x, CO, SO_2, BC, and HC, from 26 different local sources of air pollution.

A source apportionment study of $PM_{2.5}$ to identify the emission characteristic from different sectors of Delhi during winter revealed that incineration contributes about 19% at Ayanagar and 18% at Okhla to $PM_{2.5}$ in Delhi. Metal industries in Okhla contribute about 19% to $PM_{2.5.}$ Considerable secondary aerosol contribution (15-24%) indicates that gaseous emissions must be reduced to improve air quality.

The SAFAR operational model prediction skill for four cities was tested for a year (2019-20) which was found to be reasonable. The normalised gross error of $PM_{2.5}$ for Delhi was found to be the highest (35%), whereas it is ~13-20% for other cities.

Biomass burning was found to contribute up to 58% of black carbon (BC) mass over Satopanth glacier in the central Himalayas, with lower contribution during June and higher during May. Concentration weighted trajectory (CWT) analysis showed that the air masses from Indo-Gangetic Plains (IGP) were responsible for the majority of transported BC in July and August months (up to 65%) and partially in September (up to 40%).

The impact of urbanisation over the Mumbai Metropolitan Region from 2018 to 2050 was assessed using projected land-use/land-cover change in the WRF model. Simulation results showed that the average maximum (minimum) surface air temperature of the region would increase by 1.41°C (1.27°C) due to future urbanisation. However, if the mitigation strategy is adopted, this growth can be restricted to 0.69°C (0.92°C).

The ratio of isoprene to benzene (anthropogenic exhaust tracers) was used to quantify the contributions of biogenic and anthropogenic isoprene. The contributions of biogenic sources to isoprene were in the ranges of ~40-65% in winter and ~56-85% in the pre-monsoon season during daytime (11-17 hrs, IST).

Climate Variability and Prediction (CVP)

A series of decadal hindcast runs was carried out every five years, starting from 1982 till 2017. The skill of decadal hindcasts was assessed based on the available decadal hindcasts from CMIP5/CMIP6 models and IITM's decadal prediction system (IITM-DPS).

Post-processing tools for extracting IITM-DPS atmospheric decadal outputs have been developed. A new initialisation strategy suppressing the initial shocks in coupled models for seasonal/decadal prediction is also developed.

An investigation of the variability of summer monsoon rainfall over the Western Ghats using century (1900-2010) long observed rainfall data revealed significant decadal variability (at 90% confidence level) in rainfall over the Western Ghats, which is higher compared to that in most other regions of India. Such findings may add value in understanding the evolution of the Western Ghats ecosystem and developing decadal prediction systems.

Examining the impact of meridional displacement of the Asian jet on the Indian summer monsoon (ISM) rainfall from 1985 to 2019 in observations and CFSv2 hindcast showed the meridional displacement/loading strength of the summer Asian jet was robust over the East Asian region in the observations. In contrast, the signals were strong over both the West and East Asian regions in CFSv2. It is suggested that the teleconnections of the Asian jet variability and ISM rainfall are over-dependent on ENSO in the model, which might limit its prediction skill, not only over India but also for the entire Asian region.

Discussing the latest knowledge and future directions for Indian Monsoon teleconnections, a new book, 'Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond' is published with Elsevier.

Monsoon Mission

Short and Medium Range

The convective nature and predictability of extreme precipitation during August 2018 and 2019 over Kerala, which led to widespread flooding, were investigated using three state-of-the-art global prediction systems: the NCEP-based IMD's operational Global Forecast System (GFS), the ECMWF Integrated Forecast System (IFS), and the Unified Model-based NCUM being run at NCMRWF. Evaluation of the deterministic and ensemble rainfall predictions revealed systematic differences in rainfall over the Western Ghats and the coastline. The ensemble predictions were more skilful than the deterministic forecasts.

An evaluation of the performance of the high-resolution (~12 km) Global Forecasting System (GFS) model in capturing the transition of low-pressure areas to monsoon depressions revealed that it has good fidelity in simulating the dynamical parameters, such as the potential vorticity associated with L2D cases but shows lesser fidelity for RL cases.

Another investigation involving process-based analyses of CFSv2 simulations revealed that the model has a significant deficiency in capturing the energy conversions and circulation-heating feedback processes, leading to lesser fidelity of the model in capturing the organisation and intensification of Boreal Summer Intra-Seasonal Oscillation.

Replacing the RSAS scheme by SMCM parameterisation in CFSv2 showed essential improvements in different large-scale features of tropical convection. Further calibration of SMCM using DYNAMO radar observations improved many aspects of the mean state climate compared to RSAS and SMCM. This has resulted in significant improvement in the rainfall probability distribution function over the global tropics.

Satellite and reanalysis data were used to understand the processes involved during the genesis of a tropical cyclone and the changing status of tropical cyclones over the north Indian Ocean. Madden-Julian oscillation and equatorial Rossby wave were found to facilitate intense convection through moisture supply at mid-level and vorticity at lower levels. A climatological study of tropical cyclones over the north Indian Ocean during 1982-2019 (38 Years) showed a significant increasing trend in the intensity, frequency, and duration of cyclonic storms (CS) and very severe CS over the Arabian Sea. There is a 52% increase in the frequency of CS during the recent epoch (2001-19) in the Arabian Sea, while there is a decrease of 8% in the Bay of Bengal.

Sub-seasonal Scale

Forecasts for summer monsoon 2021 were carried out on an experimental basis using a multi-physics strategy in CFSv2. It has been shown that the multi-physics CFS could capture significant sub-seasonal features of the 2021 monsoon.

Experiments with multi-physics schema in CFSv2 for sub-seasonal prediction of Indian summer monsoon demonstrated appreciable improvements over its predecessor. It is expected that the multi-physics approach could exploit individual physical schemes' strengths to yield better sub-seasonal forecasts.

A newer version of the extended range prediction system (ERP) based on a multi-physics multi-model ensemble (MPMME) is developed. This new version, seamless in resolution, includes coupled climate forecast system version 2 (CFSv2) and an atmospheric global forecast system forced with real-time bias-corrected sea-surface temperature from CFSv2. The preliminary results demonstrate appreciable improvements in its prediction skill.

The governing dynamics behind the northward propagation of convection in the intraseasonal timescale over the Arabian Sea and the Bay of Bengal during the summer monsoon was examined using the vorticity budget equation. Results have helped devise a new pathway for improving model performance for simulating intraseasonal variability and summer monsoon.

The relationship between the intra-seasonal fluctuations of ISMR with the phase propagation and amplitude of MISO and MJO was examined. It is found that long active spells predominantly occur when either MISO or MJO or both are active, and a long break spell occurs when both (MISO & MJO) or at least one (MJO/MISO) is feeble.

Seasonal Scale

The currently operational multi-physics multi-model ensemble (MPMME) version 2 (CFSVv2) has been upgraded to the new MMCFS version 3 (CFSv3). The new model has several upgrades, including the ocean model upgraded to MOM6 and the sea-ice model upgraded to the CICE5 model. Using the semi-Lagrangian dynamical core has allowed higher atmospheric model resolutions while keeping the time stepping the same.

Sensitivity experiments were performed with CFSv2 using different microphysics and convective parameterisation schemes. Results revealed that, compared to ice-free runs, the ice-phase microphysics parameterisation scheme better simulates the active and break composites of the ISMR.

An ensemble-based flow-dependent data assimilation system has been developed and integrated into the operational CFSv2 coupled model. Improving the accuracy of the ocean and atmospheric initial conditions has further enhanced the prediction skill of CFSv2. The IITM-UMD weakly coupled analysis (IWCA) initial conditions used in the new system have increased ISMR prediction skill, with a gain of one-month predictive lead time.

Simulation of lightning flash counts based on various lightning parameterisation schemes and Lightning Potential Index (LPI) over Maharashtra in the WRF model were evaluated. The robustness of DLP2 is highlighted, indicating a promising future for the operational forecast of lightning prediction.

A comparison study suggested that MMCFS has an advantage over SINTEX-F2 in predicting ISMR. At a longer lead time, ENSO indices are better in MMCFS than in SINTEX-F2. Also, MMCFS has an advantage, over SINTEX-F2, due to better predictability of SST and vertical wind shear in several parts of the Indo-Pacific domain.

Dynamical downscaling of seasonal reforecasts of the Indian Monsoon in CFSv2 significantly reduces most of the systematic rainfall biases over the Indian region.

A systematic examination of the convective auto-conversion and microphysical auto-conversion coefficients using sensitivity experiments in the CFSv2 model revealed that the mean and intra-seasonal features of MISO and MJO could be improved with a proper combination of convective and microphysical auto-conversion. Such a combination may be useful in improving the long-standing problem of climate models concerning to the ratio of convective to total rainfall.

International Monsoon Project Office (IMPO)

MoES has approved hosting of the International Monsoons Project Office (IMPO) at IITM, initially for five years, with effect from 30 July 2021. A joint effort by WMO and IITM, IMPO functions as a global hub of monsoon research coordination, covering all monsoon regions of the world and spanning weather to climate change time scales. It is India's contribution to WMO's monsoon research coordination activities under WWRP and WCRP. During the year, IMPO contributed extensively to supporting various monsoon research activities of WMO's WWRP and WCRP and CLIVAR/GEWEX Monsoons Panel.

High-Performance Computing Services

Adequate efforts were made to run both the HPC systems (Aaditya and Pratyush) at IITM and maintain uptime, resolving users' issues within the stipulated time frame, even during the lockdown period. User support was made available through email and a web-based system for a one-stop solution. Emergency services were made available over the phone, even on non-working days and national holidays.

Capacity Building and Human Resource Development

The Institute is actively involved in human resource development and capacity building in weather and climate sciences. Under the DESK programme, continuous efforts are being made to develop trained human resources in Earth System Sciences. Such efforts include 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 specialised short-term training programmes.

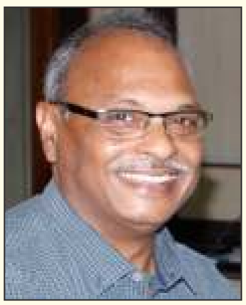
Seven students graduated with a PhD, while eleven more have submitted their doctoral thesis during the year. The M.Sc. and M.Tech. Programmes in Atmospheric and Space Sciences are continued in collaboration with S.P. Pune University, Pune. More than 150 students of different UG/PG courses in science and engineering from various colleges, universities and institutions across the country were provided research guidance and facilities for their short-term project/internship under the guidance of IITM scientists through remote/online or on-campus mode. IITM organised 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.

SWACHHATA PAKHWADA CELEBRATIONS

Inaugural Address by
Dr. M. Rajeevan
Secretary, MoES

Webinar by
Dr. Pravakar Mishra
NCCR

Webinar by
Dr. O.N. Shukla
IITM



Webinar by
Dr. Kaushar Ali, IITM

Webinar by Dr. Ojaswini Valsangakar
Medical Consultant, IITM

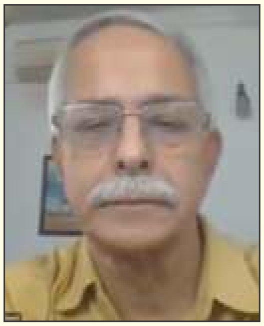
Different Activities under Swachhata Pakhwada Celebrations at IITM, Pashan Campus

HINDI PAKHWADA CELEBRATIONS

Glimpses of Hindi Play 'वासांसि जीर्णानि'

VIGILANCE AWARENESS WEEK

Webinar by
Mr. Apendu Ganguly
Retd. Director
Ministry of Defence



Webinar by
Mr. Mukesh Chaturvedi
Retd. Director
DoP&T

Webinar by
Dr. V.G. Anand
Prof. & Chief Vigilance Officer
IISER, Pune

AZADI KA AMRIT MAHOTSAV

Fit India Freedom Run 2.0

Health Check-up Campaign at the Institute

COVID-19 Vaccination Campaign at the Institute

AZADI KA AMRIT MAHOTSAV: IITM SPECIAL LECTURE SERIES

Dr. J.R. Kulkarni
IITM, Pune

Dr. Milind Mujumdar
IITM, Pune

Dr. A.A. Deo
IITM, Pune

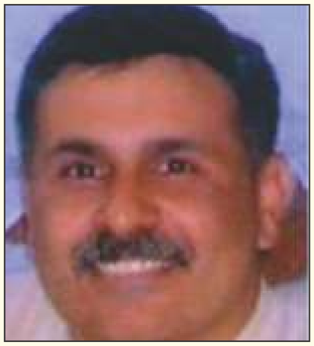
Dr. Medha Deshpande
IITM, Pune

Dr. Swati Samvatsar

Dr. S.D. Pawar
IITM, Pune

Dr. R. Krishnan
IITM, Pune

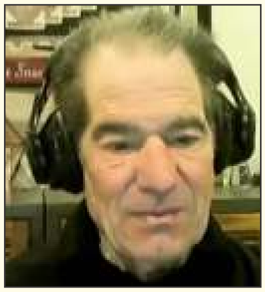
Prof. S. N. Patil
KBC-NMU, Jalgaon

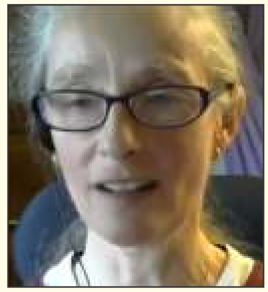


Mr. Shirish Kanitkar

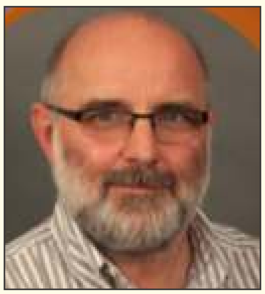
LECTURE SERIES ON CLOUD AND PRECIPITATION PHYSICS AND DYNAMICS


Prof. Andrea Flossmann
France


Dr. Andrew Heymsfield
USA

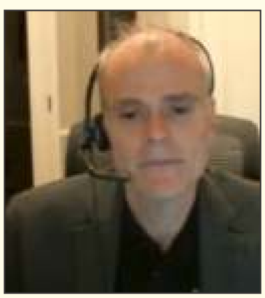

Dr. Heike Wex
Germany


Dr. Alexei Korolev
Canada


Dr. Wojciech Grabowski
USA

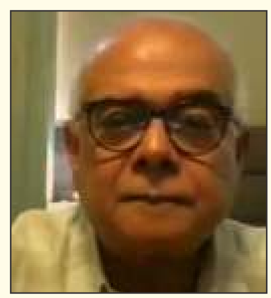

Dr. Darrel Baumgardner
USA


Dr. Johannes Quaas
Germany

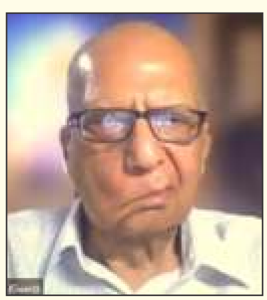

Dr. Greg McFarquhar
USA


Dr. Jiwen Fan
USA


Prof. Alexander Khain
Israel


Prof. Satyajit Ghosh
UK


Dr. Rama Govindarajan
TIFR, India


Dr. A.K. Kamra
IITM, Pune


Dr. Karanam Kishore Kumar
India

INAUGURATION OF MULTI-UTILITY BUILDING "RITURANG"


Welcome by Prof. Ravi Nanjundiah (R) and Inauguration by Dr. M. Ravichandran, Secretary, MoES








Glimpses of the Inaugural Function

LAUNCH OF INTERNATIONAL MONSOONS PROJECT OFFICE (IMPO)

Top Row (L-R):
Prof. Dr. Detlef Stammer,
Chair, WCRP JSC and
Dr. Chris Davies,
Chair, WWRP SSC

Bottom Row (L-R):
Prof. Chih-Pei Chang, USA
and
Dr. Helen Cleugh,
Member, WCRP JSC

Address by Dr. Jitendra Singh
Minister of Earth Sciences, Government of India

Top Row (L-R):
Dr. M. Ravichandran,
Secretary, MoES;
Dr. R. Krishnan,
Director, IITM and
Dr. Estelle de Coning,
WMO

Bottom Row (L-R):
Dr. Rupakumar Kolli, IITM;
Dr. Susmitha Joseph, IITM
and
Dr Munehiko Yamaguchi,
WMO

60th IITM FOUNDATION DAY CELEBRATIONS

Top Row (L-R):
Welcome Address by Dr. R. Krishnan, Director, IITM and Inaugural Address by Dr. M. Ravichandran, Secretary, MoES

Bottom Row (L-R):
Address by Dr. V.K. Dadhwal, IIST and Foundation Day Lecture by Prof. V. Ramaswamy, USA

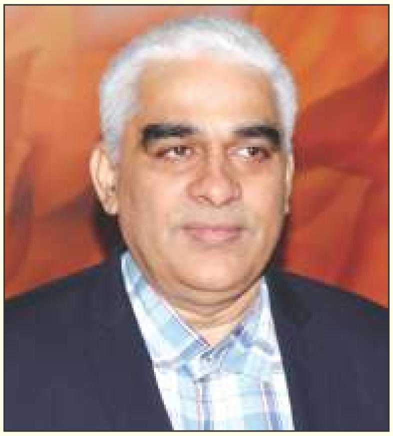
(L-R) Mr. Ushnanshu Dutta and Mr. Panini Dasgupta receiving 'Prof. D.R. Sikka Best Student Paper Award'

(L-R) Mrs. Swati Athale and Mrs. Bhavana Naik receiving 'IITM Excellent Performance Award'

(L-R) Mr. Bhupendra Singh, Mrs. Sunita Kharbanda and Mr. Shafi Sayyed receiving 'Hindi Rajbhasha Puraskar'

(L-R) Computer and Accounts Section received 'Outstanding Performance Award (Division)'

MoES FOUNDATION DAY AWARDS 2021



Dr. R. Krishnan received MoES
'National Award for Excellence in Atmospheric Science and Technology'

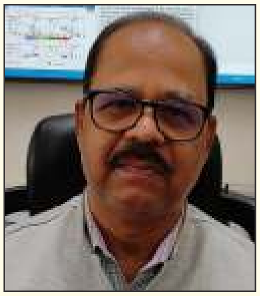
Dr. Thara Prabhakaran received MoES
'Anna Mani Award for Woman Scientist'

Dr. Supriyo Chakraborty received MoES
'Certificate of Merit'

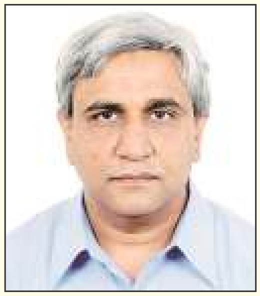
RECOGNITION FOR OFFICIAL LANGUAGE IMPLEMENTATION

IITM received 'Parivartan Rajbhasha Academy Award'

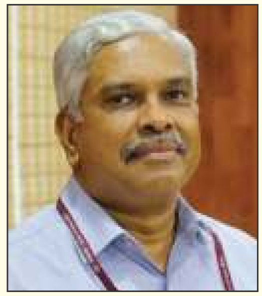
VIRTUAL INTERNATIONAL CONFERENCE ON THE FUTURE DIRECTIONS OF SUBSEASONAL TO SEASONAL PREDICTION OVER SOUTH ASIA



Introduction by
Dr. A.K. Sahai
IITM, Pune



Welcome Address by
Prof. Ravi S. Nanjundiah
Director, IITM, Pune



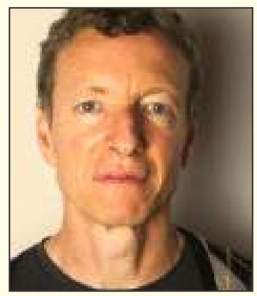
Inaugural Address by
Dr. M. Rajeevan
Secretary, MoES, GoI

Opening Remarks by
Dr. Estelle De Coning
Head, WWRP, WMO, Geneva

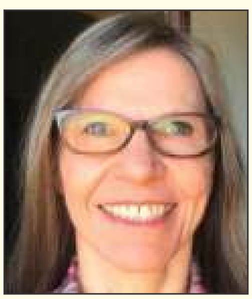
Dr. Frederic Vitart
ECMWF, UK

Prof. Raghu Murtugudde
Univ. Maryland, USA

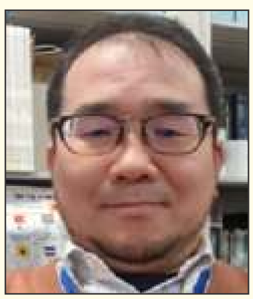
Dr. Gill Martin
UK Met Office, UK



Dr. Andrew Robertson
IRI, USA



Prof. Alice Grimm
UFPR, Brazil



Dr. Kunio Yoneyama
Japan

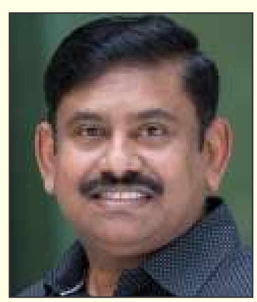
Mr. Thierry Lefort
Meteo-France, France

Dr. Francisco Doblas-Reyes
BSC, Spain

Dr. Vincent Moron
A.M. Univ., France

Dr. Kieran M R Hunt
Univ. Reading, UK

Dr. Thea Turkingon
CCRS, Singapore



Dr. Ajaya Mohan
NYU, Abu Dhabi

AWARENESS WORKSHOP ON LIGHTNING AND THUNDERSTORMS

Top Row (L-R): Dr. A.K. Sahai, Dr. P.N. Rai, Dr. M. Mohapatra
Bottom Row (L-R): Mr. Rajendra Singh, Col. Sanjay Srivastava, Dr. P. Mukhopadhyay

WORKSHOP ON METEOROLOGICAL FORECAST FOR WIND AND SOLAR ENERGY GENERATION: CURRENT STATUS AND FUTURE PERSPECTIVE

Top Row (L-R): Prof. Ravi Nanjundiah, Dr. M. Mohapatra, Dr. M. Rajeevan,
Bottom Row (L-R): Dr. Raghavendra Ashrit, Dr. Ashis Mitra, Dr. P. Mukhopadhyay

INTERNATIONAL CONFERENCE ON CLOUDS AND PRECIPITATION (ICCP) 2021

Prof. Ashutosh Sharma
Secretary, DST

Prof. Andrea Flossmann
President, ICCP

Dr. M. Mohapatra
DG, IMD

Prof. Ravi Nanjundaiah
Director, IITM

Prof. G.S. Bhat
Chair, NOC

Dr. Thara Prabhakaran
Chair, LOC

Dr. Anoop Mahajan
Co-Chair, LOC

S2S FORECAST AND ITS APPLICATIONS IN SOUTH ASIA

Top Row (L-R): Dr. A.K. Sahai, Dr. R. Krishnan, Prof. Subimal Ghosh, Dr. Frederic Vitart, UK
Bottom Row (L-R): Prof. Andrew Robertson, USA; Prof. Nachiketa Acharya, USA;
Dr. Giriraj Amarnath, Sri Lanka; Dr. Rupa Kumar Kolli

TRIBUTE TO PROFESSOR SYUKURO MANABE

(L-R): Dr. Abhay Rajput, IITM; Prof. Joy Monteiro, IISER, Pune and Dr. R. Krishnan, IITM

NATIONAL (TRAINING) WORKSHOP ON GREENHOUSE GASES (GHG-3): OBSERVATIONS AND INVERSE MODELLING ON INDIAN REGIONAL PERSPECTIVE

Top Row (L-R): Dr. Prabir Patra, Dr. R. Krishnan, Dr. Paul Palmer, UK
Bottom Row (L-R): Dr. Supriyo Chakraborty, Dr. Vinu Valsala, Dr. Harjinder Sembhi, UK

NATIONAL SCIENCE DAY CELEBRATIONS

Top Row (L-R): Dr. Kaushar Ali, Dr. B.S. Murty
Bottom Row (L-R): Dr. R. Krishnan, Mr. Gaurav Shinde

INTERNATIOAL BIOLOGICAL DIVERSITY DAY CELEBRATIONS

Top Row (L-R) Prof. Ravi Nanjundiah, Prof. Nitin Karmalkar, VC, SPPU, Pune
Bottom Row (L-R) Dr. G. Beig, Dr. B.S. Murty

Release of 'SAFAR-Emission Inventory PMR-2020 Report'

WORLD ENVIRONMENT DAY CELEBRATIONS

Lecture by
Dr. Anoop Tiwari, NCAOR, Goa

Selfie Point and
Distribution of Medicinal Plants

INDIA INTERNATIONAL SCIENCE FESTIVAL (IISF) 2021

IISF-2021 Outreach Event at IITM: Top Row (L-R): Dr. Abhay Rajput, Dr. Milind Mujumdar, Mrs. S.A. Athale; Bottom Row (L-R): Dr. Vijay P. Bhatkar, President, Vijnana Bharati, Dr. Mansi Mangaonkar, Vijnana Bharati, Dr. R. Krishnan

IISF-2021 Brainstorming Session on Soil Moisture Monitoring in India:
Top Row (L-R): Dr. Milind Mujumdar and Dr. Trinton Franz, COSMOS-USA
Bottom Row (L-R): Prof. N.B. Chopade, PCCoE, Pune; Dr. R. Krishnan, Director, IITM and Mr. Shantanu Pendharkar, Ashay Measurements, Pune

Institute's Participation in India International Science Festival (IISF) 2021 Exhibition, Goa
10-13 December 2021

VIGYAN SARVATRA PUJYATE MEGA EXPO 2022






Institute's participation in Vigyan Sarvatra Pujyate Mega Expo, New Delhi, 22-28 February 2022.

Independence Day Celebrations at the Institute

Republic Day Celebrations at the Institute

MARATHI LANGUAGE TRAINING PROGRAMME



Marathi Language Training Session in progress

INTERNATIONAL WOMEN'S DAY CELEBRATIONS 2022

Mrs. Indira Murthy
Joint Secretary, MoES

Prof. Vineeta Ba
IISER, Pune

Mrs. Archana Rai
IITM, Pune

Dr. P. Swapna
IITM, Pune

Dr. Rashmi Kakatkar
IITM, Pune

Dr. Suvarna Fadnavis
IITM, Pune

MEMORANDUM OF UNDERSTANDING

MoU between Suzlon, India and IITM, Pune

INTERNATIONAL DAY OF YOGA 2021 CELEBRATIONS

Webinar by
Dr. Rima Dada, AIIMS, New Delhi

1.1.1. 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 the 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 vapour and quantification of these fluxes at different time scales by establishing eddy covariance (EC) flux towers at a variety of ecosystems.
- Observations and modelling of greenhouses gases to better understand the carbon dynamics.
- To create and update information reservoirs for better assessment of changes and impacts.
- To generate technology-based knowledge products based on climate studies.
- To build linkages with national and international research groups to optimally leverage scientific capabilities for climate change research.

Highlights of Major Achievements:

- Using the latest version of IITM-ESM, India has contributed significantly for the first time to IPCC AR6.
- CCCR scientists have played leading roles in preparing the IPCC AR6 report.
- Analysis of 120-year historical records suggests a weakening of the AMO-SASM relationship in recent decades.
- Reasons for the increasing frequency of extremely severe cyclonic storms in the north Indian Ocean were investigated.
- An outflow of Asian biomass burning carbonaceous aerosols into the Upper Troposphere and Lower Stratosphere (UTLS) was observed.
- Observations of NO_2 and HCHO using MAX-DOAS from Pune are reported.
- Carbon sequestration of forest environments in northeast and southeast India was studied.
- Potential benefits of atmospheric CO_2 observations and satellite XCO_2 in constraining regional CO_2 fluxes over India were investigated.
- Variations in daily field-scale soil moisture measured using IITM-COSMOS during 2017-2020 were analysed.
- Importance of precipitation (speleothem) isotopic records in paleo-monsoon reconstruction is highlighted.

R&D Activities

CCCR executes the following major R&D activities and developmental works:

- Earth System Model Development
- Climate Change Science and Applications
- Atmospheric Chemistry and Climate
- Paleoclimate
- MetFlux Project, GHG Observations and Modelling

Developmental Activities

IITM Earth System Model (IITM-ESM) and Contributions to IPCC AR6 Report: CCCR at IITM has been actively and continuously working for several years to develop an Indian climate model called IITM Earth System Model (IITM-ESM). With the help of the latest version of IITM-ESM, India has contributed significantly for the first time to the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6), which was recently published on 9 August 2021. CCCR scientists played leading roles in the preparation of the report:

- Dr. R. Krishnan: Coordinating Lead Author (CLA) for Chapter 8: Water Cycle Changes, Drafting Author in Summary for Policymakers (SPM), Author in Technical Summary (TS) Contributing Author in Chapter 3 and Chapter 10 of the IPCC AR6 WG1 report.
- Dr. P. Swapna: Lead Author for Chapter 4: Future Global Climate: Scenario-Based Projections and Near-Term Information.
- Dr. T.P. Sabin: Chapter Scientist for Chapter 8: Water Cycle Changes, Lead Author for Monsoon Annexe, and Contributing Lead Author for Technical Summary.
- Dr. R.M. Koll: Contributing Author for Chapter 9: Ocean, Cryosphere and Sea Level Change.

Also, CCCR has archived IITM-ESM CMIP6 data on a portal which has recorded more than two lakh downloads by different users across the globe. Utilising these IITM-ESM CMIP6 data, CCCR scientists have published several manuscripts in reputed and high-impact international peer-reviewed journals. Further efforts are on to develop the next version of IITM-ESM by incorporating an interactive land-ice model (Community Ice-sheet Model, CISM) and a new spectral dynamical core.

Basic Research

On the weakening association between South Asian monsoon and Atlantic multidecadal oscillation

Long-term multi-decadal scale variability of the South Asian Summer Monsoon (SASM) is known to be associated with the Atlantic Multidecadal Oscillation (AMO), with a positive phase associated with above-normal rainfall and vice-versa over the SASM region. Analysis of 120-year historical records suggests that the relationship between AMO and SASM has weakened in recent decades. Two possible reasons emerge from the analysis of observational datasets and model experiments. Enhanced Indian Ocean warming and weakened North Atlantic Subtropical High (NASH) are the prime factors weakening AMO-SASM association in recent decades. Indian Ocean warming co-occurred during the recent AMO warm phase weakens the meridional temperature gradient, weakening the regional Hadley cell, large-scale monsoon circulation and precipitation. The suppressed convection triggers a Rossby wave which manifests as a cyclonic circulation over west-central Asia, weakening the Tibetan anticyclone. In addition, the weakening of NASH weakens the Circum-Global Teleconnection connecting AMO to SASM, leading to the weakening of the AMO-SASM association. Projected warming of the Indian Ocean and the Atlantic demands a better understanding of the AMO-SASM teleconnection and their projected changes for assessing future changes in SASM in a warming world. *[**Sandeep N., Swapna P., Krishnan R.,** Farneti R., Kucharski F., **Modi A., Prajeesh A.G., Ayantika D.C., Singh Manmeet**, On the weakening association between South Asian Monsoon and Atlantic Multidecadal Oscillation, **Climate Dynamics**, Online, March 2022, DOI:10.1007/s00382-022-06224-1]*

Increasing frequency of extremely severe cyclonic storms in the north Indian Ocean by anthropogenic warming and southwest monsoon weakening

The north Indian Ocean (NIO) has shown an increase in the frequency of extremely severe and higher-category cyclonic storms (ESCS), with maximum frequency during May. IITM-ESM CMIP6 experiments and observed datasets are utilised to understand the mechanism for increasing ESCS in NIO. Results reveal that an anomalous increase in potential intensity (PI) and ocean heat-content with a higher increase during May and weakening summer monsoon circulation has led to increasing ESCS with peak frequency during May. PI is a function of environmental conditions that influence thermodynamic atmosphere-ocean disequilibrium and thermodynamic efficiency. An increase in air-sea disequilibrium by the accelerated warming of NIO dominates the PI trend and contributes more than 70% of the PI trend, while the remaining is contributed by the thermodynamic efficiency from increased tropical-tropopause layer cooling. Additionally, the weakening of summer monsoon circulation weakens vertical wind-shear, weakens southward ocean heat-transport and enhances heat accumulation, leading to an increase in ESCS. The projected increase in PI and weakening wind-shear over the 21st century from the ITM-ESM scenarioMIP experiment revealed that ESCS may further increase in NIO. *[**Swapna P., Sreeraj P., Narayanasetti S., Jyoti J., Krishnan R., Prajeesh A.G., Ayantika D.C., Singh Manmeet**, Increasing frequency of extremely severe cyclonic storms in the North Indian Ocean by anthropogenic warming and southwest monsoon weakening, **Geophysical Research Letters**, 49: e2021GL094650, February 2022, DOI:10.1029/2021GL094650]*

The outflow of Asian biomass burning carbonaceous aerosol into the UTLS in spring: Radiative effects seen in a global model

Biomass burning (BB) over Asia is a strong source of carbonaceous aerosols during spring. From ECHAM6-HAMMOZ model simulations and satellite observations, it is shown that there is an outflow of Asian BB carbonaceous aerosols into the Upper Troposphere and Lower Stratosphere (UTLS) (black carbon: 0.1 to 6 ng m^{-3} and organic carbon: 0.2 to 10 ng m^{-3}) during the spring season **(Fig. 1.1a-b)**. The model simulations show that the greatest transport of BB carbonaceous aerosols into the UTLS occurs from the Indochina and East Asia region by deep convection over the Malay Peninsula and Indonesia. The increase in BB carbonaceous aerosols enhances atmospheric heating by 0.001 to 0.02 K d^{-1} in the UTLS (**Fig. 1.1c**). The aerosol-induced heating and circulation changes increase the water vapour mixing ratios in the upper troposphere (by 20-80 ppmv) and in the lowermost stratosphere (by 0.02-0.3 ppmv) over the tropics

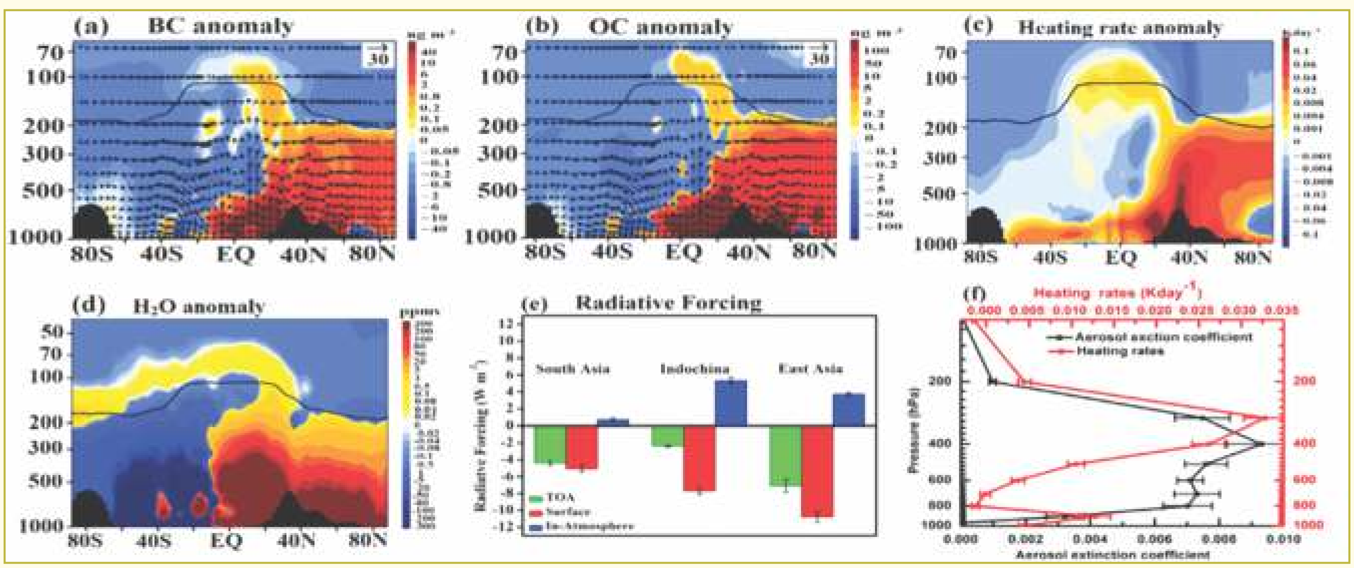


*Fig. 1.1: **(a)** Vertical cross-section of anomalies (BMaeroon – BMaerooff) of black carbon (BC) aerosols (ng m^{-3}) averaged for spring 2013 and 91°E-107°E, **(b)** same as **(a)** but for organic carbon (OC) aerosols, **(c)** same as **(a)** but for heating rate anomalies (K day^{-1}), **(d)** same as **(a)**, but for water vapour, A black line in figs **(a-d)** indicates tropopause, **(e)** anomalies of radiative forcing (W m^{-2}) at the TOA, surface, and in-atmosphere (TOA-Surface) averaged over South Asia, Indochina, and East Asia, **(f)** vertical profile of anomalies of extinction (km^{-1}) and heating rate (K day^{-1}) over the Arctic region (65°N-85°N).*

(**Fig. 1.1d**). Once in the lower stratosphere, water vapour is further transported to the South Pole by the lowermost branch of the Brewer-Dobson circulation. These aerosols enhance the in-atmosphere radiative forcing (0.68±0.25 W m^{-2} to 5.30±0.37 W m^{-2}), exacerbating atmospheric warming while producing a cooling effect on climate (TOA: -2.38±0.12 W m^{-2} to -7.08±0.72 W m^{-2}) (**Fig. 1.1e**). The model simulations also show that Asian carbonaceous aerosols are transported to the Arctic in the troposphere. The maximum enhancement in aerosol extinction is seen at 400 hPa (by 0.0093 km^{-1}) and associated heating rates at 300 hPa (by 0.032 K d^{-1}) in the Arctic (**Fig. 1.1f**). *[**Chavan P., Fadnavis S., Chakroborty T.,** Sioris C.E., Griessbach S., Müller R., The outflow of Asian biomass burning carbonaceous aerosol into the upper troposphere and lower stratosphere in spring: radiative effects seen in a global model, **Atmospheric Chemistry and Physics**, 21, September 2021, DOI:10.5194/acp-21-14371-2021, 14371-14384]*

Year-long concurrent MAX-DOAS observations of nitrogen dioxide and formaldehyde at Pune: Understanding diurnal and seasonal variation drivers

Year-long observations of nitrogen dioxide (NO_2) and formaldehyde (HCHO) using the Multi-Axis Differential Absorption Spectroscopy (MAX-DOAS) technique are reported from Pune city, India. The diurnal and seasonal variations, the effect of biomass burning and the weekend effect on both the species were studied. NO_2 diurnal profiles displayed a traffic-induced peak at ~09:00 hrs. HCHO also showed a morning peak ~10:00 hrs due to production from oxidation of VOCs in the presence of solar radiation. Both NO_2 and HCHO show the highest average concentrations during the winter (October, November, December, January and February – ONDJF), with mean mixing ratios of 2.0 ± 1.4 ppb and 3.0 ± 1.4 ppb, respectively. These observations suggest that a lower boundary layer height during ONDJF leads to higher concentrations of trace gases. During June, July, August, and September (JJAS), both the trace gases show a minimum in their concentrations, with average mixing ratios for NO_2 and HCHO being 0.9 ± 0.6 ppb and 1.1 ± 0.7 ppb, most likely due to removal by wet deposition. There was no significant difference in both the trace gases on weekdays and weekends. Using back-trajectory analysis, it is concluded that air parcels coming from regions of biomass burning increased the concentrations in Pune. Emissions from nearby industrial areas of Bhosari and Pimpri-Chinchwad increased NO_2 concentrations in Pune city. Finally, comparing the observations with previous reports over India, it is found that both HCHO and NO_2 concentrations are lower in Pune compared to the other large cities in India. *[**Biswas M.S., Mahajan A.S.**, Year-long concurrent MAX-DOAS observations of nitrogen dioxide and formaldehyde at Pune: understanding diurnal and seasonal variation drivers, **Aerosol and Air Quality Research**, 21: 200524, June 2021, DOI:10.4209/aaqr.200524]*

Carbon sequestration studies of forest environments in northeast and southeast India

The carbon sequestration potential of Indian forests is believed to be at its peak during the monsoon season. However, regional-scale meteorological and environmental conditions may significantly impact the carbon dynamics in specific regions. Northeast India receives significant rainfall during the pre-monsoon season (March to May), followed by heavy to very heavy rainfall during the monsoon season (July to September). Eddy covariance based observations were carried out at the Kaziranga National Park (KNP), a deciduous forest in Assam, to study the seasonal variability of carbon dynamics. Similar observations were also undertaken in the coastal region of Tamil Nadu, the Pichavaram Mangrove Forest (PVM), to compare specific parameters that contributed differently to the land surface processes at these two contrasting ecosystems.

Analysis of three-year eddy covariance data at KNP shows that maximum carbon uptake occurs during the pre-monsoon season (March to May), followed by reduced uptake during the monsoon season. The process further weakens during the post-monsoon and winter seasons, resulting in a net carbon source during this time. It is observed that the KNP soils emitted significantly more amount of CO_2 compared to other Indian forests. Observed carbon fluxes (NEE or the net ecosystem exchange) were partitioned into gross primary productivity (GPP) and ecosystem respiration (R_{eco}). The results (**Fig. 1.2**) showed that the KNP ecosystem released more carbon than it absorbed during the observational period from 2016 to 2018. It is also observed that the diurnal pattern of rainfall significantly contributed to the carbon uptake process (Sarma et al., 2022).

In conjunction with the eddy covariance measurements, concentration and carbon isotopic ratios of CO_2 and CH_4 were also measured during a campaign in February 2019. A novel technique is developed to partition the net ecosystem exchange into the GPP and R_{eco} components using the isotopic records. This exercise helped constrain the traditional means of NEE partitioning into the photosynthetic uptake and respiratory release of carbon (Metya et al., 2021).

The photosynthetic carbon uptake and evapotranspiration processes at KNP and PVM were compared using multi-year eddy covariance observations from flux towers. It is found that the PVM ecosystem provided stronger sensible heat flux than latent heat flux to the atmosphere throughout the year and thus behaved like a semi-arid ecosystem. Stomatal transpiration was more significant than the physical evaporation of water at PVM throughout the year, whereas at KNP, these two factors dominated each other alternatively. Using the dimensionality reduction technique, it is shown that the basin salinity restricted the transpiration at PVM through the inhibition of

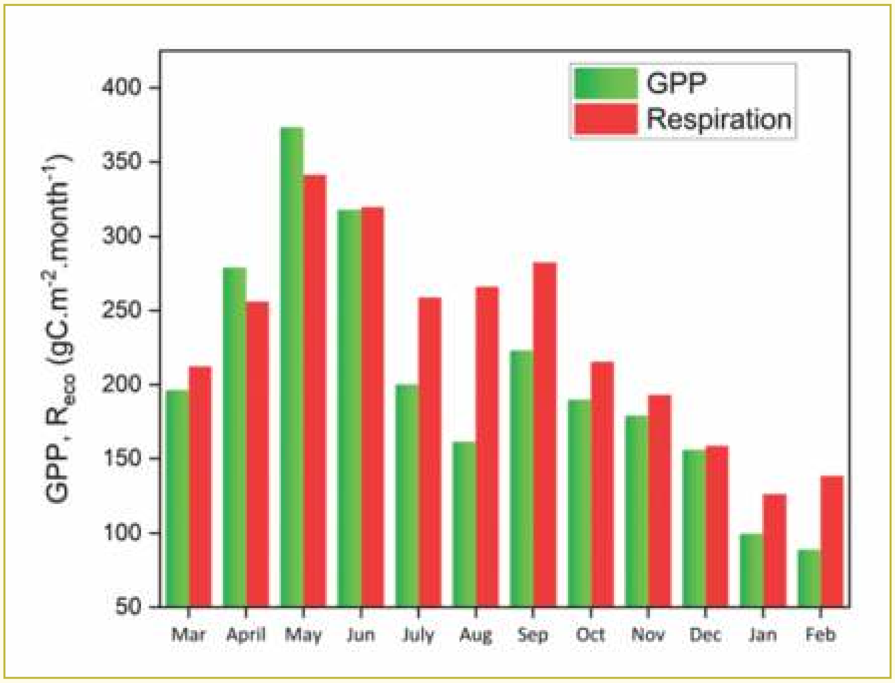


Fig. 1.2: *Seasonal variation of carbon dynamics at Kaziranga forest, northeast India. In pre-monsoon, moderate rainfall and abundant radiation help enhance photosynthetic activity, so productivity (GPP) is high. Green bars depict this feature. From the monsoon season starting in June, productivity decreases. But the respiration (R_{eco}) process, as shown by the red bars, exceeds productivity. So, the forest ecosystem emits a significant amount of carbon.*

stomatal conductance and resulted in such counterintuitive behaviour. On the contrary, KNP behaved as a well-watered ecosystem throughout the year, with latent heat flux dominating the sensible heat flux. Salinity regulation of transpiration played a critical role in the carbon cycle process of the mangrove ecosystem. (Deb Burman et al., 2022). *[1)* ***Sarma D., Deb Burman P.K., Chakraborty S.,*** *Gogoi N., Bora A.,* ***Metya A., Datye A., Murkute C.****, Karipot A., Quantifying the net ecosystem exchange at a semi-deciduous forest in northeast India from intra-seasonal to the seasonal time scale,* ***Agricultural and Forest Meteorology****, 314: 108786, March 2022, DOI:10.1016/j.agrformet.2021.108786.*

2) ***Metya Abirlal, Chakraborty S.,*** *Bhattacharya S.K.,* ***Datye Amey, Deb Burman P.K., Dasgupta P., Sarma D.****, Gogoi N., Bora A., Isotopic and concentration analyses of CO2 and CH4 in association with the eddy-covariance based measurements in a tropical forest of northeast India,* ***Earth and Space Science****, 8: e2020EA001504, June 2021, DOI:10.1029/2020EA001504.*

3) ***Deb Burman P.K., Chakraborty S.****, El-Madany T.S., Ramasubramanian R., Gogoi N., Gnanamoorthy P.,* ***Murkute C.****, Nagarajan R., Karipot A., A comparative study of ecohydrologies of a tropical mangrove and a broadleaf deciduous forest using eddy covariance measurement,* ***Meteorology and Atmospheric Physics****, 134: 4, February 2022, DOI:10.1007/s00703-021-00840-y*]

Benefits of atmospheric CO_2 observations and satellite XCO_2 in constraining regional CO_2 fluxes over India

Top-down modelling estimates are among the most reliable information available on the CO_2 fluxes of the earth system. The inadequate coverage of CO_2 observing stations over the tropical regions adds a limitation to this estimate, especially when the satellite XCO_2 is strictly screened for cloud contamination, aerosol, dust, etc. Efforts were made to investigate the potential benefits of a global ground-based observing station network, 17 newly proposed stations over India, and global satellite XCO_2 in reducing the uncertainty of terrestrial biospheric fluxes of Tropical Asia-Eurasia in TransCom cyclo-stationary inversion. The data from selected 80 global ground-based CO_2 observation stations, along with two additional stations from India (i.e., Cape Rama and Sinhagad) and satellite XCO_2, helped reduce the temperate Eurasian terrestrial flux uncertainty by 23.8%, 26.4%, and 36.2%, respectively. This further improved to 54.7% by adding the newly proposed stations over India into the inversion. By separating the Indian sub-continent from temperate Eurasia (as inspired by the heterogeneity in the terrestrial ecosystems, prevailing meteorological conditions, and the orography of this vast region), the inversion evinces the capacity of existing CO_2 observations to reduce the Indian terrestrial flux uncertainty by 20.5%. The largest benefit (70% reduction of annual mean uncertainty) for estimating Indian terrestrial fluxes could be achieved by combining these global observations with data from the newly proposed stations over India. The existing two stations from India suggest temperate Eurasia as a mild source of CO_2 (0.33 ± 0.57 PgC yr^{-1}), albeit with prominent anthropogenic influences visible in these two stations during the dry seasons. This implies that the proposed new stations should be cautiously placed to avoid such effects. It is also found that the newly proposed stations over India have an impact in constraining nearby oceanic CO_2 fluxes. *[****Halder S., Tiwari Y.K., Valsala V.****, Sijikumar S., Janardanan R., Maksyutov S., Benefits of satellite XCO2 and newly proposed atmospheric CO_2 observation network over India in constraining regional CO2 fluxes,* ***Science of The Total Environment****, 812: 151508, March 2022, DOI:10.1016/j.scitotenv.2021.151508]*

An intensification of atmospheric CO_2 concentrations due to the surface temperature extremes in India

The terrestrial biosphere plays a pivotal role in removing carbon from the atmosphere. The removal processes are primarily affected by extreme temperatures in the atmosphere. Little information is available on carbon removal response by the terrestrial biosphere during extreme temperature events over the Indian region. Surface CO_2 flux observations (Net Ecosystem exchange NEE) and satellite retrieved columnar and mid-tropospheric CO_2 concentrations were used to understand atmospheric CO_2 variability and its transport patterns with anomalously high-temperature events such as heatwave conditions over India, focusing on the year 2015 heatwaves, which were one of the dreadful heatwaves in recent years. Intensification of temperatures up to 32°C has increased the atmosphere-biosphere CO_2 fluxes or NEE (carbon sink). But further intensification in temperature (> 32-33°C), as observed during summer seasons or heatwaves, tends to drive the ecosystem to act as a CO_2 source in the atmosphere. This is due to the reduced ability to absorb atmospheric CO_2 due to other prevalent limiting factors such as VPD (seen at Barkaccha) or rainfall (seen at Pichavaram) in those environmental conditions (**Fig. 1.3**), leaving excess CO_2 in the atmosphere. Such excess CO_2 fluxes may lead to change in the atmospheric CO_2 concentration via atmospheric circulation or the vertical transport of the air masses from the near-surface to the upper levels in the atmosphere. Strengthening of wind circulation parameters associated with the heatwave supports the increase in CO_2 levels in the upper atmosphere. The satellite retrievals also noticed an increase in atmospheric CO_2 concentrations by 2-3 ppm during the heatwave period compared to the non-heatwave

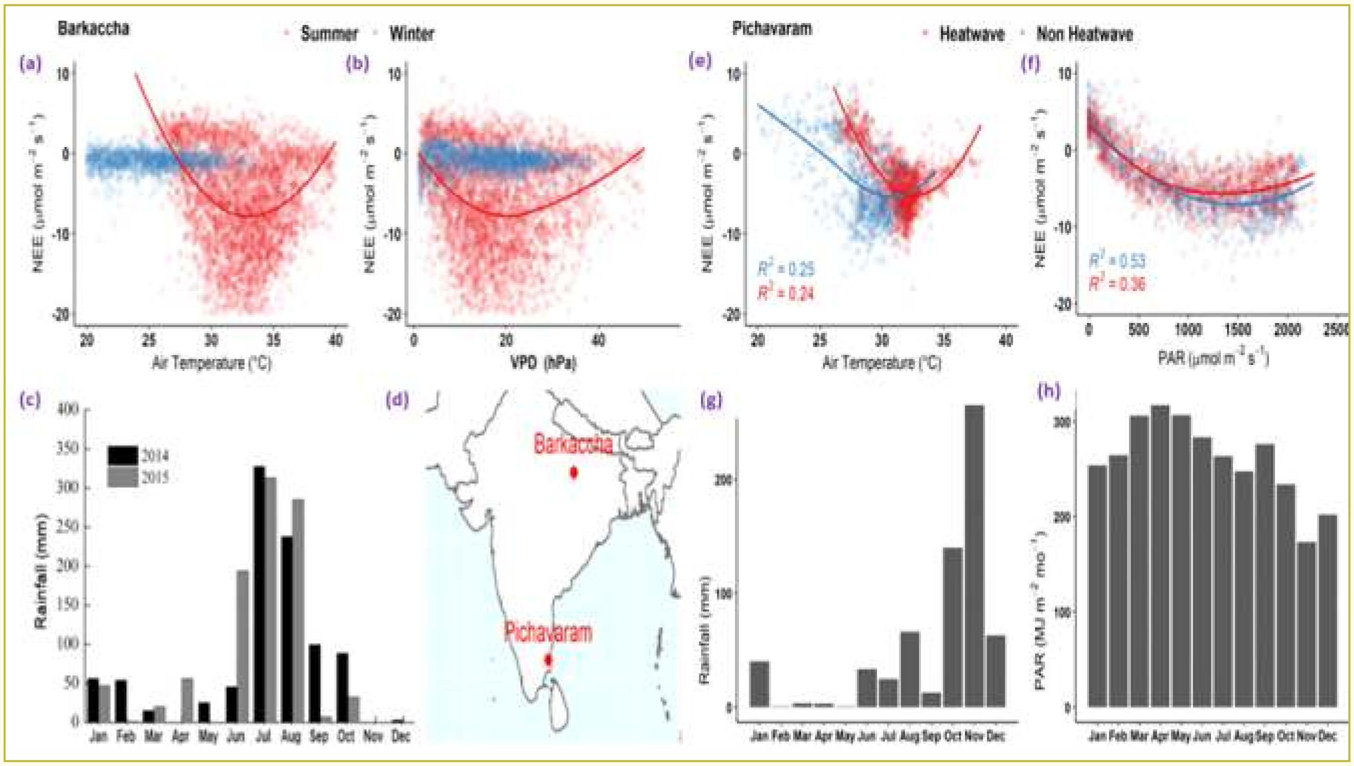


__Fig. 1.3:__ The dependence of NEE on __(a)__ air temperature and __(b)__ vapour pressure deficit (VPD) during the summer monsoon months of 2014-16 at Barkachha, Uttar Pradesh, India, and __(e)__ air temperature and __(f)__ photosynthetically active radiation (PAR) in the daytimes of MAM months during 2018 at Pichavaram mangrove forest site location. __(c, g)__ show cumulative monthly rainfall at the location of observation sites __(d)__. __(h)__ shows monthly total PAR recorded in the study area for a 1-year duration between October 2017 to September 2018.

period. The impact and feedback of heatwaves on the biospheric component of the carbon cycle is highlighted. *[**Gupta Smrati, Tiwari Y.K., Revadekar J.V., Deb Burman P.K., Chakraborty S.**, Gnanamoorthy P., An intensification of atmospheric CO_2 concentrations due to the surface temperature extremes in India, **Meteorology and Atmospheric Physics**, 133, December 2021, DOI:10.1007/s00703-021-00834-w, 1647-1659]*

Study of field-scale soil moisture variability using the COsmic-ray Soil Moisture Observing System (COSMOS) at the IITM Pune site

Variations in daily field-scale soil-moisture (SM) measured using the COsmic-ray Soil Moisture Observing System (COSMOS) over a tropical monsoon site (IITM, Pune) in India for the period 2017-2020 were analysed. Being located in the core zone of the Indian summer monsoon, the daily field-scale SM observations at IITM-COSMOS provide a unique opportunity to understand the SM response to monsoon precipitation variations on sub-seasonal, seasonal and interannual time scales. In addition to the IITM-COSMOS observations, SM variations over this location were also evaluated using satellite, reanalysis and model products for the same period. A significant result from this analysis reveals the presence of biweekly (time-scale ~10-20 days) and low-frequency intra-seasonal (time-scale ~30-60 days) variations in the field-scale SM, which are linked to the dominant modes of Indian summer monsoon sub-seasonal variability. In particular, it is found that a pronounced enhancement of the low-frequency signal of SM variations during the 2019 monsoon which was characterised by abnormally excess precipitation and prolongation of rains well beyond the summer monsoon season, in contrast to the 2018 monsoon. Moreover, it is highlighted that a longer persistence of SM memory time-scale (about 60 days) during 2019 as compared to 2017, 2018 and 2020. The validation of coarser resolution datasets revealed that GLDAS and ERA5 reasonably capture a range of observed field-scale SM variabilities over the COSMOS-IITM site. *[Mujumdar M., Goswami M.M., Morrison R., Evans J.G., **Ganeshi N., Sabade S.S., Krishnan R.,** Patil S.N., A study of field-scale soil moisture variability using the COsmic-ray Soil Moisture Observing System (COSMOS) at IITM Pune site, **Journal of Hydrology**, 597: 126102, June 2021, DOI: 10.1016/j.jhydrol.2021.126102]*

Application of precipitation isotopes in quest of paleo-monsoon reconstruction

Quantitative rainfall information retrieved from the speleothem oxygen isotopic record depends greatly on the oxygen isotopes' response to large-scale processes. Since a speleothem isotopic record is considered a point-scale observation, it is necessary to investigate how well the record captures the large-scale climate signal. Analysis of modern-day precipitation isotopic data could be used to examine this aspect. Precipitation isotopic records were generated from the Andaman Islands in the Bay of Bengal to investigate how the precipitation isotopes respond to monsoon rainfall over a varying spatial domain that ranged from a local scale to a continental scale. Analysis of moisture transport parameters revealed that the precipitation isotopes are more sensitive to the moisture fluxes than the rainfall amount. The relation between precipitation isotopes and moisture dynamics remains robust, encompassing a large portion of the Bay of Bengal, but weakens beyond its geographical domain. The amount effect was observed to be decreasing with an increasing spatial domain. It is predicted that point scale observations, such as speleothem isotopic records, respond to large-scale processes; however, rainfall quantification for a vast region may be underestimated. *[**Chakraborty S., Datye A., Murkute C., Halder S., Parekh A., Sinha N.,** Mohan P.M., 2021 Application of precipitation isotopes in pursuit of paleo-monsoon reconstruction: an Indian perspective, p. 413-427. In: Holocene Climate Change and Environment (eds) Kumaran, N., and Damodaran, P. Elsevier; Amsterdam, Netherlands; 693p]*

Indian summer monsoon variability in the Holocene

The late Holocene encompasses notable global warm periods viz., Medieval Climate Anomaly, Roman Warm Period (RWP) and Minoan Warm Period; and cold periods viz., Dark Age cold period and Little Ice Age (LIA). Speleothem records show that Indian summer monsoon (ISM) rainfall declines until the middle of RWP. The decline is linked with the southward migration of the Intertropical convergence zone caused by the northern Hemisphere summer insolation. Though the solar insolation follows the same trend, all the records show large variability with the disappearance of the declining trend around the middle of RWP. This change coincided with the reversal in the north Atlantic Sea surface temperature (SST) trend, northern hemisphere temperature, and abrupt changes in the southeastern Indian Ocean SST. This period also witnessed high El-Nino Southern Oscillation activities. Spectral analysis of speleothem records exhibited 2-3 years to multi-centennial periodicities in ISM during the Holocene epoch. The peninsular region showed strong statistically significant ~5-year time scale variations attributed to the Southern Oscillation Index. The tropical, North Pacific, and North Atlantic Oceans influenced the 5-20 years scale variations in ISM. Also, 40-80 year multi-decadal periodicities in these records showed coherent behaviour, indicating the monsoon teleconnection with the global climate variables on these timescales. The centennial to multi-centennial ISM variations are tied with the North Atlantic circulation. ***[Phanindra Reddy A., Gandhi N., Krishnan R.,*** *Review of speleothem records of the late Holocene: Indian summer monsoon variability & interplay between the Solar and oceanic forcing,* ***Quaternary International****, online, June 2021, doi:10.1016/j.quaint.2021.06.018; and* ***Phanindra Reddy A., Gandhi N.*** *(2021) Indian summer monsoon variability on different time scales and deciphering its oscillations from irregularly spaced paleoclimate data using different spectral techniques. p. 339-368. In: Holocene Climate Change and Environment, 1st Ed. (Eds) Kumaran, N., and Padmala, D. Elsevier, Amsterdam, Netherlands; 693p.]*

1.1.2. Physics and Dynamics of Tropical Clouds (PDTC)

Project Directors:
Dr. Thara Prabhakaran and Dr. S.D. Pawar

Objectives

- To generate long-term observational data for understanding the boundary layer processes, aerosol, cloud and rainfall properties over the rain shadow region of India.
- To prepare a weather modification research strategy over the rain shadow region of India.
- To develop a laboratory for cloud seeding flare testing.
- To understand the boundary layer processes in a Fluid Dynamics Laboratory developed at IITM, Pune.
- To study the interaction of electrical, microphysical and dynamical properties of thunderstorms.
- To study lightning in different environmental conditions.
- To study lightning damages over India.
- To develop better now-casting (next 6 hours) and forecasting of winter fog on various time and spatial scales and help reduce the adverse impact of fog on aviation, transportation and economy, and loss of human life due to accidents.
- To create a state-of-the-art air pollution forecasting system to assist policy-makers in managing air quality in the heavily polluted regions of the country and thus avoiding public exposure to acute levels of air pollution.

Highlights of Major Achievements:

- CAIPEEX Phase-IV ground-based observations are continued at Solapur and Tuljapur sites.
- Experiments and direct numerical simulations at the Fluid Dynamics Laboratory are being conducted.
- Characteristics of CCN activation and cloud microphysics during the northeast monsoon onset were investigated.
- The impact of middle atmospheric humidity on boundary layer turbulence and clouds was examined.
- The performance of different microphysics schemes in simulating various rainfall types was evaluated.
- Surface raindrop size distributions over a rain shadow region were investigated using polarimetric and micro rain radars.
- A visibility network analysis was carried out on a field-experimental dataset for exploring convective atmospheric surface layer flows.
- Analysis of data from the Lightning Location Network shows a strong association between the electrification of clouds and precipitation intensity.
- A new 21 ensemble probability forecast system for fog has been developed and operationalised.
- A new technique is developed to implement the high-resolution land surface data assimilation to increase the performance of WRF model for improving fog prediction.
- The frozen version of the Air Quality Early Warning System (AQEWS) for Delhi NCR region was handed over to IMD in June 2021.
- A decision support system for air quality management in Delhi was developed and implemented operationally in October 2021.

R&D Activities

Under PDTC, the following major R&D activities and developmental works are executed:

- **Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)**
- **Thunderstorm Dynamics**
- **Winter Fog Experiment (WiFEX) & Air Quality Early Warning System (AQEWS)**

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

Developmental Activities

CAIPEEX Phase-IV Solapur and Tuljapur sites: All ground-based observations are ongoing except for the C-band radar and radiosonde. Tuljapur site measurements are continuing without any interruption. A special radiosonde observational campaign was conducted at Solapur to validate wind products from wind profiler observations at Solapur and Tuljapur, after implementing the quality control algorithm in the online data analysis software WPR.

Fluid Dynamics Lab: Wall jet PIV experiments Phase-II were conducted during February- October 2021. Phase-I and Phase-II data analyses are in progress. Drag scaling in wall turbulence, atmospheric surface layers, etc. is being analysed. Direct Numerical Simulations of turbulent boundary layers are being carried out.

Basic Research

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

A prominent influence of submicron particles on the cloud microphysical parameters is observed. 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. *[**Varghese M., Prabhakaran Thara, 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**, 257: 105589, August 2021, DOI:10.1016/j.atmosres.2021.105589]*

Impact of middle atmospheric humidity on boundary layer turbulence and clouds

Large Eddy Simulation (LES) derived turbulent fluxes and variances were verified with aircraft observations. Drier conditions above boundary layer resulted in deeper, warmer and drier boundary layer with an enhanced boundary layer turbulent kinetic energy. Dynamic feedback from dry air intrusion into the boundary layer resulted in energetic boundary layer eddies in the dry conditions and a doubling of moisture exchange coefficients. The liquid water content in cloud updrafts rather than in downdrafts was depleted significantly in dry conditions. The middle atmospheric water vapour alone could influence the shallow to deep cumulus cloud transitions in the monsoon regime in a dramatic way by changing the population of cumulus, congestus or deep cumulus clouds. A 30% drying above the boundary layer could drastically reduce the liquid water path and cloud albedo by 10-15%. *[**Malap N., Prabhakaran Thara**, Karipot A., Impact of middle atmospheric humidity on boundary layer turbulence and clouds, **Journal of Atmospheric and Solar Terrestrial Physics**, 215: 105553, April 2021, DOI: 10.1016/j.jastp.2021.105553]*

Cloud microphysical structure analysis based on high-resolution in situ measurements within a few metres

The horizontal liquid water content (LWC) distribution resembles a trapezoidal shape with steep gradients near the cloud edges, indicating subsiding regions with liquid water depletion. The LWC maximums (LWCmax) are lower than the adiabatic LWCs, but the high adiabatic fractions in the cloud core indicate low dilution. High LWC/LWCmax, largest droplets, and narrow and similarly shaped droplet size distributions (DSDs) are found in the regions of high updrafts. The effective radii change slightly across cloud updraft zones but decrease at the zone of low LWC/LWCmax ratio close to cloud edges. The spectra of LWC and droplet number concentration (N_c) obey Kolmogorov −5/3 turbulence law. *[**Konwar M., Prabhakaran Thara**, Khain A., Pinsky M., Cloud microphysical structure analysis based on high-resolution in situ measurements, **Journal of the***

***Atmospheric Sciences**, 78, July 2021, DOI:10.1175/ JAS-D-20-0229.1, 2265-2285]*

Rainfall types in the lifecycle of a stationary cloud cluster during the Indian summer monsoon: An investigation with numerical simulations and radar observation

The performance of three microphysics schemes (WRF Double Moment 6-class (WDM6), Morrison double moment (MORR), and spectral bin microphysics (Fast version) (SBMF)) in simulating various rainfall-types during the lifecycle of a tropical continental mesoscale cloud cluster (observed with Solapur C-band radar) was evaluated. The microphysics scheme with the least complexities produced the highest convective rainfall-type, lowest stratiform rainfall-type, and a remarkable early cessation of the cloud cluster. With increasing complexities, the microphysics schemes are found to represent the rainfall-types closer to radar observations. Major differences are noted during the mature and dissipation phases, especially in the stratiform rainfall-type. The rainfall-types derived from radar, as well as from three simulations with WDM6, MORR, and SBMF schemes, showed ~18%, ~54%, ~41%, and ~29% of convective rainfall fraction (including isolated convective categories), ~14%, ~33%, ~18%, and ~20% of mixed rainfall fraction and ~68%, ~13%, ~42%, and ~50% of stratiform rainfall fraction respectively during the lifecycle of the cloud cluster. The accumulated rainfall derived from radar observations, using a blended rainfall estimation algorithm, indicated substantial differences in the observed and simulated rainfall pattern. The lower moment scheme has a tendency to produce lighter as well as heavy rainfall compared to the higher moment schemes. *[**Samanta S., Prabhakaran Thara, Murugavel P.**, Suneetha P., Rainfall types in the lifecycle of a stationary cloud cluster during the Indian Summer Monsoon: An investigation with numerical simulations and radar observation, **Atmospheric Research**, 263: 105794, December 2021, DOI:10.1016/j.atmosres. 2021.105794]*

Hygroscopic growth and CCN activation of aerosols during Indian summer monsoon over a rain-shadow region

During the intermittent rainy, wet and cloudy days, the total aerosol (≈ 966 cm^{-3}), cloud condensation nuclei (CCN) (≈ 587 cm^{-3} at 0.4% S) number concentrations, and black carbon (BC) (≈482 ng m^{-3}) mass concentrations were less, which increased to the mean values of ≈ 3754 cm^{-3}, ≈ 974 cm^{-3}, and ≈ 892 ng m^{-3} respectively during the dry and clear-sky period. Multiple mode aerosol number size distribution prevailed irrespective of the meteorological conditions, while a prominent nucleation mode was observed during dry conditions. The nucleation mode was consistent from 09:00 h local time (IST) during dry conditions, apart from those associated with the local emissions during the sunset. The nucleation mode associated with the sharp enhancement in the absorption of the Angstrom exponent after the BC peak during the early morning hours of dry days indicated secondary organic aerosol formation. However, the hygroscopicity derived from CCN measurements K_{CCN} at 0.2 and 1.0% Ss were higher than the K_{HTDMA} values. The high K_{CCN} (≈ 0.44) during wet conditions was reduced to ≈ 0.28 during dry conditions for 1.0% S (corresponding to ~40 nm). The hygroscopicity and CCN efficiency of aerosols were high during the daytime and from midnight to sunrise for the dry and wet periods, respectively. *[**Jayachandran V., Bera S., Bankar S.P., Malap N., Varghese M., Safai P.D., Konwar M. Todekar K.S., Jaya Rao Y., Murugavel P., Prabhakaran Thara**, Hygroscopic growth and CCN activation of aerosols during Indian Summer Monsoon over a rain-shadow region, **Atmospheric Research**, Online, December 2021, DOI:10.1016/j.atmosres.2021.105976]*

Vertical profile of aerosol size characteristics including activation over a rain shadow region in India

Multimodal lognormal distributions were required to fit the observed *in situ* aerosol size distribution.

The aerosol composition and mixing state was deduced from the single-particle analyses of aerosols using the transmission electron microscope and soot photometer coupled with satellite retrieved aerosol classification and back trajectory analyses. Organic carbon was the most prominent aerosol type found at all altitudes. Refractory black carbon aerosols, which constituted about 10-12% of the aerosols in the boundary layer, were primarily internally mixed with both the inorganic and organic coatings. A cloud condensation nuclei closure was carried out with CAIPEEX observations. The effective hygroscopicity decreased above the cloud base due to the absence of sea salt aerosols. The change in large-scale winds with altitude affected the aerosol composition and hygroscopicity. The multimodal aerosol size distribution and hygroscopicity parameter (κ = 0.18) were obtained for the cloud base aerosols over the rain shadow region for constraining models to study aerosol-cloud interactions in the regional scale models. *[**Varghese M.,** Jose J., Anu A.S., Konwar M., Murugavel P., Kalarikkal N., **Deshpande M., Prabha T.V** ., Vertical profile of aerosol size characteristics including activation over a rain shadow region in India, **Atmospheric Environment**, 262, October 2021, 118653]*

Microphysical origin of raindrop size distributions during the Indian monsoon

Surface raindrop size distributions over a rain shadow region during the Indian summer monsoon are clustered using the k-means algorithm. The rainfall for five dominant clusters has distinct vertical features in polarimetric radar and micro rain radar. The deep convection with low cloud bases and high liquid water is associated with sharply increasing radar reflectivity at low levels and the largest drops at the surface. The large drops originated by ice processes break while falling below the melting layer, causing a peak in raindrops smaller than 0.5 mm in diameter near the cloud base, where the falling raindrops rapidly grow by collision-coalescence without breaking. The number concentration in the stratiform rain is relatively moderate; hence a gradual raindrop growth and uniform vertical reflectivity. However, few raindrops in stratiform rain grow to a larger diameter than in convective rain, for the same rain rate due to the absence of collisional breakup. *[**Raut B.A., Konwar M., Murugavel P., Kadge D., Gurnule D., Sayyed I., Todekar K., Malap N., Bankar S., Prabhakaran Thara**, Microphysical origin of raindrop size distributions during the Indian monsoon, **Geophysical Research Letters**, 48: e2021GL093581, August 2021, DOI:10.1029/2021GL093581]*

Real-time characterisation and source apportionment of fine particulate matter in the Delhi megacity area during late winter

The National Capital Region (NCR), encompassing New Delhi, is one of the world's most polluted urban metropolitan areas. Real-time chemical characterisation of fine particulate matter (PM1 and PM2.5) was carried out using three aerosol mass spectrometers, two aethalometers, and one single particle soot photometer (SP2) at two sites in Delhi (urban) and one site located ~40 km downwind of Delhi, during January-March 2018. The campaign mean PM2.5 (NR-PM2.5 + BC) concentrations at the two urban sites were 153.8 ± 109.4 $\mu g.m^{-3}$ and 127.8 ± 83.2 $\mu g.m^{-3}$ respectively, whereas PM1 (NR-PM1 + BC) was 72.3 ± 44.0 $\mu g.m^{-3}$ at the downwind site. PM2.5 particles were composed mostly of organics (43-44%) followed by chloride (14-17%), ammonium (9-11)%, nitrate (9%), sulfate (8-10%), and black carbon (11-16)%, whereas PM1 particles were composed of 47% organics, 13% sulfate as well as ammonium, 11% nitrate as well as chloride, and 5% black carbon. Organic aerosol (OA) source apportionment was done using positive matrix factorisation (PMF), solved using an advanced multi-linear engine (ME-2) model. Highly mass-resolved OA mass spectra at one urban and downwind site were factorised into three primary organic aerosol (POA) factors: one traffic-related, two solid-fuel combustion (SFC), and three oxidised

OA (OOA) factors. Whereas unit mass resolution OA at the other urban site was factorised into two POA factors related to traffic and SFC, and one OOA factor. OOA constituted a majority of the total OA mass (45-55%), with maximum contribution during afternoon hours (~70-80%). Significant differences in the absolute OOA concentration between the two urban sites indicated the influence of local emissions on the oxidised OA formation. Similar PM chemical composition, diurnal and temporal variations at the three sites suggest similar types of sources affecting the particulate pollution in Delhi and adjoining cities, but variability in mass concentration suggest more local influence than regional. *[Lalchandani V., Kumar V., Tobler A., Thamban N.M., Mishra S., Slowik J.G., Bhattu D., Rai P., Satish R., Ganguly D., **Tiwari Suresh**, Rastogi N., ... et al., Real-time characterization and source apportionment of fine particulate matter in the Delhi megacity area during late winter, **Science of the Total Environment**, 770: 145324, May 2021, DOI:10.1016/j.scitotenv.2021.145324]*

Long-term change in aerosol characteristics over Indo-Gangetic Basin: How significant is the impact of emerging anthropogenic activities?

Long-term aerosol characteristics were assessed over the Indo-Gangetic Basin (IGB) using satellite-derived aerosol properties from January 2007 to December 2017. Steadily high aerosol optical depth (AOD ~0.7) was shown with a decadal increasing trend (~20%) over the IGB. Angstrom exponent (AE) showed a relatively large increasing trend over Lucknow in the central IGB (~25%) as compared to Delhi in the north-west IGB (~18%), which suggests a relative increase in fine-mode aerosols over Lucknow (~30%). Though, single scattering albedo (SSA) did not show any considerable decadal trend at both the stations, the ultraviolet-aerosol index (UV-AI) showed an increasing trend, with a pronounced increase in Delhi (~26%) compared to Lucknow (~20%). Results suggest relative dominance of absorbing dust aerosols over Delhi. Further, to understand the impact of emerging activities, analyses were done in two sub-periods: 2007-2012 and 2013-2017. Interestingly, a relative increasing trend in AOD (~31%) is observed in Delhi compared to Lucknow during 2007-2012, which was observed in Lucknow (~22%) during 2013-2017. The emission inventory corroborates with the trend and variability of optical properties for different sub-periods, and results showed intense development activities in the region influencing vertical and horizontal aerosol load. *[Kumar S., Singh A., **Srivastava A.K.**, Sahu S.K., Hooda R.K., Dumka U.C., Pathak V., Long-term change in aerosol characteristics over Indo-Gangetic Basin: How significant is the impact of emerging anthropogenic activities? **Urban Climate**, 38: 100880, July 2021, DOI:10.1016/j.uclim.2021.100880]*

Visibility network analysis of large-scale intermittency in convective surface layer turbulence

Large-scale intermittency is a widely observed phenomenon in convective surface layer turbulence that induces non-Gaussian temperature statistics, while such a signature is not observed for velocity signals. Although approaches based on probability density functions have been used so far, those are not able to explain to what extent the signals' temporal structure impacts the statistical characteristics of velocity and temperature fluctuations. To tackle this issue through surrogate data and network-based measures, it is demonstrated that temperature intermittency is related to strong nonlinear dependencies in the temperature signals. Conversely, a competition between linear and non-linear effects tends to inhibit the temperature-like intermittency behaviour in streamwise and vertical velocities. Based on these findings, new research avenues are likely to be opened in studying large-scale intermittency in convective turbulence. *[**Chowdhuri S.,** Iacobello G., Banerjee T., Visibility network analysis of large-scale intermittency in convective surface layer turbulence, **Journal of Fluid Mechanics**, 925: A38, October 2021, DOI:10.1017/jfm.2021.720]*

1.1.2.2. Thunderstorm Dynamics

Developmental Activities

IITM, Pune and Cotton University, Guwahati have signed an MoU for thunderstorm-related studies. Under this MoU, a multichannel microwave radiometer (MMR) is installed at Cotton University, Guwahati. Observations of vertical profiles of temperature and relative humidity are being made using this MMR. This would help better understand and study the salient features of thunderstorms occurring over the foothills of the Himalayas. It is also planned to study the interactions between electrical and thermodynamical processes by establishing a co-located observatory for atmospheric electricity.

Basic Research

Role of electrical effects in intensifying rainfall rates in the tropics

The rainfall observed at the Earth's surface is a manifestation of different cloud microphysical processes. The condensation of water vapour on cloud condensation nuclei (CCN) and subsequent collision/coalescence between cloud droplets are the two dominant processes of rain formation in the warm phase of clouds. Many laboratory investigations suggest that both the processes are quite sensitive to the electrification of clouds. But direct evidence of the influence of cloud electric field on the rain formation in real atmospheric conditions was lacking till now. With simultaneous observations of the cloud electric field and the raindrop size distribution below a few strongly electrified clouds over Pune, it has been shown for the first time that a larger cloud electric field remains associated with larger raindrops at the Earth's surface. The electrification of raindrops enhances the coalescence of raindrops through electrical attraction, thereby increasing the number concentration of larger raindrops in the DSD spectrum. A mathematical framework has also been developed to support the observations. It has also been shown that a cloud electric field can modify the rain rate at the Earth's surface by enhancing the growth of raindrops. (**Fig. 1.4**) [***Mudiar D., Hazra A., Pawar S.D.***, *Karumuri R.K.*, ***Konwar M., Mukherjee Subrata***, *Srivastava M.K., Goswami B.N., Williams E., Role of electrical effects in intensifying rainfall rates in the tropics*, ***Geophysical Research Letters***, *49: e2021GL096276, January 2022, DOI:10.1029/2021GL096276*]

Lightning and precipitation: The possible electrical modification of observed raindrop size distributions

To understand the underlying microphysical processes which cause transient rain intensity

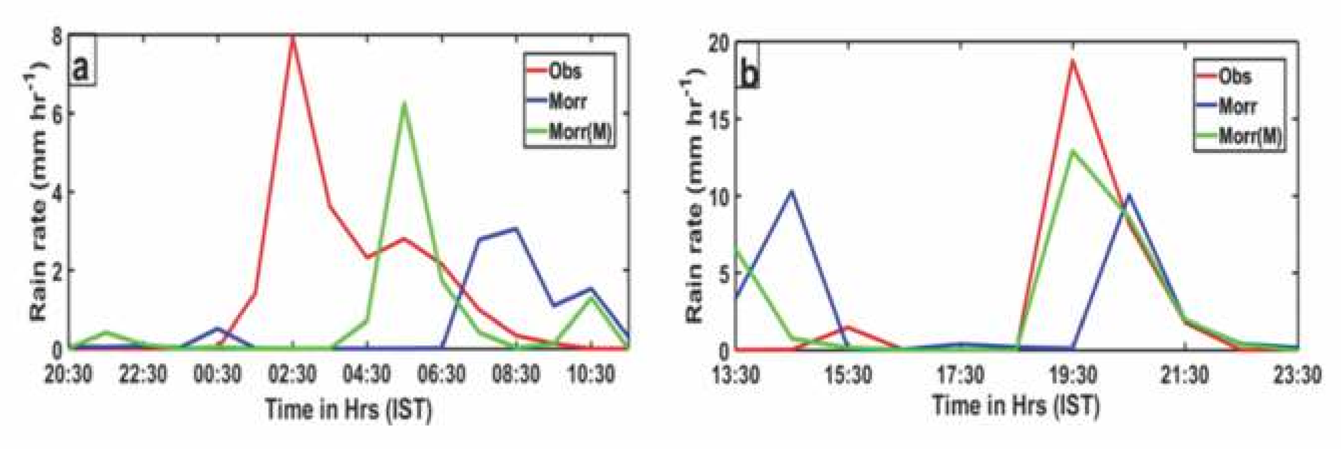


Fig. 1.4: *Comparison of simulated rain rates with the observation of two strongly electrified (SE) events over HACPL. The legends 'Obs' indicates observation (red), 'Morr' indicates Morrison double moment scheme (blue) and and 'Morr(M)' indicates modified Morrison scheme. A substantial improvement in the simulated rain rate (Morr(M)) can be observed with modification of the Morrison scheme.*

amplification at the surface after an overhead lightning, 12 isolated overhead lightning discharge events located by the Lightning Location Network are studied with time series of rain intensity recorded before and after overhead lightning. A transient amplification in the intensity of surface rain is found to be associated with an overhead lightning discharge with an average time lag of 2-4 minutes. The investigation of the corresponding RDSD before and after lightning reveals a broadening of the distribution towards larger-size bins. This broadening is attributed to the electrification of raindrops by lightning discharge in the neighbourhood cloud volume through ion deposition. The very short time lag of 2-4 minutes between lightning and amplification of surface rain suggests that the growth of raindrops that causes the observed transient amplification of rain intensity at the surface primarily takes place in the warm phase of cloud below the melting layer, indicating that collision-coalescence growth is the primary mechanism through which lightning can amplify the surface rain. An analysis of three lightning-producing-storms reveals a significant correlation [r (ave) = 0.75, p value = 0.001] between lightning rate and surface rain rate, where surface rain rate is observed to lag the lightning rate by 3-6 minutes. The results of this analysis indicate that lightning-induced atmospheric ions and prevailing electrical forces could significantly modulate the surface rain intensity. It is also observed that higher lightning intensity with higher peak current is associated with a broader RDSD spectrum. The more intense lightning is associated with more intense precipitation at the surface, which reaffirms the idea of a strong association between the electrification of clouds and precipitation intensity. (**Fig. 1.5**) [***Mudiar D., Pawar S.D., Hazra A., Gopalakrishnana V., Lal D.M., Chakravarty K., Domkawale M.A.***, *Srivastava M.K., Goswami B.N., William E., Lightning and precipitation: The possible electrical modification of observed raindrop size distributions,* ***Atmospheric Research****, 259: 105663, September 2021, DOI: 10.1016/ j.atmosres.2021. 105663*]

A laboratory investigation of electrical influence on the freezing of water drops: A cloud physics perspective

Electro-crystallisation, the freezing of water droplets induced by an electric field, has been examined by many investigators previously. But disagreements regarding the cause of freezing still

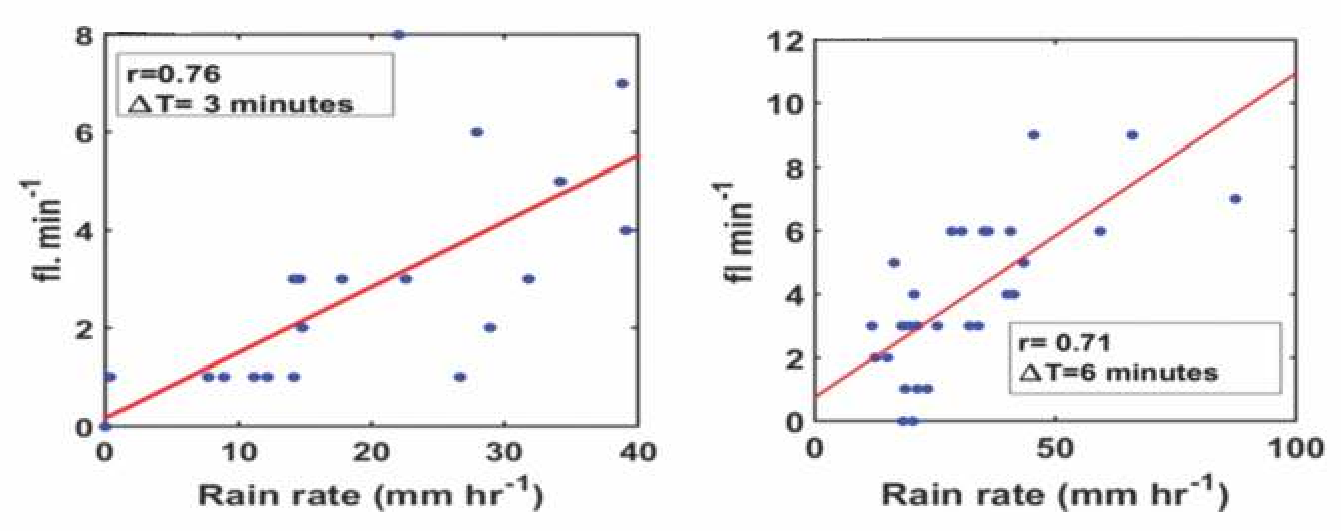


Fig. 1.5: Association between surface rain rate and flash rate for two thunderstorms observed at Mahabaleshwar on 5 May 2015 and 12 May 2017. 'r' indicates Pearson correlation coefficient. Flash rate is calculated from IITM Lightning Location Network.

persist in the literature. A cloud chamber of the internal dimension of 1ft × 1ft has been designed at IITM, Pune to study electro-crystallisation of 'mm' size pure water drops. More than 150 experiments have been performed in the chamber in the absence and presence of an electric field. Preliminary results suggest that in normal conditions, maximum drops freeze in the temperature ranging from -10°C to -15°C, consistent with the previous laboratory studies. When the drops are subjected to an electric field of magnitude 2-5 kV cm^{-1}, the drops are observed to freeze in a much warmer temperature ranging from -6°C to -10° C indicating an electric field induced crystallisation. No movement of the drops is observed during freezing, which suggests that the freezing may be initiated by absorption of the latent heat of fusion by the Nylon wire where the drops are kept suspended. The implications of electrically induced freezing from the perspective of cloud physics have also been investigated. (**Fig. 1.6**) [***Mudiar D., Pawar S.D., Hazra A., Gopalakrishnan V., Lal D.M.***, *Srivastava M.K., A laboratory investigation of electrical influence on the freezing of water drops: A cloud physics perspective,* ***Journal of Earth System Science****, 130: 222, November 2021, DOI:10.1007/s12040-021-01736-6*]

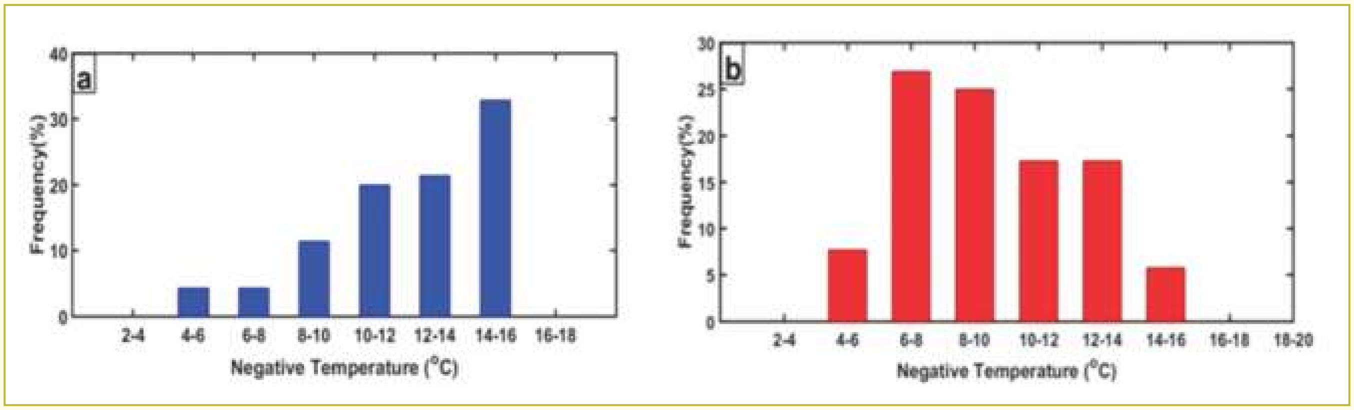


Fig. 1.6: *Frequency distribution of freezing temperature of distilled water drops (conductivity = 0.056 μsemen cm^{-1}).* ***(a)*** *No electric field is applied during the experiment.* ***(b)*** *The drops are subjected to an electric field of magnitude ranging from 2.5 to 5 kV cm^{-1}.*

1.1.2.3. Winter Fog Experiment (WiFEX) and Air Quality Early Warning System (AQEWS)

Winter Fog Experiment (WiFEX)

Field Campaign: The multidisciplinary/multi-institutional WiFEX field experiment was conducted at IGI Airport, New Delhi during 2017-22 to improve the scientific understanding and prediction of fog in a polluted IGP region. Data analysis indicates that the formation of optically thin fog before and after the dense spell is modulated tightly by the large mass of water-soluble inorganic ions where these ions hydrate in sub-saturated conditions. One of the important findings from numerical modelling suggested that the WRF model has an inability to simulate the realistic hydration of the water-soluble inorganic ions in sub-saturated conditions. The WiFEX campaign at IGI Airport could not be conducted during the 2021-22 winter due to ongoing construction work at the airport.

New 21 Member Ensemble Fog Forecast: The ensemble forecasts give a clear idea about different weather phenomena which may occur at a particular time. A new Ensemble Probability Forecast System (EPFS; 21-member) has been developed for fog and operationalised from winter 2021 onwards. The state-of-the-art numerical model is run parallel 21 times with slightly perturbed initial conditions. Based on their final products, the 21-member ensemble probability forecast of visibility is generated spatially and statistically. In addition, the EPFS product facilitates the probability forecast of visibility with four different categories (CAT2, CAT3A, CAT3B, and CAT3C) at six main airports in the IGP region. EPFS provides a spatial probability forecast of dense fog (Vis < 200 m) over the IGP region. To understand the influence of large circular patterns on fog formation, a Eurasian domain showing sea surface pressure, wind vectors and specific humidity at 850 hPa has been developed. The WiFEX fog forecasts are available at:

https://ews.tropmet.res.in/wifex/index.php.

Implementation of UK Met Office visibility code (VERA) in WRF-Chem: The new visibility, Vera, scheme of the United Kingdom Met Office is coupled in WRF-Chem model to provide diagnostic predictions of visibility over Delhi. The system has been readied to make operational visibility forecast for winter 2021-22.

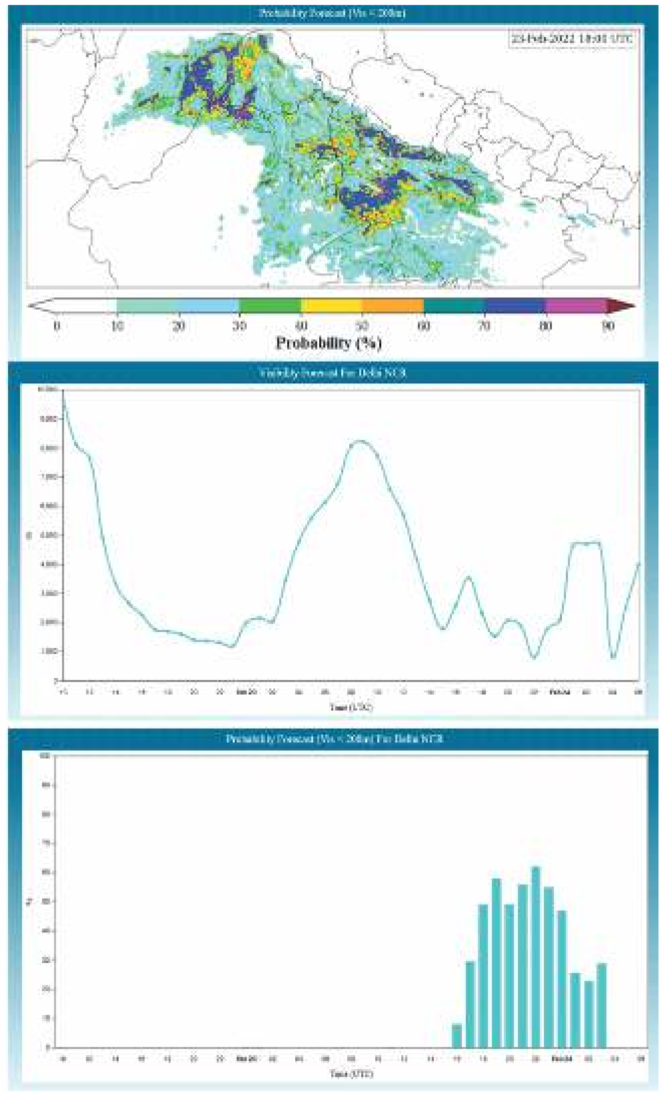


Fig. 1.7: Spatial, temporal and probabilistic forecast from VERA.

High-Resolution Land Surface Data Assimilation (HRLDAS): A new technique is developed to implement the HRLDAS to increase the performance of the Weather Research and Forecasting (WRF) model for improving the prediction of fog life cycle and near-surface meteorological parameters over Delhi. The Noah-MP Land Surface Model (LSM) based HRLDAS was used to develop fine-gridded soil states (soil moisture and soil temperature) covering the Indo Gangetic Plain (IGP) region at a 2 km horizontal grid resolution. These high-resolution soil states (SM/ST) are utilised to initialise the land surface fields in the WRF model. Currently, HRLDAS is executed in uncoupled mode at 2 km resolution to capture the heterogeneity of soil moisture and soil temperature for fog forecast (two-year spin-up). Statistical performance of the micro-meteorological variables (T2, RH2 and WS10) exhibited low variance (0.13°C, 0.10% and

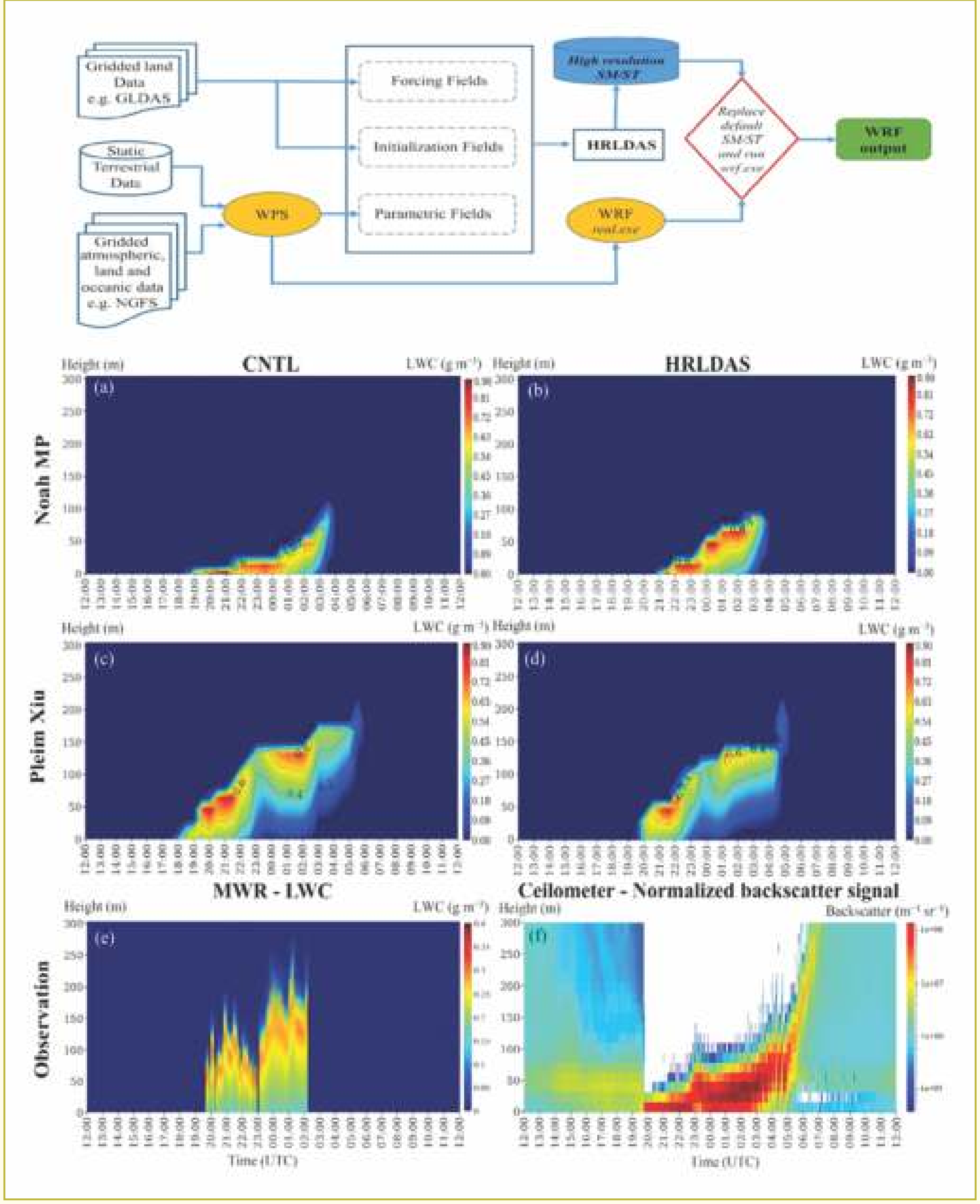


Fig. 1.8:
Flowchart of the HRLDAS used in conjunction with the WRF model and results for a dense fog case.

0.75 m s^{-1}), high correlation (0.93, 0.92 and 0.82) and high index of agreement (0.92, 0.87 and 0.78). As a result, the error in fog onset timing was notably reduced to 02 hrs, and the vertical representation of fog was skillfully demonstrated in the WRF Pleim-Xiu land surface scheme with HRLDAS soil fields. Sensitivity experiments revealed a need to revisit soil states to improve the skill of fog forecast. For more details on this work, please refer

https://doi.org/10.1016/j.atmosres.2022.106331.

Air Quality Early Warning System (AQEWS)

Air Quality Early Warning System (AQEWS) for Delhi NCR region: Air pollution is one of the major environmental hazards in many megacities in India, posing severe effects on human health. The complex interaction of physio-chemical processes makes accurate prediction of extreme air pollution episodes quite challenging. However, in response to the mandate from MoES; IITM, in collaboration with NCAR, USA, has developed an integrated technology for Air Quality Early Warning System (AQEWS) for Delhi NCR region. To address the challenges in chemical weather forecasting in India, the team has developed a chemical data assimilation system that integrates satellite aerosol optical depth (AOD) retrievals at 3 km resolution, surface data from 260 air quality monitoring stations in India and high-resolution emissions from various anthropogenic and natural sources (including dust and stubble burning). The assimilation is based on Grid-point Statistical Information (GSI) coupled with 3-dimensional variational (3D-VAR) chemical data assimilation in a numerical transport model embedded with dynamical downscaling. This extensive modelling framework has resulted in a phenomenal increase in prediction skill of extreme air quality episodes up to 3-days in advance at a city-scale to street level. IITM has further developed a very high-resolution (400 metre) operational modelling system showing an accuracy of 88% for predicting extreme pollution events, which is much higher than the estimates available for a similar system across the globe. The operational and public dissemination system (https://ews.tropmet.res.in) was developed under the Smart Cities Mission (NP15) of the Govt. of India, and the same is being used operationally by IMD, MoES, CPCB, MoEFCC, and DPCC. This early warning system provides: (1) near real-time observations of air quality and visibility over the Delhi region and details about natural aerosols like dust (from dust storms), fire information, satellite AOD; (2) predictions of air pollutants based on the state-of-the-art atmospheric chemistry transport models; (3) warning messages, alerts, and bulletins; and (4) forecast of the contribution of non-local fire emissions to the air quality in Delhi. Apart from Delhi, the specialised forecast is extended to cover a few more big cities in India, viz. Mumbai, Kolkata, Bengaluru, Pune, Hyderabad, Lucknow and Patna, at 10 km resolution. The system also provides near real-time forecast verification for Delhi on a daily and hourly basis. The frozen version of the AQEWS was officially handed over to IMD in June 2021 for operational implementation. The teams from both sides have been working on its technical implementation. IITM will continue further developments for improving the accuracy of this forecasting product and maintain the website designed for public dissemination.

Decision Support System (DSS): IITM successfully integrated Decision Support System (DSS) for air quality management in Delhi using in-house resources and implemented it operationally in October 2021. DSS employs the state-of-the-art online chemistry transport model WRF-Chem. The modelling set-up utilises the anthropogenic emissions inventory prepared by The Energy and Resources Institute (TERI) for Delhi and the surrounding 19 districts. A new tagged-tracer technique was developed, and around 490 such passive tracers are implemented in the modelling framework. The DSS was integrated with 3D-var GSI-based chemical data assimilation to assimilate surface $PM_{2.5}$ data from the air quality monitoring stations across the northern region of India, and satellite retrieved aerosol optical depth from MODIS instrument onboard TERRA and AQUA satellites. Moreover, DSS uses the Active Fire count data from the MODIS instrument to generate near-real-time fire emissions. The present version of DSS runs with a horizontal grid spacing of 10 km and generates forecasts and decision-support information for the next 120 hours (*i.e.,* five days).

The Commission for Air Quality Management (CAQM) in National Capital Region and Adjoining Areas has, in principle, accepted the DSS developed by IITM for air quality management in Delhi NCR during the 2021-2022 winter. DSS provides quantitative information about: a) the contribution of emissions from Delhi and the surrounding 19 districts to the air quality in Delhi, b) the contribution of emissions from 8 different emission sectors in Delhi to the air quality in Delhi, c) the contribution from biomass-burning activities in the neighbouring states to the degradation of air quality in Delhi, and d) the effects of possible emission source-level interventions on the forecast of severe air-quality events in Delhi. This system helped to cut Delhi's pollution peak last November by 18-22%. The operational and public dissemination system (https://ews.tropmet.res.in/dss) was developed in October 2021 under the Smart Cities Mission (NP15) of the Govt. of India and is being operationally used by IMD, CPCB, MoEFCC, DPCC and CAQM.

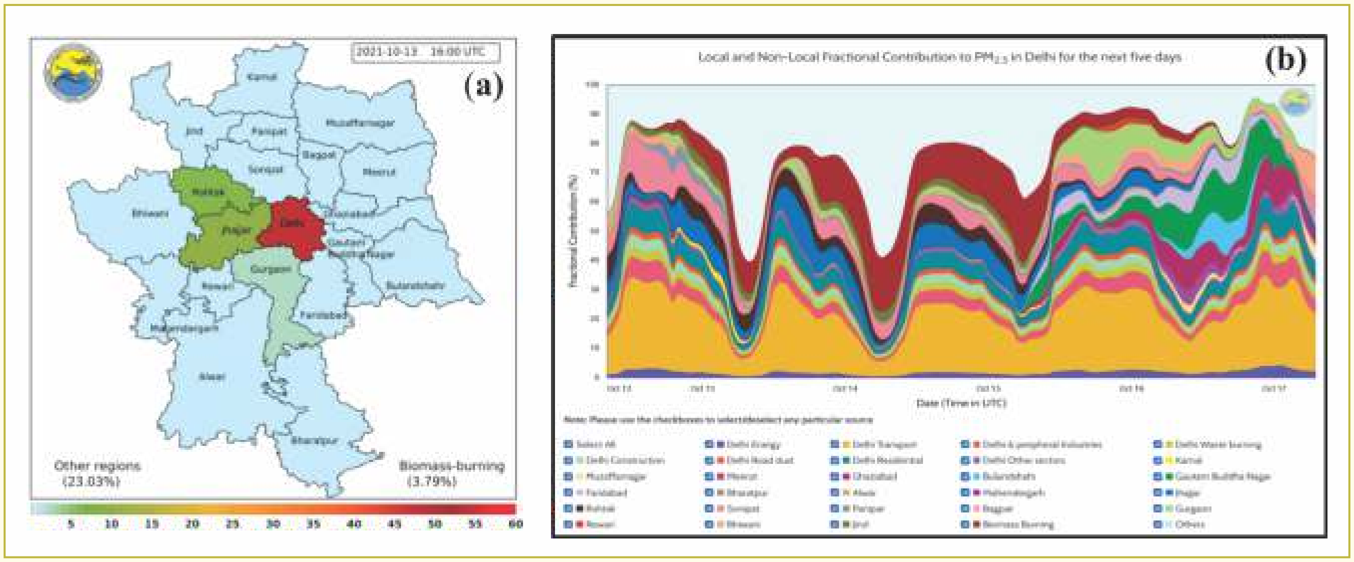


Fig. 1.9: *Sample outputs from DSS:* ***(a)*** *District-wise fractional contribution to the fine particulate matter pollution load in Delhi on 16 UTC of 13 October 2021.* ***(b)*** *Similar to* ***(a),*** *but for 120 hours from 10 UTC of 13 October 2021.*

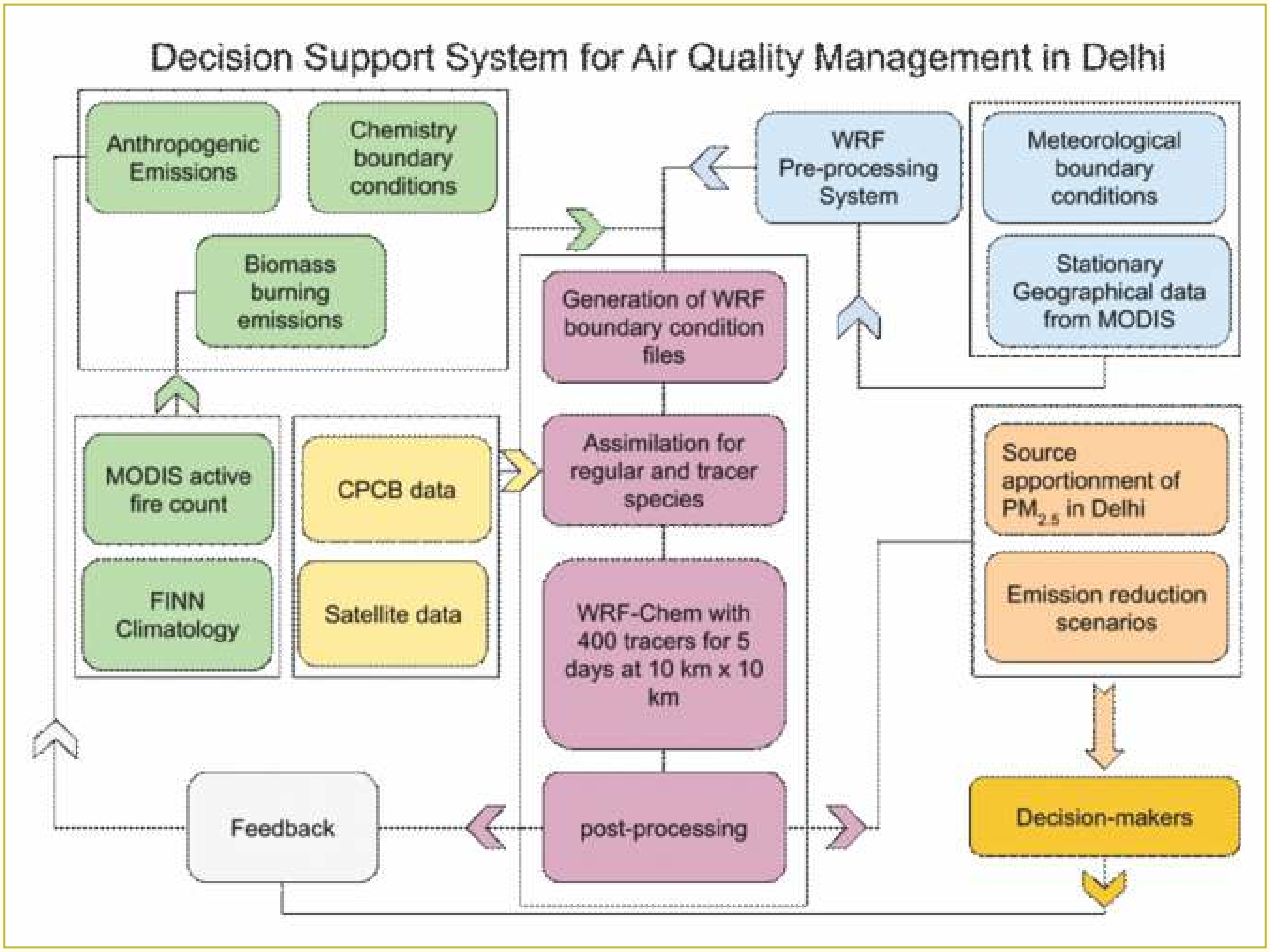


Fig. 1.10: *Overview of Decision Support System.*

1.1.3. Atmospheric Research Testbeds (ARTs)

Project Director : Dr. G. Pandithurai

Objectives

- To establish an atmospheric research testbed in central India (ART-CI) for better understanding of processes governing monsoon convection including its diurnal variation and land-atmosphere interactions over the monsoon core region. To organise intense observational campaigns along with weather prediction model runs for testing hypotheses and to improve physical parameterisations in the models related to convection and land surface processes.
- To understand the microphysical and dynamical processes involved in aerosol-cloud-precipitation interactions using *in-situ* and remote sensing measurements over a high-altitude site. Further, to understand the role of aerosol size and hygroscopicity in cloud activation processes and to develop parameterisation schemes for CCN, ice nuclei, and warm rain processes to implement in weather/climate models.
- To better understand the orographic convection, precipitation and microphysical processes of clouds and precipitation using radar and satellite remote sensing. Further, to develop the spatial distribution of rainfall from radar datasets and retrieve cloud micro/macro physical parameters using Doppler weather radars.
- To develop an urban weather radar network for rainfall mapping at a high spatial and temporal resolution to better understand heavy precipitation processes and for applications such as nowcasting and flood warning systems.
- To implement unmanned aerial vehicles (UAVs) for lower atmospheric research relevant to meteorological and aerosol properties, boundary layer and fog/haze processes.

Highlights of Major Achievements:

- Infrastructure development is underway for establishing an atmospheric research testbed (ART) facility in central India near Bhopal.
- A dual polarisation C-band Doppler weather radar was installed and commissioned in June 2021, and an observational campaign was conducted during monsoon 2021 to study convective and microphysical properties in the monsoon core zone.
- An ice parameterisation scheme is developed using ice nuclei and aerosol measurements carried out over HACPL.
- A chamber experiment was conducted to study the CCN activation fraction of aerosols emitted from different sources. An observational campaign was conducted at HACPL to better understand aerosol-cloud-precipitation interactions.
- Cloud-induced enhanced solar irradiance and its implications were investigated on windward and leeward sides of the Western Ghats.
- An automatic rain gauge network (MESONET) is established in collaboration with IMD.
- Radio Frequency (RF) noise surveys were conducted for all four radar sites in Mumbai Metropolitan Region as a part of the country's first urban weather radar network.
- The Ministry of Civil Aviation (MoCA) issued a conditional exemption to IITM for conducting UAV experiments for atmospheric research.
- Installation and training of UAV systems were commissioned, field campaigns were conducted at two locations, and UAV flights for research purposes were executed for the first time in India.

R&D Activities

Under ARTs, the following major R&D activities and developmental works are executed:

- **Central India ART, Bhopal**
- **Orographic ART (HACPL)**
- **Urban ART (Radar and Satellite Meteorology)**
- **Lower Atmospheric Research using Unmanned aerial System facility (LARUS)**

1.1.3.1. Central India ART, Bhopal

Developmental Activities

- IITM Pune is establishing an Atmospheric Research Testbed (ART) facility in central India on ~100 acres of land at Silkheda village in Sehore district of Madhya Pradesh. The facility is being established to provide important observations for a better understanding of processes related to convection, clouds and land-atmosphere interactions in the core monsoon zone region. Physical infrastructure such as civil works (boundary wall and entrance gate), laboratories, and electrical works (HT sub-station) are underway at ART, Bhopal. Instruments such as microwave radiometric profiler, ceilometer, disdrometer, micro rain radar, cloud condensation nuclei counter, and 75 m tower for greenhouse gases flux measurements will be installed once the physical infrastructure is ready. A dual polarisation C-band Doppler weather radar has been successfully installed on a 20 m tower and commissioned in June 2021 for measurements.

Fig. 1.11: *Dual polarisation C-band Doppler weather radar installed at ART, Bhopal.*

Fig. 1.12: *A microwave radiometric profiler, ceilometer, and disdrometer installed at ART, Bhopal.*

- An observational campaign during monsoon (01 June - 30 September 2021) with the C-band radar was conducted to collect polarimetric data on 3-D structures of convective and microphysical properties in the monsoon core zone for the first time. The cloud radar (Ka-band) is moved from the Western Ghats to central India, and efforts are underway to operationalise it in collocation with the C-band radar.

Basic Research

During the 2021 monsoon, 3-D radar observations were conducted with mesoscale coverage (300 km x 300 km) and highly time resolved (every 6 min). The polarimetric data will aid in a better understanding of the nature of cloud systems, as well as related convective and microphysical processes in the monsoon core zone. In **Fig. 1.13**, quasi-vertical profiles (QVPs) of C-band polarimetric radar variables were constructed to examine the temporal evolution of microphysical characteristics during 04-06 August 2021. The figure shows the height-time representation of QVPs of (a) horizontal radar reflectivity (ZH), (b) differential reflectivity (ZDR), (c) differential phase (PhiDP), and (d) cross-correlation coefficient (RhoHV) retrieved from C-Pol radar data at 10° elevation. Each panel in **Fig. 1.13** illustrates the QVP evolution during 60 hrs (600 profiles) and reveals the complicated internal structure of the precipitating system. A well-defined signature of melting layer (at~5 km) in stratiform clouds is characterised by an elevated Z, ZDR, and depressed RhoHV. A high-resolution representation of the melting layer with some undulations is seen.

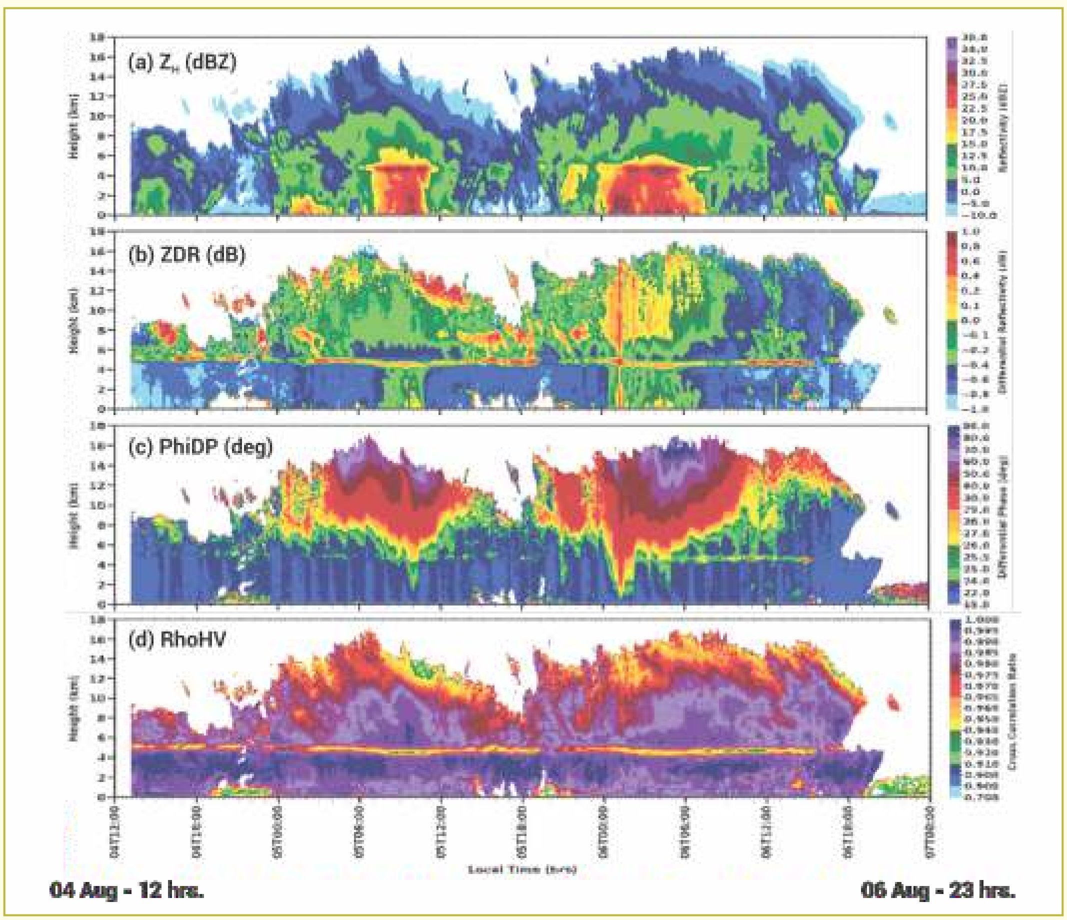


Fig. 1.13: *Quasi vertical profiles (QVPs) of polarimetric radar variables from C-band dual-polarised Doppler weather radar.*

1.1.3.2. Orographic ART (HACPL)

Developmental Activities

- An ice parameterisation scheme is developed using ice nuclei and aerosol measurements at the High-Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar. A chamber experiment was conducted to study the CCN activation fraction of aerosols emitted from different sources such as diesel emissions, charcoal burning, wood burning, grass, and cow dung. Further, the role of size distribution and chemistry on CCN activity is studied in detail using the observational facilities at HACPL. Measurements of volatile organic compounds are being used to better understand their role in secondary organic aerosols and CCN activation processes. Aerosol hygroscopicity (water uptake) measurements are being investigated to understand their variability and role in CCN activation processes. An observational campaign was conducted at HACPL to capture cloud and rainfall characteristics along with aerosol measurements to better understand aerosol-cloud-precipitation interactions.

Basic Research

Droplet characteristics in monsoon clouds before the rain as observed over a high-altitude site in the Western Ghats

The cloud droplet size distribution (CDSD) and microphysical properties before monsoon rain events are studied using *in-situ* ground observations over a high altitude site (17.92°N, 73.66°E, and 1348 m above mean sea level) in the Western Ghats. Microphysical properties such as cloud droplet number concentration (CDNC), liquid water content (LWC), cloud droplet spectrum, droplet effective diameter (ED), droplet mean radius (R_m), spectral width (σ), and relative dispersion (ε) of monsoon clouds analysed showed clouds contained both small and large droplets (**Fig. 1.14**). Clear variation in the CDSD is noted before rain events showing single, two, and three modes distribution, further categorised into single- and multi- modes. An apparent variation in cloud microphysical properties is noted for both single- and multi-mode cases. Analysis revealed the

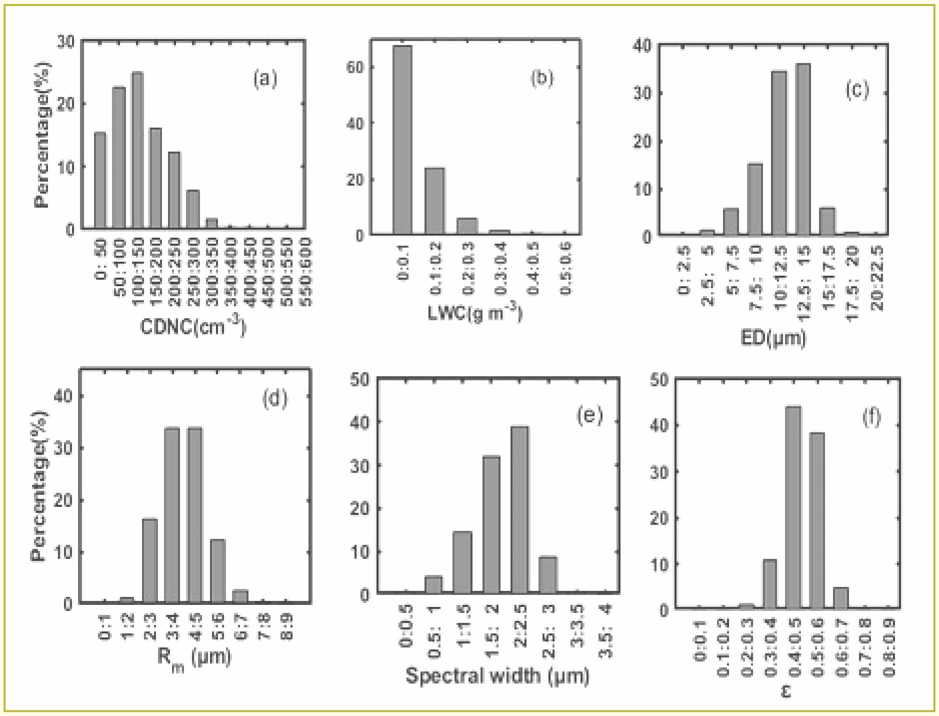


Fig. 1.14: *Bar plot showing the seasonal percentage of occurrences in* ***(a)*** *CDNC,* ***(b)*** *LWC,* ***(c)*** *ED,* ***(d)*** *Rm,* ***(e)*** *Spectral width and* ***(f)*** *ε.*

possibility of entrainment of aerosols into these clouds leading to multi modes in the CDSD. Observed rain event duration indirectly suggested higher warm rain depths (D*) when multi-mode cases are observed. *[**Leena P.P., Varghese M., Anil kumar V., Basheer A.I., Pandithurai G.**, Droplet characteristics in monsoon clouds before rain as observed over a high altitude site in Western Ghats, India, **Journal of Atmospheric and Solar Terrestrial Physics**, 221: 105709, September 2021, DOI:10.1016/j.jastp.2021.105709, 1-9]*

Investigation of physico-chemical characteristics and associated CCN activation for different combustion sources through chamber experiment approach

The aerosol physico-chemical properties and their CCN activation characteristics were studied for different combustion source types such as diesel generators (DG), wood, leaf, charcoal, grass, and cow dung through chamber-based experiments. **Fig. 1.15a** depicts the schematic diagram of the chamber experiment where Aethalometer (AE-33), high resolution time-of-flight aerosol mass spectrometer (HR-TOF-AMS), scanning mobility particle sizer (SMPS) and cloud condensation nuclei (CCN) counter were connected in line to derive the absorption properties, chemical composition, size distribution and CCN number concentrations respectively. Angstrom absorption exponent (AAE) and Angstrom absorption exponent ratio (AAER) were estimated utilising the Aethalometer data. The analysis reveals that the DG emission was associated with the lowest AAE value (0.92), and the AAE value was highest for cow dung emissions (2.15). The chemical composition data revealed that the organics contributes more than 90% to most of the combustion sources except charcoal, for which the organic contribution is 78%. The chemical composition was then utilised to derive the hygroscopicity parameter (κ) for each combustion source type (plotted in **Fig. 1.15b**). As shown in **Fig. 1.15b** (right axis), κ was estimated to be highest for charcoal emissions and lowest for diesel and cooking emissions. Hygroscopicity parameter (κ) was also evaluated utilising CCN and SMPS data. The CCN activation (**Fig. 1.15c**) and size distribution analysis revealed that the CCN activation of cow dung was highest at 0.1% and 0.3% super-saturations. This is associated with the higher geometric mean diameter (GMD) of emitted aerosols (**Fig. 1.15b;** left axis), indicating the importance of size compared to the chemical composition. The activation fraction of charcoal emission was found to be higher than DG emission (**Fig. 1.15c**) in these super-saturations, indicating the importance of hygroscopicity in addition to size for governing the CCN activation when the GMD is on the lower side (as the geometric mean diameter of emitted aerosol from these sources were similar in nature). *[**Mukherjee S., Anil Kumar V., Patil R.D., Meena G.S., Buchunde P., Waghmare V., Deshmukh S., Dhavale V., Ray A., Panicker A.S., Sonbawne S.M., Safai P.D., Pandithurai G.**, Investigation of physico-chemical characteristics and associated CCN activation for different combustion sources through Chamber experiment approach, **Atmospheric Environment**, 266: 118726, December 2021, DOI:10.1016/j.atmosenv.2021.118726, 1-9]*

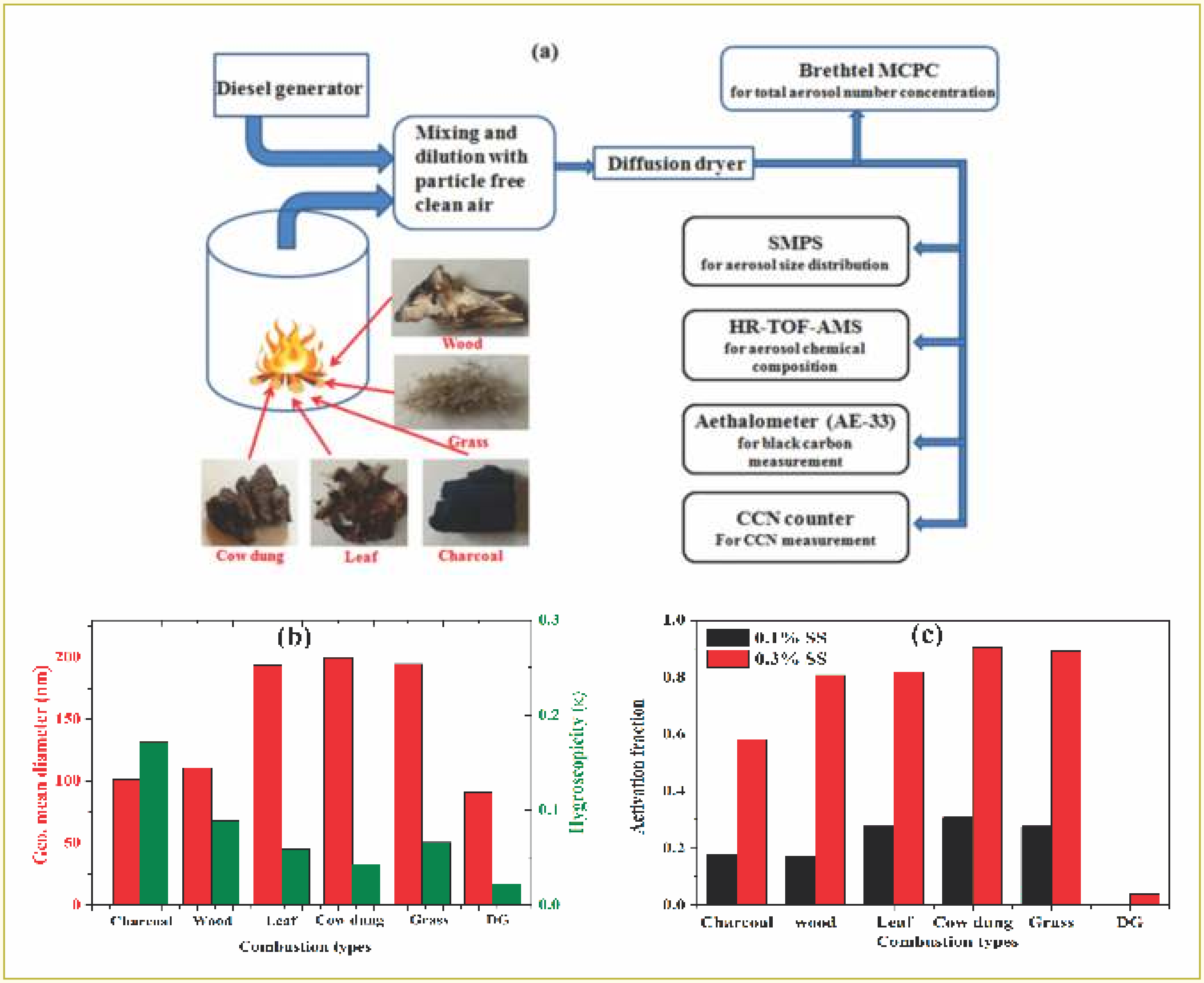


Fig. 1.15: *The schematic diagram of the chamber experiment conducted for the study is shown in figure* ***(a)***. ***(b)*** *depicts the chemical composition derived hygroscopicity parameter and estimated geometric mean diameter of emitted aerosols from each combustion source type.* ***(c)*** *represents the associated CCN activity for all combustion source types at 0.1% and 0.3% super-saturations.*

1.1.3.3. Urban ART (Radar and Satellite Meteorology)

Developmental Activities

- **Automatic Rain Gauge Network:** An automatic rain gauge network (MESONET) was established in collaboration with IMD and collated data from Municipal Corporation for Greater Mumbai (MCGM). Real-time data are being disseminated to the disaster management department, NCMRWF and NCCR, Chennai, to assist the flood warning system.
- **Urban Weather Radar Network:** Radio Frequency (RF) noise surveys were conducted for all four sites in the Mumbai metropolitan region, wherein radar installation is planned as a part of the country's first urban weather radar network. The central frequencies were selected from the RF survey, and the frequency clearance from WPC is being sought. Other logistics, such as suitable towers for installation at the four sites in Mumbai metropolitan region, are being designed.

Basic Research

Physical processes controlling the diurnal cycle of convective storms in the Western Ghats

Diurnal variation of convective storms (CSs) during monsoon season and associated physical mechanisms are significantly important for an accurate forecast of short-time and extreme precipitation. The diurnal cycle of CSs is investigated using ground-based X-band radar and reanalysis data during the summer monsoon (June-September 2014) over the complex mountain terrain of the Western Ghats, India. A convective storm is determined by considering the CAPPI at 2 km with a reflectivity threshold of 35 dBZ using the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) cell-tracking method. CSs showed a clear diurnal cycle over different topographic regions (**Fig. 1.16a**). A prominent bimodal distribution in the CS occurrence is observed along the coastal regions and a weak bimodal distribution on the mountain peak; however, their frequency is different. The afternoon peak is stronger over high altitude regions, whereas the early morning peak is stronger over coastal regions. In the early morning hours (**Fig. 1.16b**), a significantly weakened flow (colour-filled contours) exists from the surface to 950 hPa level beyond 72.5°E longitude. This could be due to the downslope winds coming from the mountains during the night times. The vertical motion deviations (contours) are negative over coastal and oceanic regions during 0830 LT, indicating updrafts

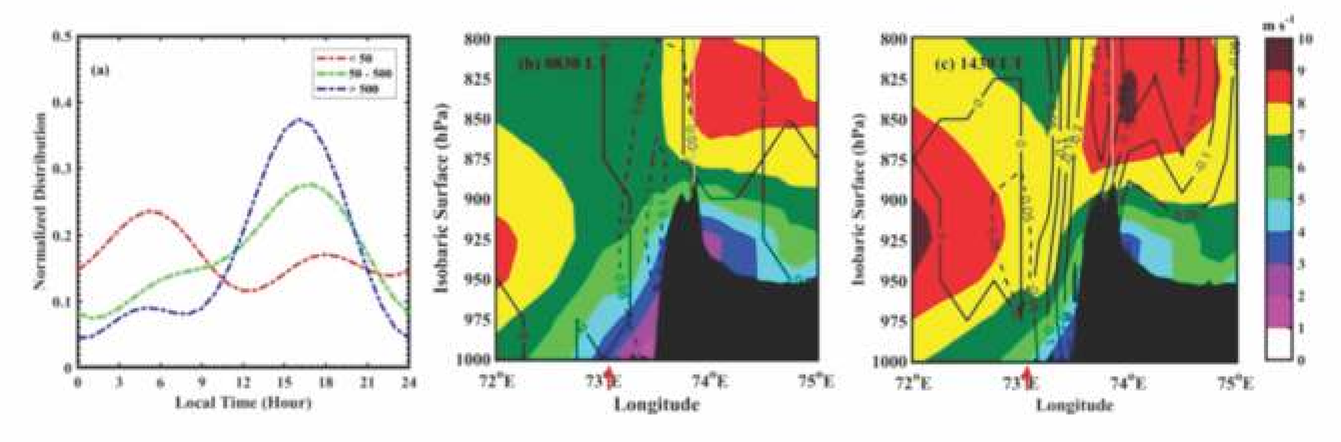


*Fig. 1.16: **(a)** Diurnal cycle of CS occurrence with the topography (height in metres) on the windward side of the radar. The mean wind speed (colour-filled contours) and vertical velocity (in pressure coordinate) deviation from the mean (black contours) along 18°N during **(b)** 0830 LT and **(c)** 1430 LT. The solid contours represent negative vertical velocity (upward motion), and the dashed contours represent positive vertical velocity (downward motion). The coastline is indicated with a red colour arrow below the X-axis. The topography along 18°N is shown by black shading.*

during this time. So the early morning peak over coastal areas is induced by the low-level convergence between the prevailing monsoon winds and the thermally induced downslope winds. The vertical motion deviations are negative over higher altitudes during afternoon hours (**Fig. 1.16c**). With the maximum solar heating in the afternoon, the rising motion induced by the low-level convergence between the sea breeze front/ seasonal winds and the mountain enhances. This indicates that the orographic response to the prevailing monsoon flow from the surrounding oceanic regions superimposed with the land-sea thermal contrast is responsible for the afternoon maximum in the CSs occurrence over high-altitude regions in the Western Ghats. So, the afternoon maximum (over high altitude regions) is related to local topographical lifting, likely aided by solar heating. *[**Murali Krishna U.V., Das Subrata Kumar, Deshpande S.M., Pandithurai G.**, Physical processes controlling the diurnal cycle of convective storms in the Western Ghats, **Scientific Reports**, 11: 14103, July 2021, DOI:10.1038/s41598-021-93173-0, 1-13]*

A mesoscale rain gauge network (MESONET) over Mumbai: Preliminary results and applications

A mesoscale rain gauge network (MESONET) comprising 143 rain gauges scattered over the Mumbai metropolitan region is set up to have instantaneous rainfall information. The real-time rainfall measurements are utilised for real-time web-based rainfall data portals and mobile-based apps. These apps are developed as a public information/awareness system that would help the public cope with unanticipated situations caused by massive rainfall events. The initial results show that the maximum contribution (~60%) of seasonal rainfall is from heavy to extreme rainfall events in 2019. Temporal distribution of event duration for heavy rainfall events (65-125 mm) implies the possible occurrence of heavy rainfall events at a sub-daily scale. The real-time rainfall observations from the MESONET network enabled better monitoring of the extreme rainfall events (for example, 1-2 July 2019) and issuing timely nowcast to various stakeholders throughout the events by RMC, Mumbai. Apart from the standard public utility on real-time rainfall information, Integrated Flood Warning System for Mumbai (iFLOWS-Mumbai) also utilises the current MESONET real-time data for verification. (**Fig. 1.17**) *[**Sunilkumar K., Das Subrata K., Kalekar P., Kolte Y., MuraliKrishna U. V., Deshpande S., Dani K.K., Nitha T.S.,** Hosalikar K.S., Narvekar M., Mohan K.N., **Pandithurai G.**, A MESO-*

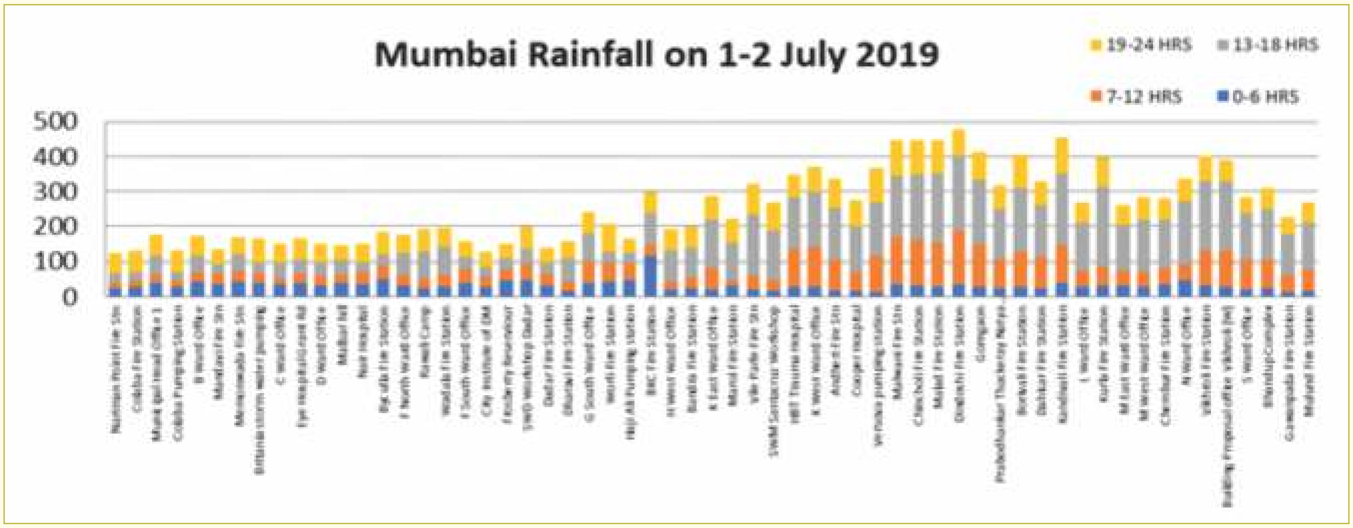


Fig. 1.17: *Temporal evolvement of extreme precipitation rainfall event on 01-07-2019 by six hourly rainfall analyses based on the MESONET rain gauge observations.*

scale Rain gauge NETwork-MESONET over Mumbai: Preliminary results and applications, ***Urban Climate****, 41: 101029, January 2022, DOI:10.1016/j.uclim.2021.101029, 1-12]*

Regional perspectives in Eurasian snow - Indian monsoon relationship: An observational study

The relationship between Indian summer monsoon rainfall and Eurasian snow in the preceding seasons has been studied extensively. However, spatial structures of this snow-monsoon relation have rarely been investigated. An attempt is made to diagnose the nature of the observed linkage between Eurasian winter snow and the spatial distribution of the following summer monsoon rainfall over India. Eurasian snow association with the spatial distribution of rainfall over India features a tri-polar pattern of significant negative-positive-negative correlations over India's northern, east-central and peninsular regions (**Fig. 1.18**). The physical mechanism underlying the snow-monsoon connection is envisaged through two pathways. One of the channels is through Eurasian winter snow that directly affects the monsoon by modulating large-scale circulation, while the other is indirectly through Tropical Eastern Pacific (TEP) sea surface temperatures (SSTs). Enhanced Eurasian wintertime snow is associated with warm TEP SSTs from the preceding winter through to the following summer, leading to anomalous large-scale zonal circulation during the summer monsoon season, thereby affecting rainfall over India. The spatial facets of the snow-monsoon relationship remain unaltered by Indian Ocean Dipole and North Atlantic Oscillation modes. [***Prabhu A., Mandke S.K., Pandithurai G.****, Regional perspectives in Eurasian snow - Indian monsoon relationship: An observational study,* ***Polar Science****, 30: 100718, December 2021, DOI:10.1016/j.polar.2021.100718, 1-15*]

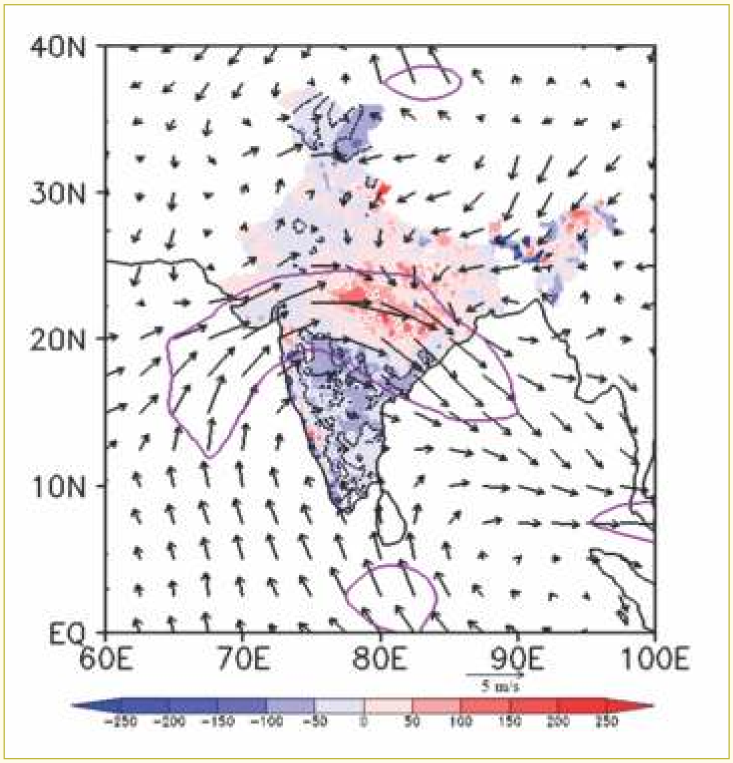


Fig. 1.18: *IMD-based summer monsoon (JJAS) rainfall in mm/season (shaded) overlaid by wind (vector) at 850 hPa during JJAS constructed from composites of five strongest episodes of (high-low) winter (DJFM) Eurasian snow extremes. Dotted black (white) contours show a significant negative (positive) difference in rainfall at a 95% confidence level. Solid purple contours represent a significant difference in wind vectors at a 95% confidence level.*

1.1.3.4. Lower Atmospheric Research Using Unmanned Aerial System Facility (LARUS)

Developmental Activities

- The Ministry of Civil Aviation (MoCA) has issued a conditional exemption to IITM for conducting beyond the visual line-of-sight experiments for atmospheric research using UAVs. IITM is the first institution in the country to obtain such permission for using UAVs for atmospheric research. The Airport Authority of India (AAI) and the Indian Air Force (IAF) have also given clearances/NOC for conducting IITM-UAV operations at the proposed locations. UAV system's installation and demonstration commissioned at IITM. Training sessions were organised for a group of project personnel at IITM on UAV systems, instrument integration and operation, engine maintenance and ground station operations. Field campaigns were conducted and executed for UAV operations at two locations in Maharashtra. UAV's first flights in India for atmospheric research purposes, one test flight and one mission flight were conducted at different airfields successfully in coordination with the Air Traffic Control (ATC).

Basic Research

Investigation of cloud-induced enhanced solar irradiance and its implications using high-frequency ground observations

The Western Ghats (WG) mountains along the west coast of peninsular India play an important role in the distribution of monsoon rainfall on its windward and leeward sides. An investigation unravels the increase in cloudiness in the dry season and the increase in the Cloud-induced Enhancement of Solar irradiance (CES) during the dry and wet seasons as observed in the windward and the leeward sides of WG. From May 2018 to May 2021, the global horizontal irradiance (GHI) revealed wide temporal and spatial variability with a high frequency of CES events, even exceeding the extraterrestrial value around the noontime during the wet season. The observed excess irradiance due to partial/transparent clouds compared to clear sky maxima is more than 400 W/m^2 on the windward and 350 W/m^2 on the leeward. CES induced positive shortwave cloud radiative forcing (CRF) varied up to

Fig. 1.19: UAV system for lower atmospheric research.

+400 W/m^2 (warming effect), while negative CRF varied up to -1000 W/m^2 (cooling effect) (**Fig. 1.20**). During monsoon, the warming effect due to frequent CES events could offset a large cooling effect locally, leading to uncertainty in regional cloud models. Clouds resulting in huge irradiance variability in a day could also induce large fluctuations in renewable solar energy. *[**Padmakumari B., Sanket K., Sneha S., Mahesh N., Pandithurai G.**, High temporal variability of surface solar irradiance due to cloud enhancement effect over the Western Ghat mountains in peninsular India, **Journal of Atmospheric and Solar Terrestrial Physics**, Online, March 2022, DOI:10.1016/j.jastp.2022.105867, 1-11].*

Interannual crisscross pattern observed in South Asian monsoon rainfall and its relationship with aerosols

The interannual variability of South Asian summer monsoon rainfall (SAMR) is examined using a linear trend analysis for the recent 17-year period from 2000 to 2016. The trends in SAMR analysed from multiple rainfall datasets showed a unique crisscross-like pattern over South Asia and its surrounding oceans. Significant positive trends in SAMR occur over the middle and south Bay of Bengal (BOB) and North-West India (NWI) aligned in the SE-NW direction. Similarly, significant negative trends are observed over North-East India and head Bay of Bengal (NEI) as well as over the middle and south Arabian Sea (AS) oriented in SW-NE direction. The Western Ghats make an exception to this pattern where significant positive trends have been observed. Interestingly, the trends in aerosol optical depth (AOD) for the same period closely follow the trends in SAMR (**Fig. 1.21**). The relationship of AOD averaged over each of the significant aerosol trend regions with the SAMR suggests aerosol-induced suppression in moisture transport from a region covering the southern Arabian Sea and the Bay of Bengal played a dominant role over the negative trend regions. *[**Raja B.**, Maheskumar R.S., **Padmakumari B.**, Sunitha Devi S., Interannual crisscross pattern observed in South Asian monsoon rainfall and its relationship with aerosols, **Atmospheric Research**, Online, February 2022, DOI:10.1016/j.atmosres.2022.106112, 1-10]*

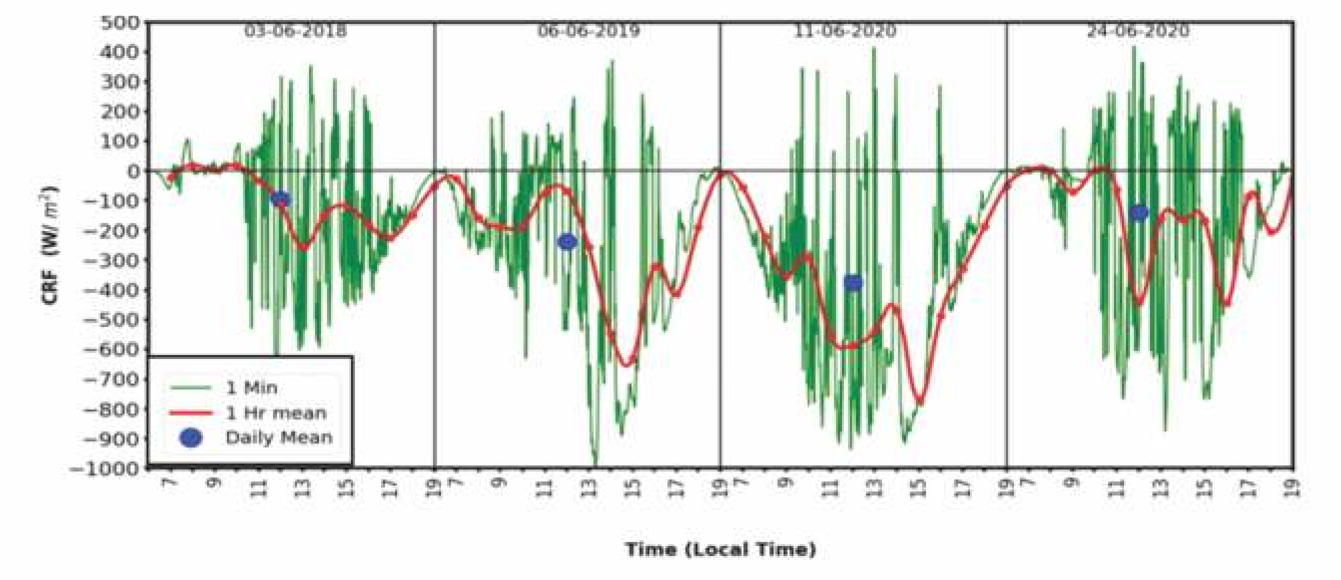


Fig. 1.20: *Temporal variability of surface shortwave cloud radiative forcing (CRF) for different typical cases at the Western Ghats overlapped with hourly and daily means.*

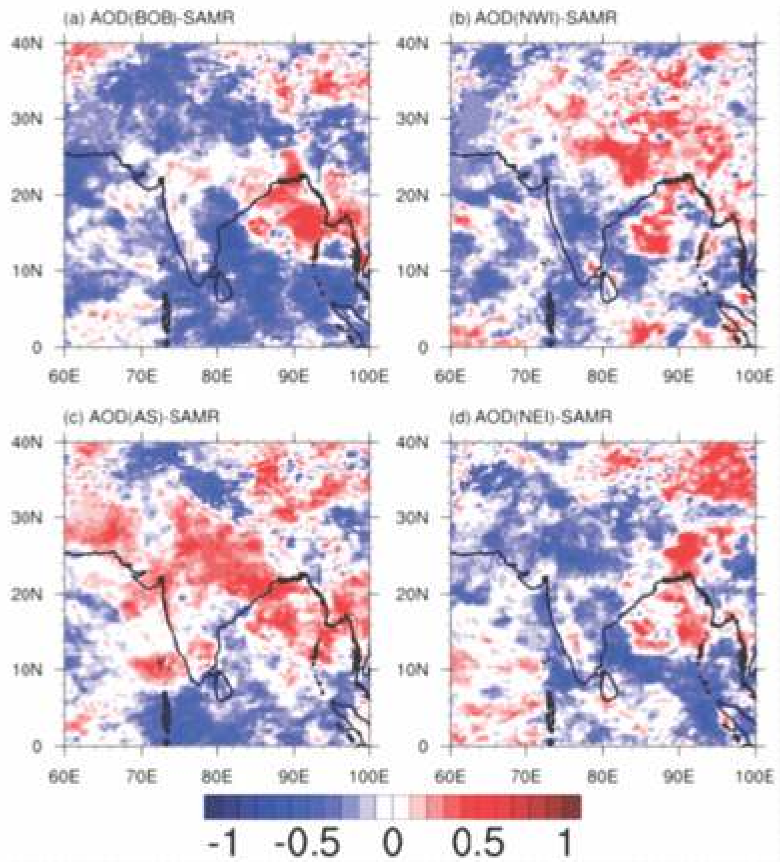


Fig. 1.21: *Correlation coefficient between MERRA2 AOD averaged over individual positive trend regions consisting of **(a)** BOB, **(b)** NWI (top) and negative trend regions consisting of **(c)** AS and **(d)** NEI (bottom) and SAMR from TRMM for the period 2000-16.*

Cloud-Aerosol interactions induced catastrophic widespread lightning: Inferences from satellite data

A record for an abysmally high number of lightning discharges in a single day occurred on 16 April 2019, where almost 58,066 flashes (cloud to ground + inter cloud) with a maximum of 179 flashes/min were observed over India. Researchers have hypothesised that an intense Western Disturbance (WD) caused these high numbers of lightning flashes, which prevailed in northwestern India and spread over much of the country. Instead, it is suggested and shown through multiple datasets that a dust intrusion into the storm altered cloud characteristics at the microphysical level, most likely favouring charge separation in cloud particles. The back trajectory calculation indicated a south-westerly transport of dust/aerosol, which converged within the secondary flow associated with the WD and lofted into the higher levels. It is hypothesised that the entrainment of dust acting as cloud condensation nuclei and ice nuclei induced a favourable condition for charge separation (**Fig. 1.22**). Also, a dust-boosting feedback loop was set up due to the prevailing intense WD, which further accelerated the electrification process and led to the catastrophic lightning. *[Shukla B.P., John J., **Padmakumari B.**, Das D., Thirugnanasambantham D., Gairola R.M., Did dust intrusion and lofting escalate the catastrophic widespread lightning on 16th April 2019, India? **Atmospheric Research**, 266: 105933, March 2022, DOI:10.1016/j.atmosres.2021.105933, 1-13]*

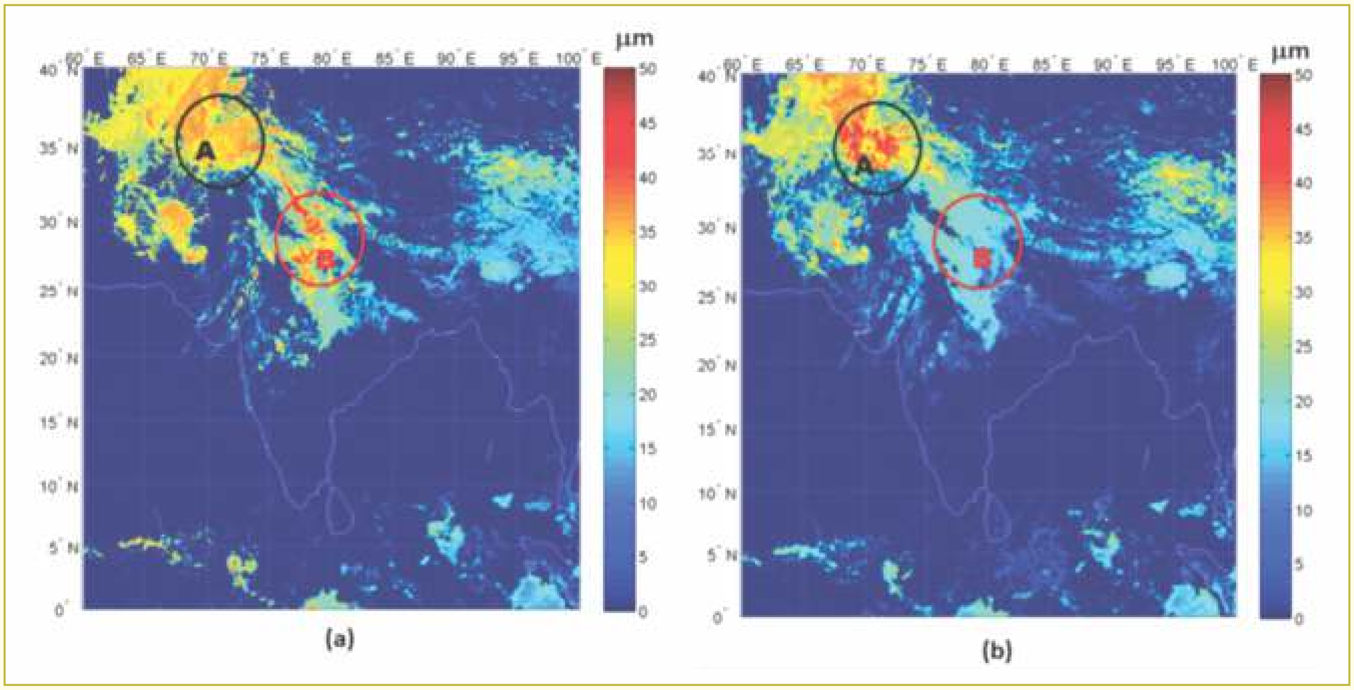


Fig. 1.22: *INSAT-3D Cloud Effective Radius (CER) at **(a)** 0500 GMT and **(b)** 0600 GMT. Two regions, Black Circle 'A' and Red Circle 'B', demonstrate spatio-temporal variation in CER distribution. The decrease in CER size in region B could be due to the increased number of CCN.*

1.1.4. Metropolitan Air Quality and Weather Services (MAQWS)

Project Director : Dr. B.S. Murthy
Deputy Project Director : Dr. R. Latha

Objectives

- To advance research on atmospheric processes governing the atmospheric chemical composition and air pollutants through modelling and observational network.
- To update current emission inventories of SAFAR cities to high-resolution to help mitigation planning.
- To investigate the role of carbonaceous species (black carbon, organic carbon, brown carbon, etc.) in different atmospheric processes.
- To develop a research-based integrated multi-hazard early warning system for air quality and health to predict environmental emergencies with air-health advisory services for Indian SAFAR megacities.

Highlights of Major Achievements:

- Publication of revised emission inventory report for Pune Municipal Region at higher resolution, 400x400 m.
- Incineration contributes about 19% at Ayanagar and 18% at Okhla to PM2.5 in Delhi. Metal industries in Okhla contribute about 19% to PM2.5.
- The prediction skill of the SAFAR operational model for four cities was tested for a year (2019-20) and found to be reasonable. The Normalised Gross error of PM2.5 for Delhi is found to be the highest (35%), whereas, for other cities, it is ~13-20%.
- Biomass burning was found to contribute up to 58% of black carbon (BC) mass over Satopanth glacier in the central Himalayas, with lower contribution during June and higher during May. Concentration weighted trajectory (CWT) analysis showed that the air mass from Indo-Gangetic Plains (IGP) was responsible for the majority of transported BC in July and August months (up to 65%) and partially in September (up to 40%).
- The impact of urbanisation over the Mumbai Metropolitan Region from 2018 to 2050 was assessed using projected land-use/land-cover change in the WRF model revealed a possible increase of average air temperature, @10m by maximum (minimum) 1.41°C (1.27°C). On adoption of a proper mitigation strategy, this growth can be restricted to 0.69°C (0.92°C).
- The ratios of isoprene to benzene (anthropogenic exhaust tracers) were used to quantify the contributions of biogenic and anthropogenic isoprene. The contributions of biogenic sources to isoprene were in the ranges of ~40-65% in winter and ~56-85% in the pre-monsoon season during daytime (11-17 hrs, IST).

Developmental Activities

Release of SAFAR-Emission Inventory 2020 Report: The high-resolution emission inventory (400 meters) mapping the local sources of air pollution in the Pune Metropolitan Region (PMR) for 2019-20 was released in May 2021. The final product yielded mapping of pollution sources in each 400m x 400m grid of PMR for eight major pollutants namely, $PM_{2.5}$, PM_{10}, NO_x, CO, SO_2, BC, and HC **(Table 1)**. The emission inventory campaign was led by IITM along with Savitribai Phule Pune University (SPPU) and Utkal University. Geographical Information System (GIS)-based statistical emission model developed by IITM scientists was used to develop fine resolution of 400m gridded products. A six-month-long emission inventory campaign was carried out during 2019-20 in PMR. More than 200 students from IITM, SPPU and Utkal University were involved in the campaign, with around 2,50,000 hours of work. This exercise was to collect real-time primary activity data of 26 different local sources of air pollution.

Model Skill Development: Presently, the real-time gridded fire count data is being used regularly as input for stubble burning contribution to Delhi's air pollution.

Operational: Regular air quality forecasts are being provided for four SAFAR cities: New Delhi, Pune, Mumbai and Ahmedabad.

Basic Research

Emission fingerprints of particulate matter over typical locations of NCR (Delhi)

Source apportionment study of PM2.5 using positive matrix factorisation was performed to identify the emission characteristic from different sectors (sub-urban residential, industrial and rapidly urbanising) of Delhi during winter. Chemical characterisation of PM2.5 included metals (Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb and Zn), water-soluble ionic compounds (WSICs) (Cl^-, NO_3^-, SO_4^{2-} and NH_4^+) and Carbon partitions (OC, EC). Particulates (PM2.5) were collected on a filter twice daily for stable and unstable atmospheric conditions at the locations with specific characteristics, viz. Ayanagar, Noida and Okhla. Ions solely occupied 50% of the total PM2.5 concentration. Irrespective of the location, a high correlation between OC and EC (0.871-0.891) at $p \leq 0.1$ is observed. A relatively lower ratio of NO_3/SO_4 at Ayanagar (0.696) and Okhla (0.84) denotes the predominance of emission from stationary sources rather than mobile sources like that observed at Noida (1.038). Using EPA PMF5.0, optimum factors for each location are fixed based on error estimation (EE). Crustal dust, vehicular emission, biomass burning and secondary aerosol are the major contributing sources in all three locations (**Fig. 1.23**). Incineration contributes about 19% at Ayanagar and 18% at Okhla. Metal industries

Table 4.1: Sectoral contribution of pollutant emissions during 2019-20.

Sector	BC	OC	NO_x	CO	SO_2	VOC
Transport	3.18	4.93	162.69	194.05	30.27	146.82
Industry	2.31	4.76	45.21	5.03	157.72	26.29
Residential*	1.33	2.71	6.94	65.67	1.97	16.13
Other#	0.65	3.10	7.17	28.10	1.61	1.20
	7.47	**15.50**	**222.01**	**292.85**	**191.57**	**190.44**

*** Residential Sector:** Residential cooking, slum, trash burning, cow dung, street vendor, household, wood burning, etc.

 # Other Sector: MSW Plants, MSW open burning, crematory, aviation, incense stick, brick clams, etc.

in Okhla contribute about 19% to PM2.5. These specific local emissions with considerable potency are to be targeted for long-term policymaking. Considerable secondary aerosol contribution (15-24%) indicates that gaseous emissions also need to be reduced to improve air quality [***Latha R., Mukherjee A., Dahiya K., Bano S., Pawar P., Kalbande R., Maji S., Beig G., Murthy B.S.***, *On the varied emission fingerprints of particulate matter over typical locations of NCR (Delhi) – A perspective for mitigation plans,* ***Journal of Environmental Management***, *March 2022, DOI:10.1016/j.jenvman.2022.114834*]

Air quality forecasting framework

Air quality is a strong health driver, so its accurate assessment and forecast are important in densely populated megacities to take preventive steps. The first Indian operational air quality framework – SAFAR (System of Air Quality and Weather Forecasting And Research) – has been developed for decision-makers and as a research tool with a capability of three days advance forecast in four Indian megacities of distinct environments and topography. The framework includes six different components from observations and modelling to outreach. To evaluate the performance of the

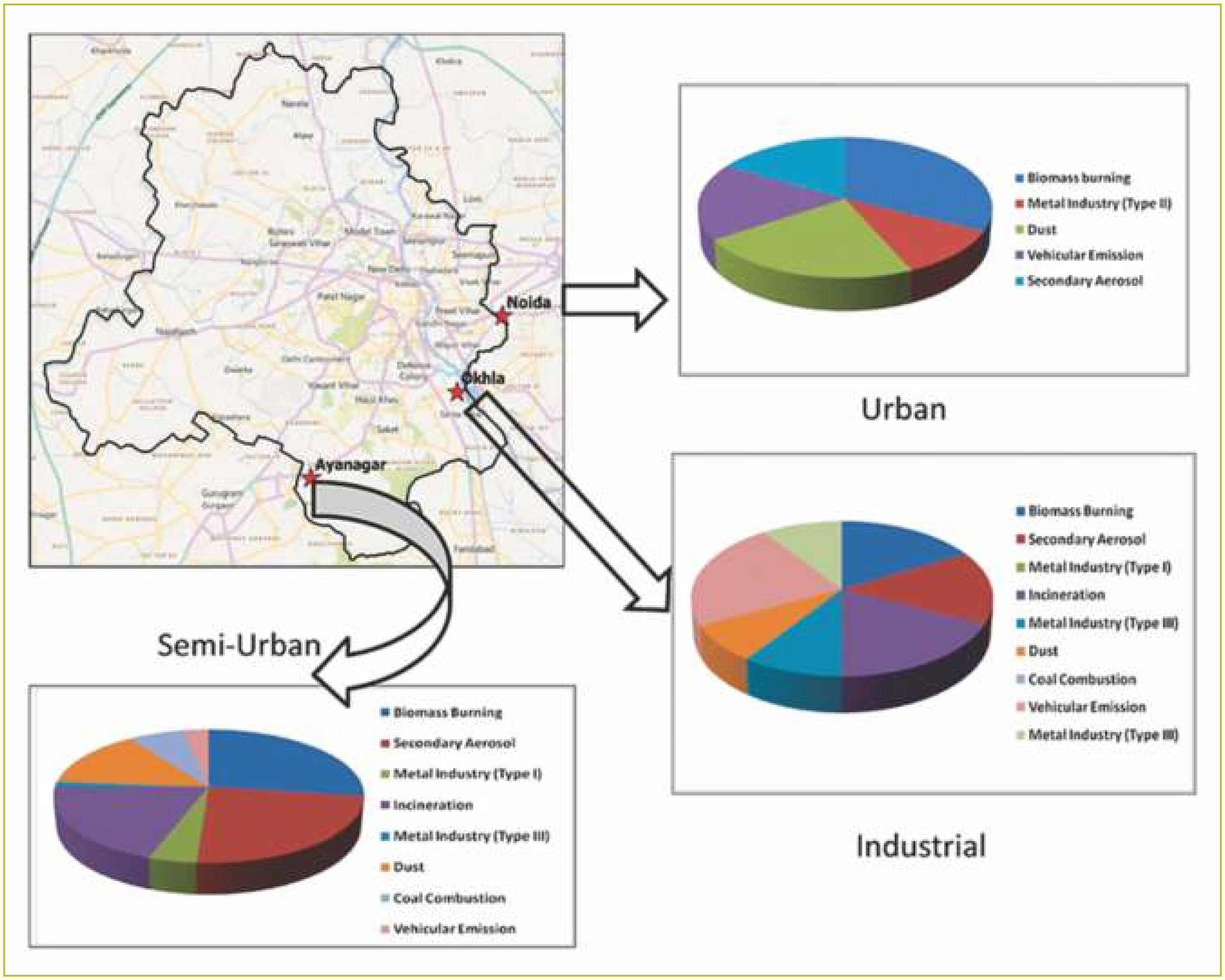


Fig. 1.23: *Source contributions to PM2.5 in three typical areas in Delhi.*

forecast, the model prediction skill with a focus on particulate pollutants which largely define the air quality of Indian metropolis, was tested for the pilot year 2019-20 and found to be reasonable. The Normalised Gross error of PM2.5 for Delhi was found to be the highest (35%), whereas, for other cities, it was ~13-20%. The Model Output Statistics (MOS) application enhanced the numerical model's operational forecast ability, which improved the accuracy for specific seasons (winter). [*Beig G., Sahu S.K.,* ***Anand V., Bano S., Maji S., Rathod A., Korhale N., Sobhana S.B., Parkhi N.****, Mangaraj P.,* ***Srinivas R.,*** *Peshin S.K., Singh S.,* ***Shinde R., Trimbake H.K.****, India's Maiden air quality forecasting framework for megacities of divergent environments: The SAFAR-project,* ***Environmental Modelling & Software****, 145: 105204, November 2021, DOI:10.1016/j.envsoft.2021. 105204*]

Black carbon impact on the Himalayan glaciers

Continuous measurement of black carbon (BC) concentration was carried out during May-October 2018 over Satopanth Glacier in the central Himalayas. BC concentrations varied between 28 and 287 ngm^{-3} on different days during the observational period. A high concentration of BC was observed in May (monthly mean of 221 ± 79 ngm^{-3}), and a lower concentration was observed in August (monthly mean of 92 ± 58 ngm^{-3}). Biomass burning was found to contribute up to 58% of BC mass over the region, with lower contribution during June and higher during May. Compensation parameter (K) values were found to vary between −0.005 and 0.005 in different months, asserting the presence of aged BC from June to October and relatively fresh BC in May. Concentration weighted trajectory (CWT) analysis showed that the air mass from Indo-Gangetic Plains (IGP) was responsible for the majority of transported BC in July and August (up to 65%) and partially in September (up to 40%). However, the transport from the Middle East and far northwestern regions was found to be the major contributor to BC concentrations in other months. The estimated BC direct radiative forcing was found to induce a 4.5 to 7.6 Wm^{-2} reduction of radiation at the surface (SFC), and the forcing was +2.3 to +3.5 Wm^{-2} at the Top of the Atmosphere (TOA), a schematic is shown in **Fig. 1.24**. The BC-induced atmospheric heating rates were found to be up to 0.35 k day^{-1} over the region. The sensitivity of snow albedo to radiative forcing was studied, and it is found that BC albedo changes tend to decrease albedo with an increase in BC-snow deposition, leading to a decrease in atmospheric absorption. [***Panicker A.S., Sandeep K.,*** *Gautam A.S.,* ***Trimbake H.K.,*** *Nainwal H.C.,* ***Beig G., Bisht D.S.,*** *Das S., Black carbon over a central Himalayan Glacier (Satopanth): Pathwaysand direct radiative impacts,* ***Science of the Total Environment****, 766: 144242, April 2021, DOI:10.1016/j.scitotenv.2020.144242*]

VOC characterisation over Pune

The rapidly increasing industrialisation and urbanisation combined with underrepresented in-situ measurements, especially volatile organic compounds (VOCs), pose serious challenges in understanding India's air quality and atmospheric chemistry. To address this concern, yearlong measurements of VOCs were carried out using a Proton Transfer Reaction Mass Spectrometer (PTR-MS) at an urban site in Pune (18.58°N, 73.91°E, 559 m amsl) in western India from March 2014 to February 2015. The averaged diurnal variation in VOCs in Pune exhibited a characteristic bimodal pattern, with a highly pronounced peak

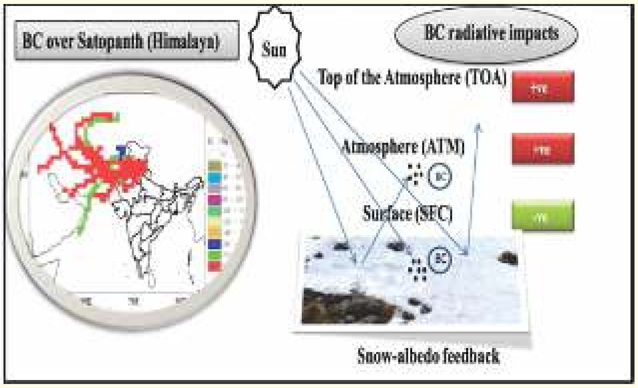


Fig. 1.24: Summary of BC radiative interactions at Satopanth Glacier.

during morning hours and secondary enhancement during the late evening/night, except for isoprene. Isoprene mixing ratios were observed to be higher (1.30 ± 0.69 ppbv) during the daytime (0900-1800 hrs) and lower (0.89 ± 0.65 ppbv) during the nighttime (after 1900 hrs and before 0900 hrs). While methanol, acetonitrile, and acetaldehyde are observed to be the highest (14.3 ± 5.9, 0.9 ± 0.4, and 6.1 ± 2.6 ppbv, respectively) during spring, benzene and toluene were the highest (1.6 ± 1.1, 2.6 ± 2.2 ppbv respectively) during winter. Correlation plots with VOCs vs acetonitrile are shown in **Fig. 1.25**. Isoprene mixing ratios showed broader maxima during autumn and winter (1.3 ppbv). Nominally, all the VOCs were observed to be the lowest during the monsoon season. The two peaks in the seasonal cycle of acetonitrile, along with VIIRS retrieved fire counts, indicated an impact of regional biomass burning during spring and winter. Analysis of air-mass residence time further revealed potential influences from the highly polluted Indo-Gangetic Plain during the autumn and winter, whereas local pollution supplemented with regional biomass burning was found to be the dominant process during spring. These yearlong measurements are a step forward in filling a major gap in observational data of VOCs over the tropical Indian region, which would be invaluable for evaluating chemistry transport models and understanding regional tropospheric chemistry. [***Maji S., Yadav R., Beig G.,*** *Gunthe S.S., Ojha N., On the processes governing the variability of PTR-MS based VOCs and OVOCs in different seasons of a year over hillocky mega city of India,* ***Atmospheric Research****, 261: 105736, October 2021, DOI:10.1016/j.atmosres.2021.105736*]

Impact of urbanisation on thermal comfort in Mumbai

The microclimatic impacts of future urbanisation over the Mumbai Metropolitan Region (MMR) in India were examined using a dynamic downscaling approach. Initially, two numerical experiments (curr_exp and fut_exp) were carried out by integrating 2018 and 2050 land-use/land-cover patterns under the same meteorological conditions. Afterwards, the spatial and temporal changes in surface air temperature, wind speed, and thermal discomfort were assessed by comparing the simulated results between curr_exp and fut_exp. To remediate the observed adverse microclimatic impacts of future urbanisation, a mitigation strategy was designed and implemented in the third experiment (miti_exp). Simulation results showed that the average maximum (minimum) surface air temperature of the region would increase by 1.41°C (1.27°C) due to future urbanisation. However, if the mitigation strategy is adopted, this growth can be restricted to 0.69°C (0.92°C) (**Fig. 1.26**). In the context of thermal discomfort, an additional 20% of the total area can undergo hyperthermal treatment by 2050. It is revealed that although the implemented mitigation strategy can restrict the increasing temperature, it is ineffective in minimising the thermal discomfort level. These results will help design area-specific climate action plans through which goals of sustainable urban development can be accomplished. [*Vinayak B., Lee H.S., Gedam S.,* ***Latha R.****, Impacts of future urbanization on urban microclimate and thermal comfort over the Mumbai metropolitan region, India,* ***Sustainable Cities and Society****, Online, January 2022, DOI: 10.1016/j.scs.2022.103703*]

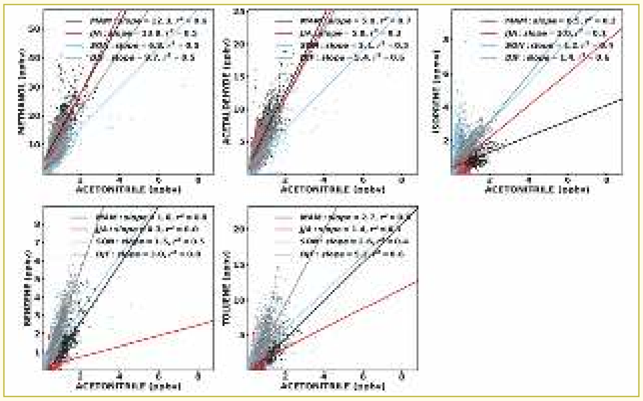


Fig. 1.25: *The correlation plots of all VOCs with acetonitrile (biomass burning tracer) during the four seasons.*

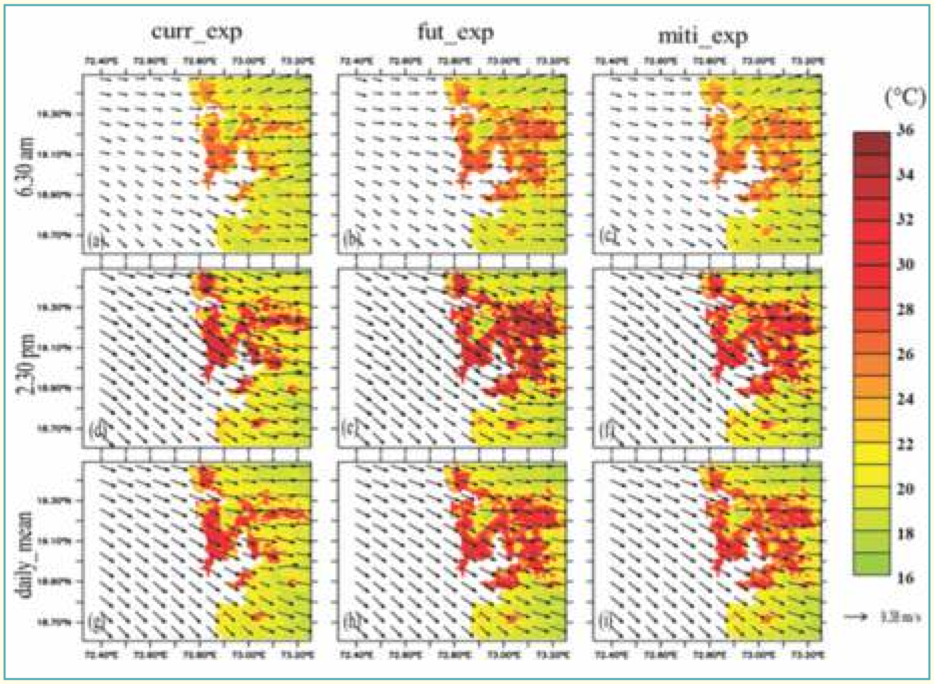


Fig. 1.26: *Scenario-wise spatial distribution simulated air temperature and winds at three different timescales.*

1.1.5. Climate Variability and Prediction (CVP)

Project Director : Dr. C. Gnanaseelan
Deputy Project Director : Dr. Anant Parekh

Objectives

- To conduct basic research on Indian summer monsoon rainfall (ISMR) variability and its teleconnections.
- To study ocean variability and its impact on monsoon variability.
- To investigate the processes associated with climate variability using observations and models.
- To identify predictors for monsoon variability using both observations and models.
- To understand the predictability of ISMR, surface temperature over India, the Indian Ocean SST and sea level in the models.
- To develop a decadal prediction system (DPS) for India and the Indian Ocean.

Highlights of Major Achievements:

- Carried out a series of decadal hindcast runs every five years from 1982 till 2017.
- The skill of decadal hindcasts based on IITM-DPS was assessed.
- Post-processing tools for extracting IITM-DPS atmospheric decadal outputs were developed.
- Developed a new initialisation strategy suppressing the initial shocks in coupled models for seasonal/decadal prediction.
- The impact of meridional displacement of the Asian jet on the Indian summer monsoon rainfall in observations and CFSv2 hindcast is examined.
- Discussing the latest knowledge and future directions for Indian Monsoon teleconnections, a new book, 'Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond' is published with Elsevier.

Developmental Activities

- The decadal hindcast skill assessment of the Indian Ocean SST is carried out with the available decadal hindcasts from CMIP5/CMIP6 models and IITM-DPS. It is found that IITM-DPS showed good skills in predicting SST at different lead years, similar to CMIP6 models **(Fig. 1.27).**

- **Developed a new strategy for initial condition suppressing the initial shock in coupled models for seasonal/decadal prediction:** The new initialisation strategy adopted could reduce the initial shocks observed in MayIC (**Fig. 1.28b-c**), a step as a follow-up of Shukla et al. (2018). According to Shukla et al. (2018), the initial shocks generated in the CFSv2 MayIC hindcasts are primarily responsible for its weaker forecast skill compared to FebIC hindcasts, which is also supported by other studies (*e.g.,* Chattopadhyay et al., 2016; Saha et al., 2016). The initial shocks in SST and OHC_{100} in one day of integration in FebIC, Exp and MayIC can be seen respectively in **Fig. 1.28a-f**. It is noticed that the one-day shock is less and negligible in Exp compared to the high and random shocks seen in the case of MayIC (**Fig. 1.28b-c, e-f**), which was achieved by allowing the ocean to evolve more realistically and systematically from February onwards in Exp. For example, **Fig. 1.28 (b, e)** shows the one-day shock in OHC_{100} and SST in the new approach,

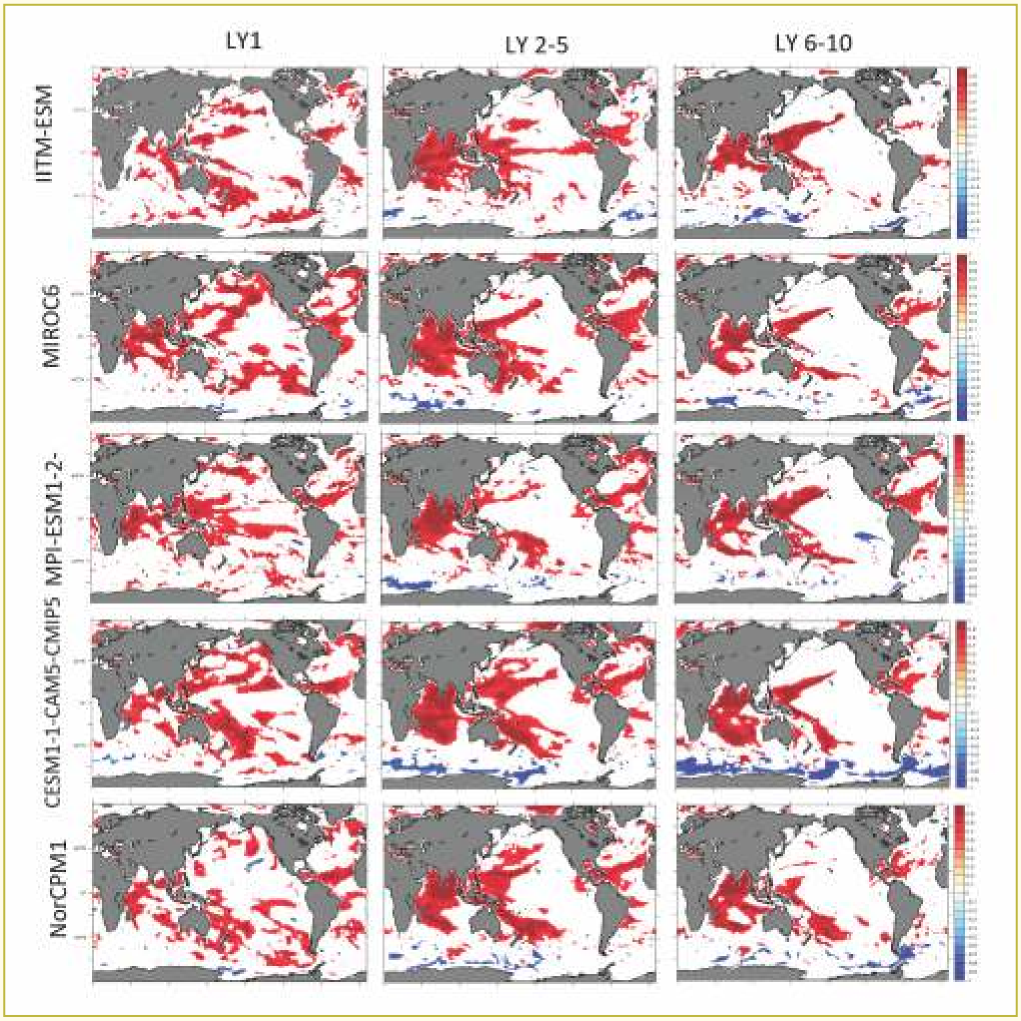


***Fig. 1.27:** Decadal hindcast SST anomalies evolution for JJAS season using IITM-DPS and CMIP6 models.*

whereas the respective shock in MayIC for the same period is shown in **Fig. 1.28c**, **f**. In fact, the one-day shock has reduced drastically in the new approach, where the atmosphere is initialised in the same way as MayIC, but the ocean is initialised in February. Consistent with Shukla et al. (2018), larger and more significant initial shocks are evident in the case of MayIC in both OHC_{100} (**Fig. 1.28a-c**) and SST (**Fig. 1.28d-f**), making model initialisation in May a challenge. In this context, the new approach, wherein the ocean model is initialised in February but periodic reinitialisation of the atmosphere (with realistic data) up to May, keeps the evolution of oceanic fields more realistic and stable in May when the atmosphere is reinitialised, thereby reducing the initial shock in May, which otherwise is very significant in MayIC.

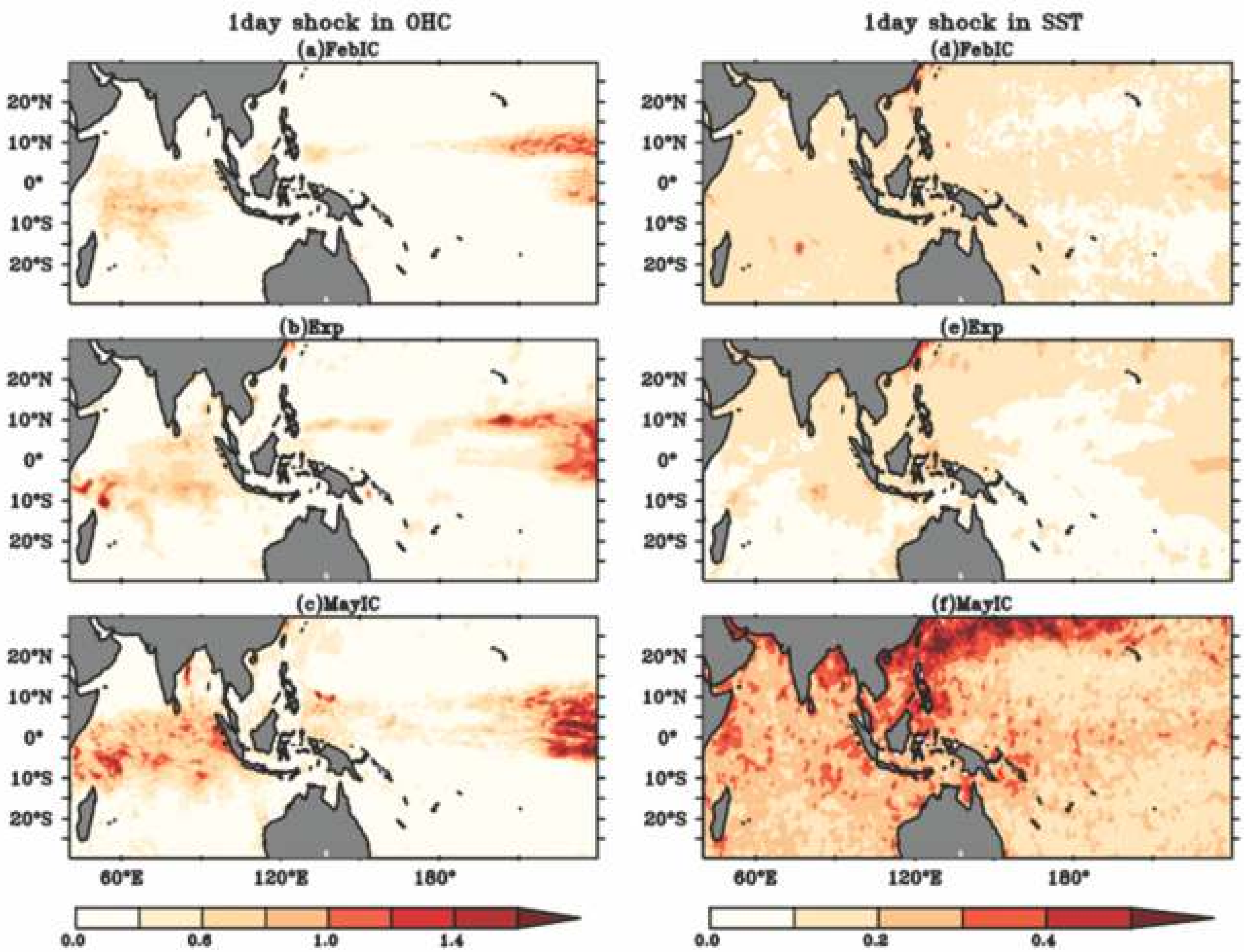


Fig. 1.28: *Composite one-day shock in the mean upper ocean (0-100 m) heat content (OHC_{100}, $\times 10^8$ J m^{-2} day^{-1}) during 1st to 10th February in **(a)** FebIC, 1st to 10th May in **(b)** Exp and **(c)** MayIC. Panels **(d)** to **(e)** are the same as **(a)** to **(c)** but for one-day shock in SST (°C day^{-1}) for the period 1993-2019. FebIC/Exp and MayIC are initialised during 1-10 February and May, respectively, using NCEP CFSR. The Exp reinitialises the atmosphere every month up to May. The composite initial shocks are computed as the root mean square of one-day change over all the ensemble members and years of hindcasts, and called as a one-day shock.*

Basic Research

Dynamical and moist thermodynamical processes associated with the Western Ghats rainfall decadal variability

The Western Ghats (WG) is a vast montane forest ecosystem known for its biodiversity and endemism. The variability of summer monsoon rainfall over the WG is examined using century (1900-2010) long observed rainfall data. Spectrum and wavelet analysis of rainfall observation reveal significant decadal variability (at 90% confidence level) in WG rainfall. The decadal variability of WG summer monsoon rainfall is higher than in most other regions of India. Wavelet analysis also revealed that in the recent period, the amplitude of decadal variability is amplified by 1.5 to 2 times compared to the prior half-century. Correlation analysis with dominant sea surface temperature (SST) indices of the global ocean confirms that WG rainfall decadal variability undergoes temporal modulations. The Indian Ocean SST variability displayed a significant correlation during 1901-42, whereas the Pacific Ocean SST variability displayed a significant correlation during 1943-77 and 1978-2010 with WG rainfall variability (**Fig. 1.29**, upper panel). The analysis associated with decadal rainfall variability reveals the dominance of dynamical processes during 1901-42 and moist thermodynamical processes during 1943-77 and 1978-2010 (**Fig. 1.29 a-g**). It is concluded that the decadal variability of WG rainfall is robust, and the forcing mechanisms are essentially maintained by the Indian and Pacific Oceans variability, adding value to developing decadal prediction systems. It may also contribute to understanding the evolution of the WG ecosystem. *[**Halder S., Parekh A., Chowdary J.S., Gnanaseelan C.**, Dynamical and moist thermodynamical processes associated with Western Ghats rainfall decadal variability, **npj Climate and Atmospheric Science**, 5: 8, February 2022, DOI:10.1038/s41612-022-00232-y, 1-11]*

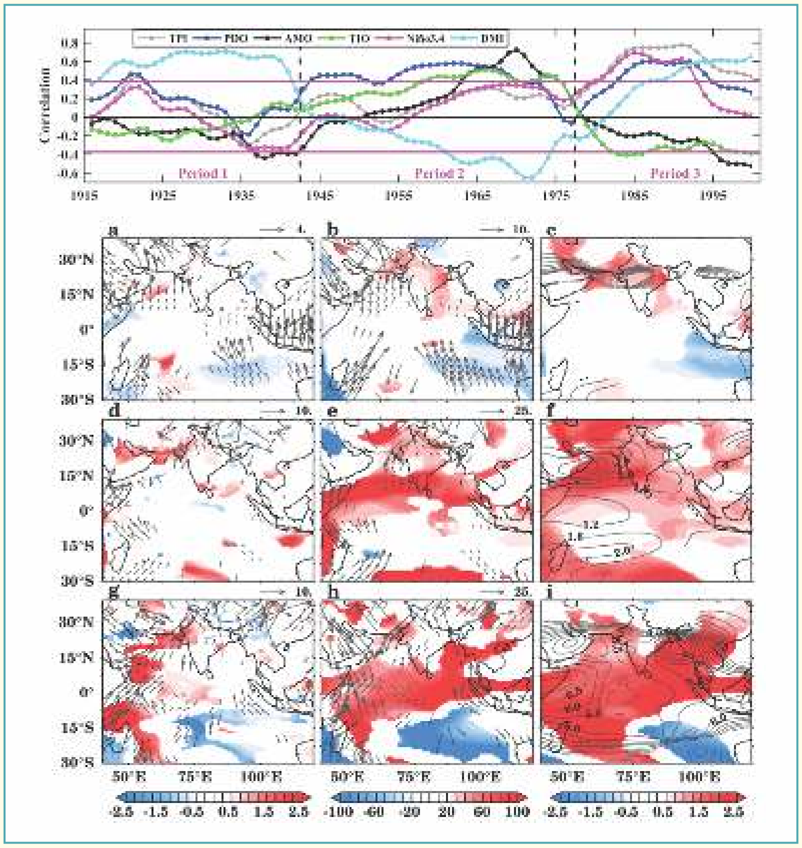


Fig. 1.29: *(Top panel) 31-year running correlation of 9-30 years bandpass filtered WG rainfall anomaly with different filtered SST indices manifest major climate variability over the different parts of the global ocean. The solid magenta line represents the 90% confidence level for the correlation. Regression of WGI (mm/day) with anomaly of **(a)** wind vector (m/s) at 850 hPa and vertical wind at 500 hPa (shaded; mm/s). **(b)** Vertically integrated (1000-300 hPa) moisture transport (vector; kg/m.s) and vertically integrated moisture (shaded; kg/m^2). **(c)** Tropospheric Temperature averaged over 600-200 hPa (contour, °C), and moist static energy averaged over 1000-200 hPa (shaded; kJ/kg) for period 1 (during 1901-42). **(d-f)** and **(g-i)** same as **(a-c)** but for period 2 (during 1943-77) and period 3 (during 1978-2010) respectively.*

Relationship between Azores High and Indian summer monsoon

The interannual variation of the Indian summer monsoon (ISM) affects not only millions of people in India but also the global weather and climate. The teleconnections of this variation are not stable. A dominant mode of the recent four decades of ISM rainfall shows a west-east dipole pattern with above normal rainfall towards the west and central India and subdued rainfall towards the east and northeast India, and is related to the vigorous Azores High (**Fig. 1.30**). The vigorous Azores High is accompanied by enhanced subsidence resulting in well-built widespread upper-troposphere convergence. This forms the meridional vorticity dipole consisting of anomalous cyclonic and anti-cyclonic circulation at 30ºN and 50ºN, respectively. The meridional vorticity dipole increases the Asian jet at its entrance. In addition, the widespread North Atlantic convergence boosts the Rossby wave source. The cascading down Rossby wave train imposes successive negative, positive and negative Geopotential height (GPH) anomalies over the north Mediterranean, northwest India and northeast India, respectively. The negative GPH anomaly in the north Mediterranean further increases the Asian jet towards the Caspian Sea. The increased Asian jet strengthens the monsoon circulation through the 'silk-road' pattern. The dipole GPH anomalies in the north of India shift the core of the Tibetan High westward, triggering monsoon activity towards the west and central India and subdued monsoon over east and northeast India, forming an anomalous west-east dipole rainfall pattern and vice-versa. Future work should examine how these teleconnections are represented in the climate forecast models to aid the seasonal prediction of ISM rainfall. ***[Yadav R.K.**, Relationship between Azores High and Indian summer monsoon, **npj Climate and Atmospheric Science**, 4:26, April 2021, DOI: 10.1038/s41612-021-00180-z, 1-9]*

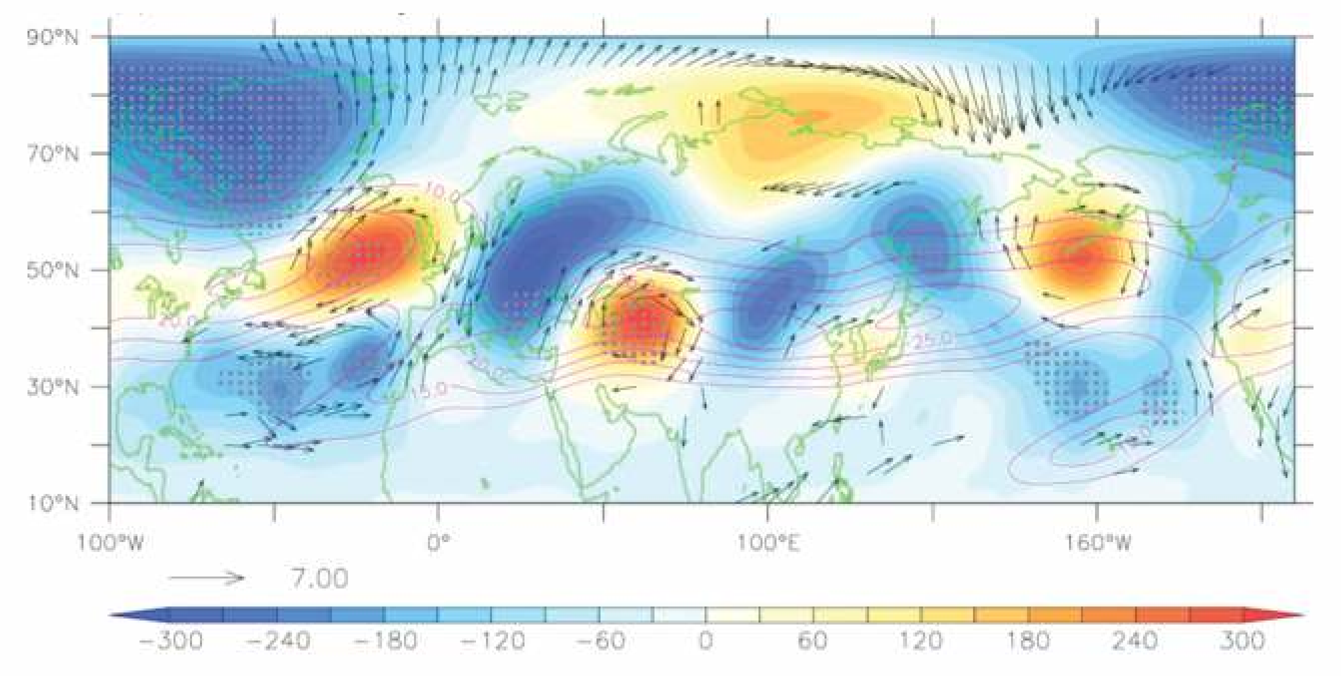


Fig. 1.30: *Composite of excess years Azores High. Composite anomaly of 200-hPa GPH (shaded), 95% statistical significance of composite of GPH (grey dots) and wind (black arrows) and composite of zonal wind >5 ms^{-1} (Cray contours) for excess years of Azores High.*

Meridional displacement of the Asian jet and its impact on Indian summer monsoon rainfall in observations and CFSv2 hindcast

The impact of meridional displacement of the Asian jet on the Indian summer monsoon (ISM) rainfall in observations and Climate Forecast System version 2 (CFSv2) hindcast is examined from 1985 to 2019. The observations showed that during boreal summer (June to September), the leading mode of variability in the upper-tropospheric zonal wind anomalies along the Asian jet exhibits a north-south seesaw pattern on the interannual time scale. The strength of the meridional displacement/ loading of the summer Asian jet is robust over the East Asian region in the observations, whereas in the case of CFSv2, the signals are strong both over the West and East Asian regions. The analyses of the observations suggest that the southward displacement of the Asian jet (SWDAJ) provokes reduced precipitation over the central and northern India regions. This reduced rainfall over northern India is well captured by the model with a slight overestimation of its strength. Physical mechanisms that link the SWDAJ and monsoon rainfall are unravelled in this study. It is found that SWDAJ weakens the upper-level Tropical Easterly Jet (TEJ) over the Indian subcontinent and reinforces the lower-level anticyclone, thereby reducing the rainfall, as evidenced in both observations and the model. Southward gradients

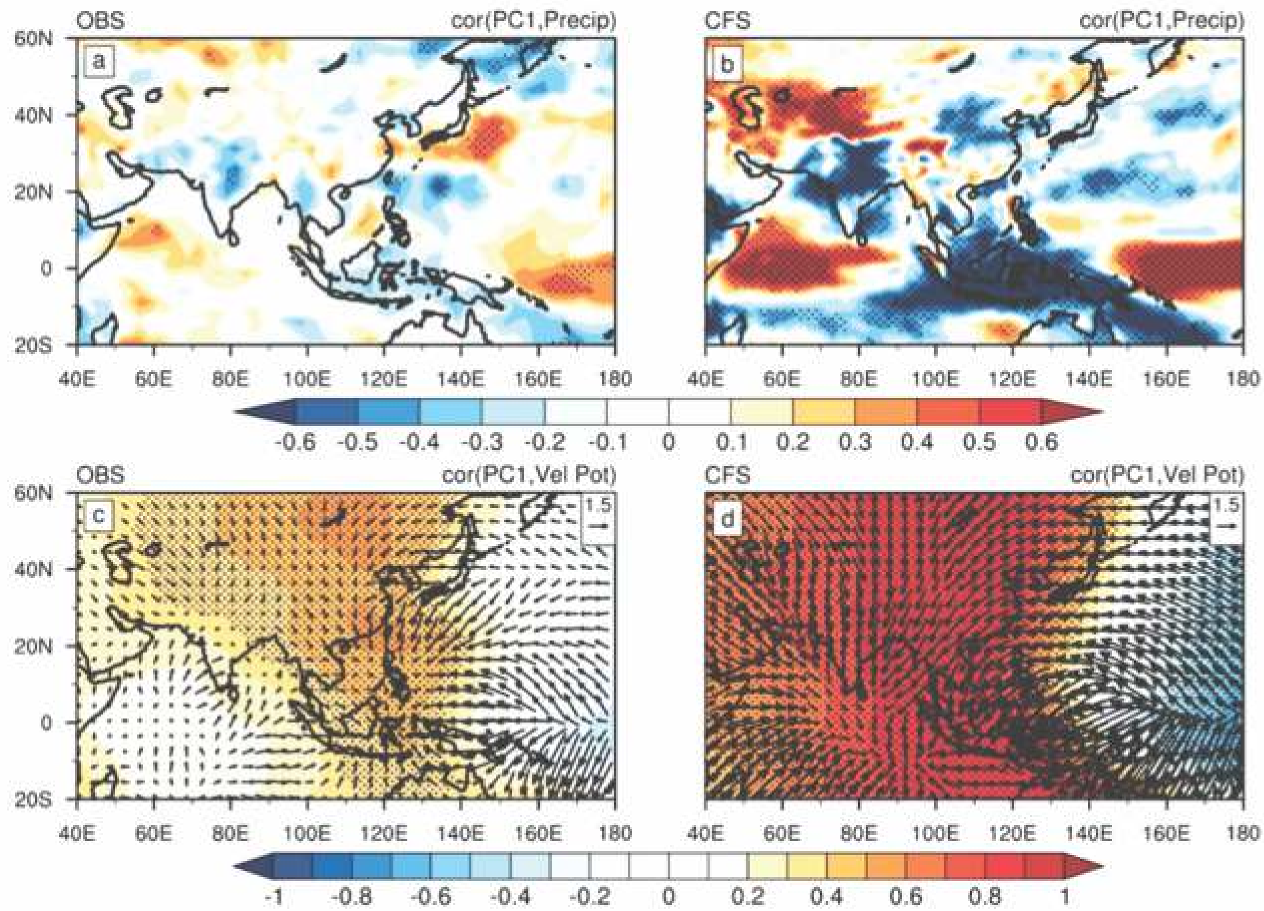


Fig. 1.31: Correlation between PC1 of JJAS zonal wind at 200 hPa and JJAS ***(a)*** *precipitation anomalies for the observations.* ***(b)*** *Same as in (a) but for the CFSv2 model.* ***(c)*** *Correlation of the PC1 with the velocity potential anomaly, and regression of 200 hPa divergent wind anomaly (vectors; m/s) onto the PC1 for the observations, and* ***(d)*** *same as in* ***(c)*** *but for CFSv2 model. Stippling indicates significant values at a 95% level of confidence.*

in the tropospheric temperature and low-level moisture divergence also support the reduced rainfall over India. Observed precipitation enhancement in the Meiyu-Baiu rain band and the associated low-level convergence are the characteristics of SWDAJ over East Asia, linked with divergence over India, which is completely absent in the model (**Fig. 1.31**). Detailed analysis of individual summer months in the observations and model revealed that during early summer (June and July), the dominant meridional displacement of the Asian jet is located over the West and East Asian regions. In the observation, these dominant anomalies are migrated to the east of the East Asian region by September, whereas they persisted over both West Asia and East Asia regions in the model. In addition to this, the meridional displacement of the Asian jet in the model is strongly influenced by the El Niño-Southern Oscillation (ENSO), predominantly in the late monsoon season. It is suggested that the teleconnections of the Asian jet variability and ISM rainfall are over-dependent on ENSO in the model, which might limit its prediction skill, not only over India but also for the entire Asian region. *[**Chowdary J.S., Vibhute A.S., Patekar P., Parekh A., Gnanaseelan C.**, Attada R., Meridional displacement of the Asian jet and its impact on Indian summer monsoon rainfall in observations and CFSv2 hindcast, **Climate Dynamics**, 58, February 2022, DOI:10.1007/s00382-021-05935-1, 811-829]*

Published edited book on "Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond"

Scientists of the CVP group have brought out an edited book titled "Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond" that covers the important aspects of teleconnection pathways of ISM. A wide spectrum of remote and local forcing mechanisms that potentially affect the ISM rainfall variability from interannual through decadal time scales and the climate change impacts are presented in this book (**Fig. 1.32** shows its cover page). It emphasises both ENSO and non-ENSO teleconnections to ISM variability. Unlike many other books on climate variability, this book highlights the potential research problems of relevance in different chapters, which may motivate young researchers and students. It also brings out the existing knowledge gap in the field and recommends the requirement of additional long-term observations. The current status of climate models is emphasised in many chapters to possibly help and motivate the modellers to address the challenging issues of climate science and ISM variability. *[**Chowdary J.S., Parekh Anant,** and **Gnanaseelan C.** (Eds.), Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond, Elsevier, 2021, ISBN: 978-0-12-822402-1, DOI: https://doi.org/10.1016/C2019-0-04482-2]*

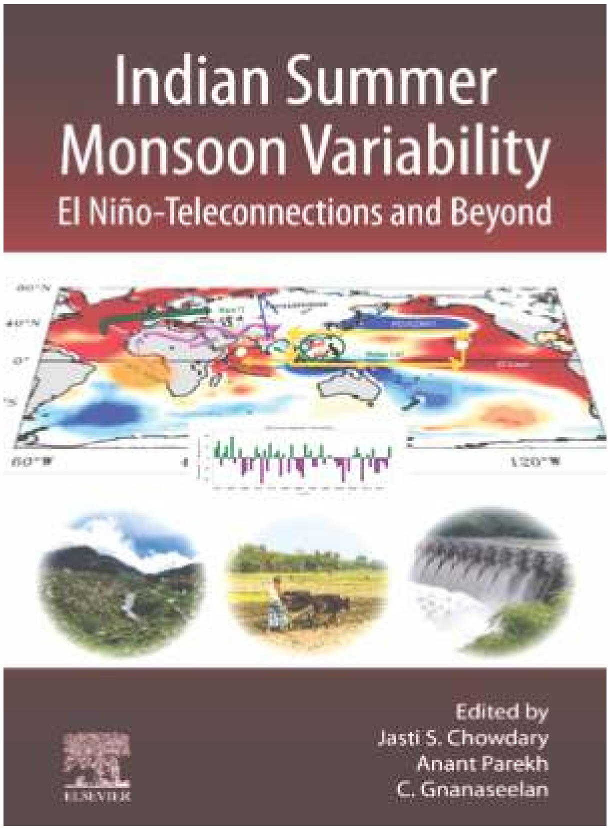


Fig. 1.32: Cover page of the book "Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond."

1.2. Monsoon Mission

Mission Director : Director, IITM
Associate Mission Director : Dr. A. Suryachandra Rao
Project Directors: Dr. A. Suryachandra Rao and Dr. P. Mukhopadhyay
Deputy Project Director : Dr. Susmitha Joseph

Objectives

The overall objective of the Monsoon Mission is to improve monsoon prediction over India on all time scales. Specific objectives are:

- To build a working partnership between the academic and R&D organisations both national and international, and MoES to improve the operational monsoon forecast skill over the country and 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 high resolution (~12 km – 6 km) short-range ensemble forecast and to improve the parameterisation of physical processes of the model for improving the short-range forecast of monsoon and high-impact weather.

Highlights of Major Achievements:

- The convective nature and predictability of extreme precipitation during August 2018 and 2019 over Kerala were investigated.
- Evaluated the performance of the GFS model in capturing the transition of low-pressure areas to monsoon depressions.
- Conducted research on tropical cyclone genesis and the changing status of the tropical cyclones over the north Indian Ocean.
- Forecasts for summer monsoon 2021 were carried out on an experimental basis using a multi-physics strategy in CFSv2.
- Experiments with multi-physics schema in CFSv2 for sub-seasonal prediction of Indian summer monsoon demonstrated appreciable improvements over its predecessor.
- The relationship between the intra-seasonal fluctuations of ISMR with the phase propagation and amplitude of MISO and MJO was examined.
- The currently operational MMCFS version 2 (CFSVv2) has been upgraded to the new MMCFS version 3 (CFSv3).
- Sensitivity experiments were performed with CFSv2 using different microphysics and convective parameterisation schemes.
- Integration of an ensemble-based flow-dependent data assimilation system in the operational CFSv2 coupled model has further enhanced its prediction skill.
- Simulation of lightning flash counts based on various lightning parameterisation schemes and Lightning Potential Index (LPI) over Maharashtra in the WRF model were evaluated.
- A comparison study suggested that MMCFS has an advantage over SINTEX-F2 in predicting ISMR.
- Dynamical downscaling of seasonal reforecasts of the Indian Monsoon in CFSv2 significantly reduces the majority of the systematic rainfall biases over the Indian region.
- MoES has approved the hosting of the International Monsoons Project Office (IMPO) at IITM, initially for five years, with effect from 30 July 2021.
- IMPO contributed extensively in supporting monsoon research activities of WMO's WWRP and WCRP and CLIVAR/GEWEX Monsoons Panel.

R&D Activities

Under the Monsoon Mission-III, the following major R&D activities and developmental works are executed:

- **Short and Medium Range**
- **Sub-Seasonal Scale**
- **Seasonal Scale**
- **International Monsoons Project Office (IMPO)**

1.2.1. Short and Medium Range

Basic Research

Unravelling the mechanism of extreme (more than 30 sigma) precipitation during August 2018 and 2019 over Kerala

During August 2018 and 2019, Kerala (a southern state of India) received unprecedented heavy rainfall, which led to widespread flooding. An attempt is made to characterise the convective nature of these events and the large-scale atmospheric forcing while exploring their predictability by three state-of-the-art global prediction systems: the NCEP-based IMD's operational Global Forecast System (GFS), the ECMWF Integrated Forecast System (IFS), and the Unified Model-based NCUM being run at NCMRWF. Satellite, radar, and lightning observations suggested that these rain events were dominated by cumulus congestus and shallow convection with strong zonal flow leading to orographically enhanced rainfall over the Western Ghats mountain range; sporadic deep convection was also present during the 2019 event. A moisture budget analysis using the fifth major global reanalysis produced by ECMWF (ERA5) and forecast output revealed significantly increased moisture convergence below 800 hPa during the main rain events compared to August climatology. However, the total column-integrated precipitable water tendency was found to be small throughout August, indicating a balance between moisture convergence and drying by precipitation. Applying a Rossby wave filter to the rainfall anomalies shows that the large-scale moisture convergence was associated with westward-propagating barotropic Rossby waves over Kerala, leading to increased predictability of these events, especially for 2019. Evaluation of the deterministic and ensemble rainfall predictions revealed systematic rainfall differences over the Western Ghats and the coastline. The ensemble predictions were more skilful than the deterministic forecasts (**Fig. 1.33**), as these were able to predict rainfall anomalies (greater than three standard deviations from climatology) beyond day 5 for August 2019 and up to day 3 for 2018. [***Mukhopadhyay P.***, *Bechtold P., Zhu Y., Krishna R.P.M., Kumar Siddharth, Ganai M., Tirkey S., Goswami T., Mahakur M., Deshpande M., Prasad V.S., Johny C.J., Mitra A., Ashrit R., Sarkar A.,* ***Sarkar Sahadat, Roy Kumar****, Andrews E., Kanase R., Malviya S., Abhilash S.,* ***Domkawle M., Pawar S.D.****, Mamgain A., Durai V.R.,* ***Nanjundiah R.S.****, Mitra A.K., Rajagopal E.N., Mohapatra M., Rajeevan M., Unravelling the mechanism of extreme (more than 30 sigma) precipitation during August 2018 and 2019 over Kerala, India,* ***Weather and Forecasting****, 36, August 2021, DOI:10.1175/WAF-D-20-0162.1, 1253-1273*]

Atmospheric dynamics and internal processes in CFSv2 model during organisation and intensification of BSISO

The fidelity of Climate Forecast System (CFS) version 2 (CFSv2T126 and CFSv2T382) models was investigated in capturing mean flow-eddy interaction, circulation-heating feedback and the energy conversion processes during the organisation and intensification of Boreal Summer Intra-Seasonal Oscillation (BSISO) in the backdrop of the mechanism put forward by an earlier observation-based study. Ten years of free-run is used to evaluate the models. CFSv2-T126 overestimates the BSISO intensity from lag −24, and the overestimation is even more for CFSv2-T382 compared to the observation-based study. T126 model underestimates the mean kinetic energy (MKE) related to upper-level easterly wind, and the underestimation is notably more prominent for strong events. The underestimation is more for T382 model, and the model has difficulty capturing the upper-level MKE. However, both models can capture the lower level MKE structure with a slight overestimation for both events (**Fig. 1.34**). At the upper level, MKE to eddy kinetic energy (EKE) conversion for T126 model is significantly weak and contrary to the observation-based study which showed a decrease in conversion in the subsequent lags. Nevertheless, T382 model showed an increase in MKE to EKE conversion for strong events, which agrees with ERA analysis. CFSv2-T126 showed decreasing mean available potential energy (MAPE) to MKE conversion (CA process) for the strong events at the upper level in complete contrast to the observation-based study. CFSv2-T382 model could capture the increasing MAPE to MKE conversion as BSISO approaches the organised and intense phase. For weak events, the CA process was very weak in both models. Both models showed a very weak vertical eddy momentum-vertical wind shear interaction (CK3 conversion) for strong events at the upper level. T126 model could capture the conversion for strong events at the lower level but underestimated the magnitude. The process-based analyses of CFSv2 simulations revealed that the model has a significant deficiency in capturing the energy conversions and circulation-heating

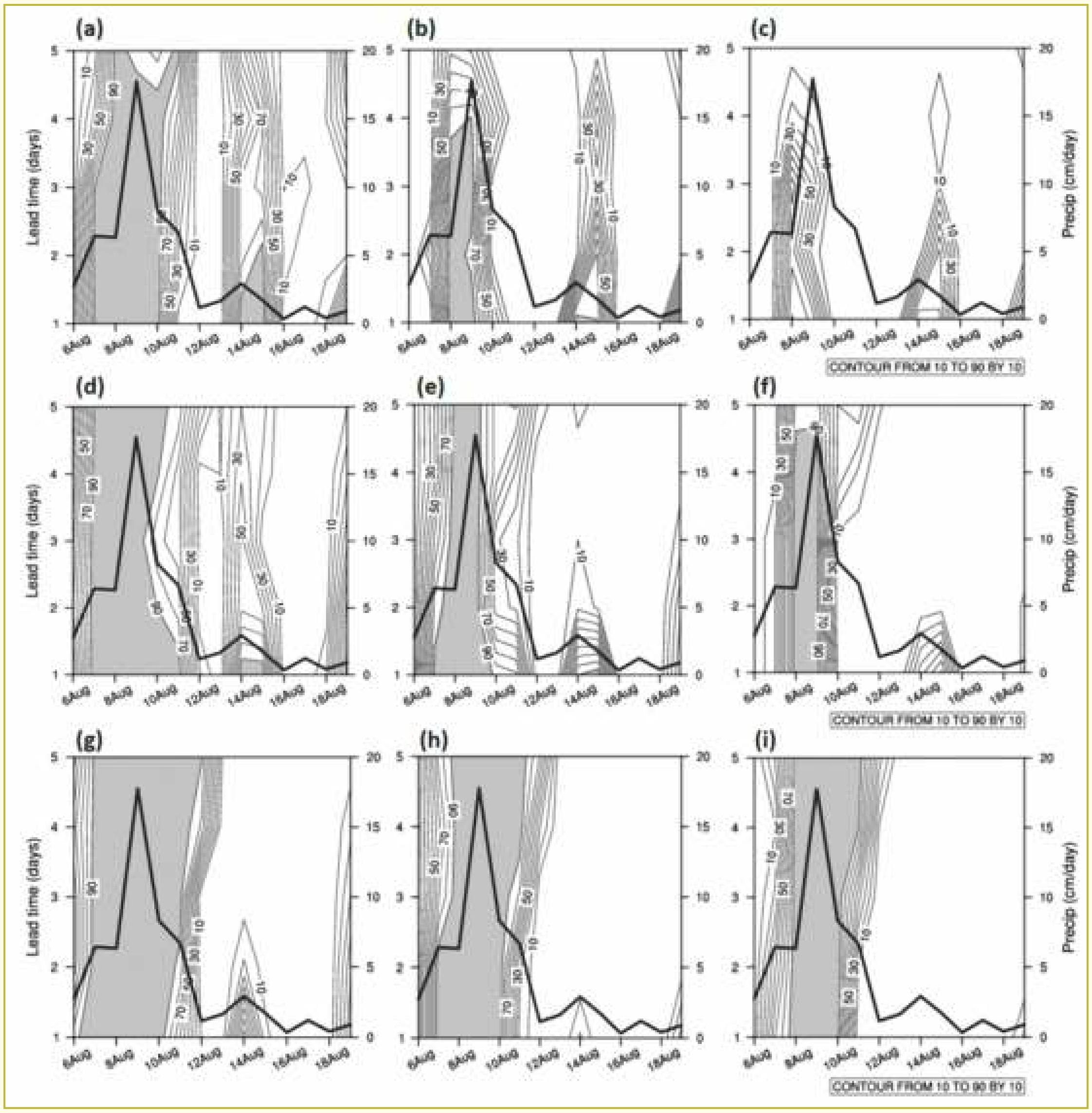


*Fig. 1.33: Forecast lead time diagram of the probability (%) from **(a-c)** GEFS, **(d-f)** ECMWF, and **(g-i)** NCUM forecasts for the daily accumulated rain over Kerala (9.5°-11.5°N, 76°-77.5°E) exceeding the observed daily climatology (left) plus one standard deviation (SD), (centre) two SD, and (right) three SD. The thick black line represents the IMD-GPM rainfall (cm day^{-1}) averaged for the same region for the period of 6-19 Aug 2019. The grey shading represents a probability of 90%.*

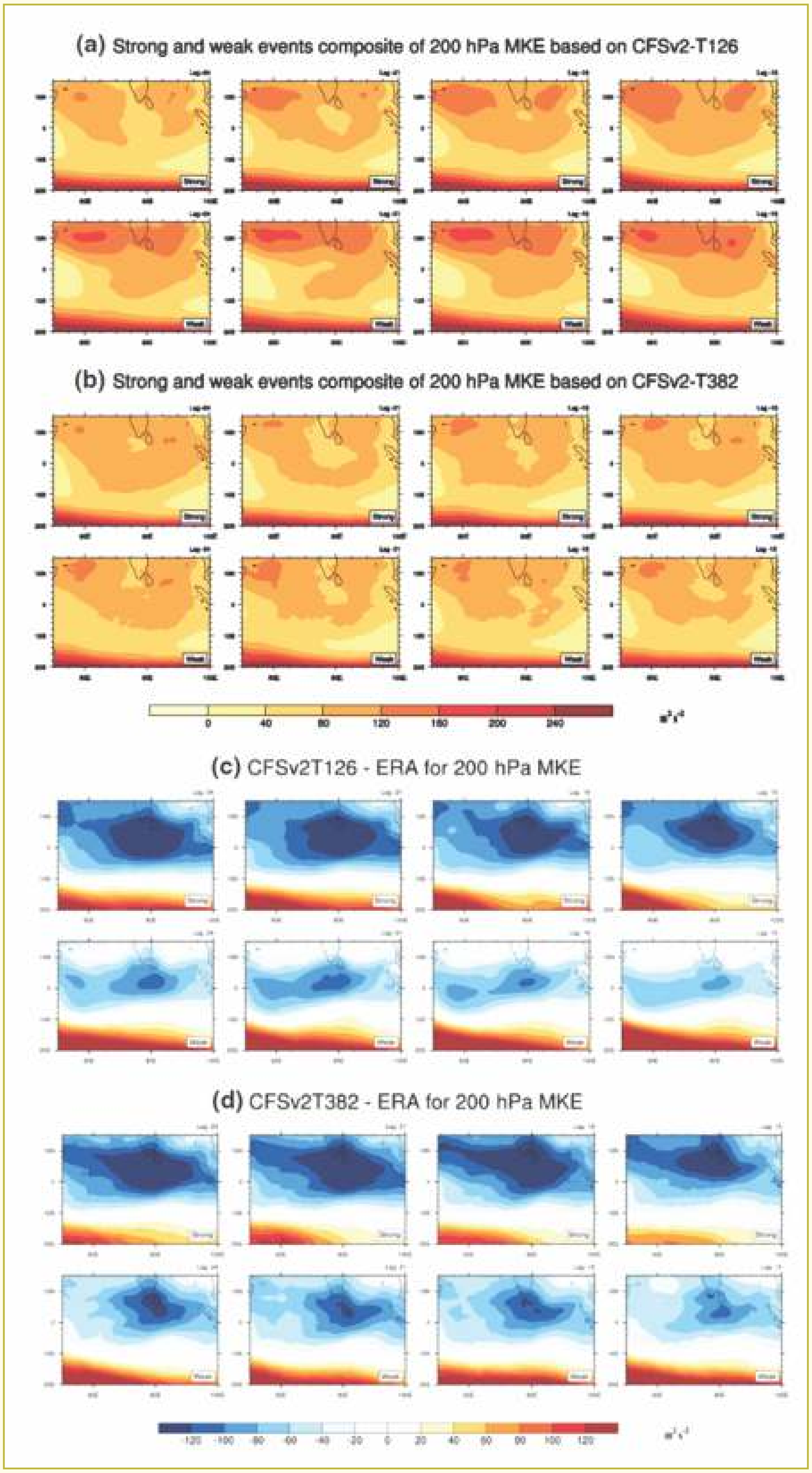


Fig. 1.34: *Composite 200 hPa MKE (units: $m^2 s^{-2}$) during the evolution of strong and weak events based on **(a)** CFSv2-T126 and **(b)** CFSv2-T382. Difference of **(c)** T126 and **(d)** T382 model with respect to ERA.*

feedback processes. All these eventually led to lesser fidelity of the model in capturing the organisation and intensification of BSISO. [***Sarkar S., Mukhopadhyay P., Krishna R.P.M.***, *Dutta S., Atmospheric dynamics and internal processes in CFSv2 model during organization and intensification of BSISO,* ***Journal of Earth System Science****, 130: 229, November 2021, DOI:10.1007/s12040-021-01727-7, 1-18*]

GFS model fidelity in capturing the transition of low-pressure area to monsoon depression

IMD currently uses a high-resolution (~12 km) Global Forecasting System (GFS) model for short- and medium-range operational forecasts over the Indian region. The performance of the GFS model in capturing the transition of low-pressure areas (LPAs) to monsoon depressions (L2D) was evaluated. GFS has a good fidelity in capturing synoptic variance over the Indian region and can simulate the composite precipitation structure for L2D cases. The upper-level warm core temperature structure is prominent for L2D cases, while it is at the lower level for the cases where the LPA does not intensify and remains as low (RL) pressure area. GFS can simulate the upper-level warm core temperature structure for up to 24 hours. The model has good fidelity in capturing the upper-level potential vorticity maxima for L2D cases, but amplitude is underestimated as the lead time increases. GFS fails to reproduce the potential vorticity structure and amplitude for RL cases. Positive lower- to middle-level heating to the west/southwest sector of the system is seen for L2D cases, but the heating is at the lower level for RL cases. GFS slightly underestimates heating structures for L2D cases but fails to simulate the structure for RL cases. The model greatly underestimates the vertical velocity for L2D cases and RL cases with increasing lead time. Positive moisture convergence is seen at the lower level near the system centre. GFS underestimates the

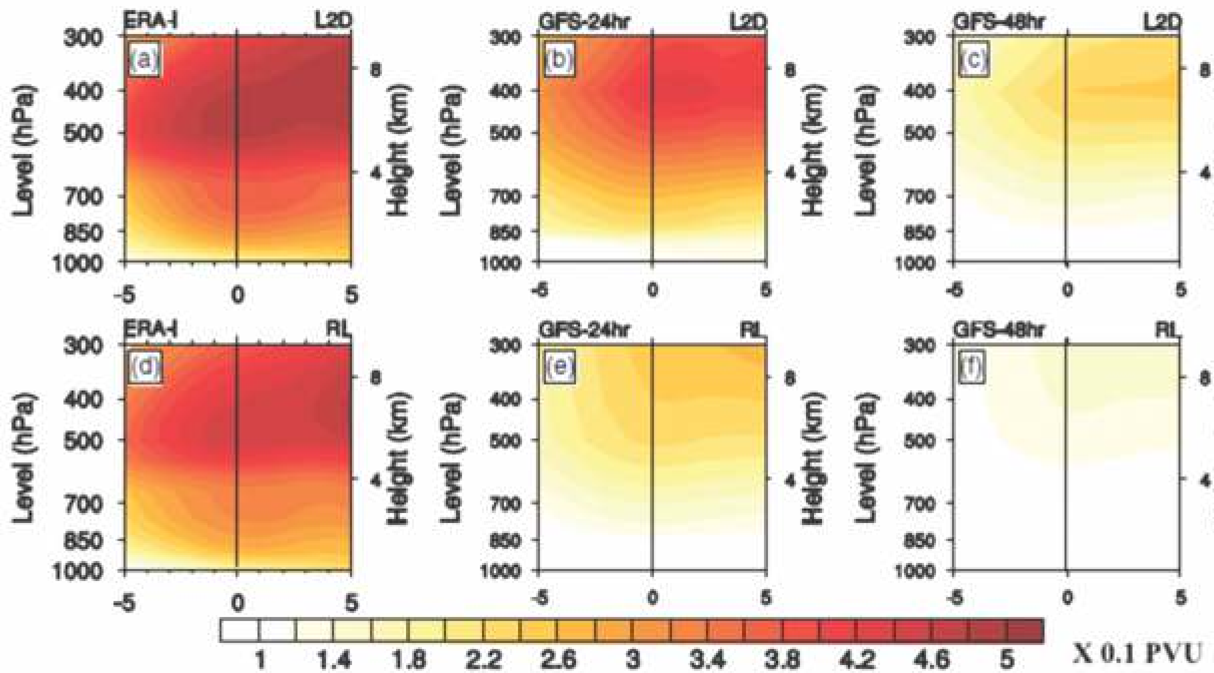


Fig. 1.35: *Latitude-height plot of potential vorticity (× 0.1 PVU) based on* ***(a)*** *ERA,* ***(b)*** *GFS (24 hrs forecast) and* ***(c)*** *GFS (48 hrs forecast) for L2D cases. Panels* ***(d-f)*** *are the same as* ***(a-c)*** *respectively, except for RL cases. Positive (negative) in the x-axis means to the north (south) from the centre (represented by "0") of the system in degrees.*

moisture convergence for both cases, and the southward tilt with height is also not captured well. GFS has good fidelity in simulating the dynamical parameters, such as the potential vorticity (**Fig. 1.35**) associated with L2D cases but shows lesser fidelity for RL cases. [***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***, *147, July 2021, DOI:10.1002/qj.4024, 2625-2637*]

Evaluation of mean state in NCEP Climate Forecast System (Version 2) simulation using a stochastic multicloud model calibrated with DYNAMO radar data

Stochastic parameterisations continuously provide promising simulations of unresolved atmospheric processes for global climate models (GCMs). One of the stochastic multi-cloud model (SMCM) features is to mimic the life cycle of the three most common cloud types (congestus, deep, and stratiform) in tropical convective systems. To better represent organised convection in the Climate Forecast System version 2 (CFSv2), the SMCM parameterisation is adopted in CFSv2 (SMCMCTRL) in lieu of the pre-existing revised simplified Arakawa-Schubert (RSAS) cumulus scheme. It has shown essential improvements in different large-scale features of tropical convection. But the sensitivity of the SMCM parameterisation from the observations is yet to be ascertained. Radar data during the Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign was used to tune the SMCM. The DYNAMO radar observations were used to calibrate the SMCM using a Bayesian inference procedure to generate key time scale parameters for the transition probabilities of the underlying Markov chains of the SMCM as implemented in CFS (hereafter SMCM-DYNAMO). SMCMDYNAMO improved many aspects of the mean state climate compared to RSAS and SMCM-CTRL. Significant improvement is noted in the rainfall probability distribution function over the global tropics (**Fig. 1.36**). The global distribution of

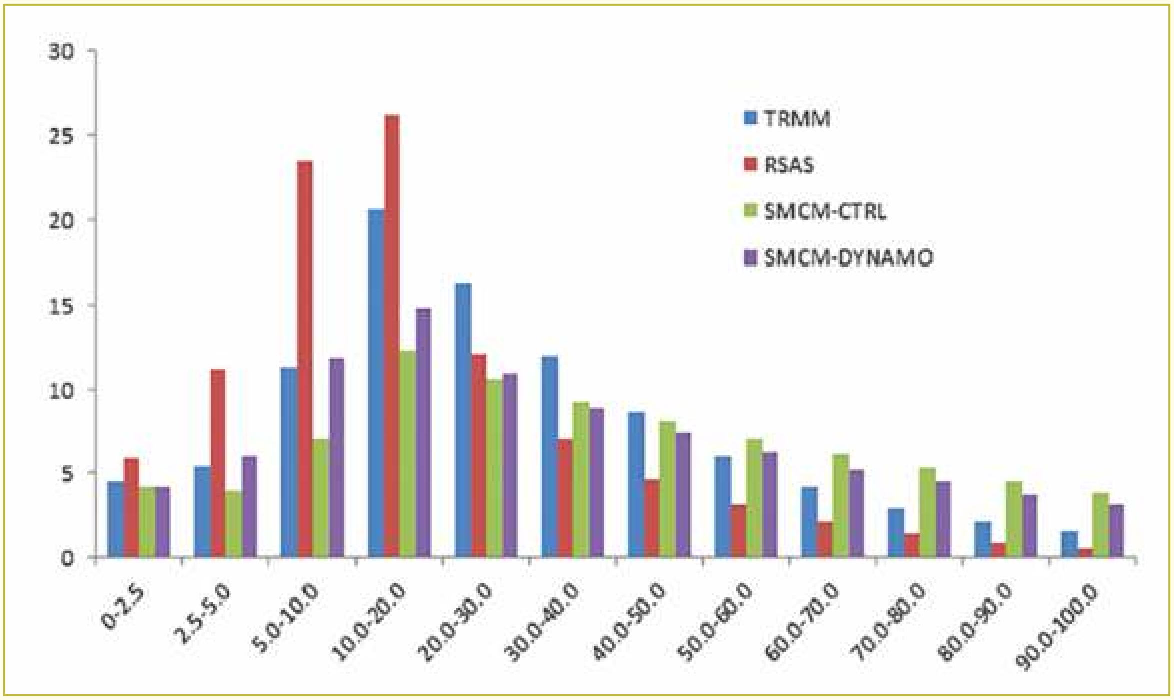


Fig. 1.36: *Rainfall probability distribution function (PDF) averaged over 10°S-10°N for TRMM-3B42, simplified Arakawa-Schubert (RSAS), SMCM-CTRL, and SMCM DYNAMO, respectively. The ranges of rain rate are (mm day^{-1}) along the X axis and rainfall PDF (in fraction) along the Y axis.*

different types of clouds, particularly low-level clouds, is also improved. The convective and large-scale rainfall simulations are investigated in detail. [***Roy K., Mukhopadhyay P., Krishna R.P.M.***, *Khouider B., Goswami B.B., Evaluation of mean state in NCEP Climate Forecast System (version 2) simulation using a stochastic multicloud model calibrated with DYNAMO RADAR data*, ***Earth and Space Science***, *8: e2020EA001455, August 2021, DOI:10.1029/2020EA001455, 1-14*]

Research on tropical cyclone genesis and the changing status of tropical cyclones over the north Indian Ocean

The physics and dynamics of a tropical cyclone were studied using satellite and reanalysis data to understand the processes involved during the genesis. The aim is to understand the pathway for less organised convection leading to the genesis of a tropical cyclone as a depression. Considering the case of Mora (28-31 May 2017), it was found that the presence of Madden-Julian oscillation and equatorial Rossby wave facilitated the intense convection through the supply of moisture at mid-level and vorticity at lower levels. Further, a methodology has been formulated to track the quasi-closed circulation (QCC) for about five days prior to the formation of depression, as shown in **Fig. 1.37**. A study of the process within QCC revealed that the existence of divergence at the upper level and updraft throughout the troposphere seems to be crucial for enhancing the vorticity from lower to mid-level.

Climatologically, the frequency of tropical cyclones (TCs) in the Bay of Bengal (BoB) is higher relative to that over the Arabian Sea (ARB). However, a greater number of TCs forming in the ARB than in the BoB was exhibited in recent years. So to understand the changing status of tropical cyclones, the climatology of tropical cyclones over the north Indian Ocean during 1982-2019 (38 Years) was studied. During the study period (1982-2019), a significant increasing trend in the intensity, frequency, and duration of cyclonic storms (CS) and very severe CS (VSCS) is observed over the ARB. There is a 52% increase in the frequency of CS during the recent epoch (2001-19) in the ARB, while there is a decrease of 8% in the BoB. Over the ARB, the increment in CS duration is 80%, and VSCS is almost threefold in the recent epoch compared to the past epoch (1982-2000). Also, lifetime maximum intensity and accumulated cyclone energy have increased over the ARB, implying an increase in the strength of TCs. The increase in TC duration over the ARB is prominent during May, June, and October, and a decrease over the BoB is noted during November. The increase in the duration of TCs in the ARB is associated with an increase in mid-level relative humidity and column-averaged (950-150 hPa) moist static energy, which is significantly correlated to an increase in sea surface temperatures and tropical cyclone heat potential in the basin. In the recent epoch, TC genesis is observed at lower latitudes (< 8°N), which is another factor contributing to longer durations of TCs. This increases the probability of TC intensification with support from other favourable environmental parameters. Significant changes in TC tracks are also noted in May, June, and October due to changes in steering currents. [***Emmanuel R., Deshpande M., Gandhi M.K.***, *Ingle S.T., Genesis of severe cyclonic storm Mora in the presence of tropical waves over the North Indian Ocean*, ***Quarterly Journal of the Royal Meteorological Society***, *147, July 2021, DOI:10.1002/qj.4113, 3017-3031;* and ***Deshpande M., Singh V.K., Ganadhi M.K., Roxy M.K., Emmanuel R., Kumar Umesh***, *Changing status of tropical cyclones over the north Indian Ocean*, ***Climate Dynamics***, *57, December 2021, DOI:10.1007/s00382-021-05880-z, 3545-3567*]

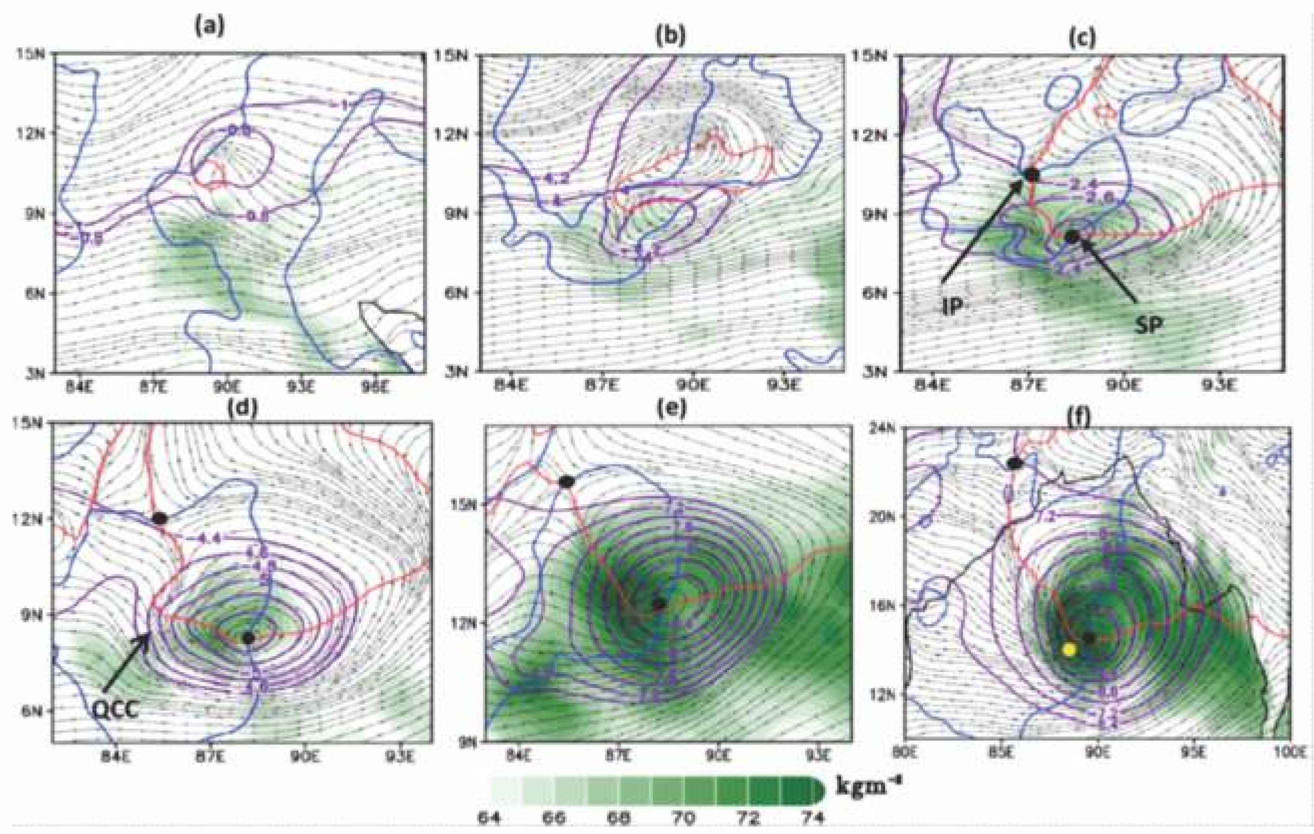


Fig. 1.37: *Streamlines at 850 hPa for **(a)** 0900 UTC on May 20, 2017, **(b)** 2100 UTC on May 21, 2017, **(c)** 0600 UTC on May 22, 2017, **(d)** 0000 UTC on May 23, 2017, **(e)** 0000 UTC on May 26, 2017, and **(f)** 0000 UTC on May 28, 2017. Background green shades represent total precipitable water (TPW). Blue and red lines indicate Isopleth (zero zonal and meridional wind). Purple contours indicate the stream function (interval 106 m^2 s^{-1}). The yellow dot indicates the depression location.*

1.2.2. Sub-Seasonal Scale

Development Activities

Monsoon 2021 in a multi-physics framework for extended range

The 2021 Summer Monsoon (June-September) forecast was carried out on an experimental basis using a multi-physics strategy in Climate Forecast System version 2 (CFSv2). A total of six physics combinations were initialised six times every month during JJAS using NCEP initial conditions. These predictions were evaluated against observations and showed that the multi-physics CFS could capture significant sub-seasonal features of the 2021 monsoon (**Fig. 1.38**).

Basic Research

Multi-physics schema for sub-seasonal prediction of Indian summer monsoon

The biases due to model physics in simulating the Indian summer monsoon are investigated to construct a multi-physics forecast strategy for sub-seasonal prediction. A 15-year hindcast from May to September (model is initialised six times every month) is produced with Climate Forecast System version 2 (CFSv2) using four physics combinations. These physics schemes include simplified Arakawa Shubert (SAS) and revised Arakawa Shubert (NSAS) convection parameterization coupled with Zhao and Carr (ZC) and Ferrier (FER) microphysics. The spatial and temporal characteristics of predicted monsoon climatology and its biases are evaluated using observation and reanalysis datasets. All physics schemes could predict rainfall distribution but have biases in predicted spatial rainfall maxima, and low-level circulation resulted from erroneous diabatic heating. Stronger deep convection in NSAS increased rainfall over the Indian landmass and caused excessive precipitation over oceanic regions. Including critical mixed-phase microphysical processes tends to reduce high cloud fraction in FER. It is illustrated that such constraining refinements due to one or more modified aspects of these physics schemes can be utilised to create a multi-physics prediction scenario. The multi-physics ensemble's mean showcases the considerable skill and controlled error growth up to a 20-day lead time compared to each physics combination for the monsoon zone. The study anticipates that the multi-physics approach could exploit individual physical schemes' strengths to yield better sub-seasonal forecasts.

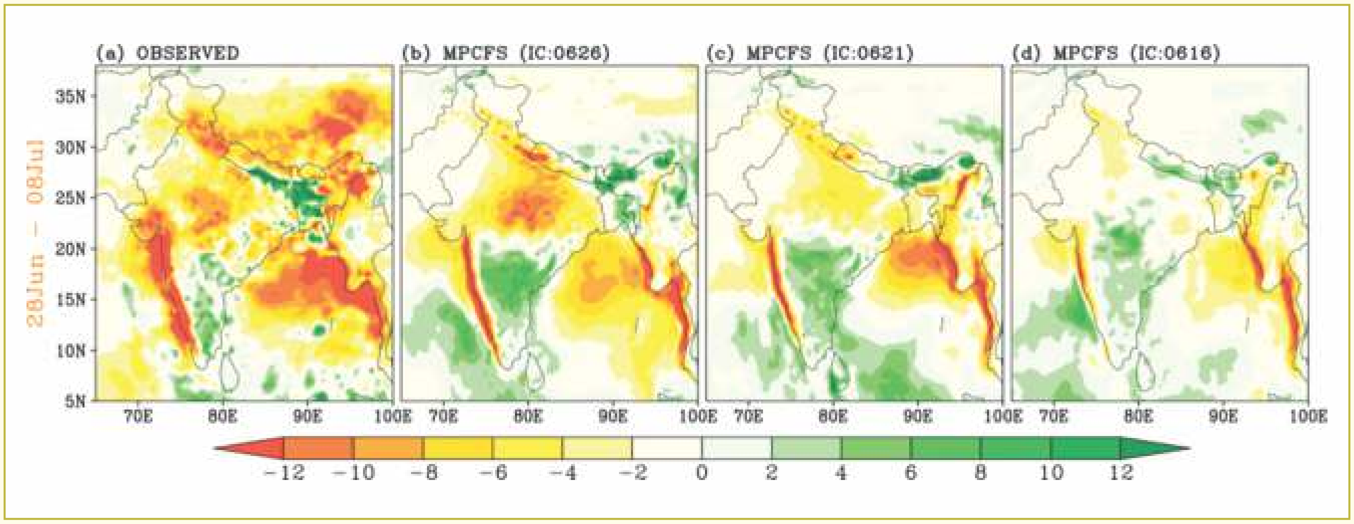


Fig. 1.38: *Rainfall anomaly from **(a)** Observation and **(b-c)** multi-physics framework prediction from different initial conditions for a break period (28 June - 08 July) during the 2021 monsoon.*

(**Fig. 1.39**) ***[Kaur M., Sahai A.K., Krishna R.P.M., Joseph S., Mandal R., Dey Avijit,*** *Chattopadhyay R., Multi-physics schema for sub-seasonal prediction of Indian summer monsoon,* ***Climate Dynamics****, Online, August 2021, DOI:10.1007/ s00382-021-05926-2, 1-22]*

Multi-model multi-physics ensemble: A futuristic way to the extended range prediction system

In an endeavour to design better forecasting tools for real-time prediction, the strength of the multi-model multi-physics ensemble over its operational predecessor version is highlighted. The exiting operational extended range prediction system (ERPv1) combines the coupled and its bias-corrected sea-surface temperature forced atmospheric model running at two resolutions with a perturbed initial condition ensemble. This system had accomplished important goals on the sub-seasonal scale skilful forecast; however, the system's skill is limited only up to 2 weeks. The next version of this ERP system is seamless in resolution and based on a multi-physics multi-model ensemble (MPMME). Similar to the earlier version, this system includes coupled climate forecast system version 2 (CFSv2) and an atmospheric global forecast system forced with real-time bias-corrected sea-surface temperature from CFSv2. In the newer version, model integrations are performed six times a month for real-time prediction, selecting the combination of convective and microphysics parameterisation schemes. Additionally, more than 15 years of hindcast are also generated for these initial conditions. The preliminary results from this system demonstrate appreciable improvements over its predecessor in predicting the large-scale low variability signal and weekly mean rainfall up to 3 weeks lead. The subdivision-wise skill analysis shows that MPMME

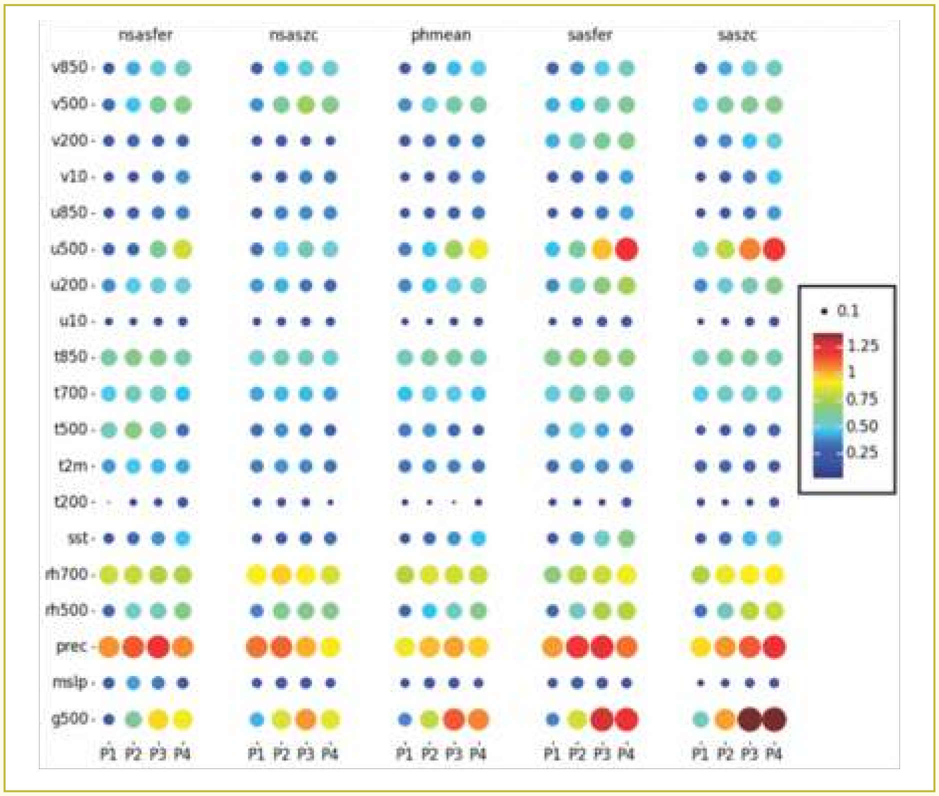


Fig. 1.39: *Standardised RMSE (coloured circles) for four pentad leads for all physics combinations and phmean (the black dot in legend depicts the size of 0.1 std. RMSE) for the monsoon region extended from 10°S to 30°N and 60°E to 90°E.*

performs better, especially in the northwest and central parts of India (**Fig. 1.40**). *[**Sahai A.K., Kaur Manpreet, Joseph S., Dey Avijit, Phani R., Mandal R.**, Chattopadhyay R., Multi-model Multi-Physics ensemble: A futuristic way to extended range prediction system, **Frontiers in Climate**, 3: 655919, May 2021, DOI:10.3389/fclim.2021.655919, 1-11]*

Northward propagation of convection over the Arabian Sea and the Bay of Bengal: A perspective from vorticity equation

The governing dynamics behind the northward propagation of convection in the intraseasonal timescale over the Arabian Sea (AS) and Bay of Bengal (BoB) during the summer monsoon was examined using the vorticity budget equation. Previous theories of northward propagation suggested that generation of vorticity to the north of an existing convection centre in the presence of mean easterly shear is essential. Using observational analysis, it is found that the tilting term in the vorticity equation leads the precipitation maxima by about 6-8 days over BoB and 2-3 days over AS. The tilting term exhibits stronger behaviour over BoB as compared to AS. Further investigation showed that the component of the tilting term associated with the meridional gradients in vertical velocity in intraseasonal timescale acts on the vertical gradient of the zonal mean flow to generate positive anomalies in tilting. Convective updrafts are stronger and more vertically stretched over BoB, which could be responsible for the enhanced tilting. A component of the tilting term associated with vertical shear of mean meridional winds showed a strong signal over AS, which could be related to the higher phase speed over AS compared to BoB. Moreover, although the beta effect contributes negatively to the vorticity equation, it induces an asymmetry in the meridional winds around the convection maxima over BoB, which drives dry air into the convection centre and helps develop a new

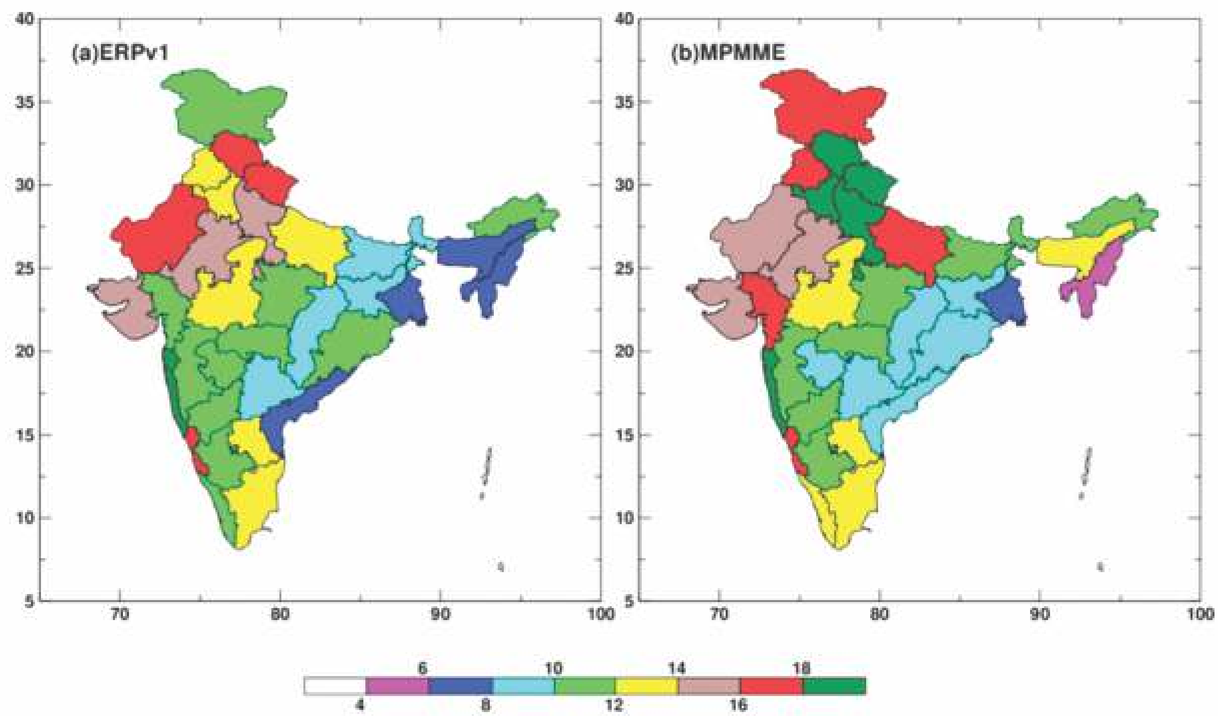


*Fig. 1.40: Subdivision-wise predictability limit for **(a)** extended range prediction system (ERPv1) and **(b)** multi-physics multi-model ensemble (MPMME) during monsoon.*

centre to the north. This mechanism is relatively weak in the AS. While highlighting the importance of convection in northward propagation, a pathway is presented for improving model performance for simulating intraseasonal variability and summer monsoon. (**Fig. 1.41**) *[**Karmakar N., Joseph S. and Sahai A.K.**, Northward propagation of convection over Arabian Sea and Bay of Bengal: A perspective from vorticity equation, **Climate Dynamics**, Online, march 2022, doi:10.1007/s00382-022-06248-7]*

Some aspects of the weak rainfall spells during the Indian summer monsoon 2018

The large-scale pattern of convection and circulation anomalies associated with the weak rainfall spells of the Indian summer monsoon 2018 were examined using observations. The periods were isolated as weak rainfall spells when the normalised rainfall anomaly averaged over the monsoon core zone (MCZ;18°-28°N, 65°-88°E) was less than -1.0 for at least three consecutive days. Four weak rainfall spells during June to September 2018 identified based on this criterion were: 14-21 June (WS1), 27 July - 7 August (WS2), 9-20 September (WS3), and 24-30 September (WS4). Large differences in the distribution of rainfall anomalies over India and the Indian Ocean during these four weak rainfall spells were noticed. Rainfall anomaly patterns of WS2 over India were characterised by large negative anomalies over the monsoon core zone (MCZ), negative anomalies over the west coast, while positive anomalies over northeast India in association with the northward shift of the monsoon trough to the foothills of the Himalayas. Rainfall anomaly patterns of WS2 and WS3 were similar over India except for the absence of increased rainfall over the foothills in WS3. Rainfall anomalies of WS4 displayed opposite signs over MCZ and Equatorial Indian Ocean (EIO), indicative of the mutual competition between convection over India and EIO. Out-of-phase OLR anomalies over MCZ and Northwest Pacific Ocean (NWPO) were linked with the occurrence of WS1 and WS4. A quadrupole pattern comprising positive (negative) OLR anomalies over the Indian region and equatorial west Pacific (EIO and NWPO) was observed during WS1 and WS4. Enhanced convection over the foothills of the Himalayas and larger parts of the tropical Pacific Ocean possibly caused WS2. The influence of the intrusion of deep troughs in the mid-latitude westerlies in the upper troposphere over northern India on the formation of WS3 was evident. *[**Mandke S.K.**, Some aspects of the weak rainfall spells of the Indian summer monsoon 2018, **Research activities in earth system modeling**, Ed. E. Astakhova, Working Group on Numerical Experimentation, Report No. 51. WCRP Report No.4/2021, July 2021, WMO, Geneva, 2-11]*

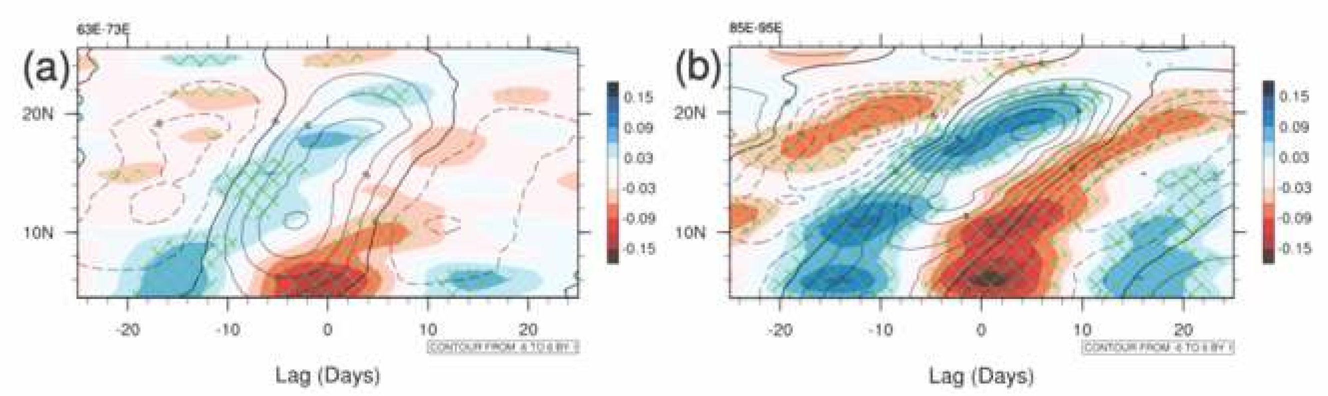


***Fig. 1.41:** **(a)** Lag-latitude diagrams of ISO-filtered rainfall (in contours; negative values in dashed contours) and vertically integrated tilting term in vorticity budget equation (in colours) averaged over AS longitudes during the strong convective events. **(b)** Same as **(a)** but for BoB longitudes. Units of rainfall and tilting term are mm/day and $10^{-6} \times kgm^{-2}s^{-2}$, respectively. A randomisation test is used for significance, and green hatched areas show where tilting is significant at a 5% level.*

The intraseasonal fluctuation of Indian summer monsoon rainfall and its relation with monsoon intraseasonal oscillation and Madden-Julian oscillation

The intra-seasonal fluctuations of Indian summer monsoon rainfall (ISMR) are mainly controlled by northward propagating Monsoon Intra-seasonal Oscillation (MISO) and eastward propagating Madden Julian Oscillation (MJO). An attempt was made to examine the relationship between the intra-seasonal fluctuations (active and break spells) of ISMR with the phase propagation and amplitude of MISO and MJO. It is noticed that active spells generally occur during MISO phase 2-5 (MJO phase 3-6), and break spells mainly occur during MISO phase 6-8 (MJO phases 6-8 and 1). The association of active/break spells with MISO phases is more prominent than with MJO phases. It is shown that the phase composite of unfiltered and regression-based reconstructed rainfall for eight MISO and MJO phases, which is consistent with the earlier findings. The reconstructed field also showed a systematic and well-organised northward propagation compared to the unfiltered field. Phase composite also indicates a lead-lag relationship between MISO and MJO phases. MISO phase composite shows more robust northward propagation than the MJO phase composite. MISO reconstructed rainfall explained more percentage variance than MJO reconstructed rainfall with reference to 20-90 days filtered rainfall. It is found that long active (>7 days) predominantly occurs when either MISO or MJO, or both are active, and the associated signal is somewhere between phases 2-5. A long break occurs when both (MISO & MJO) or at least one (MJO/MISO) is feeble, or even though associated signals are strong, they are primarily located in phases 1, 6, 7 and 8. (**Fig. 1.42**) *[**Dey Avijit**, Chattopadhyay R., **Joseph S., Kaur M., Mandal R., Phani R., Sahai A.K.**, Pattanaik D.R., The intraseasonal fluctuation of Indian summer monsoon rainfall and its relation with monsoon intraseasonal oscillation (MISO) and Madden Julian oscillation (MJO). **Theoretical and Applied Climatology**, Online, February 2022, DOI:10.1007/s00704-022-03970-4]*

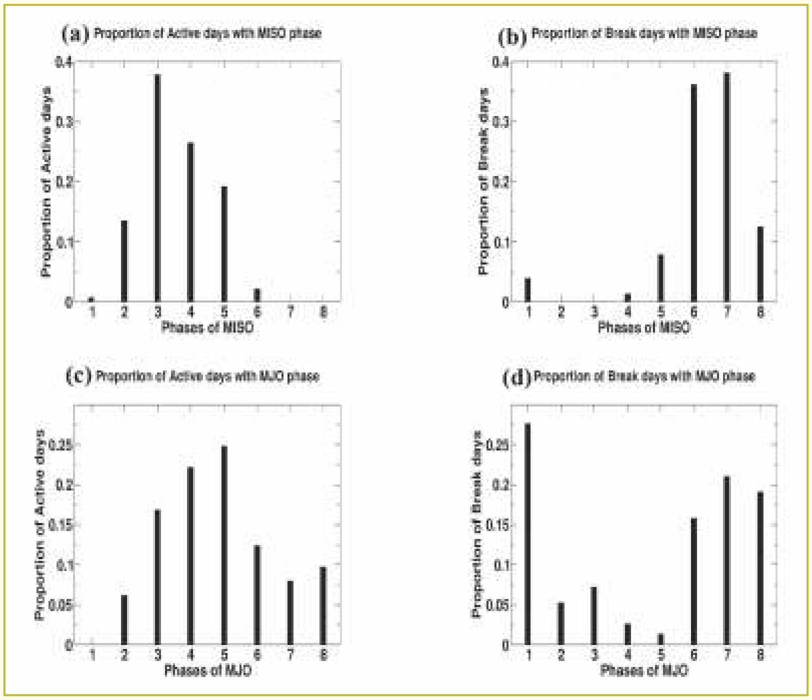


***Fig. 1.42:** **(a)** Frequency of active days with MISO phase, **(b)** Frequency of break days with MISO phase, **(c)** Frequency of active days with MJO phase, and **(d)** Frequency of break days with MJO phase.*

1.2.3. Seasonal Scale

Developmental Activities

- **Next-generation MMCFS model development:** The new MMCFS version 3 (CFSv3) brings in many upgrades to the individual model components of the currently operational MMCFS version 2 (CFSVv2). The ocean model has been upgraded to MOM6 over MOM4 (MOM4p0). The sea-ice model from Winton, 2000 (GFDL) has been upgraded to the CICE5 model from LANL, and the Eulerian dynamical core in GFS (the atmospheric model component) has been changed to the Lagrangian dynamical core. Using the Semi-Lagrangian dynamical core in the atmospheric component of the CFS (the GFS) over the existing Eulerian one allows us to use higher atmospheric model resolutions while keeping the time stepping same. CICE5 is designed to be used in coupled models and is highly parallelizable. The major improvements of CICE5 over the Sea-ice model of CFSv2 include ice velocity in atmosphere-ice coupling updates and allowing a variable coefficient for the ice-ocean heat flux. Work is progressing to include other developmental activities, such as incorporating the COARE3 bulk flux algorithm and river routing model.
- **CFSv2 sensitivity experiments:** Sensitivity experiments have been performed with CFSv2 using different microphysics (with and without ice-phase processes) and convective parameterisation schemes. Results revealed that the ice-phase (i.e., mixed-phase; called as ICE) microphysics parameterisation 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).
- **IITM-UMD weakly coupled analysis (IWCA) and predictions using IWCA:** With the purpose of improving the accuracy of the ocean and atmospheric initial conditions, an ensemble-based flow-dependent data assimilation system was developed for the operational CFSv2 coupled model. The data assimilation technique implemented here is the Local Ensemble

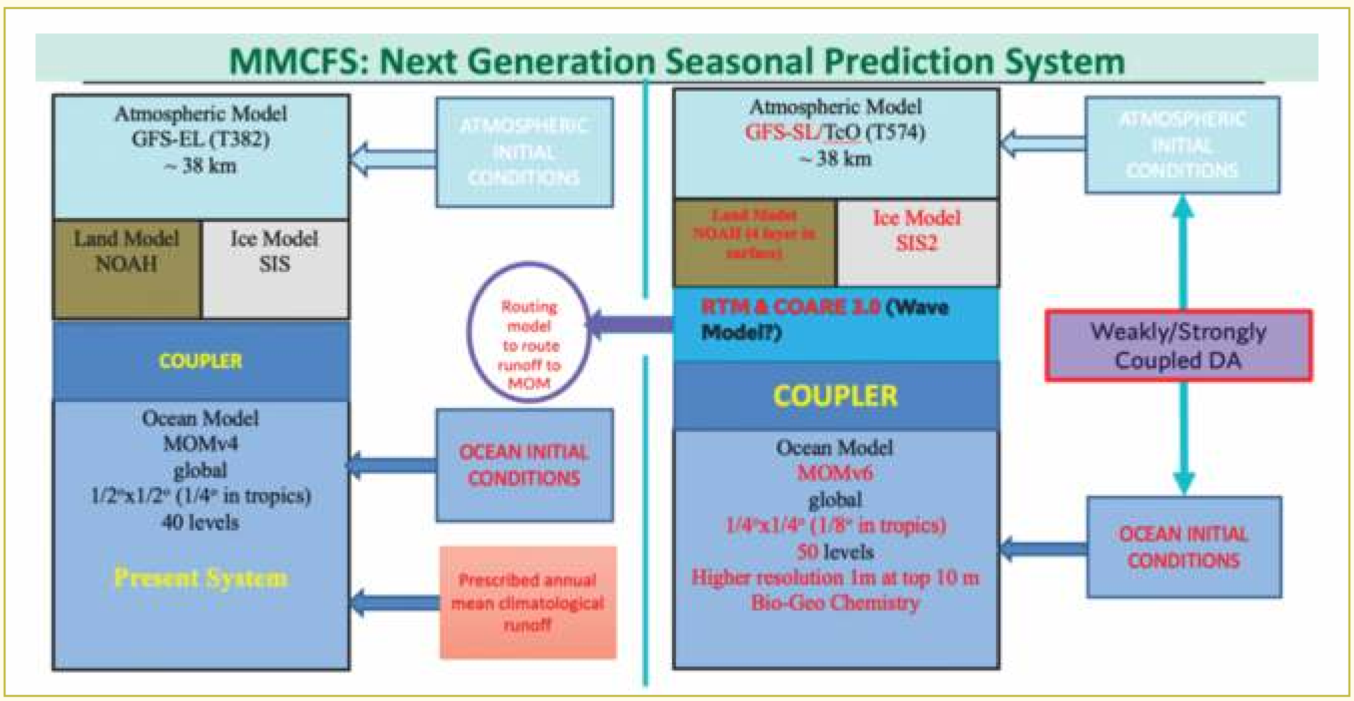


Fig. 1.43: Schematic representation of various components of next-generation MMCFS (right) together with the old version (left).

Transform Kalman Filter (LETKF, Hunt et al., 2007). Successfully created long-term (21 years) coupled ocean-atmospheric analysis (IITM-UMD weakly coupled analysis or IWCA) using CFSv2 LETKF Weakly coupled data assimilation system for the period 1999-2019. Performed seasonal prediction runs using the new IWCA perturbed initial conditions (ICs) for the period 1999-2019, for the initialisation dates 01 FEB, 01 MAR, and 01 APR (first day of each month). The predictions using IWCA ICs (T126) have outperformed CFSR ICs seasonal predictions by increasing ISMR skill with a gain of one-month predictive lead time. The causative factors responsible for observed improvement were examined. It is found that the improved analysis quality and better cross-domain equilibrium in IWCA ICs have reduced the initial shocks during springtime. The ideal ensemble nature in predictions has further enhanced the predictions.

Basic Research

Evaluating different lightning parameterisation schemes to simulate lightning flash counts over Maharashtra, India

Thunderstorms – the source of lightning discharge – are a major hazard to humans. In India, the loss of human life due to thunderstorms is high because of frequent lightning during the pre-monsoon season (March-May). Therefore, simulation of lightning flash counts based on various lightning parameterisation schemes and Lightning Potential Index (LPI) in the Weather Research and

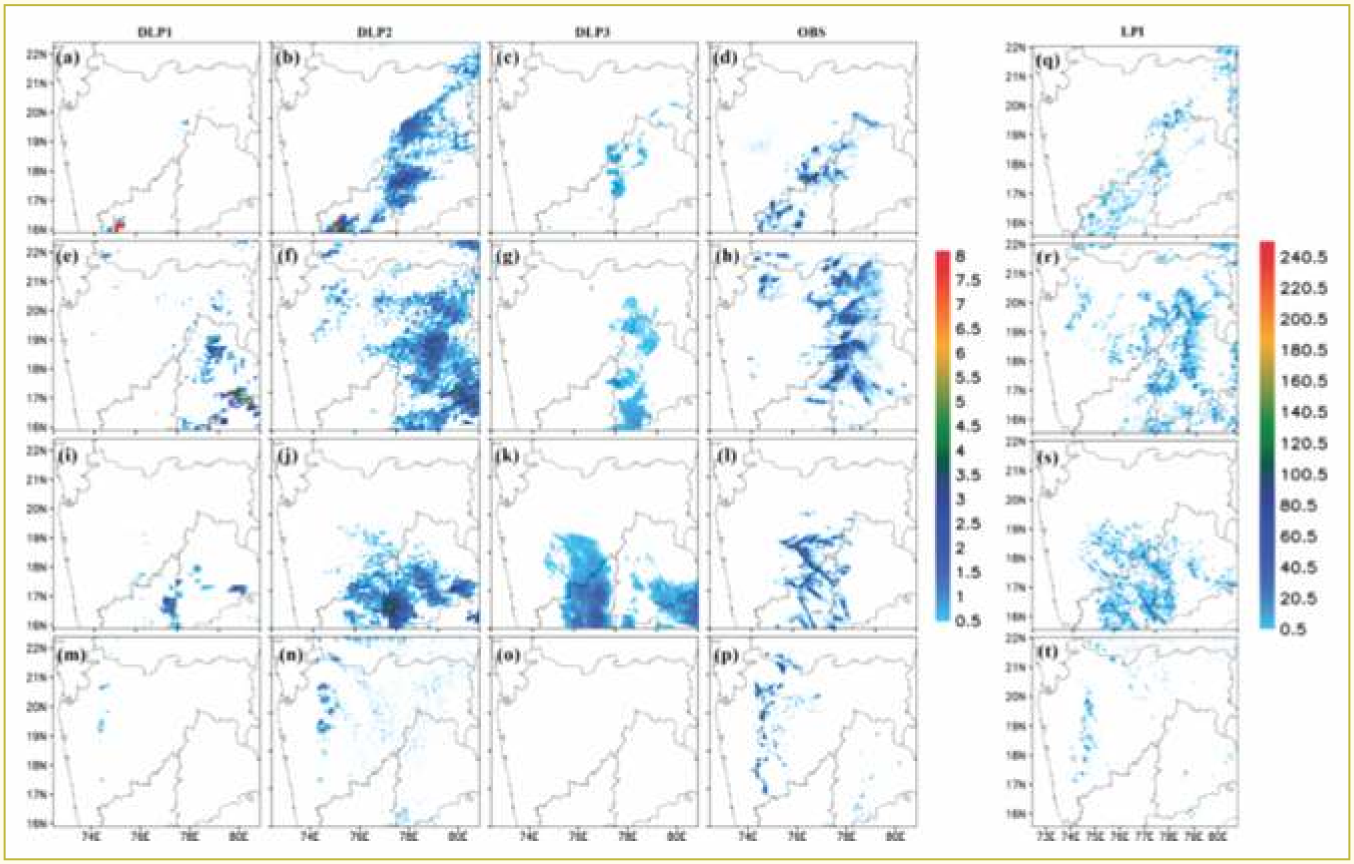


*Fig. 1.44: Spatial distribution of 24 hrs accumulated lightning flashes (# day^{-1}) from different lightning parameterisations along columns DLP1 **(a, e, i, m)**, DLP2 **(b, f, j, n)** and DLP3 **(c, g, k, o)**, and observation **(d, h, l, p)**, and lightning potential index **(LPI; q, r, s, t)**. Each row represents selected events: 29 Apr 2016 **(a, b, c, d)**, 05 May 2016 **(e, f, g, h)**, 15 Mar 2017 **(i, j, k, l)**, and 25 May 2017 **(m, n, o, p)**.*

Forecasting (WRF) model were evaluated over Maharashtra, India. The offline diagnostic methods for calculating lightning flashes were also evaluated from the model-generated storm parameters. The observations from Maharashtra Lightning Detection Network (LDN) were used to validate the simulated total lightning flash counts for four events. The lightning flashes calculations by following Price and Rind (1992) based on cloud top height (PR92CTH) and vertically integrated ice water path (IWP) simulated the spatial pattern comparably well. The lightning parameterisation based on cloud top height defined by the radar reflectivity factor threshold of 20 dBZ (DLP2) has performed better as compared to observation. The results showed: (i) better spatial pattern and frequency distribution of lightning flashes, (ii) accumulated rainfall, maximum reflectivity and time evolutions were in good agreement with the simulated flashes, (iii) correlation between simulated flash and hydrometeors was higher, (iv) the number of matching grid boxes due to randomness was also higher (74.9%, 56.5%, 68.1% and 82.7% for the four events), and (v) the results based on LPI were also consistent with the results of DLP2. These findings highlighted the robustness of DLP2 and indicated a promising future for the operational forecast of lightning prediction. (**Fig. 1.44** and **1.45**) *[**Mohan G.M., Vani K.G., Hazra A., Mallick C., Chaudhari H.S., Pokhrel S., Pawar S.D., Konwar M., Saha Subodh K., Das S.K., Deshpande S., Ghude S.,** Barth M.C., **Rao Suryachandra A., Nanjundiah R.S.,** Rajeevan M., Evaluating different lightning parameterization schemes to simulate lightning flash counts over Maharashtra, India, **Atmospheric Research**, 255: 105532, June 2021, DOI:10.1016/j.atmosres.2021.105532, 1-22]*

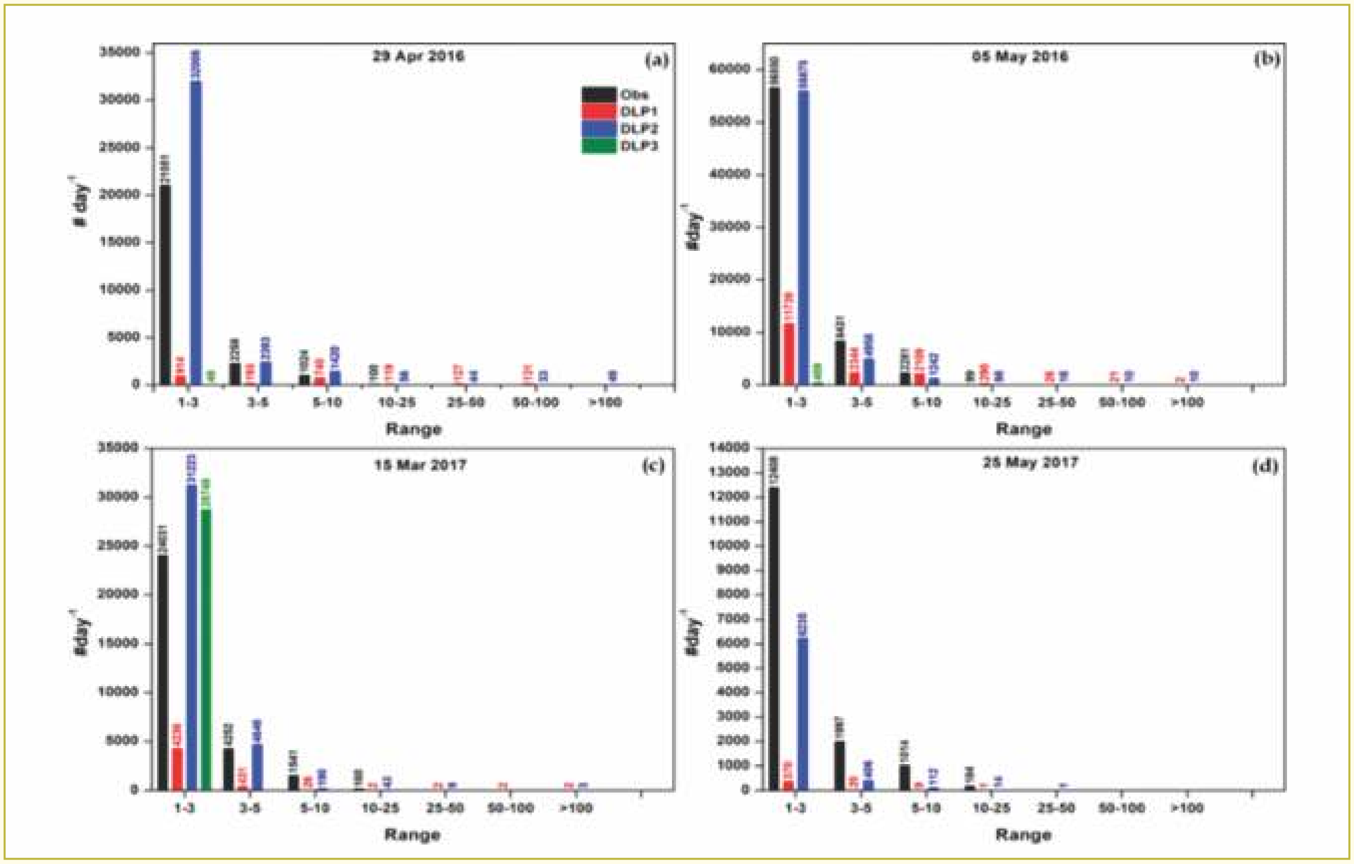


***Fig. 1.45:** Frequency distribution of lightning flashes (# day^{-1}) from different lightning parameterisations.*

Role of microphysics and convective auto-conversion for the better simulation of tropical intra-seasonal oscillations (MISO and MJO)

The seasonal prediction of the Indian summer monsoon (ISM) and Monsoon Intra-seasonal Oscillations (MISO), as well as the Madden-Julian Oscillations (MJO) that strongly modulate MISO, is of much importance to the agriculture sectors of the Indian subcontinent. The importance of selecting proper 'auto-conversion' coefficients for precipitation formation in Coupled Global Climate Model's convective and microphysical schemes is highlighted in simulating MISO and MJO. With a series of sensitivity experiments, the convective auto-conversion and microphysical auto-conversion coefficients were systematically examined in the CFSv2 model. The mean and intra-seasonal features of MISO and MJO are improved with a proper combination of convective and microphysical auto-conversion, which not only provide a better partition of cloud water and ice but also better feedback between the large-scale condensation and convective parameterisation. It is pin-pointed that proper combination/choice of the convective and microphysical auto-conversion may be useful to improve the long-standing problem of climate models with respect to RTC (ratio of convective to total rainfall, as shown in **Fig. 1.46**). ***[Dutta U., Hazra A., Chaudhari H.S., Saha Subodh K., Pokhrel S.**, Shiu C.-J., Chen J.-P., Role of microphysics and convective auto-conversion for the better simulation of Tropical Intra-seasonal Oscillations (MISO and MJO), **Journal of Advances in Modeling Earth Systems**, 13:e2021MS002540, October 2021, DOI:10.1029/2021MS002540, 1-32]*

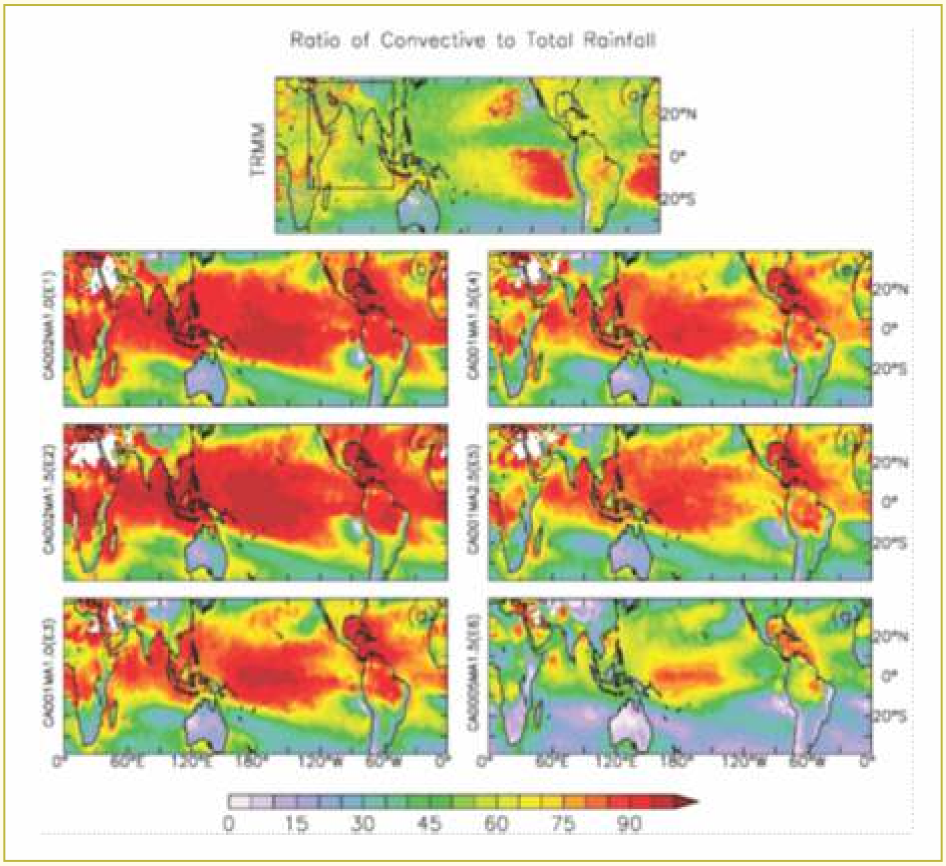


Fig. 1.46: *JJAS Climatology of Convective to Total Rainfall ratio (in percentage) over global tropics from Tropical Rainfall Measuring Mission Precipitation **(a)** and six sensitivity experiments **(b-g)**.*

Impact of initialised land surface temperature and snowpack on sub-seasonal to seasonal prediction project, Phase I (LS4P-I): Organisation and experimental design

Sub-seasonal-to-seasonal (S2S) prediction, especially the prediction of extreme hydroclimate events such as droughts and floods, is not only scientifically challenging but also has substantial societal impacts. Motivated by preliminary studies, the Global Energy and Water Exchanges (GEWEX)/Global Atmospheric System Study (GASS) has launched a new initiative called 'Impact of Initialised Land Surface Temperature and Snowpack on Sub-seasonal to Seasonal Prediction' (LS4P) as the first international grassroots effort to introduce spring land surface temperature (LST)/subsurface temperature (SUBT) anomalies over high mountain areas as a crucial factor that can lead to significant improvement in precipitation prediction through the remote effects of land-atmosphere interactions. LS4P focuses on process understanding and predictability; hence it is different from, and complements, other international projects that focus on the operational S2S prediction. More than 40 groups (including IITM CFS) worldwide have participated in this effort, including 21 earth system models, nine regional climate models, and seven data groups. While presenting an overview of the history and objectives of LS4P, the first-phase experimental protocol (LS4P-I) which focuses on the remote effect of the Tibetan Plateau, the LST/SUBT initialisation, and the preliminary results are presented. Multi-model ensemble experiments and analyses of observational data have revealed that the hydroclimatic effect of the spring LST on the Tibetan Plateau is not limited to the Yangtze River basin but may have a significant large-scale impact on summer precipitation beyond East Asia and its S2S prediction. Preliminary studies and analysis

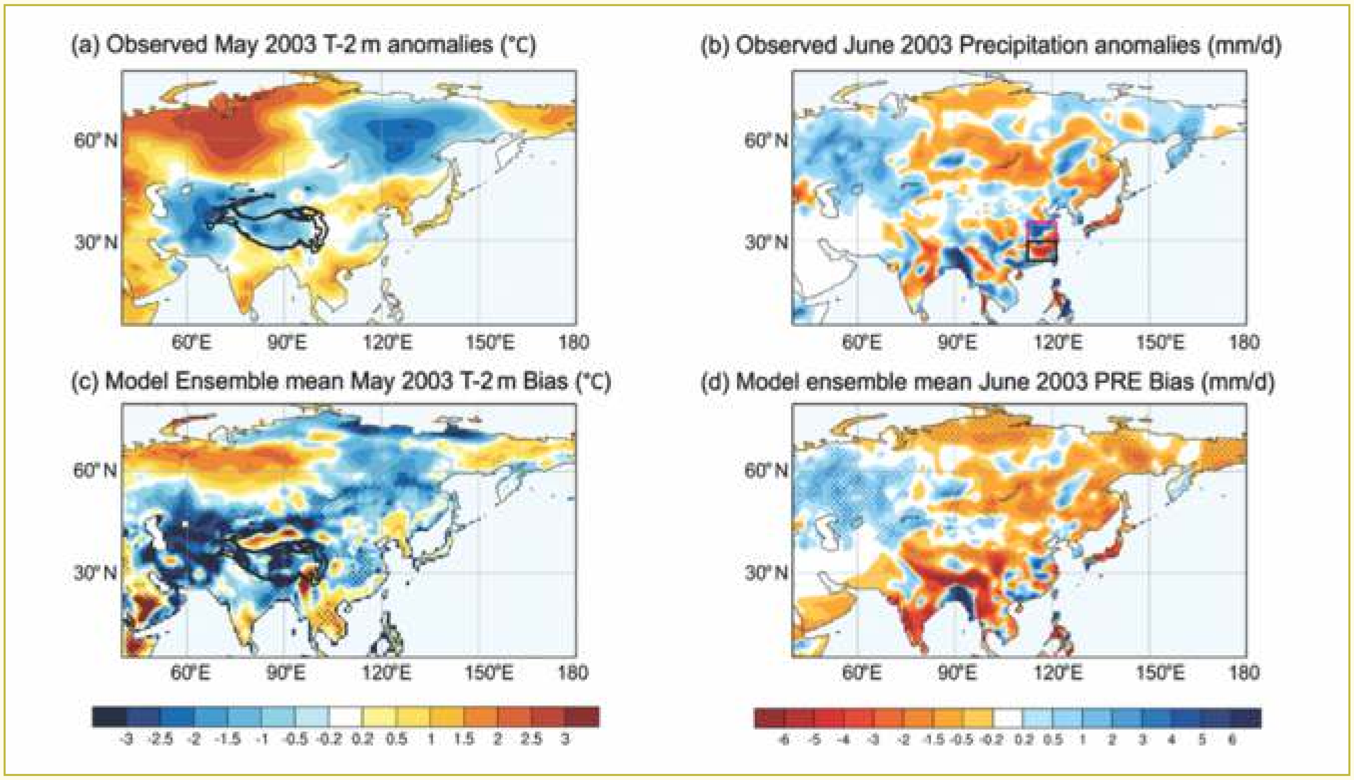


Fig. 1.47: *Comparison between the observed anomalies and the ensemble mean bias for May 2003 T2m and June 2003 precipitation from 13 LS4P-I Earth system models.*

have also shown that LS4P models are unable to preserve the initialised LST anomalies in producing the observed anomalies largely for two main reasons: (i) inadequacies in the land models arising from total soil depths which are too shallow and the use of simplified parameterisations, which both tend to limit the soil memory; and (ii) reanalysis data, which are used for initial conditions, have large discrepancies from the observed mean state and anomalies of LST over the Tibetan Plateau. Innovative approaches have been developed to largely overcome these problems. (**Fig. 1.47**) *[Xue Y., Yao T., Boone A.A., Diallo I., … , **Saha S.K.**, … et al., Impact of Initialized Land Surface Temperature and Snowpack on Sub-seasonal to Seasonal Prediction Project, Phase I (LS4P-I): Organization and Experimental design, **Geoscientific Model Development**, 14, July 2021, DOI:10.5194/gmd-14-4465-2021, 4465–4494]*

Comparison of MMCFS and SINTEX-F2 for seasonal prediction of Indian summer monsoon rainfall

A comparison of the Indian summer Monsoon Rainfall (ISMR) in two different coupled models (viz., Scale Interaction Experiment-Frontier-F2; SINTEX-F2, and Monsoon Mission Climate Forecast System; MMCFS) is carried out to ascertain the predictability sources in these models and their strengths and weaknesses. SINTEX-F2 has a stronger cold sea surface temperature (SST) bias in the central equatorial Pacific, and it simulates mean ISMR better while underestimating the interannual variability of ISMR. On the other hand, MMCFS has a warmer SST bias in the tropical Pacific off the equator, simulates a drier mean monsoon, but has a more realistic ISMR interannual variability. Further, the cold SST bias in the central tropical Pacific adversely affects the ability of the SINTEX-F2 to capture the El Niño-Southern Oscillation (ENSO) related interannual variability and teleconnection patterns with monsoon by shifting it further westward in the tropical Pacific Ocean. The models' skill in simulating various climate indices are compared by considering criteria such as anomaly correlation coefficient (ACC), spread to root mean square error (RMSE) ratio, and signal to noise ratio (SNR). The prediction skill for ISMR in terms of ACC in MMCFS (.53) and SINTEX-F2 (.45) is comparable for hindcasts initialised in February. However, RMSE for ISMR from February initial conditions in SINTEX-F2 (1.43 mm/day) is small compared to MMCFS (2.34 mm/day). A simple multi-model ensemble prediction system based on MMCFS and SINTEX-F2 results in better prediction skill in terms of ACC for tropical SST and ISMR. The spread/RMSE ratio for ISMR is similar in both models but is better for ENSO indices in MMCFS at a longer lead time than in SINTEX-F2. Considering the SNR as performance criteria, MMCFS has an advantage due to better predictability of SST and vertical wind shear in several parts of the Indo-Pacific domain. *[**Pradhan M., Rao S.A.,** Doi T., **Pillai P.A., Srivastava A.,** Behera, S., Comparison of MMCFS and SINTEX-F2 for seasonal prediction of Indian summer monsoon rainfall, **International Journal of Climatology**, 41, November 2021, DOI:10.1002/joc.7169, 6084-6108]*

Table 1.1: Skill (ACC) of various SST and rainfall indices in the ensemble mean of MMCFS, SINTEX-F2, and the multi-model mean simulations (February IC) during the monsoon season (JJAS) for the period 1983-2015. ACC significant at 95% significance level are represented in bold.

Skill	NINO3.4	NINO3	EMI	IODE	IODW	ISMR (vs. GPCP)
MMCFS	**.64**	**.66**	**.70**	**.49**	**.50**	**.53**
SINTEX	**.61**	**.61**	**.81**	.08	**.57**	**.45**
Multi-model-mean	**.67**	**.70**	**.85**	**.34**	**.57**	**.56**

Reducing systematic biases over the Indian region in CFS V2 by dynamical downscaling

The usefulness of dynamical downscaling of seasonal reforecasts of the Indian Monsoon was explored to address the seasonal mean biases in the reforecasts. Almost all the current generation global coupled models, including the Climate Forecast System version 2 (CFSv2, T126 ~110 km), exhibit systematic mean dry bias over the central Indian region during the summer monsoon season. Cold sea surface temperature (SST) biases in the Indian Ocean and a weak monsoon circulation due to a colder tropospheric temperature contribute to this dry bias. Such systematic biases restrict the use of skilful forecasts from these models in climate applications (such as agriculture or hydrology). Dynamical downscaling of seasonal forecasts (~110 km resolution) using the Weather Research and Forecasting (WRF) model coupled with a simple ocean mixed layer model (OML; WRFOML) at 38 km resolution significantly reduces the majority of the systematic rainfall biases reported (**Fig. 1.48**). The seasonal mean dry bias reduces to 16% in WRFOML compared to 44% (33%) in the CFSv2-T126 (WRFCTL) over the Indian land region. Warmer SSTs in the Indian Ocean and a more robust monsoon circulation emanating from a realistic simulation of the tropospheric temperature reduced the systematic biases in WRFOML compared to CFSv2-T126 and WRFCTL. Additionally, category-wise rainfall distributions are also drastically improved (as shown in **Fig. 1.49**) in the downscaled simulations (WRFOML). Downscaled reforecasts with reduced systematic biases have better suitability for climate applications. *[Hari Prasad K.B.R.R.,* ***Ramu D.A., Rao S.A.****, Hameed S.N., Samanta D., and* ***Srivastava A.****, Reducing systematic biases over the Indian region in CFS V2 by dynamical downscaling,* ***Earth and Space Science****, 8:e2020EA001507,June 2021, DOI:10.1029/ 2020EA001507, 1-19]*

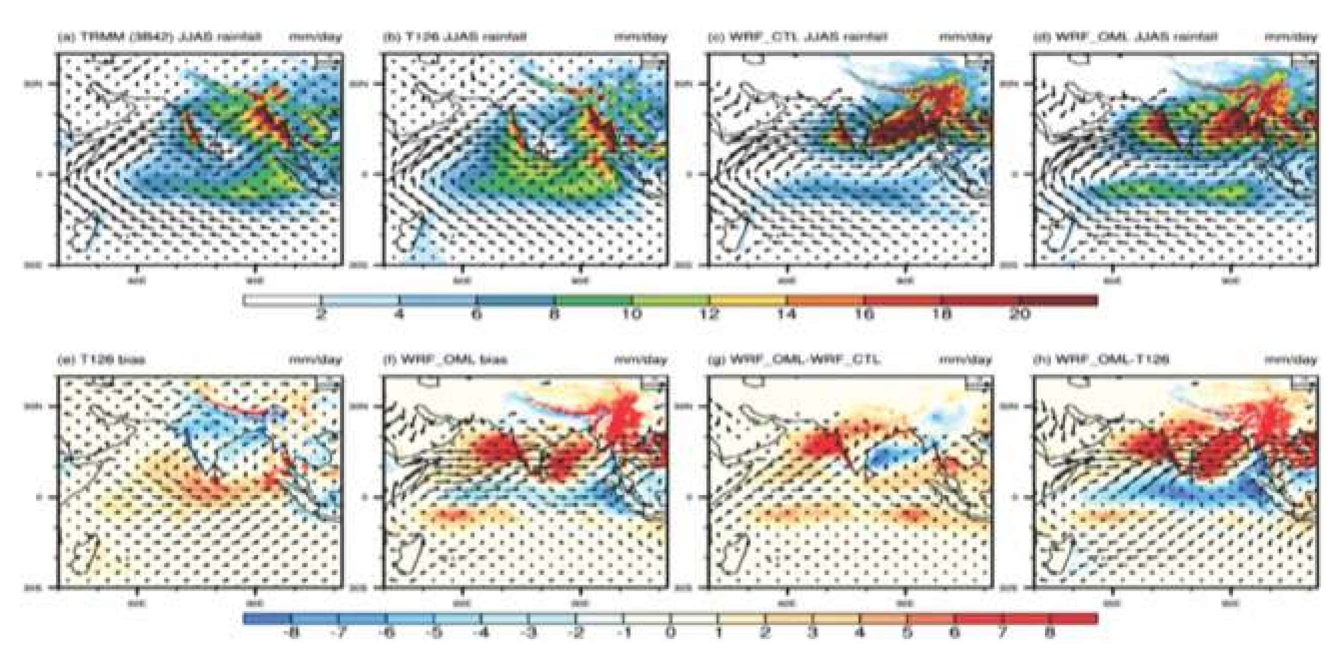


Fig. 1.48: *Spatial distribution of JJAS mean precipitation (mm/day, shaded) and winds at 850 hPa (m/s, vectors) from* ***(a)*** *observation,* ***(b)*** *CFSv2-T126,* ***(c)*** *WRFCTL, and* ***(d)*** *WRFOML. The biases of the models* ***(e)*** *CFSv2-T126 and* ***(f)*** *WRFOML from the observation and* ***(g)*** *difference between WRFOML and WRFCTL, and* ***(h)*** *difference between WRFOML and CFSv2-T126.*

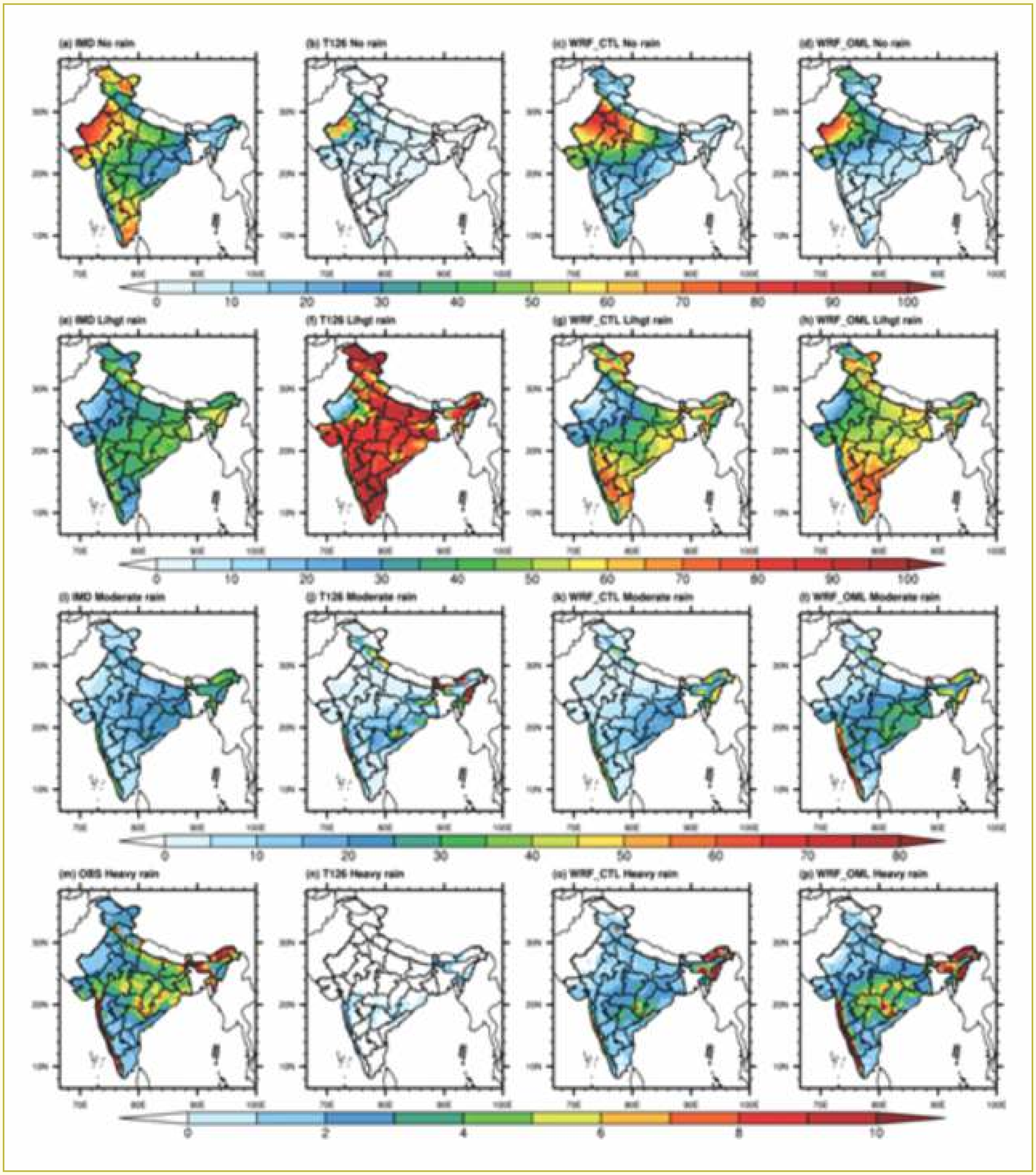


Fig. 1.49: *JJAS mean spatial frequency distribution of different rain rate categories:* ***(a-d)*** *no rainy days,* ***(e-h)*** *light rain,* ***(i-l)*** *moderate rain, and* ***(m-p)*** *heavy rain. The first column is from observation; the second, third, and fourth columns represent CFSv2-T126, WRFCTL, and WRFOML, respectively.*

1.2.4. International Monsoons Project Office (IMPO)

The International Monsoons Project Office (IMPO), hosted by IITM, is India's contribution to WMO's monsoon research coordination activities under WWRP and WCRP. IMPO functions as a global hub of monsoon research coordination, covering all monsoon regions of the world and spanning weather to climate change time scales. One of the core responsibilities of the IMPO is to support the activities of the CLIVAR/GEWEX Monsoons Panel. IMPO also supports cross-panel linkages within the working structure of the WCRP and its core projects, as well as WWRP substructures, on monsoon-related matters. A key example in this regard is the Indian Ocean Region Panel (IORP) under CLIVAR. In addition, IMPO supports the IWM (International Workshop on Monsoons) series of workshops and associated activities.

In the coming years, IMPO will coordinate various WWRP and WCRP activities with the kind support of WMO, MoES, IITM, IMD, NCMRWF, INCOIS and all related international scientists.

Establishment of IMPO at IITM

IMPO is a joint effort by WMO and IITM to help coordinate monsoon research across the world. A new agreement was signed between the Secretary-General of the World Meteorological Organisation (WMO) and the Director of the Indian Institute of Tropical Meteorology (IITM), with the kind approval of the Ministry of Earth Sciences, Govt. of India to host the International Monsoons Project Office (IMPO) at IITM, initially for five years with effect from 30 July 2021, to support monsoon research activities of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP).

Various Activities Executed During the Period

IMPO is involved with the scientific coordination of global monsoons research and has provided support to various Working Groups of the CLIVAR/GEWEX Monsoons panel (MP) of the World Climate Research Program (WCRP) and its regional Working Groups (on Asian-Australian Monsoons, American Monsoons and African Monsoons) for the advancement of basic research on global monsoons. IMPO supported various scientific activities of Southern Asian Climate Research Forum (SACRF). IMPO helped researchers to provide new challenges and new directions for achieving many research goals related to weather, climate and climate change impacts on the world. Some of the important activities are highlighted below:

- **Online International Workshop on Sub-seasonal to Seasonal (S2S) prediction:** IMPO contributed significantly to organising this important online workshop during 1-12 November 2021. It was attended by more than 100 participants from around the world. This event was an important component of the Seventh International Workshop on Monsoons (IWM-7). The training workshop focused on the sub-seasonal to seasonal (S2S) prediction of monsoons and offered short courses to NMHS (National Meteorological and Hydrological Services) forecasters. Specific topics included S2S predictability sources, Access to S2S database and tools, Model validation and forecast verification, and Calibration and ensemble techniques. A pre-workshop orientation course was offered before the main training workshop to introduce and facilitate the data and tools to be compiled by the trainees in advance and to familiarise the trainees with the workshop procedures, including the practical sessions.
- IMPO has coordinated with Co-Chairs of the CLIVAR/GEWEX Monsoons panel (MP) and all Co-Chairs of its regional Working Groups (on Asian-Australian Monsoons, American Monsoons and African Monsoons) for the formation of new Working Groups with some new members and some changes in the Monsoons Panel. Dr. Suryachandra A. Rao of IITM has been proposed as a Co-Chair of the Monsoons Panel.

- IMPO coordinated and supported the Southern Asian Climate Research Forum (SACRF) with the successful organisation of the first forum of SACRF on 30 November 2021. Several online meetings were attended by IMPO personnel with WCRP Secretariat for the preparations to organise this event successfully. A large number of participants attended this event.
- IMPO worked with the Ministry of Earth Sciences (MoES) and the WCRP Secretariat to organise the high-level launch event of IMPO on 28 February 2022, coinciding with National Science Day. The event included pre-recorded address by the Minister of Earth Sciences Dr. Jitendra Singh, addresses by Dr. M. Ravichandran, Secretary, MoES and dignitaries of WCRP & WWRP (Dr. Detlef Stammer, Chair, WCRP Joint Scientific Committee; and Dr. Chris Davis, Chair, WWRP Scientific Steering Committee), and a brief address by Dr. R. Krishnan, Acting Director, IITM. It also included an interesting science talk by Prof. C.P. Chang, an international monsoon expert from the USA.
- ICMPO/IMPO personnel attended/organised various teleconference meetings of ICPO/ICMPO/IMPO and GEWEX-CLIVAR Monsoons Panel (MP), online workshops and other internal meetings.

High Performance Computing (HPC) System

Project Director :
Dr. A. Suryachandra Rao

HPC Pratyush

Details of Storage, System Software and other hardware: The storage system consists of five Sonexion 3000 arrays, which provides two file systems (Home and Scratch). The home file system consists of 26 SSUs with a capacity of 8.6 PB, and Scratch consists of five SSUs with a total capacity of 1.1 PB.

Application software: A list of applications and libraries installed (or upgraded) during 2021-22 by the Pratyush team is provided in **Table 2.1**.

Table 2.1: Details of the application installed during 2021-22.

S. No.	Applications	S. No.	Applications
1	CFS_LETKF_SCDA	28	INCOIS_MOM5.1 (Intel)
2	CFS_LETKF_WCDA_T574	29	WPS 4.3, 4.2, 4.3.2
3	LROSE	30	comGSIv3.5_EnKFv1.1
4	JULES (v5.2, 6.1)	31	Paraview 5.2.0
5	WRF v 4.0	32	WRF-CHEM Pre-processing 1.5
6	MOM6	33	NCO
7	GODAS	34	NCVIEW
8	DNS Benchmark model	35	CDO
9	MOM5.1 Benchmark model	36	LIS
10	ROMS Benchmark model	37	WRF ELEC
11	N-NEMO Benchmark model	38	Pyferret
12	N-Coupled Benchmark model	39	UCLALES-SALSA
13	HWRF-HYCOM Benchmark Model	40	Flexpart_wrf
14	Weather-bench Benchmark Model	41	OBSGRID
15	WRF-CHEM Benchmark model	42	WRF-PGI
16	CFSV3 Benchmark model	43	PALM
17	HYCOM Benchmark model	44	Open grads 2.2.1
18	WRF Benchmark model	45	LETKF-MOM with PGI
19	GFS-TCO Benchmark model	46	GEOS-CHEM 4x5
20	LETKF-MOM Model	47	Fire_emis and mozbc
21	ECHAM	48	vapor 3.4.0
22	HYSPLIT	49	Tytrk_clim
23	R v 4.1.1	50	TRACMASS model
24	UPP	51	Ww3
25	GSI	52	pytorch, Tensorflow, Tensorflow-GPU
26	WRF GPU	53	Spyder 3
27	WRF-CHEM with KPP 4.3.2, 4.2	54	Wgrib2

User Support and Pratyush HPC team: The Pratyush team handled 834 system issues and 514 user application issues. Additionally, a comprehensive web portal has also been made available where users can inform themselves and find solutions to common queries for better issue tracking.

System Usage: Average uptime has been maintained as per the required uptime of 99.5%.

Fig. 2.1 shows the monthly average utilisation of the compute node during 2021-22. The utilisation of total allocated space from all the user groups is plotted in **Fig. 2.2**. The pie chart mentions that all the groups have used the Pratyush space. **Fig. 2.3** shows the group-wise utilisation of the Pratyush compute system. The average queue utilisation during 2021-22 is provided in **Table 2.2**. In recent months, IMD has started migrating their models on Pratyush for their operational works.

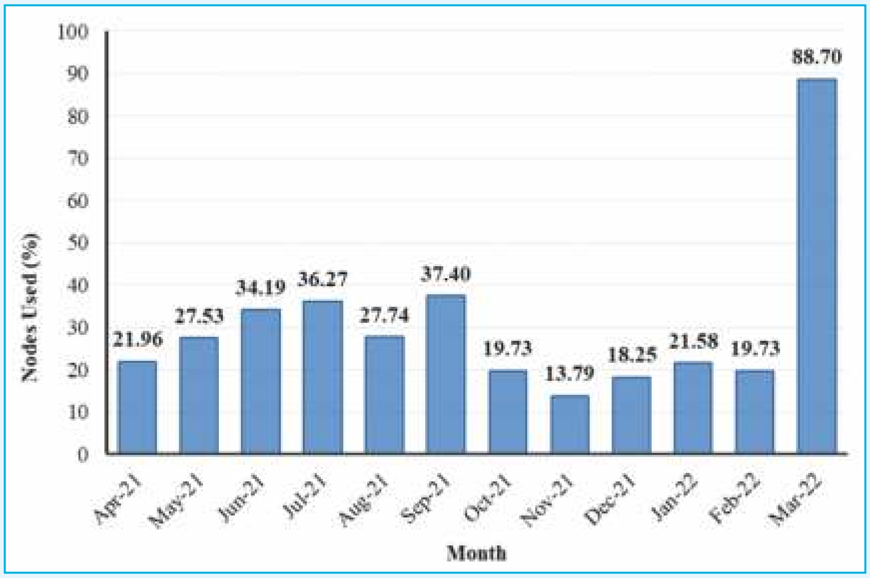


Fig. 2.1: *Monthly average node utilisation of HPC Pratyush.*

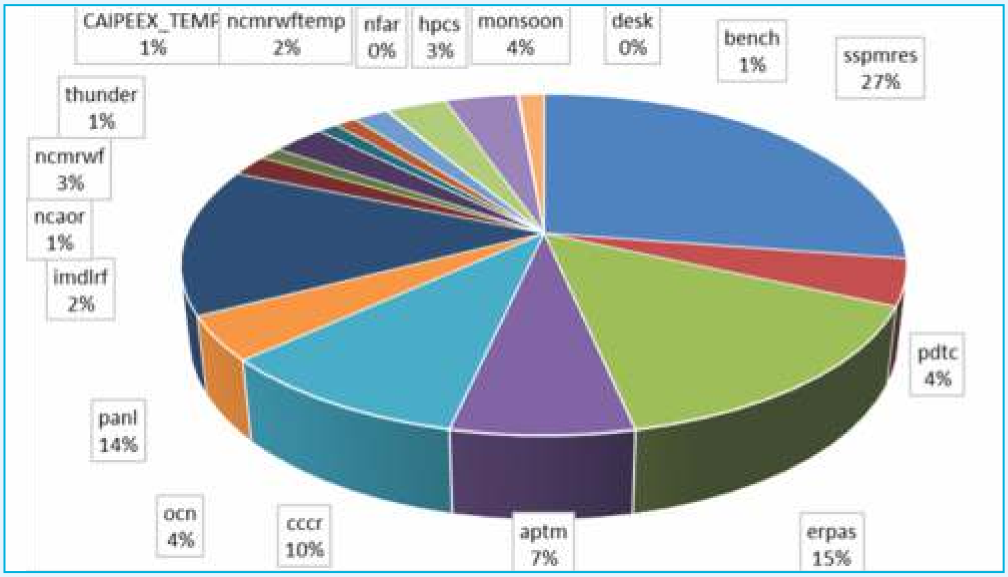


Fig. 2.2: *Space utilisation of HPC Pratyush (Percentage utilisation out of allocated).*

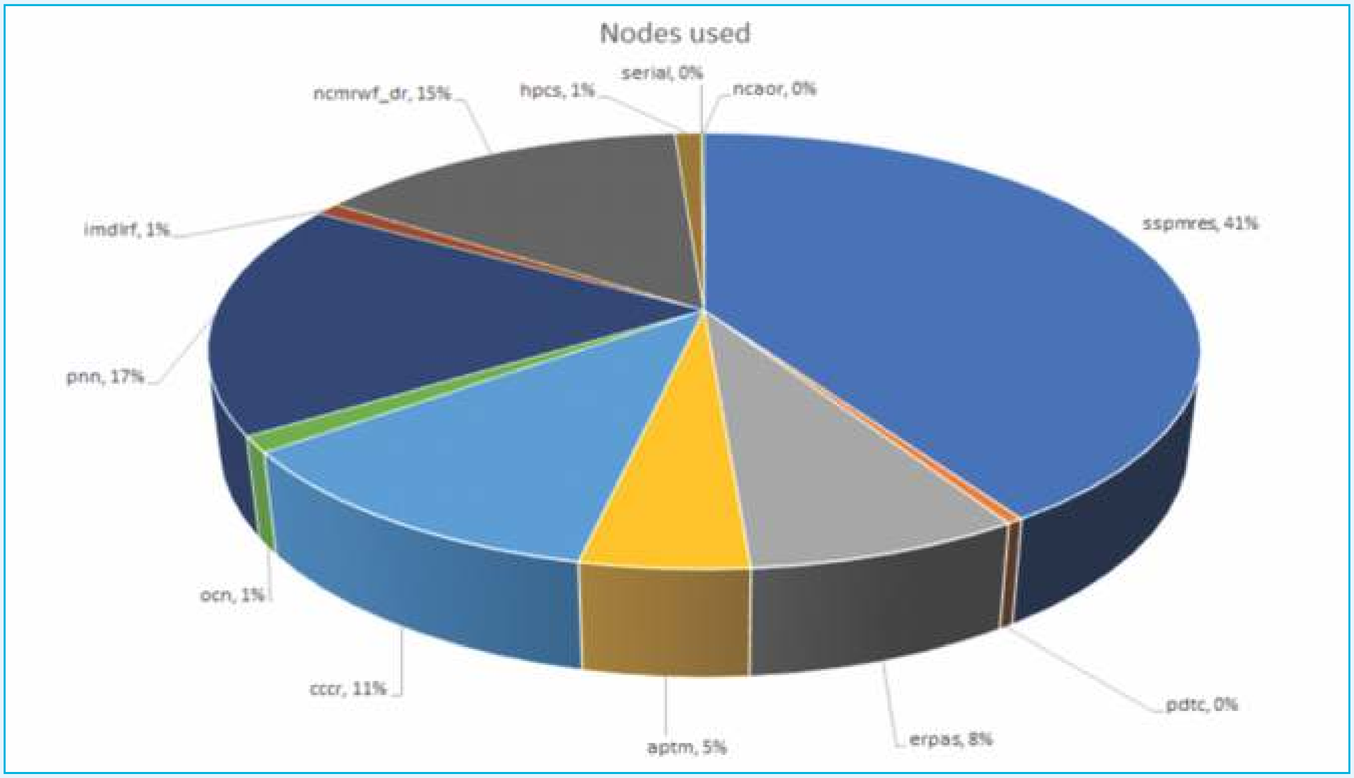


Fig. 2.3: *Group-wise utilisation of HPC Pratyush (Percentage utilisation of total system utilisation).*

Table 2.2: Details of the average utilisation for various queues on HPC Pratyush during 2021-22. The highlighted columns represent the utilisation of queues used by researchers outside of IITM under MoES.

	sspmres	pdtc	erpas	aptm	cccr	ocn	pnn	imdlrf	ncmrwf_dr	hpcs	sspmoper	serial	ncaor
Month													
Apr-21	10.79	0.07	6.78	65.55	8.56	10.11	7.95	0.37	35.79	0.59	9.46	0.31	5.08
May-21	10.14	3.35	7.95	197.62	2.51	0	27.51	4.62	2.92	0.04	34.86	0.59	0.19
Jun-21	30.32	0.1	4.27	43.79	68.12	0	22.45	0.15	2.14	18.42	13.19	0.63	0.18
Jul-21	166.36	0	5.77	116.82	15.29	1.63	30.66	0.05	20.76	2.03	1.69	0.17	0.06
Aug-21	5.69	0.39	18.72	141.39	9.29	0	9.14	0	25.7	0.18	20.23	0.01	0.25
Sep-21	62.15	11.02	0.96	27.36	2.54	3.77	44.17	5.26	17.81	0.96	39.16	0.01	1.92
Oct-21	7.62	0	0.02	30.09	3.32	24.6	27.01	9.5	8.46	11.93	17.83	0.22	1.41
Nov-21	9.02	6.38	0	23.41	1.88	5.52	10.48	10.7	0.56	0.05	23.11	0.17	2.77
Dec-21	9.09	9.68	0.01	37.93	2.02	1.19	21.77	13.76	15.68	0.02	15.77	0	1.48
Jan-22	20	0.93	0.24	29.57	4.24	0.26	7.61	12.33	17.32	0.76	30.23	0.01	1.22
Feb-22	7.62	0	0.02	30.09	3.32	24.6	27.01	9.5	8.46	11.93	17.83	0.22	1.41
Mar-22	112.34	47.48	51.86	232.30	102.42	9.47	119.74	136.81	57.57	14.39	51.64	0.10	0.55

Maintenance and general activities: The system was available most of the time. The following updates were made to the system:

- Updated CDT 17.03 Installed.
- Apollo-6500 Firmware Update with Latest SPP-2021.04.1.
- Apollo-6500 iLO-5 Firmware Update from 2.10 to 2.42.
- Docker and Kubernetes Installed on Apollo-6500.
- Prometheus Dashboard configured on Apollo-6500.
- Grafana Dashboard configured on Apollo-6500.
- Ganglia Dashboard configured on Apollo-6500.
- NVIDIA CUDA compiler update from 11.0 to 11.4.
- A common Jupyter-notebook deployed on Apollo-6500.

HPC Aaditya

Applications Software: The software stack is designed to be extremely flexible, keeping in mind the requirements of end-users from various backgrounds. High-end post-processing and visualisation servers are made available to end-users. Based on user requirements, the application models/tools/libraries have been updated/newly installed during the last year.

Storage, System Software and other hardware: The total disk storage of the system is 16 Peta Bytes (PB). Apart from this, 10 PB storage is available in tape archival. Each group's storage and compute quotas have been designed and assigned based on the MoES HPC committee's recommendations. Storage has been designed to be secure yet flexible so that the data can be shared freely among research and operational groups. Being an operational and research HPC, compute queues have been designed such that the operational jobs will get the highest and immediate priority while research jobs will also get their fair share.

User Support: During 2021-22, 774 system issues were reported, and all were solved, while 95 application issues were reported, out of which 94 issues were solved. User support is made available through email and a web-based system for a one-stop solution. Most user issues are dealt with within an acceptable time frame and symbiotic cooperation from the support team and end-users.

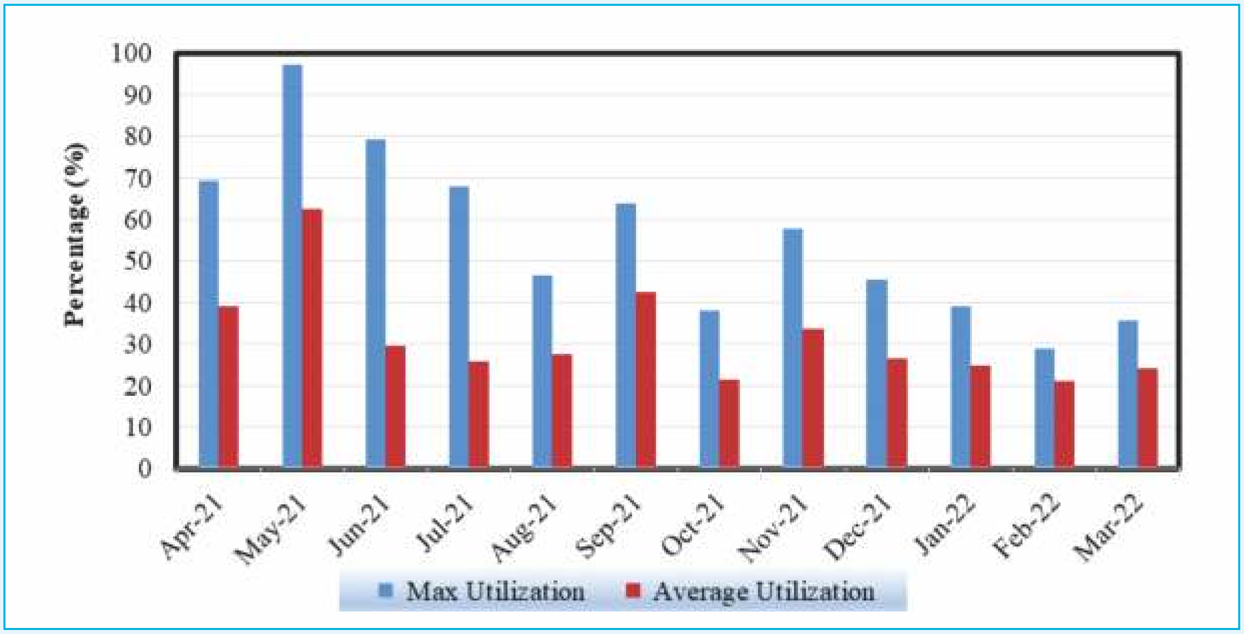


***Fig. 2.4:** HPC Aaditya node utilisation.*

Support is also available over the phone in urgent and extreme cases, even on non-working days and national holidays.

Remote support during lockdown time: During the pandemic period, the Aaditya Support Team provided extended remote support for the daily user's issues and activities. Simultaneously, a few engineers from the team visited the site for physical monitoring and replacements of faulty parts with an approved government e-pass and followed WHO provided guidelines.

System Usage: Details of node utilisation for HPC Aditya, during 2021-22, are shown in **Fig. 2.4**. In recent times, the utilisation of HPC Aaditya has come down due to the users migrating their data/models to HPC Pratyush, as HPC Aaditya is expected to be augmented with a new system in 2022. An overview of the utilisation of HPC Aaditya during the last five years is presented in **Fig. 2.5**.

Performance and updates: For approximately 25 days, there was just one maintenance activity performed on the Tape Library (Accessor Issue). Aside from this, no substantial maintenance was required, which is a remarkable accomplishment for such a large cluster of computers. All of the newly installed models are up and running without a glitch. The institution-wise monthly utilisation reports are kept online, and access has been given to the respective institutes.

Table 2.3: Details of the average utilisation reserved for outside MoES institutes during 2021-22 on HPC

Monthly Average Node Utilisation in %			
Month	**Monsoon**	**External**	**IIST**
April	8.0682171	0.9422695	2.63072
May	7.8880952	0.8476633	0.993406452
June	6.6268353	0.4654588	1.1385
July	4.255814	0.9567763	3.174096774
August	3.9836566	0.9613146	0.668322581
September	4.426412	0.2573348	1.02764
October	5.6267817	0.7072854	2.679387097
November	5.6267817	0.12422	2.794
December	3.6734541	0.207812	2.125954839
January	5.4817276	0.0559226	1.717122581
February	3.4981609	0.0515994	2.95275
March	8.5554603	0.0673768	1.067941935

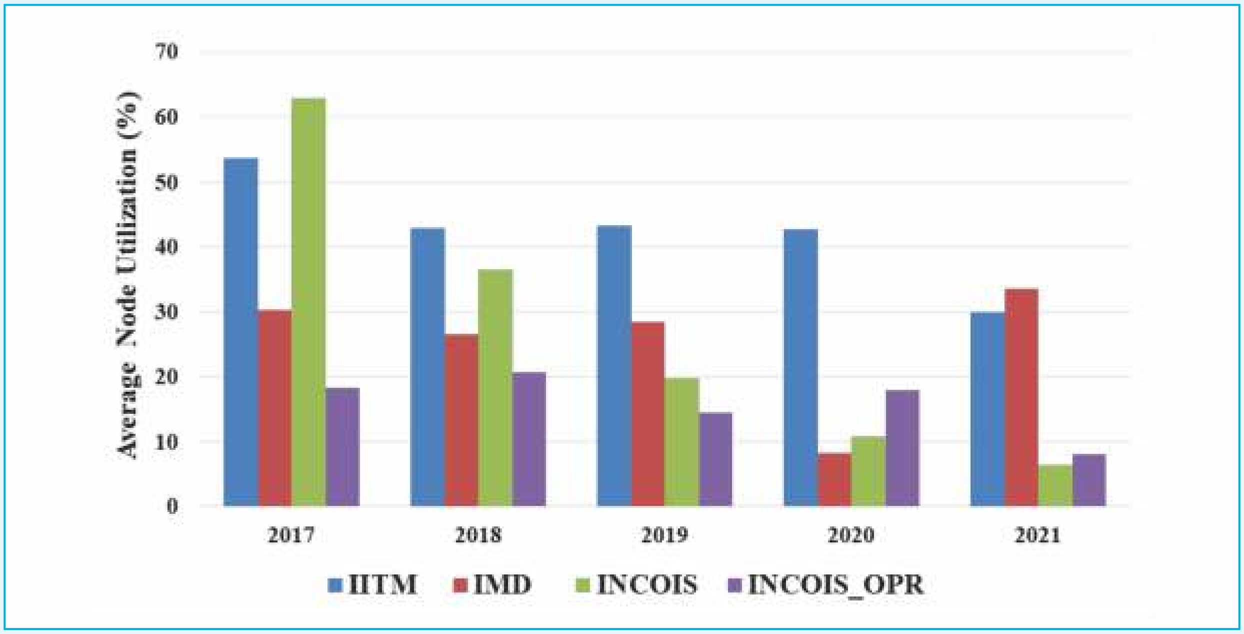


***Fig. 2.5:** HPC Aaditya node utilisation during the last 5 years.*

Aaditya.

Research and Development

Development AI/ML models: Efforts are on to develop AI/ML models applicable to weather forecasting as statistical data downscaling. Few master's students and IITM scientists are involved in this work. Forecasting lightning strikes is one such project. Observational data from IITM is being used in this study. The ConvLSTM method shows promising preliminary results. The forecast produced by this approach is proven to be significantly more accurate than the forecast produced by the dynamical model (see **Fig. 2.6**).

Small-scale simulation for cloud turbulence: This project is related to conducting Direct Numerical simulations (DNS) to investigate the cloud and aerosol dynamics at the smallest scale of turbulence. The current project aims to investigate aerosol activation in various meteorological conditions, including aerosol types and sizes and updraft velocity. Under this project, the following simulations were run:

- CCN Activation: Single Salt
- CCN Activation: Mixed organic-inorganic particles and
- CCN activation: Impact of vertical velocity

The activation of CCN and subsequent evolution of wet radii are shown in **Fig. 2.7**. At 90 m, both pristine and polluted cases look similar regarding CCN size alignment. Unactivated CCN are present at both ends. Droplets grow larger in the pristine case activating almost all the bigger CCN at 200 m. In polluted conditions, the growth rate is reduced since the competition for condensable moisture is high; consequently, unactivated aerosols are

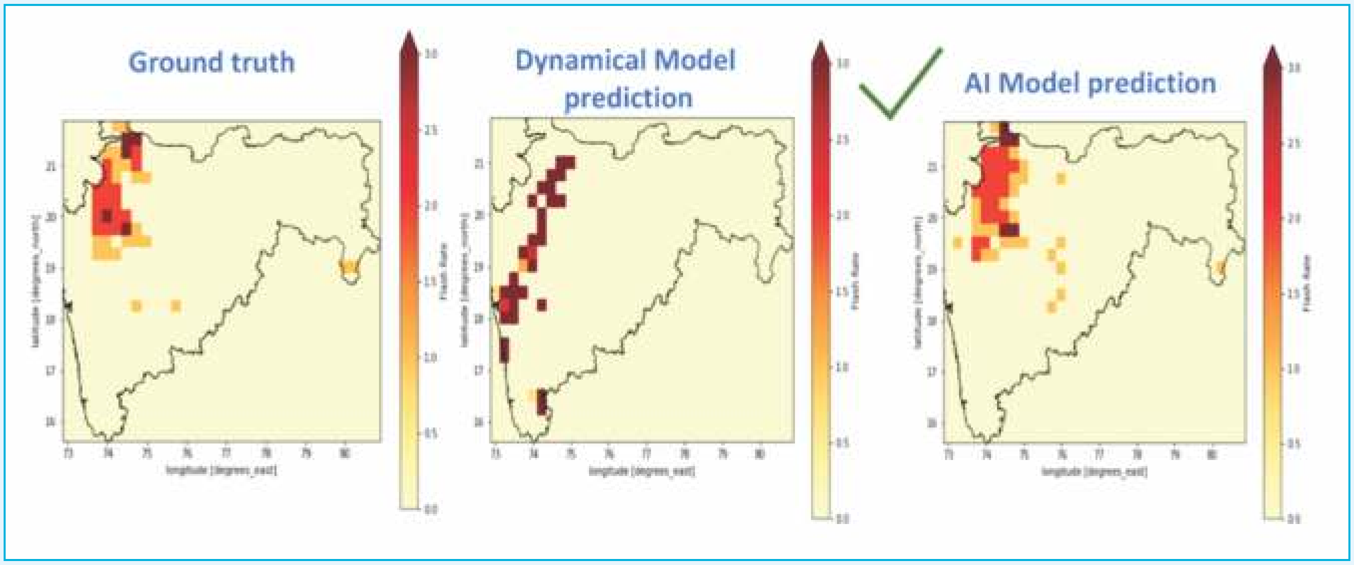


Fig. 2.6: *Comparison of lightning forecasting with ground and prediction obtained from Dynamical and AI models. The prediction by the AI model (ConvLSTM method) is significantly better than the same from a dynamical model. The model still needs some improvement to get better results.*

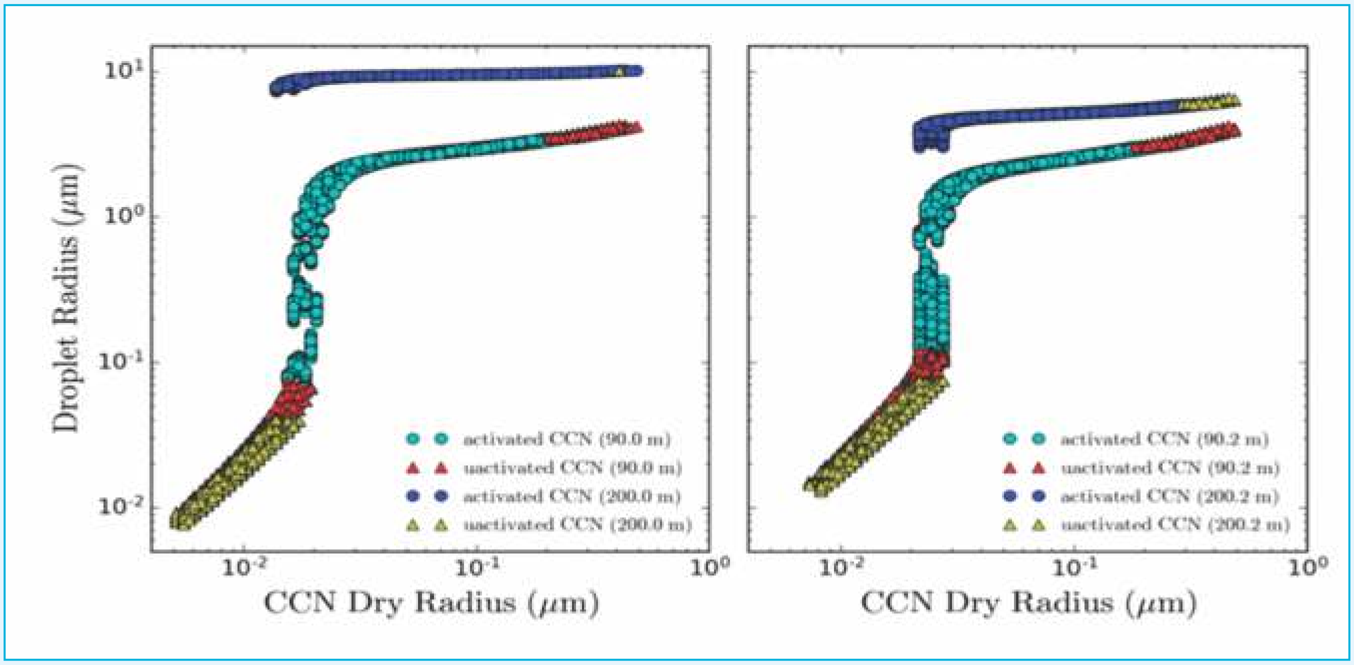


Fig. 2.7: *CCN dry size vs evolving wet radius at two heights, 90 m and 200 m, in the pristine case (left panel) and the polluted case (right panel).*

3. Human Resource Development and Capacity Building

IITM is actively involved in human resource development and capacity building in weather and climate sciences. The institute collaborates with several universities and other degree awarding institutions to run collaborative academic courses, including M.Sc., M.Tech. and PhD degrees. IITM also organises short-term training programmes on advanced topics related to atmospheric sciences and meteorology, covering climate change and projections, monsoon prediction and variability, modelling, observations, etc. Such activities executed by IITM are grouped into the following two sub-chapters:

3.1. Development of Skilled Manpower in Earth System Sciences and Climate (DESK)
3.2. Academic Cell

3.1. Development of Skilled Manpower in Earth System Sciences and Climate (DESK)

Project Director : Dr. V. Valsala

Objectives

DESK is a major training project under the REACHOUT programme of the MoES with the 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 organise 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 organisations in the country.

MoES Research Fellowship Programme (MRFP)

DESK has successfully implemented the MoES Research Fellowship Programme (MRFP). The second batch of 11 JRFs was recruited in the year 2021.

Due to the COVID-19 outbreak, a nationwide advertisement process, written examination, and interviews were conducted online. The *ab-initio* online training of the selected JRFs for four months is being conducted by DESK with the following subjects :

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

A total of 11 students have joined respective institutes directly and are currently doing their coursework online.

Institutes at which MRFP JRFs are recruited to:	Number of JRFs
INCOIS	1
NCCR	1
NCPOR	0*
NIOT	0*
NCMRWF	3
CMLRE	1
NCESS	0*
NCS	1
BGRL	1
IMD- Pune	2
IMD- New Delhi	1

* These institutes didn't give nominations this year for MRFP fellows.

DESK also coordinates with the guides and fellows of 10 MoES institutes and submits timely attendance reports to IITM Administration and Accounts officials to release the stipend for both the batches of MRFP fellows.

MoES webinars and short-term training programmes organised

- Complex diseases: Yoga unravelling the pharmacy within on International Yoga Day by Dr. Rima Dada, AIIMS, New Delhi, 21 June 2021.
- Marine Litter under the Swachhata Pakhawada Abhiyaan of MoES by Dr. Pravakar Mishra, NCCR, Chennai, 06 July 2021.
- Understanding dynamics and thermodynamics of the North Indian Ocean: Major strides since independence and challenges ahead by Dr. Satish R Shetye, former Director of NIO, Goa, and former VC of Goa University, Goa, 16 August 2021.
- Advanced seismic tools for imaging and interpretation of subsurface features from surface data: Application to Indian Provinces by Dr. Kalachand Sain, Wadia Institute of Himalayan Geology, Dehradun, 07 September 2021.
- Climate change and monsoon projections: Challenges and opportunities by Dr. R. Krishnan, Scientist-G, Executive Director, CCCR, IITM, Pune, 01 October 2021.
- National (Training) Workshop on Greenhouse Gases (GHG-3): Observations and Inverse Modelling on Indian Regional Perspective (Virtual Workshop), 14-17 December 2021.
- **Cloud and Precipitation Physics and Dynamics Lecture Series:** Details are provided in chapter 13 on Seminars.

Basic Research

Is Amundsen-Bellingshausen Seas-Low affecting trace gas air-sea fluxes in the Antarctic Ocean?

Observations of chlorofluorocarbon in the Antarctic Ocean and a concomitant analysis of its life history for the past 80 years reveal that the recently identified Amundsen-Bellingshausen Seas Low (ABSL) persuaded the invasion of chlorofluorocarbon in the Antarctic/Southern Ocean sectors. Two distinct roles of ABSL in trace gas fluxes in the Antarctic Ocean are identified: (a) ABSL helps to localise the prominent invasion zones of trace gases in the Antarctic sector to specific areas over the Amundsen-Bellingshausen Seas, and (b) it modulates the 'grip' of southern annular mode in trace gas fluxes of the Antarctic Ocean. The ABSL region is a gateway to ~25% of southern hemispheric chlorofluorocarbon invading the ocean. These findings have implications on trace gas fluxes and their Antarctic sector changes under present and future climate. [***Valsala V.***, *Is Amundsen-Bellingshausen Seas-Low affecting trace gas air-sea fluxes in the Antarctic Ocean?* ***Deep Sea Research-I***, *Online, February 2022, doi:10.1016/j.dsr.2022.103725*]

Observed denitrification in the northeast Arabian Sea during the winter-spring transition of 2009

The central and northeast Arabian Sea (AS) has an intense and thick oxygen minimum zone (OMZ) and denitrification zone. It is comparable with the strongest OMZ of the north-equatorial Pacific Ocean. Denitrification in the AS is revisited using a set of cruise observations collected during February-March 2009 by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi. The region possesses one of the most robust N* depleted water reaching as low as -20 μmol l^{-1} at depths (~600 m). In AS, oxygen depletion is mainly due to sluggish circulation and weak lateral and vertical ventilation. The biological respiration in oxygen deficit conditions depletes nitrate and further modifies the Redfield ratio at intermediate depths (200-600 m) from 16N:1P to 8N:1P. Further analysis of phytoplankton groups present at the surface identifies the presence of Trichodesmium erythraeum, a nitrogen-fixing species. The denitrification rate is estimated as 25.3 ± 7.0 Tg N yr^{-1}. It is consistent with past estimates, and no dramatic change in denitrification in the AS was noticed. These findings highlight the potential for further research on N_2 production from the Arabian Sea Oxygen Minimum Zones in a changing climate. [***Anju M., Valsala V.***, *B.R. Smitha, Bharathi G., Naidu C.V., Observed denitrification in the northeast Arabian Sea during the winter-spring transition of 2009,* ***Journal of Marine Systems***, *227: 103680, March 2022, DOI:10.1016/j.jmarsys.2021.103680*]

3.2. Academic Cell

Coordinator : Dr. V. Valsala

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 encouraging IITM scientists to opt for higher studies.
- **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. Six (08) students were admitted to this programme for the academic session 2021-23. The 1st-semester classes were started on 05 October 2021 at DASS, SPPU. The 2nd year students (12) of the M.Tech. 2020-22 batch are doing their project work at IITM and DASS, SPPU.

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, 15 students were admitted for the academic session 2021-23. The M.Sc. second-year students (08) of the batch 2020-22 are doing their project work at IITM and DASS, SPPU.

PhD Degree Awarded during 2021-22:

S. No.	Student	Guide	Co-guide	Name of University	Thesis Title
1.	Mr. Anil Kumar V.	Dr. G. Pandithurai	Prof. Prasad D.S.V.V.D.	Andhra University	On the Influence of Atmospheric Aerosols in Ice Nuclei Characteristics and its Parameterization
2.	Mr. Dipjyoti Mudiar	Dr. S.D. Pawar (External Supervisor), Dr. Anupam Hazra and Dr. D.M. Lal (External Co-Supervisors)	Dr. M.K. Srivastava, BHU, Varanasi (Internal Supervisor)	BHU	Effects of Electric Forces on Rain Formation Processes in Tropical Clouds
3.	Ms. Jyoti A. Jadhav	Dr. Panickal Swapna	Dr. R. Krishnan and Dr. C.V. Naidu	Andhra University	Multi- Decadal Sea-Level Variability in the Indian Ocean and its Possible Driving Mechanism in a Changing Climate

S. No.	Student	Guide	Co-guide	Name of University	Thesis Title
4.	Mr. Pramit Kumar Deb Burman	Dr. S. Chakraborty	Prof. Ananda K. Karipot	SPPU	Carbon Sequestration Studies in Forest Ecosystems Using Tower- Based Observations and GPP- NEE Modelling
5.	Mr. Sandeep Mahapatra	Dr. C. Gnanaseelan	-	SPPU	Understanding the decadal variability of the Indian Ocean from observations and model
6.	Ms. Manpreet Kaur	Dr. Susmitha Joseph	Dr. A.K. Sahai	SPPU	Development for a framework for Improved Extended Range Prediction of Extreme Weather Events
7.	Mr. Kumar Roy	Dr. P. Mukhopadhyay (Internal Guide)	Prof. S.S.V.S. Ramakrishna, A.U. (External Guide)	Andhra University	Observational and modelling studies of cloud and convective processes with emphasis to low- level clouds and its microphysical impact on precipitation

PhD Thesis Submitted during 2021-22:

S. No.	*Student*	*Guide*	*Co-guide*	*Name of University*	*Thesis Title*
1.	Mr. Somaru Ram	Dr. M. K. Srivastava (Internal Guide)	Dr. H. N. Singh and Dr. Ramesh Kumar Yadav (External Guide)	BHU	Climate Change and Climate Variability Studies Based on Tree Ring Records of Himalayan Region
2.	Mrs. Anju M.	Dr. Vinu Valsala (Internal Guide, IITM)	Prof . G. Bharathi (External Guide, AU) and Prof. C.V. Naidu (External Co-Guide, AU)	Andhra University	Development and implementation of a multi- component ecosystem model with linkage between lower and upper trophic levels for the North Indian Ocean and its applications

S. No.	Student	Guide	Co-guide	Name of University	Thesis Title
3.	Mrs. Vrinda Anand	Dr. G. Beig	Dr. A. Panicker	SPPU	The variability of air pollutants in various micro-environments of Pune under SAFAR
4.	Mr. Sandeep K.	Dr. A. Panicker	-	SPPU	Understanding the variability and radiative impact of aerosols over Himalayan region
5.	Mrs. Dipti Hingmire	Dr. Ramesh Vellore	-	SPPU	Large-scale dynamical controls relevant to wintertime widespread fog over the Indo-Gangetic Plains
6.	Mr. Nikhil Korhale	Dr. G. Beig	-	SPPU	Impact of Coastal Meteorology and Emission Sources in the Distribution of Air Pollutants over Mumbai Region under SAFAR
7.	Mr. Soumya Samanta	Dr. Thara V. Prabhakaran (Internal Guide, IITM)	Prof. P. Suneetha, AU (External Guide, AU)	Andhra University	Unravelling the lifecycle of organized convective systems and associated aerosol-cloud-precipitation interaction
8.	Mr. Santanu Halder	Dr. Yogesh Tiwari	Dr. Vinu Valsala	SPPU	Investigating long-lived Greenhouse Gas fluxes using forward & inverse modelling and concentration observations over India
9.	Mrs. Sneha Sunil	Dr. Padmakumari (Internal Guide, IITM)	Dr. C.V. Naidu (External Guide, AU)	Andhra University	Study of Cloud properties and their Radiative effects: Implications to climate system
10.	Mr. Panini Dasgupta	Dr. Roxy Mathew Koll (Internal Guide, IITM)	Prof. C.V. Naidu (External Guide, AU)	Andhra University	Madden Julian Oscillation in a Changing Climate
11.	Ms. Shikha Singh	Prof. Sridhar Balasubramanian Internal Co-Supervisor. Prof Subimal Ghosh (IIT Mumbai)	Dr. Vinu Valsala	IIT Bombay	A modelling study of upper ocean processes, mixing dynamics and deep ocean biases in tropical Indian Ocean

Research guidance to students for project work

IITM is committed to offering its expertise in Weather and Climate Sciences and extending 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 undergraduate (UG) and post-graduate (PG) students for their internship/coursework. During the year 2021-22, 157 students of different UG/PG courses in science and engineering from various colleges, universities and institutions across the country have completed or are working on their short-term project/internship under the guidance of IITM scientists through remote/online or on-campus mode.

4. Important Events and Activities

Important Events

Vaccination Drives: IITM, Pune, in association with Pune Municipal Corporation (PMC)/ Aundh Institute of Medical Sciences (AiMS), Pune, conducted several vaccination drives for its employees at the IITM campus on 28 May 2021, 25 June 2021, 28 July 2021 and 21 August 2021.

Awareness Workshop on Lightning and Thunderstorms: As an initiative to bridge the communication gap between the public and disaster management authorities, the Indian Meteorological Society (IMS), along with IMD, IITM, NCMRWF and NDMA, organised a workshop/ brainstorming session for the media and disaster managers from West Bengal, Odisha, Kerala, Maharashtra, Bihar and Uttar Pradesh for lightning forecast, warning dissemination, dos and don'ts on 28 June 2021.

An online workshop on '**Meteorological Forecast for Wind and Solar Energy Generation: Current Status and Future Perspective**' was jointly organised by IITM, MoES, IMD and NCMRWF on 14 July 2021. The workshop was conducted under the Chairmanship of Secretary, MoES, in the presence of Director, IITM, Director General, IMD and Head, NCMWRF. Based on the feedback received from stakeholders, a draft recommendation document was prepared and submitted to MoES.

10th International Cloud Modelling Workshop (ICMW): 10th International Cloud Modelling Workshop (ICMW) was held online during 26-30 July 2021. Such cloud modelling workshops are traditionally conducted in association with the International Conferences on Clouds and Precipitation (ICCP) to discuss cloud case studies. The workshop was open to all the ICCP/ICMW registered participants and interested researchers for free. The workshop was attended by over 120 participants from around the world. For the first time, a CAIPEEX cloud modelling case was presented in the ICMW.

Training in Marathi Language: Under the Seven Point Charter for promoting regional languages, MoES has asked all its institutes to make necessary arrangements for training their employees in the respective regional language of the region where the institute is located. Accordingly, classes for training IITM employees in the regional language Marathi have been arranged since 27 July 2021.

S2S Forecast and its Applications in South Asia: WMO S2S Working Group and the International CLIVAR Monsoon Project Office (ICMPO), with the active support from IITM, organised a one-day webinar on "S2S forecast and its applications in South Asia" on 28 July 2021. The webinar included talks by leading scientists and users at the forefront of S2S prediction and application areas.

18th International Conference on Clouds and Precipitation (ICCP-2021): For the first time in India, ICCP-2021 was organised by the International Commission on Clouds and Precipitation (ICCP) and hosted in virtual mode by IITM during 2-6 August 2021. The conference hosted 639 authors contributing to the conference from 32 countries. There were 81 students. Over 27% of participants were from India. There were over 200 oral presentations in 40 sessions of the conference. Over 400 posters were presented in the interactive mode. There were three monsoon sessions and a dedicated poster session on monsoon clouds and precipitation. Research and advances from basic studies to more applied fields such as weather modification and extreme rainfall were discussed at the conference. Several legendary scientists from the cloud physics community attended this unique conference organised for the first time in Asia. The opportunity and exposure received by students and early career scientists will spark new research advances. Panel discussions were conducted on specific topics such as cloud physics observations, numerical model improvements, diversity and women in cloud physics, and the future and needs of laboratory studies.

ICCP Short Course on Radar was conducted on 7 August 2021 by IITM in association with ICCP-2021 to introduce the principles of Doppler and polarimetric radar and its application to observing cloud microphysical processes. The instructors for this course were Prof. V. Chandrasekar, Colorado State University, USA, and Dr. Renzo Bechini, Radar Scientist, Regional Meteorological Service, Italy. The course was attended by about 160 participants from around the world.

IPCC AR6 WG1 Press Conference: Embargoed media briefing event was held jointly by IPCC, IITM and MoES during 8-9 August 2021. In the press conference held on 9 August 2021, the IPCC AR6 WG1 report titled 'Climate Change 2021: the Physical Science Basis' was released. Dr. R. Krishnan and Dr. P. Swapna also addressed the media, which was streamed live through the IPCC YouTube channel and IPCC Facebook page. They also addressed the media regarding IITM's contributions towards the IPCC Report in an IITM press meet organised jointly by IITM and MoES on 9 August 2021.

Fit India Freedom Run 2.0: IITM participated in the fitness campaign on 13 August 2021, organised by the Ministry of Youth Affairs and Sports (Govt. of India). The campaign was aimed at spreading awareness about the importance of physical activity for healthy life and to pledge at least 30 minutes of daily physical activity for our own fitness.

Iconic Week Celebrations: Under the guidelines of MoEF&CC, IITM-ENVIS celebrated the Iconic Week on the theme 'Atmospheric Chemistry and Climate Change' during 4-10 October 2021. A 2-day online workshop on 'Science of Air Pollution Monitoring and Measurement' was arranged specifically for the skill development of teachers and educational professionals during 6-7 October 2021. The workshop was attended by 138 teachers and educational professionals. Along with technical sessions, various competitions were also arranged for participants. An action-based awareness programme for avoiding the use of single-use plastics was arranged. It consisted of an online open webinar by Mr. Amogh from SWaCH, Pune on 8 October 2021, and a waste collection campaign at the IITM official and residential complex with the help of SWaCh, Pune. The collected plastic waste was sent for recycling.

Decision Support System (DSS): IITM has developed a new Decision Support System (DSS) and extended the ability of the existing air quality early warning system (AQWES) to have decision-making capability for air quality management in the Delhi NCR region. The website for DSS was officially launched by the Hon'ble Minister of MoES Dr. Jitendra Singh on 18 October 2021 in MoES HQ during the Iconic Week 18-24 October 2021, part of *Azadi ka Amrit Mahotsav* celebrations. The website (https://ews.tropmet.res.in/dss/) is designed to deliver quantitative information about a) the contribution of emissions from Delhi and the surrounding 19 districts to the air quality in Delhi; b) the contribution of emissions from 8 different sectors in Delhi to the air quality in Delhi; c) the contribution from biomass-burning activities in the neighbouring states to the degradation of air quality in Delhi; and d) the possible quantitative effects of emission source-level interventions on the forecast air quality event in Delhi.

Inauguration of Multi-utility Building: The recently constructed multi-utility building (Riturang) at IITM, Pune was inaugurated by Dr. M. Ravichandran, Secretary MoES on 28 October 2021.

COSMOS Internship Programme: IITM-COSMOS team interacted with Dr. P.K. Rajani, Associate Professor and six internship students from Pimpri Chinchwad College of Engineering, Pune at the IITM-COSMOS site on 28 October 2021. This internship programme is dedicated to capacity building of faculty and students from techno-scientific fields to develop a wireless sensor network for field-scale soil moisture measurements across the core monsoon zone of central India. The COSMOS team (4 members) also visited Pimpri Chinchwad College of Engineering (PCCOEngg), Pune, for techno-scientific interactions on

26 November 2021. At this event, Dr. Milind Mujmdar, who is leading COSMOS at IITM, made a brief presentation on 'Importance of field-scale hydro-meteorological measurements across core monsoon zone in India.' Project and learning experience of faculty and students relevant to the internship programme at CCCR-IITM in e-Yantra Lab (Embedded System Lab) of PCCOEngg were also demonstrated.

IITM Directorship: Consequent to Prof. Ravi S. Nanjundiah completing his tenure as Director ITM on 31 October 2021, Dr. R. Krishnan, Scientist-G and Executive Director of CCCR at IITM, has been appointed as Acting Director w.e.f. 1 November 2021.

Virtual Lecture Series on Cloud and Precipitation Physics and Dynamics: IITM organised a virtual lecture series with a goal to enhance knowledge through instructions and discussions on cloud and precipitation physics and dynamics once in two weeks during October 2021 to March 2022. The lecture series aimed to understand cloud and precipitation processes through state-of-the-art approaches to observe, simulate, and identify key uncertainties associated with aerosol-cloud-precipitation interactions. Eminent cloud physicists from around the globe gave lectures on various topics ranging from basic cloud physics to advanced topics such as new instruments and technological advances, and model development. These lectures were also cited and streamed by IAMAS/ICCP. These lectures were conducted by DESK at IITM. Details of these lectures are given in chapter 13 on Seminars.

Tribute to Professor Syukuro Manabe: IITM, Pune and IISER, Pune jointly organised a seminar on 'Tribute to Professor Syukuro Manabe' by Dr. R. Krishnan, Scientist-G and Acting Director, IITM, Pune, to celebrate the Nobel Laureate Prof. Syukuro Manabe's ground-breaking contributions to climate science on 11 November 2021. Dr. Argha Banerjee and Dr. Joy Monteiro from IISER, Pune, and Dr. P. Mukhopadhyay and Dr. M. Mujumdar from IITM also participated in the online event. Mr. Abhay SD Rajput, IITM moderated the session. (Link: https://youtu.be/kLAIrLZ3J30).

IITM Foundation Day Celebrations: IITM celebrated its 60th Foundation Day on 17 November 2021. Keeping in view COVID-19 pandemic situation and austerity measures, it was celebrated virtually. On this occasion, Prof. V.K. Dadhwal, Former Director, Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram, was the Chief Guest and Prof. V. Ramaswamy, Director, Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, USA was the Guest of Honour. The celebrations included the presentation of various awards and Prof. D.R. Sikka Best Student Award lecture.

- Dr. R. Krishnan, Director-in-Charge, IITM, gave welcome remarks and briefed about the Institute's achievements and activities during 2021.
- Dr. M. Ravichandran, Secretary, MoES delivered the opening address.
- Prof. V. Ramaswamy delivered the special IITM Foundation Day Lecture on 'The Physics Nobel, IPCC 6th Assessment, and Unequivocal Anthropogenic Climate Change: What are the next Frontiers in Climate Science?'
- Best Employee Award 2020 (Scientific/ Technical Support Staff Category) to Mrs. Swati Athale, Scientific Officer Grade-II.
- Best Employee Award 2020 (Administrative Staff Category) to Mrs. Bhavana Naik, Senior Executive.
- Prof. D.R. Sikka Best Student Award for the year 2020 to Mr. Ushnanshu Dutta and Mr. Panini Dasgupta for their respective papers: "Role of convective and microphysical processes on the simulation of monsoon intraseasonal oscillation" by Dutta U., Chaudhari H.S., Hazra A., Pokhrel S., Saha Subodh Kumar, Veeranjaneyulu C. published in the Climate Dynamics, 55, November 2020, DOI:10.1007/s00382-020-05387-z, 2377–2403; and "Exploring the long-term changes in the Madden Julian Oscillation using machine learning" by Dasgupta P., Metya

A., Naidu C.V., Singh M., Roxy M.K. published in the Scientific Reports, 10: 18567, October 2020, DOI:10.1038/s41598-020-75508-5, 1-13.

- Hindi Rajbhasha Puraskar for the year 2021 to Mr. B.B. Singh, Scientist-D; Mrs. Sunita Kharbanda, Assistant Manager; Mr. Safi Sayyed, Senior Executive; and Mr. Sachin Gaikwad, Senior Executive.
- Outstanding Performance Award for the year 2021 to Mr. Padmakar Domutwar (Assistant Engineer, Audio Video), Mr. Suresh Nivalakar (Office Boy) and Mr. Krishna Gote (Housekeeping Staff).

Free Eye Health Check-up Camp at IITM: A free eye health check-up camp was organised on 15 and 18 November 2021 for all IITM employees and their families. The advanced testing facility was provided by the ASG Eye Hospital (CGHS accredited), Pune. More than 300 people (staff and their family members) benefited from this camp.

IISF-2021 Outreach Event at IITM: The Government of India, in collaboration with Vijnana Bharati (VIBHA), organised the India International Science Festival (IISF) 2021 under the theme 'Celebrating Creativity in Science, Technology and Innovation for Prosperous India' at NCPOR, Goa during 10-13 December 2021. IITM organised an online outreach programme on 29 November 2021 to highlight and showcase Institute's R&D achievements and scientific activities for the larger societal benefit. The outreach programme consisted of two components: an inaugural (popular) session and a technical session. The event was inaugurated by the Chief Guest, Prof. Vijay P. Bhatkar, President, VIBHA and Chancellor, Nalanda University. Dr. R. Krishnan, Acting Director, IITM, delivered the welcome address. Dr. Milind Mujumdar, a scientist at IITM, delivered a popular science talk on 'Importance of soil moisture in weather and climate (in Marathi). The brainstorming technical session on 'Soil moisture monitoring in India: Challenges and opportunities' was arranged, where select experts discussed the possibilities of expanding soil moisture observations in the country.

International Workshop on Fires in South Asia: Current Status and Future Challenges in Modeling, Predictions and Mitigation was organised online by iLEAPS, C-DAC and IITM during 3-4 December 2021. The purpose of the workshop was to provide a forum to discuss the current status and future challenges in modelling predictions and mitigation of fire emissions and to strengthen collaborations between different international and national groups.

Internship/Field Work at the COSMOS-IITM site was conducted under Azadi Ka Amrit Mahotsav from 11-13 December 2021. Students from Pimpri Chinchwad College of Engineering (PCCoE), Pune did their internship on wireless soil moisture and temperature sensors at the COSMOS-IITM site under the guidance of CCCR-IITM scientists. Dr. R. Krishnan, Acting Director, IITM, also interacted with the PCCoE faculty and students.

Development of AI/ML tools for weather/climate: MoES has approved the establishment of a Virtual Centre on Development of Artificial Intelligence (AI)/Machine Learning (ML)/Deep Learning (DL) at IITM Pune in order to expand the domain through multidisciplinary programmes in the field of earth system sciences. This virtual centre will coordinate with the units of MoES to identify problems that can be addressed with AI/ML tools and to further strategise and plan the development of such AI/ML based tools. This centre will also be responsible for conducting seminars, workshops and other capacity-building activities in the related areas.

International Women's Day Celebrations at IITM: IITM celebrated International Women's Day 2022 under the theme of 'gender equality today for a sustainable tomorrow' by organizing a series of webinars by women scientists:

- विज्ञान आणि तंत्रज्ञानात महिलांचे सक्षमीकरण (in Marathi) by Dr. Rashmi Kakatkar, Scientist-D, IITM, Pune, 4 March 2022.
- महिला सशक्तिकरण : सशक्त समाज (in Hindi) by Smt. Archana Rai, Scientist-D, IITM, Pune, 4 March 2022.

- Women in Science by Dr. Suvarna Fadnavis, Scientist-F, IITM, Pune, 7 March 2022.
- Women in Climate Science by Dr. Swapna Panickal, Scientist-E, IITM, Pune, 7 March 2022.
- Women scientists doing their job: How does it benefit the society? by Dr. Vineeta Bal, Visiting Professor, Indian Institute of Science Education and Research (IISER), Pune, 8 March 2021.
- Women's Day special address by Mrs. Indira Murthy, Joint Secretary, Ministry of Earth Sciences, Govt. of India, 8 March 2021.

Important Meetings/Events Held at/by IITM

- A review meeting was held on 24 April 2021 to discuss the progress of the NCAP-COALESCE project during the year 2020-21.
- CAIPEEX National Science Steering Committee meeting was conducted on 26 April 2021.
- 11th meeting of the Scientific Review and Monitoring Committee (SRMC) of Monsoon Mission (MM) Phase-II was conducted online on 18 May 2021 to review the progress of CRIDA/ICRISAT projects and other pending issues.
- To discuss the scope of approvals for IITM UAS operations for atmospheric research purpose at higher altitudes and approval of SOPs, an online meeting was conducted by Directorate General of Civil Aviation (DGCA)/Ministry of Civil Aviation (MoCA) with participation from the Airport Authority of India (AAI) in coordination with IITM on 23 June 2021.
- A meeting with Mr. Kunal Satyarthi, Joint Secretary, National Disaster Management Authority (NDMA) was held at IITM, Pune on 21 December 2021 to discuss activities related to lightning and thunderstorms, and possible collaboration of NDMA to develop a National Lightning Mitigation Programme (NLMP).
- To explore the possibilities for knowledge and data sharing with the Kerala Institute of Local Administration (KILA) for supporting climate resilient planning and local governance in Kerala, initial online interaction with KILA was held on 9 December 2021.
- 1st meeting of the Scientific Review and Monitoring Committee (SRMC) of Monsoon Mission (MM) Phase-III was conducted online on 19 January 2022.
- Site Acceptance Test (SAT) committee meeting was held on 17 March 2022 through video conference to review the status and performance of Wind Profiler Radars.
- A meeting with Mr. Kunal Satyarthi, Joint Secretary, National Disaster Management Authority was held at IITM, Pune on 21 December 2021 to discuss the activities related to lightning and thunderstorms and the collaboration of NDMA to develop the National Lightning Mitigation Programme (NLMP).

Observational Programmes/Field Campaigns

- The feasibility of civil works for radar installation at four locations in Mumbai was assessed on 15 September 2021.
- An observational campaign was conducted at HACPL, Mahabaleshwar to capture cloud and rainfall characteristics along with aerosol measurements for better understanding of aerosol-cloud-precipitation interactions.
- As a part of the Monsoon-2021 campaign, dual-polarimetric C-band Doppler weather radar was operated at the ART-CI facility to study cloud and precipitation processes in the core monsoon zone.
- Twilight photometry observations are being carried out at IITM, Pune during evening twilight to study aerosol vertical distribution in the UTLS region. Data processing and analysis are completed.
- In-house built portable sensor 'Mini Visible Sky Imager' for cloud detection is being operated at IITM, Pune for continuous measurements of real-time sky images.
- UAV field campaigns were conducted at two different airfields/locations in Maharashtra during 11-12 March 2022 and 15 March 2022.
- The Kaziranga Tower Site was visited several

times in May 2021 to monitor the eddy-covariance observational programme. A system has been implemented to carry out vertical profiling of CO_2 concentrations from the surface to about 35 m.

- IITM-COSMOS site was upgraded to facilitate the real-time monitoring of field scale soil moisture and surface fluxes. Soil moisture and soil temperature profile sensors were installed at the IITM-COSMOS site during 11-13 December 2021.
- Necessary fieldwork for observations of greenhouse gases concentration and isotopic properties in Bhopal was carried out during 1-10 December 2021.
- An observational campaign for 72 m tower installation at the institute's ART site in Bhopal was carried out during 15-18 February 2022.
- Calibration and installation of microwave radiometer at IITM, New Delhi, was carried out during 22-25 February 2022.
- Boundary layer observations were conducted at S.G. University, Kolhapur on 2 March 2022.
- Microwave radiometer observations were carried out at Cotton University, Guwahati during 9-12 March 2022.

Collaborative Programmes

- **MoU between IITM and Suzlon Energy Limited, Pune:** An MoU was signed by Prof. Ravi S. Nanjundiah, Director, IITM and Mr. Suresh Pillai, Vice President, Suzlon Energy Limited, Pune on 26 October 2021 for the potential collaboration in the field of mesoscale modelling in both forecast and hind-cast mode as well as in rain forecasting domain. The MoU is initially for a period of three years.
- **Collaboration with NRSC, Hyderabad:** Dr. B. Padmakumari is collaborating with ISRO's National Remote Sensing Centre (NRSC), Hyderabad on the project 'UV-radiation Monitoring Program for Climate, Health and Agricultural studies.' As a part of this project, UV radiation sensors of ISRO are installed at IITM, Pune for long-term measurements.
- **Collaboration with SAC, Ahmedabad:** Dr. B. Padmakumari carried out collaborative research work with ISRO's Space Applications Center (SAC), Ahmedabad on the subject 'the catastrophic widespread lightning due to Cloud-Aerosol interactions' using INSAT-3D retrieved cloud microphysical parameters and IITM lightning network data.
- IITM is working with the UK Met Office team on the UK Aid-funded Asia Regional Resilience to a Changing Climate (ARRCC) programme for a new Regional Forum on Climate Change Science and Services in South Asia. This forum would initially be supported through the ARRCC programme in partnership with other relevant initiatives, aiming to interface with other networks and forums in the region such as SASCOF and WCRP activities. In this regard, IITM representatives attended the first and second online meetings of the initial steering group on 25 January 2022 and 15 March 2022.
- CCCR-IITM will be collaborating with Integrated Research and Action for Development (IRADe), New Delhi to provide expertise and guidance needed for accessing and analysing the global (CMIP) and downscaled regional (CORDEX South Asia) climate model projections under their CRRP and CAPaBLE programmes.
- A National Aquifer Mapping and Management (NAQUIM) programme is being implemented by the Central Ground Water Board (CGWB). To discuss a CGWB's collaborative research proposal with IITM for studying the impact of climate change on ground water resources, an online meeting with CGWB officers was held on 22 March 2022.
- IITM and NBNSCoE, Solapur agreed mutually to continue the existing technical and academic cooperation and converted the existing tenure-based MoU into a perpetual MoU. Both institutes signed the perpetual MoU on 25 February 2022.
- Under an MoU signed between IITM, Pune and Cotton University, Guwahati, a Multi-Channel

Microwave Radiometer was installed at Cotton University, Guwahati on 7 April 2021. Vertical profiles of temperature and humidity obtained from this radiometer would help in understanding the thermodynamic conditions of the atmosphere during severe thunderstorms over Guwahati.

Science Popularisation Activities

- **Earth Day 2021** was celebrated on 22 April 2021 by the IITM-ENVIS centre. A webinar on 'Emerging Urban Air Quality Issues in India and Factors Responsible' was arranged, followed by an online quiz competition based on the webinar for school/college students in Maharashtra.
- **International Day for Biological Diversity 2021** was observed on 21 May 2021 by organising an educational talk on 'Biological Diversity of Odisha State' by Mr. Maloth Mohan, IFS, Chairman cum Principal Chief Conservator of Forest, Odisha Biodiversity Board. An online quiz and dance competition were also organised. Commemorating the audacious journey of 25 golden years of atmospheric chemistry research at IITM, the SAFAR-Emission Inventory PMR-2020 report was released by the Chief Guest Prof. Nitin Karmalkar, Vice Chancellor, SPPU, Pune. A video documentary in this regard was also prepared.
- **Celebrating World Environment Day 2021**, an educational and awareness event was organised on 04 June 2021 by IITM-ENVIS. A webinar on 'Antarctic Ecosystem' by Chief Guest Dr. Anoop Tiwari, Scientist E, NCAOR, Goa was arranged. As part of the programme, medicinal plants were distributed to IITM employees.
- **World Ozone Day 2021** was observed on 16 September 2021 by organising a talk on 'Tropospheric Ozone from Global to Local Scale: its threats in India and possible controls' by Prof. Oliver Wild, Lancaster University, UK. An open online quiz competition was also organised.
- **India International Science Festival (IISF) 2021:** IISF-2021 was organised by the Government of India in collaboration with Vijnana Bharati at NCPOR, Goa during 10-13 December 2021. The theme of IISF 2021 was 'Celebrating Creativity in Science, Technology and Innovation for Prosperous India.' IITM participated in the IISF exhibition in Goa to showcase the institute's R&D activities and achievements.
- Observing the **National Pollution Control Day** 2021 on 2 December 2021, an educational webinar on 'Technology Options for Air Pollution Monitoring' by Dr. Rakesh Kumar, Former Director, CSIR-NEERI was arranged. National level online quiz and drawing competitions were organised, and the results were announced during the webinar.
- **National Energy Conservation Day 2021:** On 14 December 2021, IITM-ENVIS observed National Energy Conservation Day. The National level open online quiz competition was organised and around 300 people participated in the competition.
- **National Science Day 2022:** IITM-ENVIS arranged an online educational webinar on 'Greenhouse effect: introduction and consequences' in Hindi by Dr. Kaushar Ali, former Scientist-F, IITM, Pune. Based on the webinar, a national level online quiz competition was organised.
- **Vigyan Sarvatra Pujyate Mega Expo 2022:** Under the *Azadi Ka Amrit Mahotsav*, the Office of the Principal Scientific Advisor and the Ministry of Culture, Govt. of India organised a mega science expo 'Vigyan Sarvatra Pujyate' at the Nehru Stadium, New Delhi during 22-28 February 2022 for showcasing S&T activities being executed under different science ministries/departments. IITM participated in this expo and showcased/ demonstrated the institute's R&D achievements and activities to the visitors.
- **World Meteorological Day 2022:** IITM-ENVIS celebrated the day by organising a special programme at Paradise English Medium School on 23 March 2022. The programme included an informative lecture, hands-on activities workshop, climate change action pledge and infographic poster for students.

Special Days/Weeks Observed

- **Anti-Terrorism Day,** 21 May 2021. A pledge was administered to the employees.
- **International Yoga Day,** 21 June 2021**:** A webinar on "Complex diseases: Yoga unravelling the pharmacy within" by Dr. Rima Dada, Professor, All India Institute of Medical Sciences (AIIMS), New Delhi was arranged.
- **Swachhata Pakhwada 2021** was observed during 01-15 July 2021 as per the guidelines received from MoES. Several webinars were arranged during the period.
- **74th Anniversary of Independence Day** was celebrated on 15 August 2021.
- **Sadbhavana Diwas**, 20 August 2021.
- **Vigilance Awareness Week**, 26 October - 01 November 2021. On this occasion, a pledge was administered by the Director, IITM to all the employees on 26 October 2021. As a part of Vigilance Awareness Week, competitions like elocution, slogan and essay competition were held during the week on the theme "Independent India @75: Self Reliance with Integrity" for IITM employees. IITM in coordination with MoES arranged following webinars: 1) Preventive Vigilance Measures and PIDPI (Public Interest Disclosure and Protection of Informers) by Mr. Apendu Ganguly, Retd. Director, Ministry of Defence, 27 October 2021; 2) Vigilance: A Pending Obligation by Dr. V.G. Anand, Professor and Chief Vigilance Officer, IISER, Pune, 28 October 2021; and 3) Departmental Inquiries, Mr. Mukesh Chaturvedi, Retd. Director, DoPT, 28 October 2021.
- **National Unity Day** (Rashtriya Ekta Diwas), 31 October 2021.
- **Constitution Day (Samvidhan Divas):** On this occasion, all IITM officials joined the Hon'ble President in reading the Preamble of the Constitution on 26 November 2021. As a part of the Constitution Day celebrations, a Hindi webinar on the topic 'Fundamental Rights and Duties in the Indian Constitution' by Dr. O.N. Shukla, Hindi Officer, IITM, Pune was arranged.
- **National Voters Day**, 25 January 2022.
- **73rd Republic Day**, 26 January 2022. Director, IITM addressed the IITM employees.
- **Martyrs' Day,** 30 January 2022.

Infrastructure Development at IITM

Completed work

- Construction of a multi-utility building named 'Riturang' to accommodate a workshop, canteen and recreation hall facility at IITM, Pashan, Pune has been completed by CPWD, Pune. Necessary testing for completed works, snags rectification, cleaning and site clearances etc. are under progress.
- The Pisharoty Hall in the institute's main building has been completely renovated, including installing a new audio-visual system.
- Re-construction of the compound wall near the chiller yard at IITM, Pune.
- Construction of storage cabins with aluminium partitions and doors in the old canteen building at IITM, Pune.
- Construction of 20-metre tower for C-band Doppler weather radar for ART-CI, Bhopal.

Work under progress

- Necessary works are being executed for establishing ART-CI, Bhopal. It includes the construction of boundary wall, entrance gate, and internal roads; setting up 33KV electrical substation, solar and street lights; and procurement of porta-cabins for laboratory block cluster, office block cluster, accommodation-cum-rest rooms and security cabins.

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 the latest books.

IITM subscribed 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 3 Indian journals for the year 2021 (costing approx. Rs.91.97 lakhs). Subscription to 39 journals [34 foreign (online access) and 05 Indian] for the year 2022 (costing approx. Rs.44.37 lakhs) has been processed. In addition to this, access to 131 foreign journals published by Elsevier and Nature Publishing Group, and 165 journals collection package published by Springer and the 'Web of Science' database is made available under the MoES Consortium "DERCON". Access to 28 journals (12 Indian and 16 foreign) is available either complimentary/free online or against life membership. Print versions of ten (10) books covering the majority of the Institute's research areas (costing approx. Rs. 0.685 Lakhs) were purchased. Forty-Nine (49) e-books published by Springer-Nature (costing approx. Rs. 14.5 lakhs) were added since January 2022, which is a new addition in the Library. Subscribed to the 'Grammarly Premium' software (writing support tool) for the year 2022 (costing Rs.4.56 lakhs). 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 and online IP-based institutional access to 56 titles of Cambridge e-books are working satisfactorily at IITM. Payments for paper publication charges/page charges/article processing charges/excess length fee for fifteen (15) papers of the Institute's scientists were approx. Rs. 8.02 lakhs.

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

The division is tracking news clippings on the Institute and archiving the same on DSpace (in-house developed institutional repository for news clippings) and MOES Knowledge Resource Portal.

LIP Division has contributed to developing the MoES Knowledge Resource Centre and MoES KRC Portal, which was made live during MoES Foundation Day 2020 at the hands of the Hon'ble Minister of Earth Sciences. LIP Division is constantly contributing toward further refining the MoES-KRCNet portal and enriching the portal by adding IITM contents, viz., e-resources, events, etc.

LIP Division is managing content for the digital platforms of the Institute, viz., the IITM website (www.tropmet.res.in) and IITM social media sites (Facebook, Twitter and YouTube channel).

LIP Division has also prepared short videos on IITM achievements on specific topics, training participants' feedback videos by conducting short interviews. Video compilation of online training materials, video lectures, etc. are being carried out and archived at the IITM YouTube channel. New institutional repositories have been developed in-house with advanced features for IITM's peer-reviewed research papers and lectures delivered by eminent scientists/visitors.

LIP has conducted a series of webinars on Web of Science, InCites, SCOPUS, Endnote, Grammarly, JGATE, MoES-KRCNet Portal etc. throughout the year (April 2021 – March 2022) in coordination with MoES, publishers and service providers.

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 the popularisation of Meteorology and Atmospheric Sciences among students and the public by organising open days, scientific exhibitions 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 the Institute's participation in scientific exhibitions of other organisations.

Management

IITM Society

The Ministry of Earth Sciences, Govt. of India has reconstituted the IITM Society with the Hon'ble Minister, Ministry of Earth Sciences as the ex-officio President and Director, IITM as the ex-officio Member-Secretary vide Order No. MoES/27/ 01/2017-Estt dated 16 March 2022. Details of all the new members of the Society are given in the starting pages of this report. A meeting of the newly constituted IITM Society was held on 30 September 2021.

Governing Body

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. Recently, The Ministry of Earth Sciences, Govt. of India has reconstituted the GC of IITM as the IITM Governing Body (GB) with the Secretary, MoES being the ex-officio Chairperson and Head/In-charge of Administration at IITM as the ex-officio Member-Secretary vide Order No. MoES/27/01/ 2017-Estt dated 16 March 2022. Details of all the new members of the GB are given in the starting pages of this report. During the year 2021-22, GC/GB had its 103rd and 104th meetings on 30 September 2021 and 30 April 2022 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.

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 Chairperson 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 advise 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. Consequent to the recent reconstitution of the RAC by the MoES vide Order No. MoES/27/01/2017-Estt dated 16 March 2022, Dr. L.S. Rathore, Former DG, IMD, is the new Chairperson of the RAC. Details of all the new members of the RAC are given in the starting pages of this report. The 16th meeting of the Research Advisory Committee was held during 28-29 April 2022 under the Chairmanship of Dr. L.S. Rathore. 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.

Administration

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

Personnel Profile as on 31 March 2022:

Category	No. of Posts
Research	124
Scientific Support Staff	11
Technical Support Staff	3
Administrative Staff	35
Multi-Tasking Staff	09
Total	**182**

Staff Changes

Appointments: Administrative Staff

- Mr. Y. Srinivas Rao, UDC, 20 October 2021.

Retirement on Superannuation

- Dr. Gufran Beig, Scientist-G, 31 May 2021.
- Mr. G.E. Dhongade, MTS, 30 June 2021.
- Mrs. A.A. Kulkarni, Scientist-F, 31 July 2021.
- Mr. K.K. Dani, Scientist-F, 31 July 2021.
- Mr. S.G. Narkhedkar, Scientist-F, 31 July 2021.
- Dr. N.R. Deshpande, Scientist-D, 31 August 2021.
- Mrs. S.R. Inamdar, Scientific Officer Grade-II, 31 August 2021.
- Mr. M.V. Kale, Assistant Manager, 31 August 2021.
- Mrs. M. N. Kulkarni, Scientist-E, 30 September 2021.
- Mrs. M.V. Deshpande, Junior Executive, 31 December 2021.
- Dr. Kaushar Ali, Scientist-F, 31 January 2022.
- Mrs. S.U. Athale, Scientific Officer Grade-II, 31 January 2022.
- Dr. S.K. Patwardhan, Scientist-D, 31 March 2022.
- Mrs. K.Y. Chavan, MTS, 31 March 2022.

Pre-Mature Retirement

- Mr. V. Vasudevan, Scientific Assistant-B, 11 April 2021.

Resignation

- Mrs. Sayanti Bardhan, Scientist-C, 17 June 2021.
- Mrs. Ashwini S. Bhandari, Assistant Manager, 25 August 2021.

Deputation Related

- Mr. S.M.D. Jeelani, Scientist-E (Comp. Engg.) on deputation to UIDAI w.r.f. 09 December 2021.

Status of SC/ST/OBC/ Reservation as on 31 March 2022:

Category	SC	ST	OBC	Total
Research	11	6	21	38
Scientific Support Staff	3	5	1	9
Technical Support Staff	3	0	0	3
Isolated Staff	0	0	0	0
Administrative Support Staff	5	3	5	13
MTS	2	2	1	5
Total	**24**	**16**	**28**	**68**

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, 22.22% and 22.22%, respectively.

Finance

Finance Committee

Finance Committee (FC), constituted by the Governing Council, meets twice a year and reviews the financial performance of the Institute and provides guidance for improvement of the performance. Consequent to 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 16 March 2022, Financial Adviser, MoES is now the Chairperson (Ex-Officio) of the FC. The Finance Committee held its 41st and 42nd meetings on 17 September 2021 & 07 April 2022 respectivley.

During the period, the following purchases were made:

Budget

The grant received and the actual expenditure incurred for the period 2021-22 are as follows (in Crores): The Auditors appointed by the Governing Council M/s A. R. Sulakhe & Co., Pune conducted the audit for the year 2021-22. The abstract of the report is enclosed at the end of this report.

Sr. No.	Schemes	Opening Balance	Funds received	Other Receipts & Re-appropriation	Total Funds	Cash Expenditure to MoES	Amount surrendered to MoES	Closing Balance
A	**ACROSS**							
1	MONSOON CONVECTION CLOUDS AND CLIMATE CHANGE (MC4)	-1.60	21.30	1.00	18.70	18.73	0.00	-0.03
2	HIGH PERFORMANCE COMPUTING SYSTEM (HPC)	4.87	13.50	4.11	22.48	23.57	0.00	-1.09
3	MONSOON MISSION - PHASE-II	0.63	8.20	2.25	6.58	5.96	0.58	0.04
4	NATIONAL FACILITY FOR AIRBORNE RESEARCH (NFAR)	1.31	0.00	0.86	0.45	0.25	0.00	0.20
	TOTAL (A)	**5.21**	**43.00**	**8.22**	**48.21**	**48.51**	**0.58**	**-0.88**
B	**REACHOUT**							
1	DESK	-1.41	4.11	0.00	2.70	2.54	0.00	0.16
	TOTAL (B)	-1.41	4.11	0.00	2.70	2.54	0.00	0.16
C	**ASSISTANCE TO AUTONOMOUS BODIES**							
1	IITM OPERATIONS AND MAINTENANCE	4.26	83.10	0.00	87.36	85.31	0.00	2.05
	TOTAL (C)	**4.26**	**83.10**	**0.00**	**87.36**	**85.31**	**0.00**	**2.05**
D	SPONSORED PROJECT	1.40	1.37	0.00	2.77	1.50	0.00	1.27
	TOTAL (D)	**1.40**	**1.37**	**0.00**	**2.77**	**1.50**	**0.00**	**1.27**
	TOTAL (A+B+C+D)	**9.46**	**131.58**	**8.22**	**141.04**	**137.86**	**0.58**	**2.60**

Purchase and Stores

The Institute acquired scientific equipment and accessories, data acquisition and storage systems, personal computers, workstations, 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	2,48,90,296.00	0.00	2,48,90,296.00
Dead Stock	27,71,549.00	0.00	27,71,549.00
Consumables	9,38,748.00	0.00	9,38,748.00
Total	**2,86,00,593.00**	**0.00**	**2,86,00,593.00**

Official Language Implementation

- Continuous efforts are being made to comply with the Official Language Policy of the Union.
- All documents covered under the Official Language Act 1963 Section 3(3) are issued in bilingual form.
- Due to the COVID-19 pandemic, only three of the four quarterly meetings of the Official Language Implementation Committee were conducted on 11 June 2021, 27 August 2021 and 15 December 2021.
- A meeting of the Town Official Language Implementation Committee-2 was held online in the institute on 28 June 2021. A workshop was also organised wherein Dr. Gufran Beig, a former senior scientist at IITM, delivered a scientific lecture in Hindi on the topic 'Environmental Pollution and Corona Epidemic.'
- 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 the Department of Official Language.
- During 2021-22, four Hindi workshops were organised in the institute on 9 April 2021, 28 June 2021, 9 September 2021 and 28 January 2022 respectively, in which many officers and employees of the institute participated. The invited speakers delivered lectures on various topics in these workshops.
- **Hindi Week Celebration:** Hindi week was celebrated at IITM during 06-14 September 2021. During this Hindi Week, competitions such as essay writing, solo song, noting & drafting, extempore speech and poem recitation were organised online. A large number of employees participated in these competitions. A Hindi play by IITM employees was also arranged. During the Hindi Week concluding function on 14 September 2021, a pledge received from the Department of Official Language, Ministry of Home Affairs, was administered to employees of the Institute. Prizes and gifts were distributed to all the winners and participants.
- Celebrating the Swachhta Pakhwada in the institute, an online webinar on 'E-Waste Se Raksha, Swachhta Hi Suraksha' by Dr. Omkar Nath Shukla, Hindi officer at IITM was organised.
- Hindi library is being maintained regularly, and books are being issued to employees.
- Daily translation and correspondence work is being done.
- The Hindi roaster regarding the Hindi knowledge of employees is being updated regularly.

5. Awards and Honours

Dr. R. Krishnan

- MoES National Award for Excellence in Atmospheric Science and Technology for the year 2021 for his outstanding contributions towards global climate change & variability and dynamics and variability of the Indian/Asian monsoon, 15th MoES Foundation Day 2021.

Dr. Suryachandra A. Rao

- Participated as a panellist in ForCAST INDIA 2021 (Discover the next-generation HPC & AI Solutions) to discuss the weather and climate modelling in India.

Dr. C. Gnanaseelan

- Appointed as Editor of JGR-Oceans for a term starting from 12 April 2021 to 31 December 2024.
- Invited as a Resource Person for a refresher course on 'Climate Change' organised by K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad in collaboration with UGC-HRDC (Human Resource Development Centre), University of Allahabad, 17-30 January 2022.

Dr. G. Pandithurai

- WP3 lead from India for WCSSP India/UK project.
- Invited as a Review Committee Member at Centre for High Energy Systems and Sciences (CHESS), Hyderabad to evaluate their ongoing project on 'Optical turbulence measurements using laser-based systems' on 2 and 9 August 2021.
- Invited as a Chief Guest for the inaugural session of 'International Conference on Wireless communications' organised by D.J. Sanghvi College of Engineering, Ville Parle, Mumbai on 8 October 2021.
- Chaired a session, 'Quantitative Precipitation Estimation and Hydrological Applications' in the 5th India Radar Meteorology Conference (iRAD2022) organised by IIT Bhubaneswar on 10 January 2022.

Dr. S. Chakraborty

- MoES Certificate of Merit for the year 2021 for his outstanding contributions in the field of Atmospheric Science and Technology, 15th MoES Foundation Day 2021.
- Editorial Board Member of Quaternary International for the term 2021-2025.
- Chaired a session on Climate Change at OSICON-2021 on 12 August 2021.

Dr. P. Mukhopadhyay

- Chaired a technical session on 'Extreme weather events and predictions' in the National E-Symposium on Changing Climate and Extreme Events: Impacts, Mitigation & Role of Oceans organised by IMSP and OSI during 21-23 February 2022.

Dr. S.D. Pawar

- Member of WMO ad-hoc Lightning Extreme Records Committee.
- Chaired a session on 'Convective cloud' at the International Conference on Cloud Physics held at IITM, Pune during 2-6 August 2021.
- Bestowed with Honorary Doctorate Degree by Sanjay Ghodawat University, Kolhapur.

Dr. Thara Prabhakaran

- MoES Anna Mani Award for Woman Scientist, 15th MoES Foundation Day 2021.
- Honoured by the Commission on International Commission of Clouds and Precipitation (ICCP)/IMAS for the conduct of the ICCP 2021 conference.
- Co-opted member of Project Appraisal & Monitoring Committee (PAMC)/Science and Engineering Research Board (SERB)/ Department of Science and Technology.
- Member of Teachers Associateship for Research Excellence (TARE) Scheme committee/Science and Engineering Research Board (SERB)/ Department of Science and Technology.

- Nominated in the Project Review and Steering Group (PRSG) for the project 'Development of MMW Radiometer for NE Region of India for Climate Modelling Studies for Weather Changes' by the Ministry of Electronics and Information Technology (MeitY).
- Co-editor for Atmosphere special issue on 'Weather Modification and Small-Scale Geoengineering: Theory, Practice and Technology.'
- Member, Test and Evaluation Committee for the Ka-band radar developed by SAMEER.
- Member of Expert Committee to review FTT-FTC Projects (2022-2024) under Ecology, Environment, Earth, Ocean Sciences and Water (E3OW) Theme of Council of Scientific and Industrial Research (CSIR).

Dr. J. Sanjay

- Invited as a Resource Person by ICIMOD for the Asia Regional Resilience to a Changing Climate (ARRCC) virtual training event on WCRP CORDEX data access and use for Nepal Department of Hydrology and Meteorology on 7 June 2021.
- Nominated by the IPCC National Focal Point of India in the Ministry of Environment, Forest and Climate Change, Government of India for participation as a Member of the Indian Delegation/Government Representatives in the 54th Session of the IPCC and 14th Session of Working Group I (WGI) for approval of the Summary for Policymakers (SPM) of WGI contribution to the Sixth Assessment Report and acceptance of the underlying scientific technical assessment, held online from 26 July to 6 August 2021.
- Invited as a Resource Person for the training on 'Spatial and temporal climate change analysis using CORDEX regional climate models over South Asia for Bangladesh' organised by ICIMOD, in collaboration with the UKMO, WCRP/CORDEX, SMHI, Bangladesh University of Engineering and Technology (BUET) & IITM on 13 December 2021.

Dr. Suvarna Fadnavis

- Scientific Steering Committee (SSC) Member, Chemistry-Climate Model Initiative, Stratosphere-Troposphere Processes and their role in Climate (SPARC).
- Chaired a session 'Chemistry Climate modelling Initiative' at the International Global Atmospheric Chemistry (IGAC) Program, conducted virtually on 16 September 2021.
- Editor of the Journal of Atmospheric Chemistry and Physics (ACP).

Dr. Milind Mujumdar

- Invited as a Guest of Honour in the national level webinar on 'Role of Geosciences in Drought Management: Issues, Challenges and Opportunities' jointly organised by the School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University (KBC-NMU), Jalgaon and the Association of Geologists and Hydrogeologists, GEOFORUM, Aurangabad (MH) on the occasion of 'World Day to Combat Desertification & Drought' on 17 June 2021.

Mr. Somnath Mahapatra

- Guest Speaker and Chief Guest for the inaugural ceremony of the Virtual Summer Camp organised by Vi Educational Foundation during 29 May - 5 June 2021.
- Editorial Board Member of Bulletin of IMSP (BIMSP).
- Received the Second Prize for his Hindi composition in the Pune city-level competition (among central government offices in Pune) by Central Water and Power Research Station (CWPRS), Khadakwashla, Pune.
- First Prize in the online elocution competition organised as part of the Vigilance Awareness Week 2021 celebrations at IITM during 26 October to 1 November 2021.

Dr. Swapna Panickal

- Invited as a Resource Person for the short-term course on Disaster Management and Climate Change organised by the UGC-Human Resource

Development Centre, Kannur University, Kerala, 09-15 November 2021.

- Member, Sea Level Rise Working Group, WCRP Safe Landing Climates (SLC) Lighthouse Activity.
- Membership of the Working Group on Coupled Modeling (WGCM), World Climate Research Program (WCRP) is extended till the end of 2022.

Dr. Roxy Mathew Koll

- Regional Focal Point (RFP) member and contributed to organising WCRP's First South Asia Climate Research Forum: Southern Asia, focused on the theme 'Climate research priorities for the next decade,' 16 September 2021.
- Invited as a Chief Guest and inaugurated the Carbon Auditing Programme at St. Joseph's School in Kottayam, Kerala, 12 September 2021.
- Convened and chaired the 17th Annual Meeting of the CLIVAR/IOC-GOOS Indian Ocean Region Panel on 28 April 2021.
- Convened and chaired a teleconference session organised by the Indian Ocean Region Panel for networking Early Career Researchers (ECRs) working on the Indian Ocean and bringing them together as Indian Ocean Ambassadors on 21 October 2021.
- Co-chair of the Indian Ocean Region Panel participated in the 13th Indian Ocean Observing System (IndOOS) Resource Forum (IRF-13) and presented updates on 'Tracking the Indian Ocean Observing System (IndOOS)', 9 December 2021.
- Honoured as a Distinguished Alumnus of the CMS College, by the Department of Physics, CMS College Kottayam, Kerala, during the 3rd Physics Alumni Meet held on 15 January 2022.
- Convened and chaired the 18th Annual Meeting of the CLIVAR/IOC-GOOS Indian Ocean Region Panel (IORP) on 23 March 2022.

Dr. Yogesh K. Tiwari

- Nominated as an Expert Member at the United Nations Framework Convention on Climate Change (UNFCC) for technical review of GHG inventories and other annual information reported by Annex-I Parties, in-depth review of Annex-I Party national communications, review of biennial reports of Developed Country Parties, matters related to non-Annex-I Party national communications, technical analysis of biennial update reports from non-Annex-I Parties, review of reports on systematic observation, etc.
- Chaired a session 'Advanced technologies for measuring GHGs with different platform' at the Asia-Pacific (10th) GAW workshop on greenhouse gases, KMA, South Korea during 25-26 October 2021

Dr. Sachin Ghude

- Elected as a Co-Chair by Integrated Land Ecosystem Atmosphere Process Studies (iLEPAS) from 2022 onwards. Earlier, he served iLEAPS as Member, Scientific Steering Committee.
- Member, Expert Group constituted by Commission for Air Quality Management (CAQM) to examine the suggestions before finalisation of the policy to curb air pollution in Delhi-NCR.

Dr. Ramesh Kumar Yadav

- Invited as a Resource Person for a refresher course on 'Climate Change' organised by K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad in collaboration with UGC-HRDC (Human Resource Development Centre), University of Allahabad, 17- 30 January 2022.
- Faculty member for the 5th Refresher Course in Environmental Studies (IDC), UGC-Human Resource Development Centre, Jawaharlal Nehru University, New Delhi, 20 September – 4 October 2021.

Dr. B. Padmakumari

- Nominated as a Member of the committee on 'Use of Drones in meteorological and environmental observations and applications' constituted by Director General of Meteorology, New Delhi.

- Co-Chaired a session in ICCP-2021 virtual conference organised by IITM during 2-6 August 2021

Dr. MCR Kalapureddy

- Chief Guest for the webinar on 'Facts of Weather RADAR Applications' organised by Sri Venkateswara College of Engineering, Sriperumbudur, 15 June 2021.
- Invited as an Expert Member for Remote Sensing Report on 27 July 2021.
- Chaired a session on 'Wind Profiling Radars' in iRAD-2022, 11 January 2022.

Dr. Bipin Kumar

- Invited as a panellist in a panel discussion on 'Career Orientation' at Amity University, Lucknow, 10 August 2021.
- Guest of Honour, short-term training course on 'Recent Trends in AI, ML and Deep Learning,' Parul Institute of Engineering and Technology, Barodara, 17 September 2021.

Dr. Kaustav Chakravarty

- Invited as a Chief Guest for the inaugural function of the faculty development programme on 'Computational Statistics and Big Data Analytics using Python,' organised by AISSMS College in association with IEEE Consumer Technology Society, 07 March 2022.

Dr. Anant Parekh

- Received the Reviewer Excellence Award 2020 by the Indian Academy of Sciences in recognition of his outstanding contributions as a reviewer for the Journal of Earth System Science.

Dr. J.S. Chowdary

- Member of the Advisory Committee for recommending the CSIR Young Scientist Award for the year 2021 in Earth Atmosphere Ocean and Planetary Sciences, June 2021.

Dr. Atul Kumar Srivastava

- Invited as a Resource Person for the online refresher courses on 'Environmental Science' and 'Research Methodology in Basic Sciences,' Utkal University, Bhubaneswar, Orisha.
- Jury Member for conducting online competitions for Eco-Fest during IISF 2021.

Dr. Abhay SD Rajput

- Received First Prize in both Hindi Ashubhashan Pratiyogita (Hindi extempore speech competition) and Kavita Path (poem recitation) organised online during Hindi Week Celebrations 2021 by the Hindi Section of the Institute.
- Invited as a Keynote Speaker to deliver the inaugural talk under the Lecture Series on 'Intellectual Property Rights' organised by Industry Academia Partnership Cell (IAPC) and Department of Botany, Jammu University, Jammu, 21 October 2021.

Dr. Mahen Konwar

- Reviewer of the journals 'Atmospheric Research' and 'Remote Sensing Applications: Society and Environment.'
- Member of the International Commission on Clouds and Precipitation (ICCP/IMAS) -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).
- Nominated as a Member of the sub-committee of Water Resources Division Council WRD1:1 (under Hydrometry Sectional Committee, WRD 1), Bureau of Indian Standards, New Delhi.

Dr. Deepa J.S.

- Received the Reviewer Excellence Award 2020 by Indian Academy of Sciences in recognition of her outstanding contributions as a reviewer for the Journal of Earth System Science.

Ms. Aditi Modi

- Council Member of the Ocean Society of India, Pune Chapter for the term 2021-2023.

Mrs. Smrati Gupta

- Best Performance Award as an Executive Council Member of IMSP during Annual Monsoon E-Workshop (AMW 2021) and National E-Symposium on Changing Climate and Extreme Events: Impacts, Mitigation & Role of Oceans (online) organised by the Indian Meteorological Society, Pune chapter, 21-23 February 2022.

Mr. Naresh Ganeshi

- Best Poster Presentation Award, Annual Monsoon E-Workshop (AMW 2021) and National E-Symposium on Changing Climate and Extreme Events: Impacts, Mitigation & Role of Oceans organised by the Indian Meteorological Society, Pune chapter, 21-23 February 2022.

Mr. Ambhuj Jha, Mr. Subrota Halder, Ms. Darshana Patekar and Ms. Anila Sebastian

- Best Paper Presentation Award (each separately), Annual Monsoon E-Workshop (AMW 2021) and National E-Symposium on Changing Climate and Extreme Events: Impacts, Mitigation & Role of Oceans organised by the Indian Meteorological Society, Pune chapter, 21-23 February 2022.

India Meteorological Society (IMS) Award

- The paper 'Parameterization of entrainment rate and mass-flux in continental cumulus clouds: Inference from large eddy simulation' by Bera Sudarsan and Prabhakaran Thara published in Journal of Geophysical Research: Atmospheres, 124, December 2019, DOI:10.1029/2019 JD031078, 13127-13139 was conferred the India Meteorological Society (IMS) Award for the best paper on numerical modelling study on monsoon.

30th Biennial MAUSAM Award

- The paper 'Evolution of operational extended range forecast system of IMD: Prospects of its applications in different sectors' by Pattanaik D.R., Sahai A.K., Mandal R., Muralikrishna R.P., Dey A., Chattopadhyay R., Joseph S., Tiwari A.D., Mishra V., published in Mausam, 70, April 2019, 233-264 received the 30th Biennial MAUSAM Award (2018-2019).

6. Visitors

National

- **Mr. Kunal Satyarti**, Joint Secretary, National Disaster Management Authority, New Delhi, 21 December 2021.
- **28 High Level Officers** (Officers' Training for Mid-Career Interaction between Armed Forces and Civil Services Officers) from Yashada, Pune, 06 December 2021.
- **Dr. Rajani P.K, Associate Professor, and six internship students** from Pimpri Chinchwad College of Engineering, Pune visited the IITM-COSMOS site on 28 October 2021.
- **28 High Level Officers** (Officers' Training for Mid-Career Interaction between Armed Forces and Civil Services Officers) from Yashada, Pune, 07 December 2021.
- **Mr. Kunal Satyarti**, Joint Secretary, National Disaster Management Authority, New Delhi visited IITM on 21 December 2021.

7. SEMINARS

Monsoon Discussion Forum

Mr. Maheshwar Pradhan

- Seasonal Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2021', 25 June 2021.

Mr. Avijit Dey

- Extended Range Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2021', 25 June 2021.

Ms. Snehlata Tirkey

- Short Range Prediction, 1st Seminar: focus on 'Onset and LRF of monsoon 2021', 25 June 2021.

Mr. Ankur Srivastava

- Seasonal Prediction, 2nd Seminar: focus on 'Advance of monsoon 2021', 16 July 2021.

Dr. O.P. Sreejith, IMD, Pune

- Regional Seasonal Climate Outlook for South Asia, 2nd Seminar: focus on 'Advance of monsoon 2021', 16 July 2021.

Mr. Raju Mandal

- Extended Range Prediction, 2nd Seminar: focus on 'Advance of monsoon 2021', 16 July 2021.

Dr. S.D. Sanap, IMD, Pune

- Synoptic Analysis of Monsoon, 2nd Seminar: focus on 'Advance of monsoon 2021', 16 July 2021.

Dr. Malay Ganai

- Short Range Prediction, 2nd Seminar: focus on 'Advance of monsoon 2021', 16 July 2021.

Dr. S.D. Sanap, IMD, Pune

- Observed Synoptic Features of Monsoon, 3rd Seminar: focus on 'Advance of monsoon 2021', 13 August 2021.

Dr. O.P. Sreejith, IMD, Pune

- Seasonal outlook, 3rd Seminar: focus on 'Advance of monsoon 2021', 13 August 2021.

Mr. Avijit Dey

- Extended Range Prediction, 3rd Seminar: focus on 'Advance of monsoon 2021', 13 August 2021.

Mr. Sahadat Sarkar

- Short Range Prediction, 3rd Seminar: focus on 'Advance of monsoon 2021', 13 August 2021.

Dr. S.D. Sanap, IMD, Pune

- Synoptic Analysis of Monsoon, 4th Seminar: focus on 'Advance of monsoon 2021', 8 September 2021.

Mr. Maheshwar Pradhan

- Seasonal Prediction, 4th Seminar: focus on 'Advance of monsoon 2021', 8 September 2021.

Dr. O. P. Sreejith, IMD, Pune

- Forecast for September Rainfall, 4th Seminar: focus on 'Advance of monsoon 2021', 8 September 2021.

Mr. Raju Mandal

- Extended Range Prediction, 4th Seminar: focus on 'Advance of monsoon 2021', 8 September 2021.

Mr. Tanmoy Goswami

- Short/medium range forecast, 4th Seminar: focus on 'Advance of monsoon 2021', 8 September 2021.

Virtual Lecture Series on Cloud and Precipitation Physics and Dynamics

Prof. Andrea Folssmann, Université Clermont Auvergne, Laboratoire de Météorologie Physique, Clermont-Ferrand, France

- Aerosol activation and warm cloud microphysics, 11 October 2021.

Dr. Andrew Heymsfield, Senior Scientist, National Centre for Atmospheric Research, USA

- The Ice phase: From observations in clouds and at the surface, 12 October 2021.

Prof. Rama Govindarajan, International Centre for Theoretical Sciences, TIFR

- Turbulence, droplet collisions and growth, 15 October 2021.

Dr. Darrel Baumgardner, Droplet Measurement Technologies, USA

- Autonomous, Instrumented, unmanned aircraft systems designed for cloud seeding operations, 08 November 2021.

Prof. Wojciech Grabowski, NCAR, USA

- Modeling of cloud dynamics and microphysics, 09 November 2021.

Dr. Alexei Korolev, Environment and Climate Change, Canada

- Mechanisms of secondary ice production, observations and laboratory studies, 15 November 2021.

Prof. Johannes Quaas, Leipzig University, Germany

- Aerosol-cloud effective radiative forcing, 18 November 2021.

Prof. Greg McFarquhar, University of Oklahoma, USA

- Use of in-situ cloud microphysical observations for quantifying ice cloud microphysical properties and processes, and their uncertainties, 18 November 2021.

Dr. A.K. Kamra, Indian Institute of Tropical Meteorology, Pune

- Interactions of cloud electrification with its microphysics, 16 December 2021.

Prof. Satyajit Ghosh, Vellore Institute of Technology, India; and School of Earth and Environment, Leeds University, UK

- Analytical formulations for quantifying monsoonal rain amounts with biometeorological applications over the built environment, 21 December 2021.

Dr. Karanam Kishore Kumar, Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram

- Emerging trends in synergetic approaches for remote sensing of clouds, 22 December 2021.

Dr. Jiwen Fan, Pacific Northwest National Laboratory (PNNL), USA

- Understanding and modelling aerosol impacts on convective clouds and precipitation, 16 February 2022.

Prof. Alexander Khain, Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel

- Formation of microphysical structure of convective clouds by internal cloud vortex dynamics, 24 February 2022.

Dr. Heike Wex, Leibniz Institute for Tropospheric Research, Germany

- Ice nucleating particles in the atmosphere, 16 March 2022.

Prof. R. Ananthakrishnan Seminars/Colloquium

Dr. Dipanjan Dey, Department of Meteorology, Stockholm University, Sweden

- Lagrangian Tracing and Analysis of the South Asian Summer Monsoon Precipitation, 16 June 2021.

Special Lectures organised under Azadi Ka Amrit Mahotsav at IITM

Dr. J.R. Kulkarni

- Cloud seeding: science, technology, benefits, and some misunderstandings (in Marathi), 25 May 2021.

Dr. Milind Mujumdar

- Importance of field-scale soil moisture monitoring for techno-scientific applications (in Hindi), 22 June 2021.

Dr. Asmita A. Deo

- Changes in tropical cyclones due to climate change (in Marathi), 28 July 2021.

Dr. Medha S. Deshpande

- Global ensemble forecast system (GEFS) for the weather prediction (in Marathi), 30 August 2021.

Dr. Swati Samvatsar and **Mr. Milind Pandit**

- Vulnerability assessment, planning, and execution for the climate-resilient village: Role of community to scientist (in Hindi), 28 September 2021.

Dr. S.D. Pawar

- Lightning strikes: Information and Safety (in Marathi), 22 October 2021.

Dr. R. Krishnan

- Tribute to Professor Syukuro Manabe, 11 November 2021.

Dr. Sanjay N. Patil

- An Integrated approach for geo-environmental appraisal for natural resource management: Problems and challenges, 03 February 2022.

Mr. Shirish J. Kanitkar

- Urban Forests and Habitats, 15 June 2022.

Seminar on PhD Synopsis/Submission/Proposal

Ms. Manpreet Kaur

- Development for a framework for Improved Extended Range Prediction of Extreme Weather Events, 21 April 2021

Mr. Sandeep Mahapatra

- Understanding the decadal variability of the Indian Ocean from observations and model, 23 April 2021.

Ms. Supriya M. Ovhal

- Study of large-scale Atmospheric convection over the tropical Indian Ocean and its association with Oceanic variables, 28 April 2021.

Mr. Kumar Roy

- Observational and modelling studies of cloud and convective processes with emphasis to low-level clouds and its microphysical impact on precipitation, 5 May 2021

Mr. Amit Kumar

- Raindrop characteristics over the Western Ghats and its relationship with various cloud microphysical properties, 7 May 2021.

Mrs. Vrinda Anand

- The variability of air pollutants in various micro-environments of Pune under SAFAR, 19 May 2021.

Mr. Nikhil Korhale

- Impact of Coastal Meteorology and Emission Sources in the Distribution of Air Pollutants over Mumbai Region under SAFAR, 28 May 2021.

Mrs. Anju M.

- Development and implementation of a multi-component ecosystem model with linkage between lower and upper trophic levels for the North Indian Ocean and its applications, 11 June 2021.

Mr. Sandeep K.

- Understanding the variability and radiative impact of aerosols over Himalaya, 16 June 2021.

Mr. Somaru Ram

- Climate Change and Climate Variability studies based on tree ring records of Himalayan Region, 15 June 2021.

Mrs. Dipti Hingmire

- Large-scale Dynamic Controls Relevant to widespread winter time Fog over Indo-Gangetic Plane, 18 June 2021.

Mr. Mangesh M. Goswami

- Observation and modelling studies of soil water dynamics for hydrological applications in the Indian regions, 28 August 2021.

Mr. Prodip Acharja

- Understanding chemistry of aerosols and trace gases and their source mechanisms in urban regions over India, 05 October 2021.

Mr. Santanu Halder

- Investigating long-lived Greenhouse Gas fluxes using forward & inverse modelling and concentration observations over India, 22 October 2021.

Mr. Avijit Dey

- Development of Realtime Monitory Strategy for MJO and evaluation of and its extended range forecast skills, 27 October 2021

Mr. Soumya Samanta

- Unravelling the lifecycle of organised convective systems and associated aerosol-cloud-precipitation interaction, 10 November 2021.

Mr. Mahesh Kalshetty

- Extratropical-Tropical interaction on the sub-seasonal to seasonal scale over the Indian region, 12 November 2021

Mrs. Shikha Singh

- A modelling study of upper ocean processes, mixing dynamics and deep ocean biases in tropical Indian Ocean, 16 November 2021.

Mrs. Sneha Sunil

- Study of Cloud properties and their Radiative effects: Implications to climate system, 18 November 2021.

Mr. Abhishek Gupta

- Simulating the vertical structure of atmospheric Low-Level-Jets using laboratory Wall Jets, 26 November 2021.

Mr. Manmeet Singh

- Role of volcanic and anthropogenic aerosols on the tropical ocean-atmosphere-land coupled system and the South Asian Monsoon, 30 November 2021.

Mr. Annapureddy P. Reddy

- Study of Indian monsoon variability on multi-decadal to centennial scale using oxygen isotope records of Speleothems, 08 December 2021.

Mr. Ankur Srivastava

- The Indian Summer monsoon" exploring the role of river run-off, 20 December 2021.

Ms. Swaleha Inamdar

- A study of Iodine chemistry in the Indian and Southern Ocean Marine Boundary Layer, 05 January 2022.

Mr. Panini Dasgupta

- Madden Julian Oscillation in a Changing Climate, 02 February 2022.

Mr. Subrota Halder

- The decadal variability of Tropical Indian Ocean sea surface temperature and its influence on Summer Monsoon, 16 February 2022.

Mr. Vineet Kumar Singh

- Understanding the tracks and ocean-atmosphere coupling of tropical cyclones in the north Indian Ocean in a changing climate, 18 February 2022.

Mr. Ushnanshu Dutta

- Role of Convective Microphysics Parameterization on the Simulation of Indian Summer Monsoon, 25 February 2022.

Ms. Sophia Yocob

- Understanding and Predicting the Impacts of Climate Variability and Change on Health in India, 16 March 2022.

Mr. Naresh Ganeshi

- Role of soil moisture variability on temperature extremes over the Indian subcontinent under the changing climate, 29 March 2022.

Invited Lectures/Talks Delivered Outside at Academic Institutions

Dr. R. Krishnan

- Climate Modelling and Analysis, Nobel Evening Talk Series 2021 (virtual), Science Club, IISER Pune, 21 November 2021.

Dr. C. Gnanaseelan

- Can we predict the climate few years in advance? Cochin University of Science and Technology, Kochi, 25 March 2022.

Dr. G. Pandithurai

- Aerosol-cloud interactions as observed from High-Altitude Cloud Physics Laboratory at Mahabaleshwar in Western Ghats, AICTE Virtual School on Atmospheric Pollutants and their Impacts, IIT Madras, 11 March 2022.

Dr. S. Chakraborty

- Observational aspects of atmosphere-biosphere carbon exchange processes with a special reference to Kaziranga National Park, online event on 'Climate Change Impact on Agriculture and Biodiversity in North-East India', Department of Environment Science, Tezpur University, Tezpur, 1-5 March 2022.

Dr. J. Sanjay

- Climate modelling for detailed vulnerability analysis at district level for the state of Odisha, Forest, Environment & Climate Change Department, Government of Odisha, 23 June 2021.
- Assessment of Climate Change over the Indian Region, Online Training Programme on Climate Change: Challenges and Response (for Women Scientists) organised by Centre for Disaster Management (CDM), Lal Bahadur Shastri National Academy of Administration (LBSNAA), Mussoorie, Uttarakhand and sponsored by Department of Science & Technology (DST) Ministry of Science and Technology, Government of India, New Delhi, 9 August 2021.
- Assessment of Climate Change over the Indian Region, Online Training Programme on Role of Technology in Community Level Disaster Mitigation (for Scientists and Technologists) organised by Centre for Disaster Management (CDM), Lal Bahadur Shastri National Academy of Administration (LBSNAA), Mussoorie, Uttarakhand and sponsored by Department of Science & Technology (DST) Ministry of Science and Technology, Government of India, New Delhi, 12 November 2021.
- Assessment of Climate Change over the Indian Region, Online Training Programme on Climate Change: Challenges and Response (for Scientists and Technologists) organised by Centre for Disaster Management (CDM), Lal Bahadur Shastri National Academy of Administration (LBSNAA), Mussoorie, Uttarakhand and sponsored by Department of Science & Technology (DST) Ministry of Science and Technology, Government of India, New Delhi, 20 December 2021.

Dr. S. D. Pawar

- Lightning, Festival of SCoPE for All - science communication popularisation and its Extension organised by Ministry of Culture, Government of India, Office of the Principal Scientific Advisor, Govt. of India and Vigyan Prasar at Vivekanand College, Aurangabad, Maharashtra, 27 February 2022.
- Lightning Hazards and its Nowcasting, Interpretation and Applications of Products for Nowcasting, IMD, New Delhi, 21-25 March 2022.
- Climate change and Lightning, WMO Day lecture, Yavatmal, 23 March 2022.

Dr. Milind Mujumdar

- Role of soil moisture in Land-surface processes, Prof. Ramkrishna More Arts, Commerce and Science College, Akurdi, Pune, 2 December 2021.
- Climate Change: Observations and facts, Jigyasa Vigyan Mohatsav 2022 under Azadi Ka Amrit Mahostav organised by CSIR-NCL, Pune, 14 January 2022.

Dr. S.D. Ghude

- A new very high-resolution air quality forecasting system for Delhi and South Asia, AUH Innovation Week Celebrations, 24 September 2021.

Dr. Swapna Panickal

- Major Findings of IPCC Ar6: The Physical Science Basis of Climate Change (webinar), World Water Week 2021, Centre for Water Resources Development and Management (CWRDM), Kerala, 26 August 2021.
- Climate Change Research and Earth System Modeling, Short-Term Course in Disaster Management and Climate Change organised by the UGC-Human Resource Development Centre, Kannur University, Kerala, 09-15 November 2021.

Dr. Ramesh Kumar Yadav

- Changes in the Indian monsoon circulation, Refresher Course on Climate Change, K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad in collaboration with UGC-HRDC (Human Resource Development Centre), University of Allahabad, 17-30 January 2022.

- i) Relationship between Azores High and Indian summer monsoon and ii) Relationship between Atlantic Niño and Indian summer monsoon, 5th Refresher Course in Environmental Studies (IDC), UGC-Human Resource Development Centre, Jawaharlal Nehru University, New Delhi, 21 September 2021.

Dr. J.S. Chowdary

- Indian summer Monsoon Variability: El Nino teleconnections and Beyond, International Webinar on the Recent Developments in the Research on Meteorology and Oceanography, Department of Meteorology and Oceanography, College of Science and Technology, Andhra University, Visakhapatnam, 28-29 September 2021.

Dr. Bipin Kumar

- ESS data and application of AI/ML methods, Lecture series on Data Science: Industrial Perspective, Defence Institute of Advanced Technology, Girinagar, Pune, 30 March 2022.
- Applications of deep-learning in Earth Science problem, Short Term Training Course on Recent Trends in AI, ML and Deep Learning, Parul Institute of Engineering and Technology, Barodara, 13-17 September 2021.

Mr. Somnath Mahapatra

- Earth's climate system and adverse impacts of climate change, online webinar organised by the Abhiprajna team in collaboration with Petrichor, Earth and Climate Science (ECS) Club, IISER Tirupati, 26 July 2021.

Dr. Roxy Mathew Koll

- Ocean, Weather, and Kerala, World Environment Day webinar, St. George College, Kottayam, Kerala, 5 June 2021.
- Invited talk and panel discussion on 'Coastline Management in Kerala: Socio-economic and Environmental paradigms' organised by the Association of Fisheries Graduates in connection with World Oceans Day, 12 June 2021.
- Citizen Science network monitoring rain and river water in Kerala, amidst changing monsoon patterns, monthly lecture series organised by Bhavatal, Maharashtra, 2 July 2021.
- All about Monsoons, Master Class lecture series for 5-12 graders, Centre for Science and Environment (CSE), Delhi, 7 August 2021.
- Career in Climate and Environmental Sciences, Metro Delhi International School, Delhi, 22 September 2021.
- Climate Change in the Indian Ocean, Marine Webinar Series on 'Ocean and Climate Change: the Future of our Blue Planet' organised by Bertarelli Foundation, 28 September 2021.
- Climate Change in and around the north Indian Ocean, webinar on 'Impact of Climate Change on Fisheries', College of Fisheries Panangad Alumni Association (COFPAA) and the Faculty of Fisheries, KUFOS, 15 October 2021.
- Kerala through Climate Change - today and tomorrow, organised by Meenachil River Rain Monitoring Organisation, Bhoomika Centre, Poonjar, 12 December 2021.
- Climate Change and adaptation, St. George College in Erattupetta, Kerala, 17 December 2021.
- Changing rainfall patterns over Kerala and Assam, National Service Scheme (NSS), J.J. Murphy Memorial Higher Secondary School, Yendayar, Kerala, 1 January 2022.

- **Dr. Vinu Valsala**

- Climate Modeling (Lecture series), IISER, Pune, 17-31 January 2022.
- Fundamentals of Inverse Modelling and its application on Observational Network Design, Department of Physical Oceanography, CUSAT, Kochi, 23 February 2022.

Dr. Medha Deshpande

- Physics of Tropical Cyclones and Climate Change, webinar organised by Devrukh Shikshan Prasarak Mandal, Ratnagiri, 9 April 2021.

Dr. Atul Kumar Srivastava

- Atmospheric aerosols: Unraveling the characteristics and impact assessment over the IGP, Refresher Course on Environmental Science at Utkal University, Bhubneswar, Orisha, 04 March 2022.
- Characteristics of atmospheric air pollutants and its impact assessment over the Indian summer monsoon region, Refresher Course on Research Methodology in Basic Sciences at Utkal University, Bhubneswar, Orisha, 15 March 2022.

Dr. Abhay SD Rajput

- Science communication, IPRs and ethics: Where do we lack? (inaugural invited talk), Lecture Series on 'Intellectual Property Rights' organised by Industry Academia Partnership Cell (IAPC) and Department of Botany, Jammu University, Jammu, 21 October 2021.
- Science communication: Bridging the science-society divide, Department of Chemistry, Jammu University, Jammu, 21 October 2021.

Dr. Sabin T.P.

- Climate modelling, climate change, future scenarios, climate projection, and IPCC assessments (lecture series), IMD's Direct Recruited Scientists Training Course (DRSTC), Batch No. 1, Meteorological Training Institute, IMD, Pune, June 2021.
- Science of climate change and climate modelling: are we heading towards an annual affair of weather extremes? College of Agriculture, Kerala Agricultural University, Thrissur, Kerala, 03 November 2021.
- New perspectives in climate change research and climate modelling, refresher course on Climate Change organised by the University of Allahabad in association with the UGC-HRDC, 21 January 2022.

Mr. Bhupendra Bahadur Singh

- Climate Change and IITM's valuable contributions to society, Virtual Training Workshop for Yashada's IAS Probationary Officers Batch-2019, Yashada. Pune, 12 April 2021.
- Weather, Climate and aspects of Climate Change over India, Earth Day 2021, Think India & Student for Development-Maharashtra, 22 April 2021.

Mr. Pramit Kumar Deb Burman

- Environmental Meteorology (lecture series), Advanced Meteorological Training Course (AMTC), Meteorological Training Institute, IMD, Pune, 17-25 January 2022.

Ms. Aditi Modi

- Physical Oceanography (lecture series), Forecasters Training Batch 191, Meteorological Training Institute, IMD, Pune, July-September 2021.

Mr. Sandip Ingle

- Preparation of Climate Data sets and its Sources, Impact of Climate Change on Water Resources, Rajiv Gandhi National Ground Water Training & Research Institute, Raipur, 14-18 February 2022.

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

Dr. R. Krishnan

- Asian Monsoons, UNFCCC COP26 side event 'IPCC AR6 WG1 regional climate information for Asia', 9 November 2021.
- Role of Ocean on climate-atmosphere perspective, INTROMET International conference jointly organised by Cochin University of Science and Technology, Kerala and Indian Meteorological Society, Cochin Chapter, 25 November 2021.
- Key regional climate science priorities: opportunities and challenges, First Climate Research Forum for the Southern Asia region (online), WCRP Regional Focal Points for Southern Asia, 30 November 2021.
- Climate dynamics and variability of Indian Monsoon, Azadi Ka Amrit Mahotsav (AKAM) Lecture Series, IIRS Dehradun, 4 February 2022.

Dr. A. Suryachandra Rao

- SST Fronts/Gradients in the Bay of Bengal and their Impact on Indian Summer Monsoon Rainfall at Different time scales, Workshop on Prediction and Variability of Air-Sea Interactions: the South Asian Monsoon, The Institute for Computational and Experimental Research in Mathematics, USA, 23-27 August 2021.

Dr. C. Gnanaseelan

- Decadal Variability, Predictability and Prediction (*Keynote Talk*), Annual Monsoon Workshop on Monsoon 2021 and National E-Symposium on 'Changing climate and extreme events: impacts, mitigation & Role of oceans' held online during 21-23 February 2022.

Dr. G. Pandithurai

- RADARs in Atmospheric Research (*Keynote Lecture*), International conference on Wireless communications organised by D.J. Sanghvi College of Engineering, Ville Parle, Mumbai, 8 October 2021.
- Algorithm development and visualisation requirement for weather radars, MoES Advisory Committee Meeting for the proposal on Training and Research Programme in Radar Meteorology, 04 October 2021.

Dr. S. Chakraborty

- Carbon source-sink characteristics of a semi-deciduous forest in northeast India, Frontiers in Geoscience Research Conference (Online), Physical Research Laboratory, Ahmedabad, 27-28 September 2021.
- Determination of the carbon source-sink characteristics of forest ecosystem (Online), Presidency University, Kolkata, 27 November 2021.
- Precipitation isotope: an interface between the past and present climate, Annual Monsoon E-Workshop (AMW 2021) and National E-Symposium on 'Changing Climate And Extreme Events: Impacts, Mitigation & Role of Oceans', 23 February 2022.
- Observational aspects of atmosphere-biosphere carbon exchange processes with a special reference to Kaziranga National Park, online event on 'Climate Change Impact on Agriculture and Biodiversity in North-East India,' Department of Environment Science Tezpur University, Tezpur, 1-5 March 2022.
- Investigating the atmosphere-biosphere carbon exchange processes in northeast India using the eddy-covariance technique, International Workshop on Monsoon-7 (online), New Delhi, 22-26 March 2022.

Dr. P. Mukhopadhyay

- Predicting Thunderstorm and lightning using numerical model: Current status and future challenges, National Workshop (virtual) on Technology Support and Mass Awareness for Prevention of Lightning-Casualties organised jointly by University of Calcutta, Tripura University and IET-UK Kolkata Local Network, 30 August 2021.
- Recent developments and future prospect of NWP in India (lead talk, online), INTROMET 2021, CUSAT, Kochi, Kerala, 24 November 2021.
- Weather forecasting Techniques and Applications, Two days virtual training workshop on Meteorology for System Operators, Load and RE Forecasting, POSOCO, Mumbai, 11-12 October 2021.
- How to improve prediction of extreme precipitation events, Annual Monsoon Workshop on Monsoon 2021 and National E-Symposium on changing climate and extreme events: impacts, mitigation & role of oceans, IMSP, 21-23 February 2022.
- How to improve prediction of extreme precipitation events using GFS/GEFS, Online Training on Recent Development in Weather/Climate Modelling and Data Assimilation, NCMRWF, Noida, 24-29 March 2022.

Dr. J. Sanjay

- Progress and Ongoing Activities in CORDEX South Asia, Online CORDEX Southeast Asia Outreach and Capacity Building Workshop, jointly organised by the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Ramkhamhaeng University's Center of Regional Climate Change and Renewable Energy (RUCORE) and Department of Earth Sciences and Environment, the National University of Malaysia and the CORDEX office, 15 November 2021.
- Introduction to CORDEX datasets over South Asia, ARRCC virtual training event on WCRP CORDEX data access and use for Nepal Department of Hydrology and Meteorology, ICIMOD, 7 June 2021.

Dr. Thara Prabhakaran

- Delivered a talk in the One-day Webinar on Recent Advances in Atmospheric Sciences, National Centre for Earth Science Studies, Thiruvananthapuram, 30 April 2021.
- Progress from CAIPEEX: Understanding the cloud and precipitation microphysics of cloud clusters (Lead talk), Technical Session on Clouds, Convection, and Precipitation Processes (CCP), INTROMET 2021, CUSAT, Cochin, 25 December 2021.

Dr. Anupam Hazra

- Understanding the role of deep convection on seasonal Monsoon rainfall over India, INTROMET 2021, CUSAT, Kochi, Kerala, 25 November 2021.

Dr. Milind Mujumdar

- Importance of field-scale soil moisture monitoring for techno-scientific applications, National level webinar on Role of Geosciences in Drought Management: Issues, Challenges and Opportunities, jointly organised by School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University (KBC-NMU), Jalgaon & Association of Geologists and Hydrogeologists, GEOFORUM, Aurangabad, 17 June 2021.
- Monitoring of field-scale soil moisture variations in monsoonal environment, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.
- The response of soil moisture variations to the wet and dry extremes over core monsoon zone of India, 2nd International Virtual Conference on Meteorology and Climate Science (ICMCS 2021), 10 December 2021.

Dr. Swapna Panickal

- Projections of future changes in climate, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.
- Indian Ocean warming: Increasing intense cyclonic storms and sea level rise, Multi-disciplinary Conference on Climate Change and Artisanal Fishing Communities on the Kerala Coast, Thiruvananthapuram, 25-26 March 2022.

Dr. Roxy Mathew Koll

- Climate Change in and around the Indian Ocean, IIOE-2 Steering Committee Meeting organised by IIOE-2 JPO Australia, 15 April 2021.
- Weather and Climate Extremes in the Indian Ocean, WMO Global Climate Observing System (GCOS) Meeting, 21 April 2021.
- Indian Ocean Observing System, WMO Ocean Observations Physics and Climate Panel (OOPC) Meeting, 22 April 2021.
- Understanding and Monitoring Climate Change in the Indian Ocean, First Webinar on the Effects of Climate Change on the Indian Ocean Marine Environment, Indian Ocean Rim Association (IORA), 10 May 2021.
- Cyclone and COVID - Impact and Way Forward, National Institute of Disaster Management, Ministry of Home Affairs, 2 June 2021.
- Rapid Ocean Warming and Cyclones in the Indian Ocean, World Oceans Day Webinar, Ocean Society of India (Pune), 7 June 2021.
- Increasing risks and challenges of compounding floods in a changing climate,

International Conference on Flood Management (ICFM), 15 June 2021.
- Monsoon, Kerala and Climate Change, Kerala State Disaster Management Agency (KSDMA), 15 June 2021.
- Increasing cyclones and heavy rains and the role of mangroves, Town Hall on Mangroves and Wetlands, Climate Voices and Majhi Vasundhar, Maharashtra, 26 July 2021.
- Climate Change in the Indian Ocean, Marine Webinar Series on 'Ocean and Climate Change: the Future of our Blue Planet,' Bertarelli Foundation, 28 September 2021.
- Cyclones, floods and rising sea level in a changing climate, 42nd IIG Annual Meet and International Conference, Department of Geography, University of Pune, 5 October 2021.
- Indian Ocean observing system for addressing the challenges and priorities of the next decade, First Climate Research Forum for the Southern Asia region on 'Climate science challenges and priorities in the Southern Asia region', World Climate Research Program (WCRP), 30 November 2021.
- Kerala through climate change - today and tomorrow, Meenachil River Rain Monitoring Organization, Bhoomika Centre, Poonjar, 12 December 2021.
- Engaging with the World Climate Research Programme, AGU WCRP Townhall organised by the WCRP as part of the AGU Fall Meeting 2021, 17 December 2021.
- Climate change and adaptation, St. George College, Erattupetta, Kerala, 17 December 2021.
- Climate change and impacts, Indian Farmers Movement (INFARM), INFARM Centre, Bharananganam, Kerala, 31 December 2021.
- The past and future climate of Kerala, Sastra Foundation, Kerala, 22 January 2022.
- Understanding India's Climate Vulnerabilities, PIC Online Climate Conference 2022 Decade of Change – India's Challenges in the Climate Challenged World, Pune International Centre, 18 February 2022.
- Marine heatwaves and cyclones cascading in a changing climate, Anil Agarwal Dialogue 2022 organised by the Centre for Science and Environment (CSE), Anil Agarwal Environment Training Institute, Nimli, Rajasthan, 1 March 2022.
- A roadmap to better observations of the rapidly warming Indian Ocean, International Indian Ocean Science Conference (IIOSC 2022), 15 March 2022
- Impact of Climate Change on Women and Children, Women Development Centre, Pune, 20 March 2022.

Dr. Anoop Mahajan

- Impact of oceanic emissions on ozone over India, Meeting on Ground Level Ozone: Current Understanding and Future Prospects, CSIR-NIScPR, New Delhi, 16 December 2021.

Mr. Somnath Mahapatra

- The Earth's climate system: Weather & climate and IITM, Virtual Summer Camp, Vi Educational Foundation, 29 May 2021.
- The Earth's climate system: Study of weather & climate and recent contributions of IITM (to YASHADA's Officers who visited IITM, Pune), 6 December 2021.

Dr. Prasanth A Pillai

- Impact of drop in ENSO prediction skill on ISMR prediction in recent decades (online), INTROMET 2021, CUSAT, Kochi, Kerala, 25 November 2021.

Dr. Yogesh K. Tiwari,

- Unravelling the mechanisms of atmospheric greenhouse gases variability in India, Indo-US international workshop on Water and Air Research Initiative for Societal Health - WaARISH 2021, jointly organised by SRM Institute of Science and Technology (SRMIST), SRM University, Chennai, India; Water Science Laboratory, University of Nebraska Lincoln, USA;

Department of Science and Technology (DST), and the Indo-US Science and Technology Forum (IUSSTF), held virtually at SRM Institute of Science and Technology (SRMIST), SRM University, Chennai, India, 24-25 August 2021.

- Measurement and modelling of GHGs in India, 10th Asia-Pacific GAW workshop on greenhouse gases, KMA, South Korea, 25-26 October 2021.
- On understanding effects of global warming in India using observations and modelling tools: Recent developments, Shastri Indo-Canadian Bilateral Virtual Conference on GWCE-2022 organised under Shastri Conference and Lecture Series Grant (SCLSG) 2021-22, Thanjavur, Tamil Nadu, 11-12 March 2022.

Dr. S.D. Ghude

- Air pollution studies over South Asia and its impacts on other regions, IGAC scientific session, 14 September 2021.

Dr. Atul Kumar Srivastava

- Heterogeneity in aerosol characteristics and their climatic implications over the IGB, Workshop cum training programme on 'Climate Modelling and Remote Sensing Applications for Environmental Systems' jointly organised by Amity University, Noida and India Meteorological Society (IMS), New Delhi, 07 January 2022.

Dr. Vinu Valsala

- Significance of Indian Ocean biogeochemistry and way forward, OSICON-2021, 13 August 2021.
- Climatic significance of biogeochemical interactions between the atmosphere and oceans, INTROMET-2021, 25 November 2021.
- Significance of ocean and atmosphere biogeochemical interactions in a changing climate, IMSP e-symposium, 23 February 2022.

Dr. B. Padmakumari

- IITM research program using unmanned aerial systems and standard operating procedures (SOP), during a VC meeting conducted by DGCA/MoCA with the participation of the Airport Authority of India (AAI) & IITM on 23 June 2021.

Dr. MCR Kalapureddy

- Role of radars in weather applications (webinar), Aurora's Degree and PG College, Hyderabad, 24 May 2021.
- Facts of weather radar applications (webinar), SVCE, Sriperumbudur 15 June 2021.
- Cloud radar technique inferred cloud vertical structure perspective on early identification of ISM vigor, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Dr. Anant Parekh

- Oceanic conditions during 2021, Annual Monsoon Workshop on Monsoon 2021 and National E-Symposium on 'Changing Climate And Extreme Events: Impacts, Mitigation & Role of Oceans' held online during 21-23 February 2022.
- The development of a decadal prediction system, Workshop on Ocean Climate Change Advisory Services Implementation Plan under the Vertical 2 of Deep Ocean Mission (DOM), INCOIS, Hyderabad, 15 December 2021.

Dr. Ramesh Kumar Yadav

- Climate variability and extreme weather events (CVE), INTROMET-2021 on Changing Climate: Consequences and Challenges, jointly hosted by the Cochin Chapter of the Indian Meteorological Society (IMS) and Cochin University of Science and Technology (CUSAT) during 23-26 November 2021
- Relationship between Azores High and Indian summer monsoon, Online Hindi Scientific Symposium on 75 years of independence in Earth and Atmospheric Science: Analysis and Future, NCMRWF, Noida, 21 March 2022.

Dr. Susmitha Joseph

- Recent changes in the spatio-temporal characteristics of Monsoon Intraseasonal Oscillations, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Dr. J.S. Chowdary

- Indian summer monsoon variability: El Niño-teleconnections and beyond, Annual Monsoon Workshop on Monsoon 2021 and National E-Symposium on 'Changing Climate And Extreme Events: Impacts, Mitigation & Role of Oceans' held online during 21-23 February 2022.

Dr. Bipin Kumar

- Direct numerical simulation of CCN activation: Response to particle characteristics, 4th International Workshop on Cloud Turbulence, NiTech Nagoya, Japan, 9-11 March 2022.
- Impact of turbulence on CCN activation and early growth of cloud droplets, 4th International Workshop on Cloud Turbulence, NiTech Nagoya, Japan, 9-11 March 2022.
- Introduction to ESS data, Workshop on AI/ML techniques for the Weather and Climate applications, IIT Kanpur, 12-14 March 2022.
- Deep-learning for downscaling and forecasting of meteorological variables, Workshop on AI/ML techniques for the Weather and Climate applications, IIT Kanpur, 12-14 March 2022.

Dr. Sabin T.P.

- Climate change, monsoons, IPCC-AR6 assessment of regional monsoons, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Dr. Sooraj K.P.

- Potential role of subtropical deserts in modulating Indian summer monsoon, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Mr. Bhupendra Bahadur Singh

- Links between Asian summer monsoon convection and UTLS water vapour distribution, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Mr. Raju Mandal

- Implementation of IITM-IMD extended range forecasts in the Kharif rice yield prediction on experimental basis, INTROMET-2021, CUSAT, Cochin, 23-26 November 2021.

Mr. Pramit Kumar Deb Burman

- Principle of radiative transfer, biosphere and land surface processes, Joint IMD-WMO Group Fellowship Training on Numerical Weather Prediction, Meteorological Training Institute, India Meteorological Department (IMD), Pune, 19 October 2021.
- Eddy covariance technique: theory, instrumentation and data analysis, National Training Workshop on Greenhouse Gases (GHG-3): Observations and Inverse Modeling on Indian Regional Perspective, IITM, Pune, 14-17 December 2021.

Mr. Sandip Ingle

- Preparation of Climate data sets and its sources, impact of climate change on water resources, Rajiv Gandhi National Ground Water Training & Research Institute, Raipur, 14-18 February 2022.

8. Deputations Abroad

Dr. Anoop Mahajan

- For working on the environmental and climate impacts of halogen over the 21st century – model and instrument development, Department of Atmospheric Chemistry and Climate, the Institute of Physical Chemistry Rocasolano (IQFR), CSIC, Madrid, **Spain**, 01 September to 29 November 2021.

9. Regular Staff (as on 31 March 2022)

Research Category
Director

Scientist-G
Dr. R. Krishnan
Dr. A. Suryachandra Rao
Dr. C. Gnanaseelan
Scientist-F
Dr. S.D. Pawar
Dr. Thara Prabhakaran
Dr. S. Chakraborty
Dr. G. Pandithurai
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
Dr. Padma Kumari
Mr. P. Murugvel
Dr. H.S. Chaudhari
Dr. Devendraa Siingh
Dr. Anoop Mahajan
Scientist-E
Mr. S. Mahapatra
Mr. S.M.D. Jeelani (Comp. Engg.)
Dr. Shivsai Dixit
Dr. M.N. Patil
Dr. Sachin D. Ghude
Dr. Milind Mujumdar
Dr. G.S. Meena
Mrs. Shompa Das
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.
Mr. Saumyendu De
Mr. D.K. Trivedi
Mr. Mata Mahakur
Mrs. R.V. Bhalvankar
Mr. Jnanesh S.P. (Electrical Engg.)
Dr. A.K.Srivastava
Mr. S.M. Sonbawne
Dr. P. R.C. Reddy
Dr. M.I.R. Tinmaker

Mr. N.K. Agarwal
Mrs. Anika Arora
Dr. Ayantika Dey Choudhury
Mr. Somaru Ram
Mr. Bhupendra Bahadur Singh
Scientist-D
Dr. T. Dharmaraj
Dr. Y. Jaya Rao
Dr. S.K. Mandke
Dr. Abhay SD Rajput
Dr. H.N. 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
Dr. Malay Ganai
Dr. Sudarsan Bera
Mr. Vivek Singh
Mr. Sandeep Narayanasetti
Mr. Maheswar Pradhan
Mr. Ankur Srivastava
Mr. Mriganka Sekhar Biswas
Mrs. Renu Subrata Das
Mr. Srinivasu Upparapalli
Mr. Tanmoy Goswami
Mrs. Archana Rai
Mrs. Snehlata Tirkey
Dr. Rashmi Arun Kakatkar
Mr. Raju Mandal
Mr. Avijit Dey
Ms. Chaitri Roy
Mrs. Shikha Singh
Mr. Sahadat Sarkar
Dr. Deepa J.S.
Scientist-C
Mrs. Sompriti Deb Roy
Mrs. Shilpa Malviya

Ms. Aditi Modi
Mr. Manmeet Singh
Mrs. Smrati Gupta
Mr. Subrata Mukherjee
Dr. Pramit Kumar Deb Burman
Mr. Sujit Maji
Mr. Ambuj Kumar Jha
Scientific Support Staff Category
Scientific Officer Grade-II
Mrs. S.S. Naik
Mr. D.W. Ganer
Mr. V.R. Mali
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. 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
Mrs. S.S. Kharbanda
Mr. Y.J. Pawar
Junior Translator
Mr. 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
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
Mr. Y. Srinivas Rao
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. Rakesh Bhandari
Mr. T.L. Mundhe
Mr. M.S. Waghela
Mr. I.R. Mhetre

*This list is not as per the seniority.

10. Publications

Peer-reviewed Research Publications

1. **Acharja P., Ali K., Ghude S.D.**, Sinha V., Sinha B., Kulkarn R., Gultepe I., Rajeevan M.N., Enhanced secondary aerosol formation driven by excess ammonia during fog episodes in Delhi, India, **Chemosphere**, 289: 133155, February 2022, DOI:10.1016/j.chemosphere.2021.133155, 1-11 **(Impact Factor 7.086)**
2. Afreen S., **Victor N.J.**, Nazir S., **Siingh D.**, Bashir G., Ahmad N., Ahmad S.J., Singh R.P., Fair-weather atmospheric electric field measurements at Gulmarg, India, **Journal of Earth System Science**, 131:7, March 2022, DOI:10.1007/s12040-021-01745-5, 1-19 **(Impact Factor 1.371)**
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**, 49, August 2021, DOI:10.1007/s12524-021-01340-7, 1779-1786 **(Impact Factor 1.563)**
4. Agrawal N., **Singh B.B.**, Pandey V.K., Fidelity of Regional Climate Model v4.6 in capturing seasonal and subseasonal variability of Indian summer monsoon, **Dynamics of Atmospheres and Oceans**, 94: 101203, June 2021, DOI:10.1016/j.dynatmoce.2021.101203, 1-15 **(Impact Factor 1.319)**
5. Ahmed R., **Dhanger N.**, Dwivedi S., Giri R.K., **Pithani P., Ghude S.D.,** Characteristics of fog in relation to tropical cyclone intensity: A case study for IGI airport New Delhi, **Tropical Cyclone Research and Review**, 10, September 2021, DOI:10.1016/j.tcrr.2021.09.004, 170-181 **(Impact Factor 0.000)**
6. **Akhter J., Mandal R., Chattopadhyay R., Joseph S., Dey Avijit, Nageswararao M.M.,** Pattanaik D.R., **Sahai A.K.**, Kharif rice yield prediction over Gangetic West Bengal using IITM-IMD extended range forecast products, **Theoretical and Applied Climatology**, 145, August 2021, DOI:10.1007/s00704-021-03679-w, 1089-1100 **(Impact Factor 3.179)**
7. Amat H.B., **Pradhan M.**, Tejavath C.T., **Dey Avijit**, **Rao Suryachandra A., Sahai A.K.**, Ashok K., Value addition to forecasting: towards Kharif rice crop predictability through local climate variations associated with Indo-Pacific climate drivers, **Theoretical and Applied Climatology**, 144, May 2021, DOI:10.1007/s00704-021-03572-6, 917-929 **(Impact Factor 3.179)**
8. Ambade B., Sankar T.K., **Panicker A.S.**, Gautam A.S., Gautam Sneha, Characterization, seasonal variation, source apportionment and health risk assessment of black carbon over an urban region of East India, **Urban Climate**, 38: 100896, July 2021, DOI:10.1016/j.uclim.2021.100896 **(Impact Factor 5.731)**
9. **Anand V.**, **Korhale N.**, **Tikle S.**, Rawat M.S., **Beig G.**, Is meteorology a factor to COVID-19 spread in a tropical climate?, **Earth Systems and Environment**, 5, December 2021, DOI:10.1007/s41748-021-00253-2, 939-948 **(Impact Factor 0.000)**
10. **Anandh T.S.**, Das B.K., Kuttippurath J., Chakraborty A., A comparative analysis of the Bay of Bengal Ocean state using standalone and coupled numerical models, **Asia-Pacific Journal of Atmospheric Sciences**, 57, May 2021, DOI:10.1007/s13143-020-00197-z, 347-359 **(Impact Factor 2.100)**
11. **Anil Kumar V.**, **Hazra A.**, **Pandithurai G.**, Kulkarni G., **Mohan G.M.**, **Mukherjee Subrata**, **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**, 253: 105487, May 2021, DOI:10.1016/j.atmosres.2021.105487, 1-9 **(Impact Factor 5.369)**

12. **Anju M., Valsala V.**, B.R. Smitha, Bharathi G., Naidu C.V., Observed denitrification in the northeast Arabian Sea during the winter-spring transition of 2009, **Journal of Marine Systems**, 227: 103680, March 2022, DOI:10.1016/ j.jmarsys.2021. 103680, 1-11 **(Impact Factor 2.542)**

13. Anshika, Kunchala R.K., Attada R., **Vellore R.K.**, Soni V.K., Mohan M., Chilukoti N., On the understanding of surface ozone variability, its precursors and their associations with atmospheric conditions over the Delhi region, **Atmospheric Research**, 258: 105653, August 2021, DOI:10.1016/ j.atmosres.2021.105653, 1-11 **(Impact Factor 5.369)**

14. **Arora A.,** On the role of the Arabian Sea thermal variability in governing rainfall variability over the Western Ghats, **Journal of Earth System Science**, 130: 117, June 2021, DOI:10.1007/ s12040-021-01615-0, 1-13 **(Impact Factor 1.371)**

15. **Arora A.**, The effect of the variability of wind forcing on ENSO simulation in an OGCM: case of canonical and protracted event, **Theoretical and Applied Climatology**, 147, January 2022, DOI:10.1007/s00704-021-03816-5, 265–281 **(Impact Factor 3.179)**

16. **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**, 28, July 2021, https://doi.org/ 10.1007/s11356-021-13163-7, 35266- **(Impact Factor 4.223)**

17. Asutosh A., **Fadnavis S.**, Nuncio M., Müller R., Tripathy S.C., The Arctic Temperature Response to Global and Regional Anthropogenic Sulfate Aerosols, **Frontiers in Environmental Science**, 9:766538, November 2021, DOI:0.3389/fenvs.2021.766538, 1-13 **(Impact Factor 4.581)**

18. **Beig G.**, **Rathod Aditi**, **Tikle S.**, **Maji Sujit**, **Sobhana S.B.**, Association of retreating monsoon and extreme air pollution in a megacity, **Journal of Environmental Sciences**, 106, August 2021, DOI:0.1016/j.jes.2021. 01.004, 97-104 **(Impact Factor 5.565)**

19. **Beig G.**, Sahu S.K., **Anand V.**, **Bano S.**, **Maji S.**, **Rathod A.**, **Korhale N.**, **Sobhana S.B.**, **Parkhi N.**, Mangaraj P., **Srinivas R.**, Peshin S.K., Singh S., **Shinde R.**, **Trimbake H.K.**, India's Maiden air quality forecasting framework for megacities of divergent environments: The SAFAR-project, **Environmental Modelling & Software**, 145: 105204, November 2021, DOI:10.1016/ j.envsoft.2021.105204, 1-20 **(Impact Factor 5.288)**

20. **Bera S.**, **Chowdhuri S.**, **Prabhakaran Thara**, A new methodology for the statistical descriptions of Particle-by-Particle measurements of liquid droplets in cumulus clouds, **Quarterly Journal of the Royal Meteorological Society**, 148, January 2022, DOI:10.1002/qj.4234, 842-859 **(Impact Factor 3.739)**

21. Bhaskar V.V., **Safai P.D.**, **Mukherjee S.**, Hydrochemistry of atmospheric precipitation over an urban station in the peninsular India: Assessment of the long-term data, **Atmospheric Pollution Research**, 13: 101343, March 2022, DOI: 10.1016/j.apr.2022.101343 **(Impact Factor 4.352)**

22. Bhawar R.L., **Fadnavis S.**, Vinay Kumar, **Rahul P.R.C.**, Sinha T., Lolli S., Radiative impacts of aerosols during COVID-19 lockdown period over the Indian region, **Frontiers in Environmental Science**, 9:746090, September 2021, DOI:10.3389/fenvs.2021.746090, 1-11 **(Impact Factor 4.581)**

23. **Biswas M.S.**, **Mahajan A.S.**, Year-long concurrent MAX-DOAS observations of

nitrogen dioxide and formaldehyde at Pune: understanding diurnal and seasonal variation drivers, **Aerosol and Air Quality Research**, 21: 200524, June 2021, DOI:10.4209/aaqr.200524, 1-22 **(Impact Factor 3.063)**

24. Bodaballa J.K., Geresdi I., **Ghude S.D.**, Salma I., Numerical simulation of the microphysics and liquid chemical processes occur in fog using size resolving bin scheme, **Atmospheric Research**, 266: 105972, March 2022, DOI:10.1016/j.atmosres.2021.105972 , 1-14 **(Impact Factor 5.369)**

25. **Buchunde P.S., Safai P.D., Mukherjee S., Raju M.P., Meena G.S., Sonbawne S.M., Dani K.K., Pandithurai G.,** Seasonal abundances of primary and secondary carbonaceous aerosols at a high-altitude station in the Western Ghat Mountains, India, **Air Quality Atmosphere and Health**, 15, February 2022, DOI:10.1007/s11869-021-01097-5, 209-220 **(Impact Factor 3.763)**

26. Budhavant K.B., **Gawhane R.D.**, **Rao P.S.P.**, Nair H.R.C.R., **Safai P.D.**, Long-term increasing trends in the wet deposition of secondary inorganic constituents in SW Indian precipitation, **Air Quality Atmosphere and Health**, 14, May 2021, DOI:10.1007/s11869-020-00970-z, 667-677 **(Impact Factor 3.763)**

27. Chakraborty K., **Valsala V.**, Bhattacharya T., Ghosh J., Seasonal cycle of surface ocean pCO2 and pH in the northern Indian Ocean and their controlling factors, **Progress in Oceanography**, 198: 102683, November 2021, DOI:10.1016/j.pocean.2021.102683, 1-15 **(Impact Factor 4.080)**

28. **Chakraborty S., Deb Burman P.K.**, Sarma D., Sinha N., Datye A., Metya A., Murkute C., **Saha Subodh K.**, Sujith K., Gogoi N., Bora A., Maji S., Parua D.K., **Bera S.**, Linkage between precipitation isotopes and biosphere-atmosphere interaction observed in northeast India, **npj Climate and Atmospheric Science**, 5: 8, February 2022, DOI:10.1038/s41612-022-00231-z, 1-11 **(Impact Factor 8.624)**

29. **Chakravarty K.**, Vincent V., **Vellore R.**, **Srivastava A.K.**, Rastogi R., Soni V.K., Revisiting Andhi in northern India: A case study of severe dust-storm over the urban megacity of New Delhi, **Urban Climate**, 37: 100825, May 2021, DOI:10.1016/j.uclim.2021.100825, 1-11 **(Impact Factor 5.731)**

30. **Chakravarty Kaustav**, Arun N., **Yadav P.**, Bhangale R., **Murugavel P.**, Kanawade V.P., Mohmmad J., Hosalikar K.S., **Pandithurai G.**, Characteristics of precipitation microphysics during Tropical Cyclone Nisarga (2020) as observed over the orographic region of Western Ghats in the Indian sub-continent, **Atmospheric Research**, 264: 105861, December 2021, DOI:10.1016/j.atmosres.2021.105861, 1-10 **(Impact Factor 5.369)**

31. **Chakravarty Kaustav**, 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**, 107, June 2021, DOI:10.1007/s11069-021-04637-5, 1413-1426 **(Impact Factor 3.102)**

32. **Chakravarty Kaustav**, Khandar S., Kiran Kumar N.V.P., Bhangale R., Maitra A., The interseasonal features of precipitation microphysics over Thiruvananthapuram and Kolkata - the two tropical stations of Indian sub-continent, **Journal of Atmospheric and Solar Terrestrial Physics**, 222: 105710, October 2021, DOI:10.1016/j.jastp.2021.105710, 1-11 **(Impact Factor 1.735)**

33. Chakravorty S., Perez R.C., **Gnanaseelan C.**, Anderson B.T., Revisiting the recharge and discharge processes for different flavors of El Niño, **Journal of Geophysical Research:**

Oceans, 126: e2020JC017075, November 2021, DOI:10.1029/2020JC017075, 1-15 **(Impact Factor 3.405)**

34. **Chaluvadi R., Varikoden H., Mujumdar M.**, Ingle S.T., Kuttippurath J., Changes in large-scale circulation over the Indo-Pacific region and its association with 2018 Kerala extreme rainfall event, **Atmospheric Research**, 263: 105809, December 2021, DOI:10.1016/j.atmosres. 2021.105809, 1-12 **(Impact Factor 5.369)**
35. **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**, 41, June 2021, DOI:10.1002/joc.7057, 4047-4060 **(Impact Factor 4.069)**
36. Chatterjee M., Shankar D., Vijith V., Sen G.K., Sundar D., Michael G.S., Amol P., Chatterjee A., Sanyal P., Chatterjee S., Basu A., Chakraborti S., Mishra S.K., Suprit K., Mukherjee D., Mukherjee A., **Mukhopadhyay S.**, Mondal G., Kalla A., Das M., Variation of salinity in the Sundarbans Estuarine System during the Equinoctial Spring tidal phase of March 2011, **Journal of Earth System Science**, 130: 150, July 2021, DOI: 10.1007/s12040-021-01636-9, 1-25 **(Impact Factor 1.371)**
37. **Chavan P., Fadnavis S., Chakroborty T.**, Sioris C.E., Griessbach S., Müller R., The outflow of Asian biomass burning carbonaceous aerosol into the upper troposphere and lower stratosphere in spring: radiative effects seen in a global model, **Atmospheric Chemistry and Physics**, 21, September 2021, DOI:10.5194/ acp-21-14371-2021, 14371-14384 **(Impact Factor 6.133)**
38. Chinta V., Chen Z., Du Y., **Chowdary J.S.**, Influence of the Interdecadal Pacific Oscillation on South Asian and East Asian summer monsoon rainfall in CMIP6 models, **Climate Dynamics**, 58, March 2022, DOI:10.1007/s00382-021-05992-6, 1791–1809 **(Impact Factor 4.375)**
39. **Chowdary J.S., Vibhute A.S., Patekar P., Parekh A., Gnanaseelan C.,** Attada R., Meridional displacement of the Asian jet and its impact on Indian summer monsoon rainfall in observations and CFSv2 hindcast, **Climate Dynamics**, 58, February 2022, DOI:10.1007/ s00382-021-05935-1, 811-829 **(Impact Factor 4.375)**
40. **Chowdhuri S.,** Iacobello G., Banerjee T., Visibility network analysis of large-scale intermittency in convective surface layer turbulence, **Journal of Fluid Mechanics**, 925: A38, October 2021, DOI:10.1017/ jfm.2021.720, 1-15 **(Impact Factor 3.627)**
41. **Chowdhuri S., Todekar K., Prabhakaran Thara,** The characterization of turbulent heat and moisture transport during a gust-front event over the Indian peninsula, **Environmental Fluid Mechanics**, 21, August 2021, DOI:10.1007/ s10652-021-09802-9, 907-924 **(Impact Factor 2.551)**
42. Collins M., Ashok K., Barreiro M., **Roxy M.K.**, Kang S.M., Frölicher T.L., Wang G., Tedeschi R.G., Editorial: New Techniques for Improving Climate Models, Predictions and Projections, **Frontiers in Climate**, 3: 811205, December 2021, DOI:10.3389/fclim.2021.811205, 1-3 **(Impact Factor 0.000)**
43. **Darshana P., Chowdary J.S., Parekh A., Gnanaseelan C.**, Relationship between the Indo-western Pacific Ocean capacitor mode and Indian summer monsoon rainfall in CMIP6 models, **Climate Dynamics**, Online, January 2022, DOI:10.1007/s00382-021-06133-9, 1-23 **(Impact Factor 4.375)**
44. Das S., Giorgi F., Coppola E., **Panicker A.S.**, Gautam A.S., Nair V.S., Giuliani G., Linkage between the absorbing aerosol-induced snow darkening effects over the Himalayas-Tibetan Plateau and the pre-monsoon climate over

northern India, **Theoretical and Applied Climatology**, 147, February 2022, DOI:10.1007/s00704-021-03871-y, 1033-1048 **(Impact Factor 3.179)**

45. **Dasgupta P.**, **Roxy M.K.**, **Chattopadhyay R.**, Naidu V., **Metya Abirlal**, Interannual variability of the frequency of MJO phases and its association with two types of ENSO, **Scientific Reports**, 11: 11541, June 2021, DOI:10.1038/s41598-021-91060-2, 1-15 **(Impact Factor 4.379)**
46. **Deb Burman P.K., Chakraborty S.**, El-Madany T.S., Ramasubramanian R., Gogoi N., Gnanamoorthy P., **Murkute C.**, Nagarajan R., Karipot A., A comparative study of ecohydrologies of a tropical mangrove and a broadleaf deciduous forest using eddy covariance measurement, **Meteorology and Atmospheric Physics**, 134: 4, February 2022, DOI:10.1007/s00703-021-00840-y, 1-22 **(Impact Factor 2.065)**
47. **Deb Burmana P.K.,** Launiainen S., **Mukherjee S.**, **Chakraborty S.**, Gogoi N., **Murkute C.**, Lohani P., **Sarma D.**, Kumar K., Ecosystem-atmosphere carbon and water exchanges of subtropical evergreen and deciduous forests in India, **Forest Ecology and Management**, 495: 119371, September 2021, DOI:10.1016/j.foreco. 2021.119371, 1-14 **(Impact Factor 3.558)**
48. **Debnath S., Jena C., Ghude S.D.**, Kumar Rajesh, **Govardhan G., Gunwani P., Saha Subodh K., Hazra A., Pokhrel S.**, Simulation of Indian Summer Monsoon Rainfall (ISMR) with fully coupled regional chemistry transport model: A case study for 2017, **Atmospheric Environment**, 268: 118785, January 2022, DOI:10.1016/j.atmosenv.2021.118785, 1-14 **(Impact Factor 4.798)**
49. **Deepa J.S., Gnanaseelan C., Parekh A.,** The sea level variability and its projections over the Indo-Pacifc Ocean in CMIP5 models, **Climate Dynamics**, 57, July 2021, DOI:10.1007/s00382-021-05701-3, 173-193 **(Impact Factor 4.375)**
50. **Deshpande M., Singh V.K.,** Ganadhi M.K., **Roxy M.K., Emmanuel R.**, Kumar Umesh, Changing status of tropical cyclones over the north Indian Ocean, **Climate Dynamics**, 57, December 2021, DOI:10.1007/s00382-021-05880-z, 3545-3567 **(Impact Factor 4.375)**
51. **Dhangar N.G., Lal D.M.**, **Ghude S.D.**, **Kulkarni R.**, Parde A.N., **Pithani P.**, Niranjan K., Prasad D.S.V.V.D., **Jena C.**, Sajjan V.S., **Prabhakaran Thara**, Karipot A.K., Jenamani R.K., Singh S., **Rajeevan M.**, On the conditions for onset and development of fog over New Delhi: An observational study from the WiFEX, **Pure and Applied Geophysics**, 178, September 2021, DOI:10.1007/s00024-021-02800-4, 3727-3746 **(Impact Factor 2.335)**
52. Dhanya G., Pranesha T.S., Nagaraja K., Chate D.M., **Beig G.,** Variability of ozone and oxides of nitrogen in the tropical city, Bengaluru, India, **Environmental Monitoring and Assessment**, 193: 844, November 2021, DOI:0.1007/s10661-021-09635-5, 1-15 **(Impact Factor 2.513)**
53. Dhavamurthy M., Vijayasundaram S.V., **Victor N.J.**, Investigation of Energy Transfer Mechanism and Photoluminescence Properties of Ce3+/Dy3+ and Ce3+/Sm3+ Co-Doped Barium Borate Glasses for w-LED Applications , **Glass Physics and Chemistry**, 47, December 2021, DOI:10.1134/S108765962107004X, S21–S35 **(Impact Factor 0.883)**
54. Dutta S., Jagtap M., Balasubramaniam R., Kulkarni N., Danish M., Deshpande S., Satpute U., **Sahai A.K.**, Wayal R., Bhagbat P., Nambier B., Kulkarni D., Bile L., Kamble P.V., AwateP., Ghosh K., Sawaisarje G.K., Khedikar S., Patil C., Alam O., A pilot study on assessing the effect of climate on the incidence of vector borne disease at Pune and Pimpri-Chinchwad area, Maharashtra, **Mausam**, 72, April 2021, 399-414 **(Impact Factor 0.636)**

55. **Dutta U.**, **Hazra A.**, **Chaudhari H.S.**, **Saha Subodh K.**, **Pokhrel S.**, Shiu C.-J., Chen J.-P., Role of microphysics and convective autoconversion for the better simulation of tropical intraseasonal oscillations (MISO and MJO), **Journal of Advances in Modeling Earth Systems**, 13: e2021MS002540, October 2021, DOI:10.1029/2021MS002540, 1-32 **(Impact Factor 6.660)**

56. **Emmanuel R., Deshpande M., Gandhi M.K.,** Ingle S.T., Genesis of severe cyclonic storm Mora in the presence of tropical waves over the North Indian Ocean, **Quarterly Journal of the Royal Meteorological Society**, 147, July 2021, DOI:10.1002/qj.4113, 3017-3031 **(Impact Factor 3.739)**

57. **Fadnavis S., Sabin T.P.**, Rap A., Müller R., Kubin A., Heinold B., The impact of COVID-19 lockdown measures on the Indian summer monsoon, **Environmental Research Letters**, 16: 074054, July 2021, DOI: 10.1088/1748-9326/ac109c, 1-13 **(Impact Factor 6.793)**

58. Fazli H., Janbaz A.A., Rabbaniha M., Khedmati K., **Chaudhari H.S.**, Study of environmental and three kilka species regime shifts in the Caspian Sea, **Iranian Journal of Fisheries Sciences**, 20, September 2021, 1247-1261 **(Impact Factor 0.801)**

59. 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**, 23, June 2021, DOI:10.1007/s10668-020-00994-6, 8774-8797 **(Impact Factor 3.219)**

60. Gharat J., **Kumar Bipin**, Ragha L., Barve A., **Jeelani S.M.**, Clyne J., Development of NCL equivalent serial and parallel python routines for meteorological data analysis, **International Journal of High Performance Computing Applications**, 36, March 2022, DOI:10.1177/10943420221077110, 337-355 **(Impact Factor 1.942)**

61. Gnanamoorthy P., **Chakraborty S.**, Nagarajan R., Ramasubramanian R., Selvam V., **Deb Burman P.K.**, Partha Sarathy P., Zeeshan M., Song Q., Zhang Y., Seasonal variation of methane fluxes in a mangrove ecosystem in South India: An eddy covariance-based approach, **Estuaries and Coasts**, 45, March 2022, DOI:10.1007/s12237-021-00988-1, 551–566 **(Impact Factor 2.976)**

62. Gnanamoorthy P., Song Q., Zhao J., Zhang Y., Liu Y., Zhou W., Sha L., Zexin Fan, **Deb Burman P.K.**, Altered albedo dominates the radiative forcing changes in a subtropical forest following an extreme snow event, **Global Change Biology**, 27, December 2021, DOI:10.1111/gcb.15885, 6192-6205 **(Impact Factor 10.863)**

63. **Gopalakrishnan V., Pawar S.D., Domkawale M.A.**, Charging processes during the dissipation stage of thunderstorms, **Meteorology and Atmospheric Physics**, 133, June 2021, DOI:10.1007/s00703-020-00755-0, 467-478 **(Impact Factor 2.065)**

64. Grabowski W.W., **Thomas L., Kumar Bipin**, Impact of cloud-base turbulence on CCN activation: Single-size CCN , **Journal of the Atmospheric Sciences**, 79, February 2022, DOI:10.1175/JAS-D-21-0184.1, 551–566 **(Impact Factor 3.184)**

65. Gumber S., Ghosh S., **Bera S., Prabhakaran Thara**, On the importance of non-ideal sulphate processing of multi-component aerosol haze over urban areas, **Meteorology and Atmospheric Physics**, 134: 37, March 2022, DOI:10.1007/s00703-022-00877-7, 1-18 **(Impact Factor 2.065)**

66. **Gupta S.,** Upadhayaya A.K., **Siingh D.**, Ionospheric response to sudden stratospheric warming events across longitudes during

solar cycle 24, **JGR Space Physics**, 126: e2021JA029206, October 2021, DOI:10.1029/2021JA029206, 1-21 **(Impact Factor 2.811)**

67. **Gupta Smrati, Tiwari Y.K., Revadekar J.V., Deb Burman P.K., Chakraborty S.**, Gnanamoorthy P., An intensification of atmospheric CO2 concentrations due to the surface temperature extremes in India, **Meteorology and Atmospheric Physics**, 133, December 2021, DOI:10.1007/s00703-021-00834-w, 1647-1659 **(Impact Factor 2.065)**
68. **Halder M., Kanase R., Mukhopadhyay P., Halder S., Pawar S.D.**, Domkawle M., Pandey A.C., Latest approaches to thunderstorm/lightning and severe weather forecasting using high resolution numerical model, **Vayumandal**, 47, June 2021, 42-52 **(Impact Factor 0.000)**
69. **Halder S., Parekh A., Chowdary J.S., Gnanaseelan C.**, Dynamical and moist thermodynamical processes associated with Western Ghats rainfall decadal variability, **npj Climate and Atmospheric Science**, 5: 8, February 2022, DOI:10.1038/s41612-022-00232-y, 1-11 **(Impact Factor 8.624)**
70. **Halder S., Tiwari Y.K., Valsala V.,** Sijikumar S., Janardanan R., Maksyutov S., Benefits of satellite XCO2 and newly proposed atmospheric CO2 observation network over India in constraining regional CO2 fluxes, **Science of The Total Environment**, 812: 151508, March 2022, DOI:10.1016/ j.scitotenv.2021.151508, 1-12 **(Impact Factor 7.963)**
71. **Halder Santanu., Tiwari Y.K., Valsala V., Sreeush M.G.**, Sijikumar S., Janardanan R., Maksyutov S., Quantification of enhancement in atmospheric CO2 background due to Indian biospheric fluxes and fossil fuel emissions, **Journal of Geophysical Research: Atmospheres**, 126: e2021JD034545, July 2021, DOI:10.1029/2021JD034545, 1-20 **(Impact Factor 4.261)**
72. **Hamza F.**, Anju M., **Valsala V.**, Smitha B.R., A bioenergetics model for seasonal growth of Indian oil sardine (Sardinella longiceps) in the Indian west coast, **Ecological Modelling**, 456: 109661, September 2021, DOI:10.1016/j.ecolmodel.2021.109661 **(Impact Factor 2.974)**
73. Hari Prasad K.B.R.R., **Ramu D.A.**, **Rao Suryachandra A.**, Hameed S.N., Samanta D., **Srivastava Ankur**, Reducing systematic biases over the Indian region in CFS V2 by dynamical downscaling, **Earth and Space Science**, 8: e2020EA001507, June 2021, DOI:10.1029/2020EA001507, 1-19 **(Impact Factor 2.900)**
74. Hrudya P.H., **Varikoden H.**, Vishnu R., Regional variabilities of rainfall and convective parameters during the summer monsoon period: their linkage with El Niño Southern Oscillation, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00802-4, 1223-1232 **(Impact Factor 2.065)**
75. **Hulswar S.**, Prajakta Mohite, Soni V.K., **Mahajan A.S.**, Differences between in-situ ozonesonde observations and satellite retrieved ozone vertical profiles across Antarctica, **Polar Science**, 30: 100688, December 2021, DOI:10.1016/j.polar.2021.100688, 1-13 **(Impact Factor 1.927)**
76. Jamshadali V.H., Reji M.J.K., **Varikoden H.**, Vishnu R., Spatial variability of south Asian summer monsoon extreme rainfall events and their association with global climate indices, **Journal of Atmospheric and Solar Terrestrial Physics**, 221: 105708, September 2021, DOI:10.1016/j.jastp.2021.105708, 1-14 **(Impact Factor 1.735)**
77. Jayakumar A., Gordon H., Francis T., Hill AA., Mohandas S., Sandeepan B.S., Mitra A.K., **Beig G.**, Delhi Model with Chemistry and aerosol framework (DM-Chem) for high-resolution fog forecasting, **Quarterly Journal of the Royal**

Meteorological Society, 147, October 2021, DOI:10.1002/qj.4163, 3957-3978 **(Impact Factor 3.739)**

78. Jeeva K., Seemala G.K., Selvaraj C., Rathod G., **Kamra A.K.**, Sinha A.K., Responses of various types of antennas to the globally distributed air-earth current monitored at Maitri, Antarctica, **Polar Science**, 30: 100657, December 2021, DOI:10.1016/j.polar.2021.100657, 1-9 **(Impact Factor 1.927)**

79. **Jha A.K., Das Subrata Kumar, Deshpande S.M., Murali Krishna U.V.**, Understanding the relationship of storm- to large-scale environment in the monsoon trough region: results inferred from long-term radar and reanalysis datasets, **Quarterly Journal of the Royal Meteorological Society**, 148, January 2022, DOI:10.1002/qj.4194, 97-116 **(Impact Factor 3.739)**

80. **Jha Ambuj K.**, Analysing Seasonal Variations in the Tropical Tropopause and the Impact of Deep Convection on the Tropopause Structure Over a High-Altitude Station in the Western Ghats, **Pure and Applied Geophysics**, 179, February 2022, DOI:10.1007/s00024-021-02940-7, 845–861 **(Impact Factor 2.335)**

81. **Jnanesh S.P., Lal D.M., Gopalakrishnan V., Ghude S.D., Pawar S.D., Tiwari Suresh**, Srivastava M.K., Lightning characteristics over humid regions and arid regions and their association with aerosols over Northern India, **Pure and Applied Geophysics**, Online, February 2022, DOI:10.1007/s00024-022-02981-6, 1-17 **(Impact Factor 2.335)**

82. **Joseph S., Sahai A.K.**, Shabu H., **Chattopadhyay R., Kaur Manpreet**, Recent changes in the spatio-temporal characteristics of monsoon intraseasonal oscillations, **Theoretical and Applied Climatology**, 147, January 2022, DOI:10.1007/s00704-021-03830-7, 251–264 **(Impact Factor 3.179)**

83. Joshi M.K., **Rai A., Kulkarni Ashwini**, Global-scale interdecadal variability a skillful predictor at decadal-to-multidecadal timescales for Sahelian and Indian Monsoon Rainfall, **npj Climate and Atmospheric Science**, 5: 2, January 2022, DOI:10.1038/s41612-021-00227-1, 1-8 **(Impact Factor 8.624)**

84. Kaginalkar A., **Ghude S.D.**, Mohanty U.C., Mujumdar P., … et al. , Integrated Urban Environmental System of Systems for Weather Ready Cities in India, **Bulletin of the American Meteorological Society**, 103, January 2022, DOI:10.1175/BAMS-D-20-0279.1, E54–E76 **(Impact Factor 8.766)**

85. **Kalbande R., Bano S., Beig G.**, Benzene and Toluene from Stubble Burning and Their Implications for Ozone Chemistry and Human Health in the Indo-Gangetic Plain Region, **ACS Earth and Space Chemistry**, 5, November 2021, DOI:10.1021/acsearthspacechem.1c00283, 3226-3233 **(Impact Factor 3.475)**

86. **Karmakar Ananya, Parekh A., Chowdary J.S., Gnanaseelan C.**, Influence of multi-mission chlorophyll-a data on the simulation of upper ocean thermal structure in the eastern Pacific Ocean, **International Journal of Remote Sensing**, 42, May 2021, DOI:10.1080/2150704X.2021.1875146, 3445-3455 **(Impact Factor 3.151)**

87. **Karmakar N., Joseph S., Sahai A.K.**, Northward propagation of convection over Arabian Sea and Bay of Bengal: a perspective from vorticity equation, **Climate Dynamics**, Online, March 2022, DOI:10.1007/s00382-022-06248-7, 1-17 **(Impact Factor 4.375)**

88. **Kaur M., Sahai A.K., Krishna R.P.M., Joseph S., Mandal R., Dey Avijit, Chattopadhyay R.,** Multi-physics schema for sub-seasonal prediction of Indian summer monsoon, **Climate Dynamics**, 58, February 2022, DOI:10.1007/ s00382-021-05926-2, 669–690 **(Impact Factor 4.375)**

89. **Konwar M., Prabhakaran Thara**, Khain A., Pinsky M., Cloud microphysical structure analysis based on high-resolution insitu measurements, **Journal of the Atmospheric Sciences**, 78, July 2021, DOI:10.1175/JAS-D-20-0229.1, 2265–2285 **(Impact Factor 3.184)**

90. **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**, 14, April 2021, DOI:10.1007/s11869-020-00958-9, 533-542 **(Impact Factor 3.763)**

91. **Korhale N., Anand V., Panicker A., Beig G.,** Measurements of surface ozone and its precursors in different microenvironments of coastal Indian metropolis of Mumbai, **International Journal of Environmental Science and Technology**, Online, January 2022, DOI:10.1007/s13762-022-03910-9, 1-18 **(Impact Factor 2.860)**

92. Koteswara Rao K., Lakshmi Kumar T.V., **Kulkarni Ashwini, Chowdary J.S.,** Desamsetti S., Characteristic changes in climate projections over Indus Basin using the bias corrected CMIP6 simulations, **Climate Dynamics**, Online, January 2022, DOI:10.1007/s00382-021-06108-w, 1-25 **(Impact Factor 4.375)**

93. **Kripalani R.H.**, Ha Kyung-Ja, Ho Chang-Hoi, Oh Jai-Ho, **Preethi B., Mujumdar M., Prabhu A.**, Erratic Asian summer monsoon 2020: COVID-19 lockdown initiatives possible cause for these episodes?, **Climate Dynamics**, Online, January 2022, DOI:10.1007/s00382-021-06042-x, 1-14 **(Impact Factor 4.375)**

94. **Kulkarni G.**, Patade S., Fan J., **Prabhakaran Thara**, Pathways of precipitation formation in different thermodynamic and aerosol environments over the Indian Peninsula, **Atmospheric Research**, 266: 105934, March 2022, DOI:10.1016/j.atmosres.2021.105934, 1-15 **(Impact Factor 5.369)**

95. **Kulkarni G., Sandeep J., Murugavel P., Chowdhuri S., Konwar M., Dinesh G., Todekar K., Bankar S., Dixit S.A., Malap N., Prabhakaran Thara,** Evaluation of high-resolution WRF model forecasts and their use for cloud seeding decisions, **Journal of Atmospheric and Solar Terrestrial Physics**, 228: 105825, February 2022, DOI:10.1016/j.jastp. 2022.105825, 1-14 **(Impact Factor 1.735)**

96. Kumar Ashish, Hakkima H., **Ghude S.D.**, Sinha V., Probing wintertime air pollution sources in the Indo-Gangetic Plain through 52 hydrocarbons measured rarely at Delhi & Mohali, **Science of the Total Environment**, 801: 149711, December 2021, DOI:10.1016/j. scitotenv.2021.149711, 1-15 **(Impact Factor 7.963)**

97. **Kumar Bipin**, Ranjan R., Yau M-K, Bera Sudarsan, Rao Suryachadra A., Impact of high- and low-vorticity turbulence on cloud–environment mixing and cloud microphysics processes, **Atmospheric Chemistry and Physics**, 21, August 2021, DOI:10.5194/acp-21-12317-2021, 12317-12329 **(Impact Factor 6.133)**

98. **Kumar Bipin**, Rehme M., Suresh N., Cherukuru N., Stanislaw J., Li S., Pearse S., Scheitlin T., **Rao Suryachandra A., Nanjundiah R.S.**, Optimization of DNS code and visualization of entrainment and mixing phenomena at cloud edges, **Parallel Computing**, 107:102811, August 2021, DOI:10.1016/j.parco.2021. 102811 **(Impact Factor 0.986)**

99. Kumar Sunil, Singh A., **Srivastava Atul K.**, Sahu S.K., Hooda R.K., Dumka U.C., Pathak V., Long-term change in aerosol characteristics over Indo-Gangetic Basin: How significant is the impact of emerging anthropogenic activities?, **Urban Climate**, 38: 100880, July 2021, DOI:10.1016/j.uclim.2021.100880, 1-16 **(Impact Factor 5.731)**

100. Kunchala R.K., **Singh B.B.**, Karumuri R.K., Attada R., Seelanki V., Kumar K.N., Understanding the spatiotemporal variability and trends of surface ozone over India, **Environmental Science and Pollution Research**, 29, January 2022, DOI:10.1007/s11356-021-16011-w, 6219–6236 **(Impact Factor 4.223)**

101. Kushwaha P., Sukhatme J., **Nanjundiah R.**, A Global Tropical Survey of Midtropospheric Cyclones, **Monthly Weather Review**, 149, August 2021, DOI:10.1175/MWR-D-20-0222.1, 2737–2753 **(Impact Factor 3.735)**

102. Lakshmi Kumar T.V., Durga G.P., **Koteswara Rao K.**, Barbosa H., **Kulkarni Ashwini, Patwardhan S.**, Mall R.K., Rao V.B., Connection of Quasi-Resonant Amplification to the Delay in Atmospheric Residence Times Over India , **Frontiers in Earth Science**, 9: 615325, April 2021, DOI:10.3389/feart.2021.615325, 1-10 **(Impact Factor 3.498)**

103. Lalchandani V., Kumar V., Tobler A., Thamban N.M., Mishra S., Slowik J.G., Bhattu D., Rai P., Satish R., Ganguly D., **Tiwari Suresh**, Rastogi N., … et al., Real-time characterization and source apportionment of fine particulate matter in the Delhi megacity area during late winter, **Science of the Total Environment**, 770: 145324, May 2021, DOI:10.1016/j.scitotenv.2021.145324 , 1-17 **(Impact Factor 7.963)**

104. Lalchandani V., Srivastava D., Dave J., Mishra S., Tripathi N., Shukla A.K., Sahu R., Thamban N.M., Gaddamidi S., Dixit K., Ganguly D., Tiwari S., **Srivastava Atul K.**, Sahu L., Rastogi N., Gargava P., Tripathi S.N., Effect of biomass burning on PM2.5 composition and secondary aerosol formation during post-monsoon and winter haze episodes in Delhi, **Journal of Geophysical Research: Atmospheres**, 127: e2021JD035232, January 2022, DOI:10.1029/2021JD035232, 1-21 **(Impact Factor 4.261)**

105. Lathika N., Rahaman W., Tarique M., **Gandhi N.**, Kumar A., Thambana M., Deep water circulation in the Arabian Sea during the last glacial cycle: Implications for paleo-redox condition, carbon sink and atmospheric CO2 variability, **Quaternary Science Reviews**, 257: 106853, April 2021, DOI:10.1016/j.quascirev.2021.106853, 1-16 **(Impact Factor 4.112)**

106. Lawand D., Bhakare S., **Fadnavis S.**, Bhawar R.L., **Rahul P.R.C.**, Pallath P.K., Lolli S., Variability of Aerosols and Clouds Over North Indian and Myanmar During the COVID-19 Lockdown Period, **Frontiers in Environmental Science**, 10: 838778, March 2022, DOI:10.3389/fenvs.2022.838778, 1-11 **(Impact Factor 4.581)**

107. **Leena P.P.**, Sravanthi N., **Anil Kumar V.**, **Pandithurai G.**, **Panicker A.S.**, Aerosol–Cloud–Rainfall Properties Inferred from Satellite Observations Over Different Regions of the Indian Subcontinent: Variability, Trends and Relationships During the Summer Monsoon, **Pure and Applied Geophysics**, 178, November 2021, DOI:10.1007/s00024-021-02892-y, 4619–4631 **(Impact Factor 2.335)**

108. **Leena P.P.**, **Varghese M.**, **Anil Kumar V.**, Basheer A.I., **Pandithurai G.**, Droplet characteristics in monsoon clouds before rain as observed over a high altitude site in Western Ghats, India, **Journal of Atmospheric and Solar Terrestrial Physics**, 221: 105709, September 2021, DOI:10.1016/j.jastp.2021.105709, 1-9 **(Impact Factor 1.735)**

109. Lekshmi S., **Chattopadhyay R., Kaur M., Joseph S., Phani R., Dey Avijit, Mandal R., Sahai A.K.,** Role of initial error growth in the extended range prediction skill of Madden-Julian Oscillation (MJO), **Theoretical and Applied Climatology**, 147, January 2022, DOI:10.1007/s00704-021-03818-3, 205–215 **(Impact Factor 3.179)**

110. **Mahajan A.S., Biswas M.S.**, Beirle S., Wagner T., Schönhardt A., Benavent N., Saiz-Lopez A., Observations of iodine monoxide over three summers at the Indian Antarctic bases of Bharati and Maitri , **Atmospheric Chemistry and Physics**, 21, August 2021, DOI:10.5194/acp-21-11829-2021, 11829–11842 **(Impact Factor 6.133)**

111. **Mahajan A.S.**, Li Q., **Inamdar Swaleha**, Ram K., Badia A., Saiz-Lopez A., Modelling the impacts of iodine chemistry on the northern Indian Ocean marine boundary layer, **Atmospheric Chemistry and Physics**, 21, June 2021, DOI:10.5194/acp-21-8437-2021, 8437-8454 **(Impact Factor 6.133)**

112. Mahajana S., Sathe V., Rai N., Agrawal S., **Chakraborty S.**, Human tooth enamel carbon and oxygen stable isotope dataset from chalcolithic Inamgaon (India), **Data in Brief**, 40: 107711, February 2022, DOI:10.1016/j.dib.2021.107711, 1-8 **(Impact Factor 0.000)**

113. Maheshwarkar P., Ralhan A., Sunder Raman R., Tibrewal K., ..., Lian Y., **Pandithurai G.**, ... et al., Understanding the Influence of Meteorology and Emission Sources on PM2.5 Mass Concentrations Across India: First Results From the COALESCE Network, **Journal of Geophysical Research: Atmospheres**, 127: e2021JD035663, February 2022, DOI:10.1029/2021JD035663, 1-15 **(Impact Factor 4.261)**

114. Maheskumar R.S., **Padmakumari B., Savita Morwal, Kulkarni J.R.**, Role of topography and aerosols in the rainfall over the Western Ghats and rain shadow regions as inferred from aircraft measurements, **Vayumandal**, 47, December 2021, 86-95 **(Impact Factor 0.000)**

115. **Maji S., Yadav R., Beig G.**, Gunthe S.S., Ojha N., On the processes governing the variability of PTR-MS based VOCs and OVOCs in different seasons of a year over hillocky mega city of India, **Atmospheric Research**, 261: 105736, October 2021, DOI:10.1016/j.atmosres.2021.105736, 1-13 **(Impact Factor 5.369)**

116. **Malap N., Prabhakaran Thara**, Karipot A., Impact of middle atmospheric humidity on boundary layer turbulence and clouds, **Journal of Atmospheric and Solar Terrestrial Physics**, 215: 105553, April 2021, DOI: 10.1016/j.jastp.2021.105553, 1-14 **(Impact Factor 1.735)**

117. **Mallick C., Hazra A., Saha Subodh K., Chaudhari H.S., Pokhrel S., Konwar M., Dutta U., Mohan G.M., Vani K.G.**, Seasonal predictability of lightning over the global hotspot regions , **Geophysical Research Letters**, 49: e2021GL096489, January 2022, DOI:10.1029/2021GL096489, 1-11 **(Impact Factor 4.720)**

118. Mandyam K.S., Dasgupta A.K., Sridhar U., **Dasgupta P.**, Chakrabarti A., Network approaches in anomaly detection for disease conditions, **Biomedical Signal Processing and Control**, 68: 102659, July 2021, DOI:10.1016/j.bspc.2021.102659 **(Impact Factor 3.880)**

119. Mangaraj P., Sahu S.K., Beig G., **Yadav R.**, A comprehensive high-resolution gridded emission inventory of anthropogenic sources of air pollutants in Indian megacity Kolkata, **SN Applied Sciences**, 4: 117, March 2022, DOI:10.1007/s42452-022-05001-3, 1-17 **(Impact Factor 0.000)**

120. **Marathe S.**, Terray P., Karumuri A., Tropical Indian Ocean and ENSO relationships in a changed climate, **Climate Dynamics**, 56, May 2021, DOI:10.1007/s00382-021-05641-y, 3255-3276 **(Impact Factor 4.375)**

121. **Metya Abirlal, Chakraborty S.**, Bhattacharya S.K., **Datye Amey, Deb Burman P.K., Dasgupta P.,** Sarma D., Gogoi N., Bora A., Isotopic and

concentration analyses of CO2 and CH4 in association with the eddy-covariance based measurements in a tropical forest of northeast India, **Earth and Space Science**, 8: e2020EA001504, June 2021, DOI:10.1029/2020EA001504, 1-15 **(Impact Factor 2.900)**

122. Mina U., Kandpal A., Bhatia A., **Ghude S., Bisht D.S.**, Kumar Pramod, Wheat Cultivar Growth, Biochemical, Physiological and Yield Attributes Response to Combined Exposure to Tropospheric Ozone, Particulate Matter Deposition and Ascorbic Acid Application, **Bulletin of Environmental Contamination and Toxicology**, 107, November 2021, DOI:10.1007/s00128-021-03373-7, 938-945 **(Impact Factor 2.151)**

123. **Mohan G.M.**, **Vani K.G.**, **Hazra A.**, **Mallick C.**, **Chaudhari H.S.**, **Pokhrel S.**, **Pawar S.D.**, **Konwar M.**, **Saha Subodh K.**, **Das S.K.**, **Deshpande S.**, **Ghude S.**, Barth M.C., **Rao Suryachandra A.**, **Nanjundiah R.S.**, **Rajeevan M.**, Evaluating different lightning parameterization schemes to simulate lightning flash counts over Maharashtra, India, **Atmospheric Research**, 255: 105532, June 2021, DOI:10.1016/j.atmosres.2021.105532, 1-22 **(Impact Factor 5.369)**

124. Mohanty M.R., **Pradhan M.**, Maurya R.K.S., **Rao Suryachandra A.**, Mohanty U.C., Landu K., Evaluation of state-of-the-art GCMs in simulating Indian summer monsoon rainfall, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00818-w, 1429-1445 **(Impact Factor 2.065)**

125. **Mohapatra S., Gnanaseelan C.,** A new mode of decadal variability in the Tropical Indian Ocean subsurface temperature and its association with shallow meridional overturning circulation, **Global and Planetary Change**, 207: 103656, December 2021, DOI:10.1016/j.gloplacha.2021.103656, 1-10 **(Impact Factor 5.114)**

126. Moulick D., Samanta S., Sarkar S., **Mukherjee A.**, Pattnaik B.K., … et al., Arsenic contamination, impact and mitigation strategies in rice agro-environment: An inclusive insight, **Science of the Total Environment**, 800: 149477, December 2021, DOI:10.1016/j.scitotenv.2021.149477, 1-30 **(Impact Factor 7.963)**

127. **Mudiar D., Hazra A., Pawar S.D.**, Karumuri R.K., **Konwar M., Mukherjee Subrata**, Srivastava M.K., Goswami B.N., Williams E., Role of electrical effects in intensifying rainfall rates in the tropics, **Geophysical Research Letters**, 49: e2021GL096276, January 2022, DOI:10.1029/2021GL096276, 1-11 **(Impact Factor 4.720)**

128. **Mudiar D., Pawar S.D., Gopalakrishnan V.**, Williams E., Electric field enlarges raindrops beneath electrified clouds: Observational evidence, **Geophysical Research Letters**, 48: e2021GL093577, July 2021, DOI:10.1029/2021GL093577, 1-10 **(Impact Factor 4.720)**

129. **Mudiar D., Pawar S.D., Hazra A., Gopalakrishnan V., Lal D.M.**, Srivastava M.K., A laboratory investigation of electrical influence on the freezing of water drops: A cloud physics perspective, **Journal of Earth System Science**, 130: 222, November 2021, DOI:10.1007/s12040-021-01736-6, 1-6 **(Impact Factor 1.371)**

130. **Mudiar D., Pawar S.D., Hazra A., Gopalakrishnana V., Lal D.M., Chakravarty Kaustav, Domkawale M.A.**, Srivastava M.K., Goswami B.N., William E., Lightning and precipitation: The possible electrical modification of observed raindrop size distributions, **Atmospheric Research**, 259: 105663, September 2021, DOI: 10.1016/j.atmosres.2021.105663, 1-17 **(Impact Factor 5.369)**

131. **Mujumdar M.**, Goswami M.M., Morrison R., Evans J.G., **Ganeshi N.**, **Sabade S.S.**, **Krishnan R.**, Patil S.N., A study of field-scale soil

moisture variability using the COsmic-ray Soil Moisture Observing System (COSMOS) at IITM Pune site, **Journal of Hydrology**, 597: 126102, June 2021, DOI: 10.1016/j.jhydrol. 2021.126102, 1-13 **(Impact Factor 5.722)**

132. **Mukherjee S.**, **Anil Kumar V.**, **Patil R.D.**, **Meena G.S.**, **Buchunde P.**, **Waghmare V.**, Deshmukh S., Dhavale V., Ray A., **Panicker A.S.**, **Sonbawne S.M.**, **Safai P.D.**, **Pandithurai G.**, Investigation of physico-chemical characteristics and associated CCN activation for different combustion sources through Chamber experiment approach, **Atmospheric Environment**, 266: 118726, December 2021, DOI:10.1016/j.atmosenv. 2021.118726, 1-9 **(Impact Factor 4.798)**

133. **Mukhopadhyay P.**, Bechtold P., Zhu Y., **Krishna R.P.M.**, Kumar Siddharth, **Ganai M.**, **Tirkey S.**, **Goswami T.**, **Mahakur M.**, **Deshpande M.**, Prasad V.S., Johny C.J., Mitra A., Ashrit R., Sarkar A., Sarkar Sahadat, Roy Kumar, Andrews E., **Kanase R.**, Malviya S., **Abhilash S.**, Domkawle M., **Pawar S.D.**, Mamgain A., Durai V.R., **Nanjundiah R.S.**, Mitra A.K., **Rajagopal E.N.**, Mohapatra M., **Rajeevan M.**, Unravelling the mechanism of extreme (more than 30 sigma) precipitation during August 2018 and 2019 over Kerala, India, **Weather and Forecasting**, 36, August 2021, DOI:10.1175/WAF-D-20-0162.1, 1253-1273 **(Impact Factor 3.025)**

134. **Murali Krishna U.V.**, **Das Subrata Kumar**, **Deshpande S.M.**, **Pandithurai G.**, Physical processes controlling the diurnal cycle of convective storms in the Western Ghats, **Scientific Reports**, 11: 14103, July 2021, DOI:10.1038/s41598-021-93173-0, 1-13 **(Impact Factor 4.379)**

135. **Narkhedkar S.G.**, Dutta S.N., **Anilkumar V.**, **Mukherjee S.**, **Pandithurai G.**, Rainfall characteristics and its variability over a high-altitude station in Western Ghats during southwest monsoon of 2015 - A case study, **Mausam**, 72, April 2021, 331-348 **(Impact Factor 0.636)**

136. Ningombam S.S., Dumka U.C., Mugil .SK., Kuniyal J.C., Hooda R.K., Gautam A.S., **Tiwari Suresh**, Impacts of Aerosol Loading in the Hindu Kush Himalayan Region Based on MERRA-2 Reanalysis Data, **Atmosphere**, 12: 1290, October 2021, DOI:10.3390/ atmos12101290, 1-18 **(Impact Factor 2.686)**

137. **Panicker A.S., Sandeep K.**, Gautam A.S., **Trimbake H.K.**, Nainwal H.C., **Beig G., Bisht D.S.**, Das S., Black carbon over a central Himalayan Glacier (Satopanth): Pathwaysand direct radiative impacts, **Science of the Total Environment**, 766: 144242, April 2021, DOI:10.1016/j.scitotenv. 2020.144242, 1-8 **(Impact Factor 7.963)**

138. **Panicker A.S.**, Shaima N., Aerosol oscillations over different emission regions in India, **Pure and Applied Geophysics**, 178, October 2021, DOI:10.1007/s00024-021-02833-9, 4097-4105 **(Impact Factor 2.335)**

139. **Parde A.N., Dhangar N.G.**, Nivdange S., **Ghude S.D., Pithani P., Jena C., Lal D.M., Gopalakrishnan V.**, The analysis of pre-monsoon dust storm over Delhi using ground-based observations, **Natural Hazards**, Online, February 2022, DOI:10.1007/s11069-022-05207-z, 1-16 **(Impact Factor 3.102)**

140. **Patel J., Gnanaseelan C., Chowdary J.S., Parekh A.**, A quantile mapping approach-based bias correction in Coupled Model Intercomparison Project Phase 5 models for decadal temperature predictions over India, **International Journal of Climatology**, 42, March 2022, DOI:10.1002/joc.7376, 2455-2469 **(Impact Factor 4.069)**

141. Pattanaik D.R., **Mandal R., Phani R., Dey Avijit**, **Chattopadhyay R.**, **Joseph S.**, **Sahai A.K.**, Mohapatra M., Large-scale features associated with excess monsoon rainfall over india during 2019 and the real-time

extended range forecast, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00808-y, 1275-1297 **(Impact Factor 2.065)**

142. **Pawar P.V., Ghude S.D., Jena C.**, Móring A., Sutton M.A., **Kulkarni S.**, **Lal D.M.**, Surendran D., Van Damme M., Clarisse L., Coheur P.-F., Liu X., **Govardhan G.**, Xu W., Jiang J., Adhya T.K., Analysis of atmospheric ammonia over South and East Asia based on the MOZART-4 model and its comparison with satellite and surface observations, **Atmospheric Chemistry and Physics**, 21, April 2021, DOI:10.5194/acp-21-6389-2021, 6389–6409 **(Impact Factor 6.133)**

143. Philip S., Johnson M.S., Baker D.F., Basu S., **Tiwari Y.K.**, Indira N.K., Ramonet M., Poulter B., OCO-2 satellite-imposed constraints on terrestrial biospheric CO2 fluxes over South Asia, **Journal of Geophysical Research: Atmospheres**, 127: e2021JD035035, February 2022, DOI:10.1029/2021JD035035, 1-23 **(Impact Factor 4.261)**

144. 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**, 57, July 2021, DOI:10.1007/s00382-021-05712-0, 353–373 **(Impact Factor 4.375)**

145. **Prabhu A., Mandke S.K., Kripalani R.H., Pandithurai G.,** Association between Antarctic Sea ice, Pacific SST and the Indian summer monsoon: An observational study, **Polar Science**, 30: 100746, December 2021, DOI:10.1016/j.polar.2021.100746, 1-11 **(Impact Factor 1.927)**

146. **Prabhu A., Mandke S.K., Pandithurai G.**, Regional perspectives in Eurasian snow - Indian monsoon relationship: An observational study, **Polar Science**, 30: 100718, December 2021, DOI:10.1016/j.polar.2021.100718, 1-15 **(Impact Factor 1.927)**

147. **Pradhan M, Rao Suryachandra A.**, Bhattacharya A., Balasubramanian S., Improvements in Diurnal Cycle and Its Impact on Seasonal Mean by Incorporating COARE Flux Algorithm in CFS, **Frontiers in Climate**, 3: 792980, February 2022, DOI:10.3389/fclim.2021.792980, 1-21 **(Impact Factor 0.000)**

148. **Pradhan M.**, **Rao Suryachandra A.**, Doi T., **Pillai P.A.**, **Srivastava Ankur**, Behera S., Comparison of MMCFS and SINTEX-F2 for seasonal prediction of Indian summer monsoon rainfall, **International Journal of Climatology**, 41, November 2021, DOI:10.1002/joc.7169, 6084-6108 **(Impact Factor 4.069)**

149. **Pradhan M., Srivastava Ankur, Rao Suryachandra A.**, Banerjee D.S., Chatterjee A., Francis P.A., Sreejith O.P., Gupta M.D., Prasad V.S., Are ocean-moored buoys redundant for prediction of Indian monsoon?, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00792-3, 1075-1088 **(Impact Factor 2.065)**

150. Pradhan P.K., Kumar V., **Sunilkumar K.,** Rao S.V.B., Sinha T.; Kattamanchi V.K., Pattnaik S., Demonstration of the Temporal Evolution of Tropical Cyclone “Phailin” Using Gray-Zone Simulations and Decadal Variability of Cyclones over the Bay of Bengal in a Warming Climate, **Oceans**, 2, September 2021, DOI:10.3390/oceans2030037, 648-674 **(Impact Factor 0.000)**

151. **Prajeesh A.G., Swapna P., Krishnan R., Ayantika D. C., Sandeep N., Singh Manmeet., Modi A., Ingle S.**, The Indian summer monsoon and Indian Ocean Dipole connection in the IITM Earth System Model (IITM-ESM), **Climate Dynamics**, 58, March 2022, DOI:10.1007/s00382-021-05999-z, 1877–1897 **(Impact Factor 4.375)**

152. Prasad S., Mishra P.K., **Priya P.**, Yousuf A.R., Andersen N., Anoop A., Jehangir A., Yaseen T., Gaye B., Stebich M., Impact of precipitation and temperature changes on limnology and sediment characteristics in NW Himalaya, **Applied Geochemistry**, 137: 105200, February 2022, DOI:10.1016/j.apgeochem.2022.105200, 1-11 **(Impact Factor 3.524)**

153. **Prasanna K.**, **Chowdary J.S.**, **Singh Prem, Chiranjeevi D.,** Naidu C.V., **Parekh A.**, **Gnanaseelan C.**, Assessment of APCC models fidelity in simulating the Northeast monsoon rainfall variability over Southern Peninsular India, **Theoretical and Applied Climatology**, 144, May 2021, DOI:10.1007/ s00704-021-03559-3, 931-948 **(Impact Factor 3.179)**

154. Rahman W., **Beig G.**, Barman N., Hopke P.K., Hoque R.R., Ambient ozone over mid-Brahmaputra Valley, India: effects of local emissions and atmospheric transport on the photostationary state, **Environmental Monitoring and Assessment**, 193: 790, November 2021, DOI:10.1007/s10661-021-09572-3, 1-17 **(Impact Factor 2.513)**

155. **Rajput A.S.D.,** Scientific writing: An analysis of Pune-based climate scientists' perceptions and training needs, **Weather**, 77(3), March 2022, https://doi.org/10.1002/wea.3967, 99-103 (**Impact Factor 1.596**)

156. Rana M., Mittal S.K., **Beig G.**, Assessment and prediction of surface ozone in Northwest Indo-Gangetic Plains using ensemble approach, **Environment, Development and Sustainability**, 23, April 2021, DOI:10.1007/s10668-020-00841-8, 5715-5738 **(Impact Factor 3.219)**

157. Ranade A., **Singh N.**, Evaluation of 3D structural changes in general atmospheric and monsoon circulations during Kedarnath disaster (India), 16-17 June 2013, **Meteorology and Atmospheric Physics**, 133, June 2021, DOI:10.1007/s00703-021-00780-7, 857–878 **(Impact Factor 2.065)**

158. 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**, 58, February 2022, DOI:10.1007/s13143-021-00235-4, 13–32 **(Impact Factor 2.100)**

159. **Rathod A., Beig G.**, Impact of biomass induced black carbon particles in cascading COVID-19, **Urban Climate**, 38: 100913, July 2021, DOI: 10.1016/j.uclim.2021.100913, 1-7 **(Impact Factor 5.731)**

160. **Raut B.A.**, Jackson R., Picel M., Collis S.M., Bergemann M., Jakob C., An adaptive tracking algorithm for convection in simulated and remote sensing data, **Journal of Applied Meteorology and Climatology**, 60, April 2021, DOI:10.1175/JAMC-D-20-0119.1, 513–526 **(Impact Factor 2.923)**

161. **Raut B.A.**, **Konwar M.**, **Murugavel P.**, Kadge D., **Gurnule D.**, Sayyed I., **Todekar K.**, **Malap N.**, **Bankar S.**, **Prabhakaran Thara**, Microphysical origin of raindrop size distributions during the Indian monsoon, **Geophysical Research Letters**, 48: e2021GL093581, August 2021, DOI:10.1029/2021GL093581, 1-12 **(Impact Factor 4.720)**

162. Ravi Kumar K., **Singh B.B.**, Niranjan Kumar K., Intriguing aspects of Asian summer monsoon anticyclone ozone variability from microwave limb sounder measurements, **Atmospheric Research**, 253: 105479, May 2021, DOI:10.1016/j.atmosres.2021.105479, 1-7 **(Impact Factor 5.369)**

163. Ray R., Bhattacharya A., Arora G., **Bajaj K.**, Horton K., Chen S., **Chakraborty S.**, Bazaz A., Extreme rainfall deficits were not the cause of recurring colonial era famines of southern Indian semi-arid regions, **Scientific Reports**, 11:17568, September 2021, DOI:10.1038/s41598-021-96826-2, 1-9 **(Impact Factor 4.379)**

164. Reddy M.V., Reddy K.K., **Murali Krishna U.V.**, Prasad S.B.S., Bonthu S., Mitra A.K., Simulation of tropical cyclones over the Bay of Bengal during 1999-2013 : Impact of physical parameterization schemes, Mausam, 72, December 2021, DOI:10.54302/mausam.v72i1.130, 177–186 (Impact Factor 0.636)

165. Reshma T., **Varikoden H.**, Babu C.A., Observed changes in Indian summer monsoon rainfall at different intensity bins during the past 118 years over five homogeneous regions, **Pure and Applied Geophysics**, 178, September 2021, DOI:10.1007/s00024-021-02826-8, 3655-3672 **(Impact Factor 2.335)**

166. Romshoo S.A., Bhat M.A., **Beig G.**, Particulate pollution over an urban Himalayan site: Temporal variability, impact of meteorology and potential source regions, **Science of The Total Environment**, 799: 149364, December 2021, DOI:10.1016/j.scitotenv.2021.149364, 1-19 **(Impact Factor 7.963)**

167. **Roy K.**, **Mukhopadhyay P.**, **Krishna R.P.M.**, Khouider B., Goswami B.B., Evaluation of mean state in NCEP Climate Forecast System (version 2) simulation using a stochastic multicloud model calibrated with DYNAMO RADAR data, **Earth and Space Science**, 8: e2020EA001455, August 2021, DOI:10.1029/2020EA001455, 1-14 **(Impact Factor 2.900)**

168. **Roy Kumar, Mukhopadhyay P., Krishna R.P.M.**, Nair A.K.M., Narayana Rao T., Ramakrishna S.S.V.S., Role of autoconversion process in assessing the low-level clouds over the southern Indian Ocean in Climate Forecast System (CFS) version 2, **Theoretical and Applied Climatology**, 145, July 2021, DOI:10.1007/s00704-021-03630-z, 273–284 **(Impact Factor 3.179)**

169. **Sahai A.K., Kaur Manpreet, Joseph S., Dey Avijit, Phani R., Mandal R., Chattopadhyay R.**, Multi-Model Multi-Physics Ensemble: A Futuristic Way to Extended Range Prediction System, **Frontiers in Climate**, 3: 655919, May 2021, DOI:10.3389/fclim.2021.655919, 1-11 **(Impact Factor 0.000)**

170. **Sahoo M., Yadav R.K.**, Role of equatorial central Pacific sea surface temperature in modulating rainfall over north India during Indian summer monsoon, **International Journal of Climatology**, 41, November 2021, DOI:10.1002/joc.7165, 6017-6030 **(Impact Factor 4.069)**

171. **Sahoo M., Yadav R.K.**, Teleconnection of Atlantic Nino with summer monsoon rainfall over northeast India, **Global and Planetary Change**, 203: 103550, August 2021, DOI:10.1016/j.gloplacha.2021.103550, 1-10 **(Impact Factor 5.114)**

172. Sahu L.K., Tripathi N., Gupta M., Singh V., **Yadav R.**, Patel K., Impact of COVID-19 pandemic lockdown in ambient concentrations of aromatic volatile organic compounds in a metropolitan city of western India, **Journal of Geophysical Research: Atmospheres**, 127: e2022JD036628, March 2022, DOI:10.1029/2022JD036628, 1-26 **(Impact Factor 4.261)**

173. Sahu S.K., Mangaraj P., **Beig G.**, Tyagi B., **Tikle S.**, Vinoj V., Establishing a link between fine particulate matter (PM2.5) zones and COVID-19 over India based on anthropogenic emission sources and air quality data, **Urban Climate**, 38: 100883, July 2021, DOI:10.1016/j.uclim.2021.100883, 1-12 **(Impact Factor 5.731)**

174. Saikrishna T.S., **Ramu D.A.**, Osuri K.K., Inter-comparison of high-resolution satellite precipitation products over India during the summer monsoon season, **Meteorology and Atmospheric Physics**, 133, December 2021, DOI:10.1007/s00703-021-00829-7, 1675-1690 **(Impact Factor 2.065)**

175. **Samanta S.**, **Murugavel P.**, **Gurnule D.**, **Jaya Rao Y.**, Vivekanandan J., **Prabhakaran Thara**, The Life Cycle of a Stationary Cloud Cluster during the Indian Summer Monsoon: A Microphysical Investigation Using Polarimetric C-Band Radar, **Monthly Weather Review**, 149, November 2021, DOI:10.1175/MWR-D-20-0274.1, 3761-3780 **(Impact Factor 3.735)**

176. **Samanta S., Prabhakaran Thara, Murugavel P.**, Suneetha P., Rainfall types in the lifecycle of a stationary cloud cluster during the Indian Summer Monsoon: An investigation with numerical simulations and radar observation, **Atmospheric Research**, 263: 105794, December 2021, DOI:10.1016/j.atmosres.2021.105794, 1-15 **(Impact Factor 5.369)**

177. **Sandeep K., Panicker A.S.**, Gautam A.S., **Beig G., Gandhi N.**, Sanjeev S., Shankar R., Naniwal H.C., Black carbon over a high altitude Central Himalayan Glacier: Variability, transport, and radiative impacts, **Environmental Research**, 204: 112017, March 2022, DOI:10.1016/j.envres.2021.112017, 1-11 **(Impact Factor 6.498)**

178. **Sandeep K.**, **Panicker A.S.**, Gautam, A.S., **Safai P.D.**, **Beig G.**, Nainwal H.C., **Bisht D.S.**, **Das S.**, Observations of black carbon and albedo over a Central Himalayan Glacier (Satopanth): Preliminary results, **Journal of Atmospheric and Solar Terrestrial Physics**, 216: 105580, May 2021, DOI:10.1016/j.jastp.2021.105580, 1-8 **(Impact Factor 1.735)**

179. **Sandeep N., Swapna P., Krishnan R.**, Farneti R., Kucharski F., **Modi A., Prajeesh A.G., Ayantika D.C., Singh Manmeet**, On the weakening association between South Asian Monsoon and Atlantic Multidecadal Oscillation, **Climate Dynamics**, Online, March 2022, DOI:10.1007/s00382-022-06224-1, 1-17 **(Impact Factor 4.375)**

180. **Saranya J.S., Roxy M.K., Dasgupta P., Anand A.**, Genesis and trends in marine heatwaves over the tropical Indian Ocean and their interaction with the Indian summer monsoon, **Journal of Geophysical Research: Oceans**, 127: e2021JC017427, February 2022, DOI:10.1029/2021JC017427, 1-16 **(Impact Factor 3.405)**

181. **Sarkar S., Mukhopadhyay P.**, Dutta S., Energy conversion processes associated with the transition of low-pressure area to monsoon depression during Indian summer monsoon: a study to evaluate GFS model fidelity, **Meteorology and Atmospheric Physics**, 134, February 2022, DOI:10.1007/s00703-021-00838-6, 1-16 **(Impact Factor 2.065)**

182. **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**, 147, July 2021, DOI:10.1002/qj.4024, 2625-2637 **(Impact Factor 3.739)**

183. **Sarkar S., Mukhopadhyay P., Krishna R.P.M.**, Dutta S., Atmospheric dynamics and internal processes in CFSv2 model during organization and intensification of BSISO, **Journal of Earth System Science**, 130: 229, November 2021, DOI:10.1007/s12040-021-01727-7, 1-18 **(Impact Factor 1.371)**

184. Sarla, **Srivastava Atul K.**, Ahlawat A., Mishra S.K., Impact of COVID-19 lockdown on aerosol optical and radiative properties over Indo-Gangetic Plain, **Urban Climate**, 37: 100839, May 2021, DOI:10.1016/j.uclim.2021.100839, 1-14 **(Impact Factor 5.731)**

185. **Sarma D., Deb Burman P.K., Chakraborty S.**, Gogoi N., Bora A., **Metya A., Datye A., Murkute C.**, Karipot A., Quantifying the net ecosystem exchange at a semi-deciduous forest in northeast India from intra-seasonal to the

seasonal time scale, **Agricultural and Forest Meteorology**, 314: 108786, March 2022, DOI:10.1016/j.agrformet.2021.108786, 1-12 **(Impact Factor 5.734)**

186. Sarmah S., Singha M., Wang J., Dong J., **Deb Burmana P.K.**, Goswami S., Ge Y., Ilyas S., Niu S., Mismatches between vegetation greening and primary productivity trends in South Asia – A satellite evidence, **International Journal of Applied Earth Observation and Geoinformation**, 104: 102561, December 2021, DOI:10.1016/j.jag.2021.102561, 1-12 **(Impact Factor 5.933)**

187. Sathyanadh A., **Prabhakaran Thara, Subharthi Chowdhuri S., Balaji B., Resmi E.A.**, Karipot A., Evaluation of PBL parameterization schemes against direct observations during a land depression over Central India, **Theoretical and Applied Climatology**, 144, April 2021, DOI:10.1007/s00704-021-03532-0, 253-271 **(Impact Factor 3.179)**

188. 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**, 15, January 2022, DOI:10.1080/1755876X.2020.1846266, 32-51 **(Impact Factor 3.471)**

189. Shahi N.K., Rai S., **Sahai A.K., Abhilash S.**, Prediction of dominant daily modes of the Indian summer monsoon in the NCEP GFS model, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00793-2, 1009-1027 **(Impact Factor 2.065)**

190. **Shamal M., Sanjay J.,** An observational equatorial Atlantic Ocean constraint on Indian monsoon precipitation projections, **Climate Dynamics**, 57, July 2021, DOI:10.1007/s00382-021-05703-1, 209–221 **(Impact Factor 4.375)**

191. Shroyer E., Tandon A., Sengupta D., Fernando H.J, Lucas A.J, Farrar J.T, **Chattopadhyay R.**, …, **Sahai A.K.**, … et al., Bay of Bengal Intraseasonal Oscillations and the 2018 Monsoon Onset, **Bulletin of the American Meteorological Society**, 102, October 2021, DOI:10.1175/BAMS-D-20-0113.1, E1936–E1951 **(Impact Factor 8.766)**

192. Shukla B.P., John J., **Padmakumari B.**, Das D., Thirugnanasambantham D., Gairola R.M., Did dust intrusion and lofting escalate the catastrophic widespread lightning on 16th April 2019, India?, **Atmospheric Research**, 266: 105933, March 2022, DOI:10.1016/j.atmosres.2021.105933, 1-13 **(Impact Factor 5.369)**

193. Sin'kevich A., Boe B., **Pawar S.D.**, Yang J., Abshaev A., Dovgaluk Y., Gekkieva J., **Gopalakrishnan V.**, Kurov A., Mikhailovskii Y., Toropova M., Veremei N., Investigation of thundercloud features in different regions, **Remote Sensing**, 13, August 2021, DOI:10.3390/rs13163216, 1-19 **(Impact Factor 4.848)**

194. Sin'kevich A.A., Boe B., **Pawar S.D.**, Kurov A.B., **Gopalakrishnan V.**, Investigation of Radar and Electrical Characteristics of Thunderclouds Seeded with a Glaciogenic Reagent in Karnataka, India, **Russian Meteorology and Hydrology**, 46, August 2021, DOI:10.3103/S1068373921080069, 545–552 **(Impact Factor 0.768)**

195. **Singh A., Srivastava Atul K.**, Patak V., Shukla A.K., Quantifying the impact of biomass burning and dust storm activities on aerosol characteristics over the Indo-Gangetic Basin , **Atmospheric Environment**, 270: 118893, February 2022, DOI:10.1016/j.atmosenv.2021.118893, 1-15 **(Impact Factor 4.798)**

196. **Singh A., Srivastava Atul K.**, Varaprasad V., Kumar S., Pathak V., Shukla A.K., Assessment of near-surface air pollutants at an urban

station over the central Indo-Gangetic Basin: Role of pollution transport pathways, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00798-x, 1127–1142 **(Impact Factor 2.065)**

197. Singh A.K., Bhargawa A., **Siingh D.**, Singh R.P., Physics of space weather phenomena: A Review, **Geosciences**, 11: 286, July 2021, DOI:10.3390/geosciences1107028, 1-46 **(Impact Factor 0.000)**

198. **Singh B.B., Krishnan R., Ayantika D.C., Vellore R.K., Sabin T.P., Ravi Kumar K.**, Brunamonti S., Hanumanthu S., Jorge T., Oelsner P., **Sonbawne S.**, Naja M., **Fadnavis S.**, Peter T., Srivastava M.K., Linkage of water vapor distribution in the lower stratosphere to organized Asian summer monsoon convection, **Climate Dynamics**, 57, October 2021, DOI:10.1007/s00382-021-05772-2, 1709-1731 **(Impact Factor 4.375)**

199. **Singh Manmeet, Singh B.B.**, Singh R., **Upendra B.**, Kaur R., Gill S.S., **Biswas M.S.**, Quantifying COVID-19 enforced global changes in atmospheric pollutants using cloud computing based remote sensing, **Remote Sensing Applications: Society and Environment**, 22: 100489, April 2021, DOI:10.1016/j.rsase.2021.100489 **(Impact Factor 0.000)**

200. Singh T., Ravindra K., **Beig G.**, Mor S., Influence of agricultural activities on atmospheric pollution during post-monsoon harvesting seasons at a rural location of Indo-Gangetic Plain, **Science of The Total Environment**, 796: 148903, November 2021, DOI:10.1016/j.scitotenv.2021.148903, 1-8 **(Impact Factor 7.963)**

201. **Singh Vineet K., Roxy M.K.**, A review of ocean-atmosphere interactions during tropical cyclones in the north Indian Ocean, **Earth Science Reviews**, 226: 103967, March 2022, 10.1016/j.earscirev.2022.103967, 1-23 **(Impact Factor 12.413)**

202. Sokhi R.S., Singh V., ..., Anand V., Arbilla G., Badali K., **Beig G.**, ..., **Yadav R.**, ... et al., A global observational analysis to understand changes in air quality during exceptionally low anthropogenic emission conditions, **Environment International**, 157: 106818, December 2021, DOI:10.1016/j.envint.2021.106818, 1-25 **(Impact Factor 9.621)**

203. **Sonbawne S.M., Devara P.C.S.**, Bhawar R., **Rahul P.R.C., Siingh D., Fadnavis S., Panicker A.S., Pandithurai G.**, Aerosol physico–optical–radiative characterization and classification during summer over Ny-Ålesund, Arctic , **International Journal of Remote Sensing**, 42, November 2021, DOI:10.1080/01431161.2021.1987576, 8760-8781 **(Impact Factor 3.151)**

204. **Sonbawne S.M.**, Devara P.C.S., Bhoyar P.D., Multisite characterization of concurrent black carbon and biomass burning around COVID-19 lockdown period, **Urban Climate**, 39: 100929, September 2021, DOI:10.1016/j.uclim.2021.100929, 1-14 **(Impact Factor 5.731)**

205. **Soyam P.S, Safai P.D, Mukherjee S., Todekar K., Bankar S., Gurnule D., Malap N., Prabhakaran Thara**, Black carbon aerosols over a semi-arid rain shadow location in Peninsular India: Temporal variability and sources, **Journal of Earth System Science**, 130: 95, May 2021, DOI:10.1007/s12040-021-01610-5, 1-14 **(Impact Factor 1.371)**

206. Sreenath A.V., **Malap N., Abhilash S., Kulkarni G.U., Prabhakaran Thara**, Precipitation processes over Indian region under different environmental conditions from in situ measurements, **Atmospheric Research**, 262: 105775, November 2021, DOI:10.1016/j.atmosres.2021.105775, 1-17 **(Impact Factor 5.369)**

207. Sridevi Ch., Pattanaik D.R., Das A.K., Srivastava A., Durai V.R., Johny C.J., **Deshpande Medha**, Suneetha P., **Kanase R.**,

Tropical cyclone track and intensity prediction skill of GFS model over NIO during 2019 & 2020, **Tropical Cyclone Research and Review**, 11, March 2022, DOI:10.1016/j.tcrr.2022.04.002, 36-49 **(Impact Factor 0.000)**

208. Srivastava P.K., Pradhan R.K., Petropoulos G.P., Pandey V., Gupta M., Yaduvanshi A., Jaafar W.Z.W., Mall R.K., **Sahai A.K.**, Long-Term Trend Analysis of Precipitation and Extreme Events over Kosi River Basin in India, **Water**, 13: 1695, June 2021, DOI:10.3390/w13121695, 1-13 **(Impact Factor 3.103)**

209. Sudeepkumar B.L. Babu C.A., **Varikoden H.**, Thermodynamic structure of monsoon boundary layer over the west coast of India, **Atmospheric Research**, 261: 105748, October 2021, DOI:10.1016/j.atmosres.2021.105748, 1-16 **(Impact Factor 5.369)**

210. Sudeepkumar B.L., Babu C.A., **Varikoden H.**, Variations in monsoon boundary layer structure with respect to cloudiness over the west coast of India, **Meteorology and Atmospheric Physics**, 134: 2, February 2022, DOI:10.1007/s00703-021-00839-5, 1-13 **(Impact Factor 2.065)**

211. **Sunilkumar K., Das Subrata K., Kalekar P., Kolte Y., MuraliKrishna U. V., Deshpande S., Dani K.K.**, Nitha T.S., Hosalikar K.S., Narvekar M., Mohan e K.N., **Pandithurai G.**, A MESO-scale Rain gauge NETwork-MESONET over Mumbai: Preliminary results and applications, **Urban Climate**, 41: 101029, January 2022, DOI:10.1016/j.uclim.2021.101029, 1-12 **(Impact Factor 5.731)**

212. **Sunilkumar K.**, Kumar Vinay, Pradhan P.K., The Connection between Extreme Precipitation Variability over Monsoon Asia and Large-Scale Circulation Patterns, **Atmosphere**, 12: 1492, November 2021, DOI:10.3390/atmos12111492, 1-20 **(Impact Factor 2.686)**

213. **Swapna P., Sreeraj P., Narayanasetti S., Jyoti J., Krishnan R., Prajeesh A.G., Ayantika D.C., Singh Manmeet**, Increasing frequency of extremely severe cyclonic storms in the North Indian Ocean by anthropogenic warming and southwest monsoon weakening, **Geophysical Research Letters**, 49: e2021GL094650, February 2022, DOI:10.1029/2021GL094650, 1-11 **(Impact Factor 4.720)**

214. Tang S., Xie S., Guo Z., Hong S., Khouider B., Klocke D., Köhler M., Koo M., **Phani M.K.**, ..., **Malap N.**, Neggers R., **Thara Prabhakaran**, ... et al., Long-term single-column model intercomparison of diurnal cycle of precipitation over midlatitude and tropical land, **Quarterly Journal of the Royal Meteorological Society**, 148, January 2022, DOI:10.1002/qj.4222, 641-669 **(Impact Factor 3.739)**

215. Tejavath C.T., Ashok K., **Chakraborty S.**, The Importance of the Orbital Parameters for the Indian Summer Monsoon During the Mid-Holocene, as Deciphered from Atmospheric Model Experiments, **Frontiers in Earth Science** , 9: 631310, May 2021, DOI:10.3389/feart.2021.631310, 1-14 **(Impact Factor 3.498)**

216. Thomas A., Kanawade V.P., Sarangi C., **Srivastava A.K.**, Effect of COVID-19 shutdown on aerosol direct radiative forcing over the Indo-Gangetic Plain outflow region of the Bay of Bengal, **Science of the Total Environment**, 782: 146918, August 2021, DOI:10.1016/j.scitotenv.2021.146918, 1-8 **(Impact Factor 7.963)**

217. **Tikle S.,** Ilame T., **Beig G.,** Impact of SAFAR Air Quality Forecasting Framework and advisory services in reducing the economic health burden of India, **Regional Economic Development Research**, 2, November 2021, DOI:10.37256/redr.2220211063, 211-226 **(Impact Factor 0.000)**

218. **Tinmaker M.I.R.**, Dwivedi A.K., Islam S., **Ghude S.D.**, Kulkarni S.H., Khare M., **Chate D.M.**, Lightning activity variability with prevailing weather parameters and aerosol loading over dry and wet regions of India, **Pure and Applied Geophysics**, 178, April 2021, DOI:10.1007/s00024-021-02695-1, 1445-1457 **(Impact Factor 2.335)**

219. **Tinmaker M.I.R., Ghude S.D.**, Dwivedi A.K., Islam S., Kulkarni S.H., Khare M., Chate D.M., Relationships among lightning, rainfall, and meteorological parameters over oceanic and land regions of India, **Meteorology and Atmospheric Physics**, 134, February 2022, DOI:10.1007/s00703-021-00841-x, 1-11 **(Impact Factor 2.065)**

220. **Tinmaker M.I.R.**, **Jena C.K.**, **Ghude S.D.**, Diwedi A.K., Islam S., Kulkarni S.H., Khare M.K., **Chate D.M.**, Relationship of lightning with different weather parameters during transition period of dry to wet season over Indian region, **Journal of Atmospheric and Solar Terrestrial Physics**, 220: 105673, September 2021, DOI:10.1016/j.jastp.2021.105673, 1-8 **(Impact Factor 1.735)**

221. Tripathi N., Sahu L.K., Patel K., Kumar Ashwini, **Yadav R.**, Ambient air characteristics of biogenic volatile organic compounds at a tropical evergreen forest site in Central Western Ghats of India, **Journal of Atmospheric Chemistry**, 78, June 2021, DOI:10.1007/s10874-021-09415-y, 139-159 **(Impact Factor 2.158)**

222. Uehling J., Misra V., Bhardwaj A., **Karmakar N.**, Characterizing the Local Variations of the Northern Australian Rainy Season, **Monthly Weather Review**, 149, December 2021, DOI:10.1175/MWR-D-21-0093.1, 3995-4004 **(Impact Factor 3.735)**

223. Unnikrishnan C.K., Pawar S., **Gopalakrishnan V.**, Satellite-observed lightning hotspots in India and lightning variability over tropical South India, **Advances in Space Research**, 68, August 2021, DOI:10.1016/j.asr.2021.04.009, 1690-1705 **(Impact Factor 2.152)**

224. Vaid B.H., Kripalani R.H., Monsoon 2020: An Interaction of Upper Tropospheric Thermodynamics and Dynamics Over the Tibetan Plateau and the Western Pacific, **Pure and Applied Geophysics**, 178, September 2021, DOI:10.1007/s00024-021-02844-6, 3645–3654 **(Impact Factor 2.335)**

225. **Vaid B.H., Kripalani R.H.,** Strikingly contrasting Indian monsoon progressions during 2013 and 2014: role of Western Tibetan Plateau and the South China Sea, **Theoretical and Applied Climatology**, 144, May 2021, DOI:10.1007/s00704-021-03590-4, 1131-1140 **(Impact Factor 3.179)**

226. **Valsala V.**, **Sreeush M.G.**, Anju M., **Sreenivas P.**, **Tiwari Y.K.**, Chakraborty K., Sijikumar S., An observing system simulation experiment for Indian Ocean surface pCO2 measurements, **Progress in Oceanography**, 194: 102570, June 2021, DOI: 10.1016/j.pocean.2021.102570, 1-14 **(Impact Factor 4.080)**

227. **Varghese M.**, Jose J., Anu A.S., **Konwar M.**, **Murugavel P.**, Kalarikkal N., **Deshpande M.**, **Prabhakaran Thara**, Vertical profile of aerosol characteristics including activation over a rain shadow region in India, **Atmospheric Environment**, 262: 118653, October 2021, DOI:10.1016/j.atmosenv.2021.118653, 1-13 **(Impact Factor 4.798)**

228. **Varghese M.**, Jose J., Anu A.S., **Murugavel P.**, **Resmi E.A.**, **Bera S.**, Thomas S., **Konwar M.**, Kalarikkal N., **Prabhakaran Thara**, Cloud and aerosol characteristics during dry and wet days of southwest monsoon over the rain shadow region of Western Ghats, India, **Meteorology and Atmospheric Physics**, 133, August 2021, DOI:10.1007/s00703-021-00811-3, 1299-1316 **(Impact Factor 2.065)**

229. **Varghese M., Prabhakaran Thara, 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**, 257: 105589, August 2021, DOI:10.1016/j.atmosres.2021.105589 **(Impact Factor 5.369)**

230. **Varikoden H.**, Hrudya P.P.V.H, Vishnu R.N., Kuttippurath J., Changes in the ENSO–ISMR relationship in the historical and future projection periods based on coupled models, **International Journal of Climatology**, 42, March 2022, DOI:10.1002/joc.7362, 2225-2245 **(Impact Factor 4.069)**

231. Verma S., Yadava P.K., **Lal D.M.**, Mall R.K., Kumar H., Payra S., Role of lightning NOx in ozone formation: A review, **Pure and Applied Geophysics**, 178, April 2021, DOI:10.1007/s00024-021-02710-5, 1425–1443 **(Impact Factor 2.335)**

232. **Victor N.J., Siingh D.**, Singh R.P., Gautam A.S., Gautam S., Analysis of positive and negative atmospheric air ions during New Particle Formation (NPF) events over urban city of India, **Aerosol Science and Engineering**, 5, December 2021, DOI:10.1007/s41810-021-00115-4, 460-477 **(Impact Factor 0.000)**

233. Vijayakumar P., **Abhilash S.**, Sreenath A.V., Athira U.N., Mohankumar K., Mapes B.E., Chakrapani B., **Sahai A.K.**, Niyas T.N., Sreejith O.P., Kerala floods in consecutive years - Its association with mesoscale cloudburst and structural changes in monsoon clouds over the west coast of India, **Weather and Climate Extremes**, 33: 100339, September 2021, DOI: 10.1016/j.wace.2021.100339, 1-14 **(Impact Factor 5.338)**

234. Wagh S., Singh P., **Ghude S.D., Safai P., Prabhakaran Thara**, Pradeep Kumar P., Study of ice nucleating particles in fog-haze weather at New Delhi, India: A case of polluted environment, **Atmospheric Research**, 259: 105693, September 2021, DOI:10.1016/j.atmosres.2021.105693, 1-10 **(Impact Factor 5.369)**

235. Xue Y., Yao T., Boone A.A., Diallo I., … , **Saha S.K.**, … et al., Impact of Initialized Land Surface Temperature and Snowpack on Subseasonal to Seasonal Prediction Project, Phase I (LS4P-I): organization and experimental design, **Geoscientific Model Development**, 14, July 2021, DOI:10.5194/gmd-14-4465-2021, 4465–4494 **(Impact Factor 6.135)**

236. **Yadav R.**, Vyas P., **Kumar Praveen**, Sahu L.K., Pandya U., Tripathi N., Gupta M., Singh V., Dave P.N., Rathore D.S., **Beig G.**, Jaaffrey S.N.A., Particulate matter pollution in urban cities of India during unusually restricted anthropogenic activities, **Frontiers in Sustainable Cities**, 4: 792507, March 2022, DOI:10.3389/frsc.2022.792507, 1-14 **(Impact Factor 0.000)**

237. **Yadav R.K.**, Relationship between Azores High and Indian summer monsoon, **npj Climate and Atmospheric Science**, 4: 26, April 2021, DOI: 10.1038/s41612-021-00180-z, 1-9 **(Impact Factor 8.624)**

Other Publications in Books, Reports, Proceedings, Magazines, Newsletters, etc.

1. **Beig G.**, Gosavi S., **Mukkannawar U.S.**, Sahu S.K., **Tikle S., Dole S.**, Kamble P., Kale S., **Murthy B.S., Latha R.**, Mangaraj P., **Ambulkar R., Jadhav D., Basheer I., Yadav A., Shinde N., Palampalle D., More D., Athulya S.**, SAFAR-High Resolution Gridded Emissions Inventory of Pune, Pimpri and Chinchwad Regions: System of Air Quality and Weather Forecasting and Research (SAFAR) - Pune, **Special Scientific Report: SAFAR-Pune-2020**, 2021.

2. **Chakraborty S., Datye A., Murkute C., Halder Subrota, Parekh A., Sinha N., Mohan P.M.**,

Application of precipitation isotopes in pursuit of paleomonsoon reconstruction: An Indian perspective, Chapter 16 In: Kumaran N., Damodaran P. (eds.), **Holocene Climate Change and Environment,** 1st Ed., September 2021, 413-427.

3. **Chowdary J.S, Perakh A., Gnanaseelan C. (Ed.), Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond**, August 2021, Elsevier – Netherlands, ISBN: 9780128224021.

4. **Deb Burman P.K.**, Estimation of Net Primary Productivity: An Introduction to Different Approaches, Chapter in **Spatial Modelling in Forest Resources Management** -, Edited by: Shit P.K., Pourghasemi H.R., Das P., Bhunia G.S., 2021, Springer, Switzerland; DOI:10.1007/978-3-030-56542-8_2, 33-69.

5. Gadgil S., Francis P.A., Rajendran K., **Nanjundiah R.S., Rao S.A.,** 2021, Role of land-ocean contrast in the indian summer monsoon rainfall, Chapter 1 in: Chang C-P., Ha K-J., Johnson R.H., Kim D., Lau G.N.C., Wang B. (eds) **Multiscale Global Monsoon System**, World Scientific Series on Asia-Pacific Weather and Climate, DOI:10.1142/9789811216602_0001, 3-12.

6. Garcia-Soto C., Breitburg D., … **Roxy M.K.** and co-authors, 2021, Pressures from changes in climate and atmosphere, Chapter 9 in: The Second World Ocean Assessment, Vol. II, April 2021, United Nations, 55-75.

7. **Mahapatra S.,** India's Monsoon Mission: Great success through combined and coordinated efforts, **Bulletin of IMSP (BIMSP)**, 20, April-June 2021, 18-27

8. **Mahapatra S.**, Almost Pythagorean Triples in Prime numbers: A new concept, **Bulletin of IMSP (BIMSP**), 20, October-December 2021, 14–18.

9. **Mahapatra S.**, International Monsoons Project Office (IMPO) at IITM Pune, **Bulletin of IMSP (BIMSP)**, 20, July-September 2021, 19-21, https://www.imdpune.gov.in/Links/imsp/index.html.

10. **Mahapatra S.,** Chaudhari S.K., Water quality problems in rural and mining areas of Jharkhand, **Bulletin of IMSP (BIMSP)**, 21, January-March 2022 issue, 22-30.

11. **Mandke S.K.**, Some aspects of the weak rainfall spells of the Indian summer monsoon 2018, in Astakhova E. (Ed.), **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No. 51. WCRP Report No.4/2021., July 2021, WMO, Geneva, 2-11.

12. **Mandke S.K., Prabhu A.**, Eurasian winter snow variability in the future warming scenarios of CCSM4/CMIP5, in Astakhova E. (Ed.), **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No. 51. WCRP Report No.4/2021., July 2021, WMO, Geneva, 7-11.

13. **Metya Abirlal, Deb Burman P.K., Chakraborty S.**, Carbon cycle study in the Kaziranga National Park reveals a unique characteristic of the prevailing forest ecosystem, Bulletin of IMSP (BIMSP), 20, July-September 2021, 7-13 https://www.imdpune.gov.in/Links/imsp/index.html.

14. Plummer D., Nagashima T., Tilmes S., Archibald A., Chiodo G., **Fadnavis S.**, Garny H., … et al., CCMI-2022: A new set of Chemistry-Climate Model Initiative (CCMI) Community Simulations to Update the Assessment of Models and Support Upcoming Ozone Assessment Activities, **Stratosphere-Troposphere Processes and Their Role in Climate (SPARC) Newsletter**, no. 57, July 2021, 22-3.

15. **Prabhu A., Mandke S.K.**, Relation of Eurasian snow with regional India summer monsoon rainfall, in Astakhova E. (Ed.), **WGNE Blue Book: Research Activities in Earth System Modelling**, Report No. 51. WCRP Report No.4/2021., July 2021, WMO, Geneva, 2-21.

16. **Srivastava Atul Kumar**, Air pollution: Facts, causes, and impacts, Chapter 2 in Singh R.P. (eds), **Asian Atmospheric Pollution: Sources, Characteristics and Impacts**, August 2021, DOI: 10.1016/B978-0-12-816693-2.00020-2, 39-54.

17. Tiwari S., Chen B., Singh S., Singh A.K., **Srivastava A.K.**, Impact of black carbon on environment and health, Book chapter 5 in **Functionalized Nanomaterials based Devices for Environmental Applications**, Ist Ed. (Ed.) by Hussain, Elsevier Publication, August 2021. DOI: 10.1016/B978-0-12-822245-4.00007-6, 107-125.

Summary of Publications during the year 2021-22	
Total No. of papers published in Journals	237
Papers with Impact Factor	221
Papers without Impact Factor	16
Cumulative Impact Factor	884.749
Average Impact Factor	3.733
Other Publications	17

A. R. Sulakhe & Co.
H.O. Anand Apartment, 1180/2, Shivajinagar, Pune - 411005.
Tele : +91-020-25535600, 25535221, Mobile : 9822012023
E-mail: anand@arsulakhe.com, admin@arsulakhe.com
www.arsandco.com
Branches : Mumbai | Solapur | Ahmedabad | Kolhapur | Ahmednagar | Hyderabad | Nagpur | Goa

Independent Auditors' Report

TO

THE DIRECTOR

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

Opinion

We have audited the financial statements of the Indian Institute of Tropical Meteorology ("the Institute"), which comprise the balance sheet as at March 31, 2022, and the statement of Income and Expenditure for the year then ended, and 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 effect(s) of the matter(s) described in the Basis for Qualified Opinion paragraph, 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, 2022 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.

Emphasis of Matter

We draw attention to the following aspects of the financial statements due to which our opinion is not modified.

There are ledger accounts under both assets and liabilities which are having old balances outstanding for which institute is in the process of clearing these old outstanding balance.

Other Matter

There is an unresolved Land Dispute with the National Chemical Laboratory (NCL), Pune.

Responsibilities of Management and Those Charged with the 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 the 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 a 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
A R Sulakhe & Co
Chartered Accountants
Firm Reg. No.110540W

Kaustubh Deo
PARTNER
Membership No: 134892
Date: July 26, 2022
Place: Pune
UDIN 22134892AOPHVL4243

COMPLIANCE TO AUDIT OBSERVATIONS

Land dispute with National Chemical Laboratory (NCL), Pune. Land Dispute with National Chemical Laboratory (NCL), Pune, has not been resolved.	The land to be transferred is identified by NCL. Approval of DG – CSIR & Secretary MoES has been obtained for the same. The process for actual transfer of land is being explored in consultation with Collector of Pune / Inspector General of Registration and Controller of Stamps, Pune.

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE-8
BALANCE SHEET AS AT 31-03-2022

1. CORPUS/ CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
CAPITAL FUND	1	8675173552.70	9096936661.20
RESERVES AND SURPLUS (CORPUS)	2	13708745.90	13421245.90
EARMARKED/ ENDOWMENT FUNDS	3	12689372.41	13969427.41
SECURED LOANS AND BORROWINGS			
UNSECURED LOANS AND BORROWINGS			
DEFERRED CREDIT LIABILITIES			
CURRENT LIABILITIES AND PROVISIONS	4	36273467.51	97547980.76
INTEREST	15	12212998.78	47909433.00
2. TOTAL		**8750058137.30**	**9269784748.27**
1. ASSETS			
FIXED ASSETS	5	8092500586.60	8499148960.59
INVESTMENTS - FROM EARMARKED/ ENDOWMENT FUNDS			
INVESTMENTS - OTHERS			
CURRENT ASSETS LOANS ADVANCES ETC.	6	657557550.70	770635787.68
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)			
3. TOTAL		**8750058137.30**	**9269784748.27**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS			

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE-8
INCOME & EXPENDITURE ACCOUNT FOR THE PERIOD/YEAR ENDED 31-03-2022

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services			
Grants/Subsidiser	7	1202100000.00	1292300000.00
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	4404754.40	3784002.35
Increase/(decrease) in stock of Finished goods and works-in-progress			
TOTAL (A)		**1206504754.40**	**1296084002.35**
<u>EXPENDITURE</u>			
Establishment Expenses	11	467766368.14	436798407.92
Other Administrative Expenses etc.			
Expenditure on Schemes	13	745667031.76	804679363.10
Interest			
Depreciation during the year	14	508933564.00	503807688.40
TOTAL (B)		**1722366963.90**	**1745285459.42**
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		**-515862209.50**	**-449201457.07**
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 31-03-2022

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
I Opening Balances			**I Establishment expenses**		**467766368.14**
a Cash in hand		**40000.00**	**II Payment made against various project funds**		**14978800.00**
b Bank Balances			**III Advances to Others than schemes**		**483960.00**
i State Bank of India - Current Account -11099449733		**90907715.89**	**IV Advance to Staff**		**1230346.00**
ii State Bank of India - VyaparAccount -38222234583		**257748.00**	**V Deposits with**		**512710.00**
iii Pujnab National Bank - 0495000100169650 - Saving Account		**226274081.75**	**VI Overheads**		**0.00**
iv State Bank of India - Project Current Account - 30128441802		2399770.16	VII **Funds Retained from suppliers**		**11939024.25**
v State Bank of India ENVIS - 39044342605		2684644.60	**VIII Statutory Liability**		**547524370.97**
vi State Bank of India - ENVIS - 40280284775		0.00	**IX DESK**		**25518498.26**
II II. Grants Received		**1302100000.00**	Recurring	24542703.00	
1 High Performance Computing (HPC)	135000000.00		Non-Recurring	6051127.26	
2 Monsoon Convection Clouds & Climate Change (MC4)	213000000.00		Advance	1217161.00	
3 IITM - Operations & Maintenance	831000000.00		Total	31810991.26	
4 Monsoon Mission	82000000.00		Less: Advance adjusted	6292493.00	
5 DESK	41100000.00		**X IITM Operations & Maintenance**		**385830671.00**
III Interest Received			Recurring	382085633.00	
Non-Plan Interest		**10076521.78**	Non-Recurring	1349928.00	
1 CLTD	8974437.78		Advance	5018103.00	
2 Penal Interest	9707.00		Total	388453664.00	
3 Cycle / Scooter Interest	3384.00		Less: Advance adjusted	2622993.00	
4 HBA Interest	100008.00				
5 Interest (Principle Arreares) Recd. From MSEDCL	969624.00		**XI Monsoon Mission**		**59655655.00**

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE - 08
RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31-03-2022

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
6 Computer Interest	19361.00		Recurring	60507716.00	
			Non-Recurring	0.00	
b Interest - On Schemes		**2136477.00**	Advance	215277.00	
1 High Performance Computer System (HPC)	229440.00		Total	60722993.00	
2 Monsoon Convection Clouds & Climate Change (MC4)	1402069.00		Less: Advance adjusted	1067338.00	
3 Monsoon Mission II	504968.00				
			XII HPC		**235707326.00**
IV Other Income		**4404754.40**	Recurring	182078630.00	
1 Contribution to Pensioners Medical Sch.	1485600.00		Non-Recurring	46915523.00	
2 Fees from Student	224897.00		Advance	17840712.00	
3 Guest House charges	477163.00		Total	246834865.00	
4 Licence Fees	1712370.00		Less: Advance adjusted	11127539.00	
5 Maint of Colony Welfare	45362.00				
6 Community Hall - Welfare Charges	100.00				
7 Sale of Scrap (Auction)	157309.00				
8 Misc.Receipts	11689.40				
9 Water charges	71674.00				
10 TDS refund from Income Tax Department	218590.00				
V Any other receipts		**540487167.47**	**XIII National Facility for Airborne Research**		**2546354.00**
1 Receipts from various project	13698745.00		Recurring	0.00	
2 Funds Retained from suppliers	7516930.00		Non-Recurring	0.00	
3 Claims Receivable	9174890.50		Advance	2566434.00	
4 Statutory liabilities	495139605.97		Total	2566434.00	
5 Deposits with	302209.00		Less: Advance adjusted	20080.00	
6 Advance to others than schemes	833182.00				
7 Overheads	287500.00		**XIV Monsoon Convection Clouds & Climate Change (MC4)**		**187365022.51**
8 Deposits from creditors	11752756.00		Recurring	96452349.76	
9 Advance to Staff	1781349.00		Non-Recurring	47968611.75	
			Advance	69341243.00	
			Total	213762204.51	
			Less: Advance adjusted	26397182.00	

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)
INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE - 08
RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31-03-2022

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
			XV Claims Receivable		**7565028.00**
			XVI Deposits From Creditors		**16220410.00**
			XVII Interest surrendered to MoES		**47909433.00**
			XVIII Monsoon Mission Capital unspent balance surrendered to MoES		**5900899.00**
			XIX Closing Balance		
			a Cash in hand		**40000.00**
			b Bank Balances		
			i State Bank of India - Current Account -11099449733		**154039909.27**
			ii State Bank of India ENVIS - 39044342605		**0.00**
			iii State Bank of India – Vyapar Account -38222234583		**1170015.00**
			iv Pujnab National Bank - 0495000100169650 - Saving Account -		**1300019.75**
			v State Bank of India - Project Current Account - 30128441802		**5234516.90**
			vi State Bank of India - ENVIS - 40280284775		**1329544.00**
TOTAL		**2181768881.05**	**TOTAL**		**2181768881.05**

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

(Dr. R. Krishnan)
(Director)
Pune
July 26, 2022

As per our Report on even date
For & on behalf of
A R Sulakhe & Co.
Chartered Accountants
(Firm Reg. No.110540W)

(Kaustubh Deo)
(Partner, Membership No.134892)
UDIN: 22134892AOPHVL4243

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