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ईएसएसओ–भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
ESSO-Indian Institute of Tropical Meteorology

Annual Report 2016-17

Meetings

Research Advisory Committee, 19-20 January 2017

Finance Committee 29 August 2016 and 31 January 2017

Governing Council 30 August 2016 and 01 February 2017

Annual Report
2016-17

ESSO-Indian Institute of Tropical Meteorology

(An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India)

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Director
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MD 20740 (USA)

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Harrison Building Streatham Campus
University of Exeter, North Park Road
United Kingdom

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GPO Box 1289, Melbourne, Victoria 3000
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Centre for Atmospheric Sciences
Indian Institute of Technology,
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Mr. B. Mukhopadhyay
Scientist 'F'
India Meteorological Department,
Pune - 411 005

Dr. R. Krishnan
Acting Director (from 06 December 2015)
Indian Institute of Tropical Meteorology,
Pune - 411 008

Member Secretary

Dr. G. Beig
Scientist 'G'
Indian Institute of Tropical Meteorology,
Pune - 411 008

FINANCE COMMITTEE

Chairman

Prof. V.K. Gaur
Honorary Emeritus Scientist
CSIR Fourth Paradigm Institute
NAL Belur Campus
Bengaluru - 560037

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Secretary or Representative of Secretary
Ministry of Earth Sciences
Prithvi Bhavan, Lodi Road
New Delhi - 110003

Financial Advisor
Ministry of Earth Sciences
Prithvi Bhavan, Lodi Road
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Member-Secretary

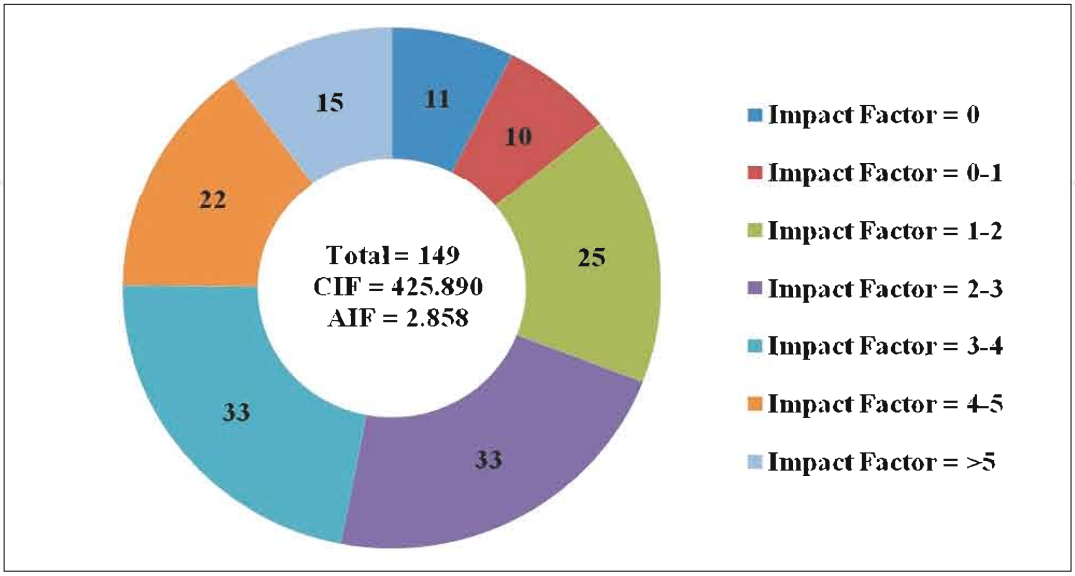
Director
Indian Institute of Tropical Meteorology,
Pune - 411008

Organizational Flow Chart of R&D Activities

CONTENTS

IITM Research Publications at a Glance

Growth of IITM publications in peer-reviewed journals since 2000.



Impact Factor wise distribution of IITM publications during the year 2016-17.

Details of Publications during the year 2016-17	
Total No. of Papers Published in Journals	149
Papers with Impact Factor	138
Papers without Impact Factor	11
Cumulative Impact Factor	425.890
Average Impact Factor	2.858

Foreword

It is my pleasure to present the annual progress and activities of the Indian Institute of Tropical Meteorology (IITM), Pune during the financial year 2016-17. IITM is one of the foremost research institutes working on weather and climate sciences globally. While being engaged in the fundamental and applied research in the area of Meteorology, Atmospheric Sciences and Climate, the Institute is consistently aspiring for better prediction of weather and climate events with emphasis on the Indian Summer Monsoon.

The Institute has made remarkable achievements in all its mission mode R&D projects during the year while keeping the standard and quality of research publications as high as ever. The report presents glimpses of the major R&D activities of the Institute. I am happy to observe that these achievements are in tune with the realization of the vision of the Institute and are contributing in the growth of IITM as a centre of excellence at the global level.

The success and growth of IITM would not be possible without the constructive, collaborative and collective contributions of all the research, scientific support, technical, engineering and administrative staff who consistently continue to work hard with dedication and devotion.

I would like to express my sincere gratitude to the Earth System Science Organisation (ESSO) and the Union Ministry of Earth Sciences for advisory and funding support, and the Governing Council, the Finance Committee and the Research Advisory Committee of the Institute for their constant support and guidance. I would like to thank different national R&D, operational and academic institutions such as IMD, NCMRWF, NCAOR, INCOIS, IISc, IITs and universities for their constant support through cooperation and collaborations. I also thank the Ministry of Science & Technology, the Ministry of Environment, Forests and Climate Change and the Indian Space Research Organisation for their continuing support and for sponsoring some important scientific projects. I also express my gratitude to our international collaborators for their scientific and technical cooperation in our R&D endeavors.

With the ever increasing scope and capabilities of the Institute, our work and expertise is helping in improving operational forecasts, benefiting different stakeholders. I hope IITM continues its success and growth story at an accelerated rate and provides global leadership in shaping the future of research and development in Weather and Climate Sciences that will help to fulfill the ever increasing demand for services/forecasts in these domains at the national and the global levels.

R. S. Nanjundiah

Ravi S. Nanjundiah
Director

Executive Summary

During the financial year 2016-17, the Indian Institute of Tropical Meteorology (IITM) made remarkable and recognizable achievements in all its mission mode R&D projects leading to enhancement in the capability to better understand and predict weather and climate phenomena. Theoretical, modeling, observational and diagnostic studies add to the existing knowledge of climate variability and predictability, especially the Indian monsoon. Enhanced understanding of the coupled land-atmosphere-ocean climate system, increased computational power and increasing capability in climate modeling have contributed in improving the skill of monsoon prediction systems for different spatio-temporal scales. IITM continues several of its observational programmes to gather empirical data on different meteorological and climatic processes, required for strengthening forecast capabilities. Under SAFAR, the air quality and weather forecast services are being extended to the twin cities of Ahmedabad and Gandhinagar (Gujrat) after its successful implementation in New Delhi, Pune and Mumbai. The Institute has made considerable research contributions in the different areas of Atmopsheric Sciences and Meteorology with 149 papers in peer-reviewed journals with a Cumulative Impact Factor of 425.890 and the Average Impact Factor of 2.858 during the year. The most important research contributions and achievements of the year 2016-17 are summarised below:

Monsoon Prediction

The CFSv2 model being used under the Monsoon Mission has been further improved, the most significant change being its spectral horizontal resolution increased from the original T126 (~110 km) to T382 (~36 km) – the highest resolution used in seasonal prediction worldwide. The high resolution model based experimental dynamical seasonal prediction for 2016 Summer Monsoon projected above normal rainfall (111% ± 5% of long period model average). However, the actual rainfall was near normal (97% of long period average (LPA) over the country. The same model succeeded in generating reliable experimental forecast for the 2016 North-East Monsoon over the Indian region by using the September initial conditions with 47 ensembles.

The CFS based Grand Ensemble Prediction System (CGEPS) provided reliable real-time extended range prediction of active/break spells of Indian summer monsoon for the 2016 monsoon season. A system for providing extended range prediction for extreme heat conditions was developed that could provide reasonably reliable guidance on the heat wave conditions experienced over various parts of the country during the summer of 2016. Extended range forecast at multiple resolutions is being implemented as a function of lead-time to reduce the growth of error at larger lead-time. Also, efforts are being made to dynamical downscale the extended range prediction products to the sub-divisional level.

Further, short range ensemble forecast system based on Global Forecast System (GFS) at ~30 km resolution and the short range deterministic forecasting system based on GFS T1534 at 12 km resolution have been developed at IITM under the NITI Aayog identified programme. These models have been transferred to IMD for operational purposes. The system is found to capture the location and intensity of extreme rain events and also, the cyclogenesis with reasonable lead time. Efforts are being made to make these forecasts at the block-level and also to develop the ensemble forecast system based on GFS T1534 at 12 km resolution.

Different studies were carried out during the year to improve the model skill of monsoon prediction or to suggest possible improvements. The analysis T126 and T382 resolutions of CFSv2 shows that higher resolution is required for distinguishing between the two El Niño flavours of summer season at lead time of about four months to enhance the seasonal prediction skill of CFSv2. Also, compared to lower resolution (T126), it is observed that high resolution model (T382) has better seasonal prediction skill for all the homogeneous regions of India except south peninsular India. T382 captures well the extreme events and the associated teleconnections at four month lead time. Further, it is also found that improving parameterization of snow/sea-ice albedo scheme in the CFSv2 model will lead to a realistic simulation of surface temperature and it may have implications on the global energy imbalance in the model.

A Self Organizing Map based and bias-corrected technique is developed for downscaling operational extended range forecasts, showing improvement in the annual cycle and the skill of deterministic as well as probabilistic forecasts.

Climate Change Research and Projections

The Earth System Model (ESM 2.0) being developed by Centre for Climate Change Research (CCCR0 at IITM has been further strengthened to provide climate simulations from India to the CMIP6 simulations. The ESM2.0, as compared to other CMIP models, shows significant improvement in representing precipitation pattern over the Asian region, especially the Indian region. In the second stage of ESM, a radiatively balanced climate modeling framework is developed. In accordance with the protocols for CMIP6 simulations, all the forcing fields including the tropospheric and volcanic aerosols, ozone and land-use land cover changes have been incorporated in the model.

CCCR is engaged in research on different aspects of climate change, especially over the Indian region. Research suggests that the anomalous decrease in productivity over southern subtropical Indian Ocean during Austral summer in the recent decades is due to increased frequency of Ningaloo Niño events associated with cold phase of Pacific Decadal Oscillation. The sub-tropical convective activities over the east Pacific may play a pivotal role in mediating the Pacific-monsoon teleconnection through the unexplored meridional SST gradient across the Pacific. Also, SST variations over the Indo-Pacific Ocean in the backdrop of global warming seem to have dominant influence on the recent rainfall trends.

The ensemble of high resolution regional climate change projections upto 2100 for RCP4.5 and RCP8.5 scenarios at 50 km spatial resolution over the South Asian region is generated by dynamical downscaling of six CMIP5 global climate model outputs and the same is standardized, quality assured and published on the Climate Data Portal.

A satellite and model based study reveals a higher-than-normal aerosol loading over the Indo-Gangetic plain (IGP) during the pre-monsoon season with a concurrent El Niño. The study suggests that such enhanced loading of pre-monsoon absorbing aerosols (mostly dust and BC) over IGP can reduce drought during El Niño years by invoking the 'Elevated-Heat-Pump' mechanism leading to relative strengthening of the cross-equatorial moisture inflow associated with monsoon.

Tree ring-index chronologies from the western Himalayas were used to reconstruct heat index of spring season (February to May) back to 1839 AD showing widest warm periods during 1952-1963 and 1966-1976 in the 20th century. The increasing heat index may enhance transpiration and evaporation over the western Himalayas, which may cause insufficient moisture at root zone of the trees. Also, a new method of reconstructing soil moisture isotope by estimating soil water oxygen isotope values (dsw) from tree ring cellulose oxygen isotope data is tested and found to be reliable. It will be useful in applying land hydrological models to the past.

Short Term Climate Variability and Prediction

A web portal 'RAINFO and TEMPINFO' is being developed to provide all the information on rainfall and temperature variability over a region in one click. The products being prepared on different spatial (sub-divisions, cities and districts) and temporal (daily, monthly and seasonal) scales would be useful to the general public, farmers and impact assessment groups.

Climatological variability and trends over the Koshi river basin have been studied by using daily temperature data (20 stations) and precipitation data (50 stations) during 1975 to 2010. The results show that the frequency and intensity of weather extremes are increasing. This indication about the increased risk of extreme climate events over the basin will increase people's vulnerability and will have strong policy implications.

A larger variation in the dates of monsoon onset over Ocean (from 17 to 29 May) and over Kerala (from 23 May to 6 June) is observed against the normal dates of 20 May and 1 June over these regions respectively during the study period 2009-2014. The study also revealed that synoptic developments occurring over the regions of southeast Bay of Bengal and southeast Arabian Sea are linked with those occurring over the tropical northwest Pacific Ocean. Proper utilisation of this synoptic analog in the global prediction models used for the onset prediction can further improve the precision of prediction.

Research suggests that large variations in decaying El Niño display profound impact on the ISM rainfall. It is found that ISM rainfall is above normal/excess during early-decay of El Niño (ED; decay during spring) years, normal during mid-summer decay (MD; decay by mid-summer) and below normal/deficit during no-decay (ND; no decay in summer).

Metropolitan Air Quality and Weather Forecasting Services

Work is at advanced level for implementing SAFAR-Ahmedabad in collaboration with the Space Application Centre (SAC), Ahmedabad Municipal Corporation (AMC) and Indian Institute of Public Health (IIPHG), Gandhinagar. A network of 10 AQMS (Air Quality Monitoring Stations), 10 AWS (Automatic Weather Stations) and 12 DDS (Digital Display Systems) is being established across Ahmedabad city area. Unique region specific primary data on the emissions have been collected, quality controlled and quality checked to develop a gridded emission inventory through the GIS based statistical model. WRF-Chem model with four-nested domain has been set-up to forecast air quality and weather parameters for Ahmedabad and surrounding regions. After successful implementation, SAFAR-Ahmedabad will provide services like Air Quality-Now, Air Quality-Tomorrow, Weather-Now, Weather-Tomorrow, UV Index-Skin Advisory, AQI-Health Advisory and City Pollution Maps for various stakeholders through different dissemination tools.

SAFAR also provided scientific and technical assistance to Rajasthan Government in developing air quality mobile app 'RajVayu' that provides information about current air quality index and weather of Jaipur, Jodhpur and Udaipur.

A big smog event was observed in New Delhi from 30 October to 07 November 2016. The smog engulfed the city for more than a week and the air quality was continuously monitored by SAFAR. The levels of toxic fine particulate matter PM2.5 were unprecedentedly higher (by about 10-13 times) than the Indian National Standards maximum recommended value (NAAQS of 60 μg/m3). The share of bio-mass transport emissions from stubble burning in PM2.5 rose from ~1.8% on 01 November to 38.6% on 02 November and to a peak of 68% on 06 November, before it started to retreat.

Physics and Dynamics of Tropical Clouds (PDTC)

PDTC and its sub-projects are working toward an advanced understanding of tropical clouds and their interaction with the environment, required for better monsoon prediction.

Under the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Phase-IV experiments during 2017-19, preparations are being made for conducting seeding experiments at Solapur as the possible site for the experiment. Different equipment like radars and several other instruments for the campaign are being put in place. A rain gauge network is also being established for evaluating seeding and calibrating radars in the rain shadow region for the CAIPEEX Phase-IV campaign. Under the Radar and Satellite Meteorology group, observational campaign using collocated X- and Ka- band radars was conducted at Mandhar Devi. The winter fog campaign has been conducted for the second consecutive year at IGI Airport New Delhi and Hissar Agricultural University (HAU), Haryana.

Efforts are being made for procuring an instrumental research aircraft for establishing a national facility for airborne research catering to the scientific needs of several national research and educational institutions in the country. An unmanned Aerial Vehicle (UAV) equipped with different instruments is also being procured to study the lower atmospheric processes.

Several studies conducted during the year have revealed various aspects of cloud miscrophysics and dynamics which will enable us to do better parameterization of cloud phenomena in the coupled dynamical forecast models, and could contribute to improving the prediction skill of the model. The Lightning Location network established in Maharashtra has enhanced our understanding of thunderstorm dynamics and will contribute in developing robust lightning prediction system in the county.

The Institute is actively contributing in capacity-building and human resource development in weather and climate sciences. Ten students graduated with PhD while four others have submitted their thesis during the year. About 100 students of different UG/PG courses in science and engineering from various colleges, universities and institutions from across the country were provided research guidance and facilities for their short-term project/internship under the guidance of IITM scientists. Centre for Advanced Training continues to conduct the pre-PhD coursework of IITM Research Fellows and has also started conducting short term training activities for the benefit of the weather and climate sciences community. IITM organized and hosted more 55 national and international workshops, seminars, conferences, meetings, etc. on different aspects of weather and climate sciences. While the past year has been a good one, we look forward to interesting and exciting times ahead.

Earth Day Celebrations

Dignitaries on dias (L-R) Dr. Milind Mujumdar and Dr. R. Krishnan

Participants of various competitions

Street-play performance by Pune Municipal Corporation (PMC) employees

Prize Distribution

National Forest Conservation Day Celebrations

Dignitaries on dias (L-R) Dr. Rahul Mungikar and Dr. G. Beig

Participants of various competitions

Prize distribution and Participants on National Forest Conservation Day Celebrations

55th Foundation Day Celebrations

Dignitaries on dias (L-R) Dr. R. Krishnan, Prof. S.K. Dube, Prof. P.C. Joshi and Dr. C. Gnanaseelan

Lamp Lighting

Welcome Address by Dr. R. Krishnan

Inagural Address by Prof. S.K. Dube

(L-R) Dr. A.K. Sahai and Dr. C. Gnanaseelan receiving 3rd Biennial Golden Jubilee Award

Dr. S.D. Ghude receiving 'Prof Ananthakrishnan Best Thesis Award-2016' on behalf of Dr. C.K. Jena

Dr. C. Gnanaseelan receiving '28th Annual IITM Silver Jubilee Award'

Ms. Priya P. receiving 'Best Student Research Paper Award-2015'

Presentation of 'IITM Excellent Performance Award' (R-L) Mrs. S.B. Patankar, Mr. S.M. Thorat, Mr. K.D. Barne and Mr. V.V. Bambale

Foundation Day Lecture by Prof. P.C. Joshi

Golden Jubilee Award Lecture by Dr. A.K. Sahai and Dr. C. Gnanaseelan

Best Student Research Paper Award Lecture by Ms. P. Priya

Cultural activities on the occasion of the 55th Foundation Day Celebrations

Visitors

Ms. Kriti Bhargava
USA

Prof. Marianne Lund
Norway

Dr. B.H. Samset
Norway

Prof. Thomas Peter
Switzerland

Dr. Andre Prevot
Switzerland

Prof. Phil Dickerson
USA

Dr. C. Nico
UK

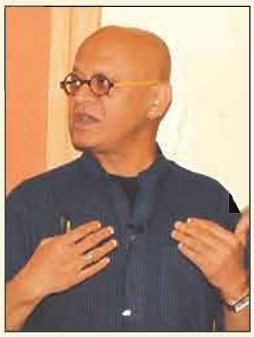
Prof. S. Bulusu
USA

Dr. Ibrahim Hoteit
Saudi Arabia

Prof. S. Laxmivarahan
USA

Prof. Atul Jain
USA

Prof. Wojciech Grabowski
USA



Prof. R. Murtugudde
USA

Prof. K.T. Paw
USA

INDO-UK Workshop

Dignitaries on dias (L-R) Dr. Harry Dixon, Prof. V.K. Gaur, Prof. Alan Jenkins and Dr. A K Sahai

Welcome Addres by Dr. A.K. Sahai

Introduction about IUKWC by Dr. Harry Dixon

Addres by Prof. Alan Jenkins

Session in progress

Participants

Cultural programme on the occasion of the Indo-UK Workshop

INDO-US Workshop

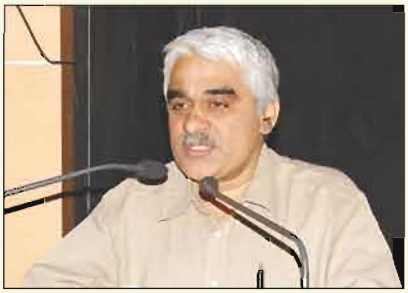
Dignitaries on dias (L-R) Dr. R. Krishnan, Prof. Ravi S. Nanjundiah, Prof. David Easterling, Prof. Ken Kunkel and Dr. (Mrs.) Ashwini Kulkarni

Lamp Lighting

Welcome Address by Prof. Ravi. S. Nanjundiah

Inaugural Address by Prof. David Easterling

Address by Prof. Ken Kunke



Address by Dr. R. Krishnan

Session in Progress

Interaction with Media Persons

Participants

INTROSPECT-2017

Dignitaries on dias (L-R) Prof. Ravi S. Nanjundiah, Prof. J. Shukla, Prof. J. Srinivasan, Prof. George Grell and Dr. P. Mukhopadhyay

Lamp Lighting

Welcome Address by
Prof. Ravi. S. Nanjundiah

Inaugural Address by
Prof. J. Srinivasan

Address by
Prof. J. Shukla

Inaugural Lecture by
Prof. George Grell

Participants

WMO Workshop

Dignitaries on dias (L-R) Dr. A.K. Sahai, Dr. Rupa Kumar Kolli, Dr. R.R. Kelkar, Dr. Toshiyuki Nakaegawa, Dr. B. Mukhopadhyay

Welcome Address by Dr. A.K. Sahai

Inaugural Address by Dr. R.R. Kelkar

Address by Dr. Rupa Kumar Kolli

Address by Dr. Toshiyuki Nakaegawa

Lecture by Dr. Rupa Kumar Kolli and Dr. Nicholas Herold

Session in Progress

Participants

Cultural programme on the occasion of the WMO Workshop

Advanced School on Earth System Modelling

Dignitaries on dias (L-R) Dr. R. Krishnan, Dr. F. Riccardo, Prof. V.K. Gaur, Dr. M. Rajeevan, Dr. V. Balaji, Dr. (Mrs.) P. Swapna

Lamp Lighting

Welcome Address by Dr. R. Krishnan

Inaugural Address by Dr. V. Balaji

Address by Dr. F. Riccardo

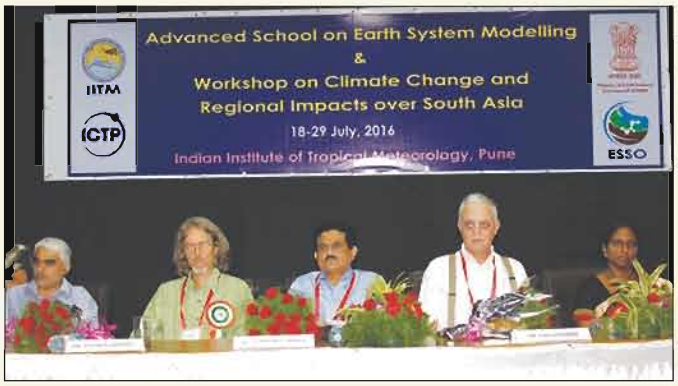
Address by Dr. M. Rajeevan

Address by Prof. V. K. Gaur

Lecture by Dr. V. Balaji and audience

Participants

Workshop on Climate Change and Regional Impacts over South Asia



Dignitaries on dias (L-R) Dr. R. Krishnan, Dr. Stephen Griffies, Dr. Satheesh Shenoi, Dr. Paulo Nobre and Dr. (Mrs.) P. Swapna

Lamp Lighting

Welcome Address by Dr. R. Krishnan

Inaugural Address by Dr. Satheesh Shenoi

Lecture by Dr. Stephen Griffies

Lecture by Dr. Paulo Nobre

Cultural programme on the occasion of the Workshop

Hindi Week Celebrations

Lamp Lighting

Kavi Sammelan

Antakshari Competition

Dignitaries on dias (L-R) Dr. O.N. Shukla,
Mr. V.R. Patil and Dr. A.K. Sahai

Address by
Dr. A.K. Sahai

PRITHVI - The Hall of Residence

Inauguration of 'Prithvi-The Hall of Residence' at the hands of
Dr. M. Rajeevan, Hon'ble Secretary, Ministry of Earth Sciences, Govt. of India

Observation of Special Days/Weeks

Pledge administered on the occasion of 'Samvidhan Divas'

Pledge administered on the occasion of 'Vigilance Awareness Week'

Pledge administered on the occasion of 'Anti Terrorism Day'

Yoga Day Celebrations

MOES Awards

Dr (Mrs.) P. Swapna receiving the 'Certificate of Merit 2016' of Ministry of Earth Sciences, Govt. of India

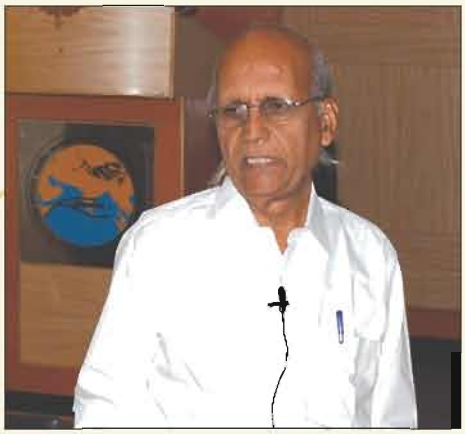
Top (L-R): Mrs. R.S. Salunke, Mr. R.D. Nair, (Bottom L-R): Mr. S.A. Sayyed and Mr. E.M. Botla receiving 'Best Employees Award 2016' of Ministry of Earth Sciences, Govt. of India for Group B, Group C and Multi Tasking Staff category respectively

National Science Day Celebrations

Visitors at IITM on Open Day, National Science Day Celebrations

Institute's participation in National Science Day Celebrations at GMRT, Narayangaon

World Meteorological Day Celebrations



WMO Day Lecture by
Dr. J.R. Kulkarni

Visitors at IITM on WMO Day Celebrations

Celebration of Ten Years of Ministry of Earth Sciences (2006-2016)

Project

Centre for Climate Change Research (CCCR)

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

Objectives

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

Sub-Projects

- Earth System Model Development
- Climate Change Science and Applications
- Atmospheric Chemistry and Climate
- Paleoclimate
- Fluxnet Programme and Modeling

Sub-Project

Earth System Modeling (ESM)

Developmental Activities

Updates on IITM ESM: A radiatively balanced climate modeling framework is developed during the second stage of ESM development activity. Following the protocols for CMIP6 simulations, all the forcing fields are incorporated in the model. These include the tropospheric and volcanic aerosols, ozone and land-use land cover changes. A 200 year pre-industrial control spin-up simulation is completed with the CMIP6-ready version of IITM ESM.2. The preliminary results indicate that the model is successful in simulating pre-industrial climate with a global mean temperature of 13.8°C and the top of atmosphere radiation imbalance within 1 Wm^{-2}. Improvement in the representation of precipitation pattern over the Asian region, especially Indian region, is a significant achievement in IITM-ESM.2 as compared to other CMIP models. CCCR is contributing to CMIP6 simulations with DECK simulations commencing from January 2017.

Basic Research

Changes in Large-scale Summer Monsoon Circulation

East Pacific Convective Activity and Summer Monsoon Teleconnection*:** The El-Niño event of 2015 happens to be the hottest on record thus placing it as one of the extreme El-Niño events since 1950, with pronounced warming peculiarly extending northward over central-eastern Pacific (**Fig. 1a**). This unusual sub-tropical central-eastern Pacific warming signature, with the *in-situ* mean SST exceeding 28°C, indicated a pronounced meridional sea surface temperature (SST) gradient across the region. The anomalous meridional SST gradient seems to be associated with the occurrence of highest number of tropical storms over eastern Pacific, with the anomalous rainfall distribution spanning northward (**Fig. 1b**). Interestingly, the east Pacific large-scale ascending motion seems to induce significant subsidence over the off-equatorial monsoon regions of south and south-east Asia, constituting an east-west circulation asymmetry over sub-tropical Indo-Pacific region (**Fig. 1c**). Thus, it is concluded that the sub-tropical convective activities over east Pacific may play a pivotal role in mediating the Pacific-monsoon teleconnection through the unexplored meridional SST gradient across Pacific. [Mujumdar M., Sooraj K.P., Krishnan R., Preethi B., Joshi M.K., Varikoden H., Singh B.B., Rajeevan M.,*** *Anomalous convective activity over sub-tropical east Pacific during 2015 and associated boreal summer monsoon teleconnections,* ***Climate Dynamics****, online, August 2016, doi:10.1007/s00382-016-3321-2*]

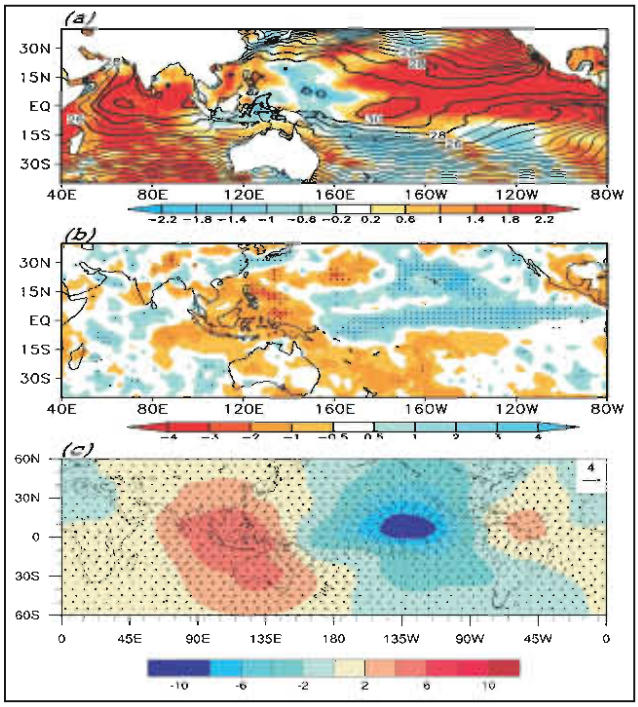


***Fig. 1:** Anomalous changes in the summer monsoon season of 2015. (a) Normalized anomalies (shadings) of SST (°C) and mean SSTs (contours). (b) Normalized anomalies of rainfall (mm day^{-1}). c) Anomalous velocity potential and divergent wind vectors at 200 hPa. Anomalies in (a) and (b), significant at 90 % confidence level are denoted by stippling.*

***Trends and Teleconnections among Asian monsoon sub-systems*:** The two major sub-systems of Asian monsoon, the South Asia and East Asia, witnessed contrasting trends in summer monsoon rainfall during recent decades (1970-2014). A significant dipole type pattern, with north (deficit) - south (excess) asymmetric rainfall trends over South as well as East Asia, is evident (**Fig. 2a**). Interestingly, these rainfall trends seem to be associated with a westward shift in large-scale monsoon circulation, especially a westward shift of south Asian monsoon trough by about 2-3° longitudes and North Pacific

Subtropical High over East Asia by about 5-7° longitudes (**Fig. 2b**). Consequently, the SST variations over the Indo-Pacific Ocean in the backdrop of global warming seem to have dominant influence on the recent rainfall trends.

[***Preethi B., Mujumdar M., Kripalani R.H., Prabhu A., Krishnan R.,*** *Recent trends and teleconnections among South and East Asian summer monsoons in a warming environment,* ***Climate Dynamics****, Online, June 2016, doi:10.1007/s00382-016-3218-0*].

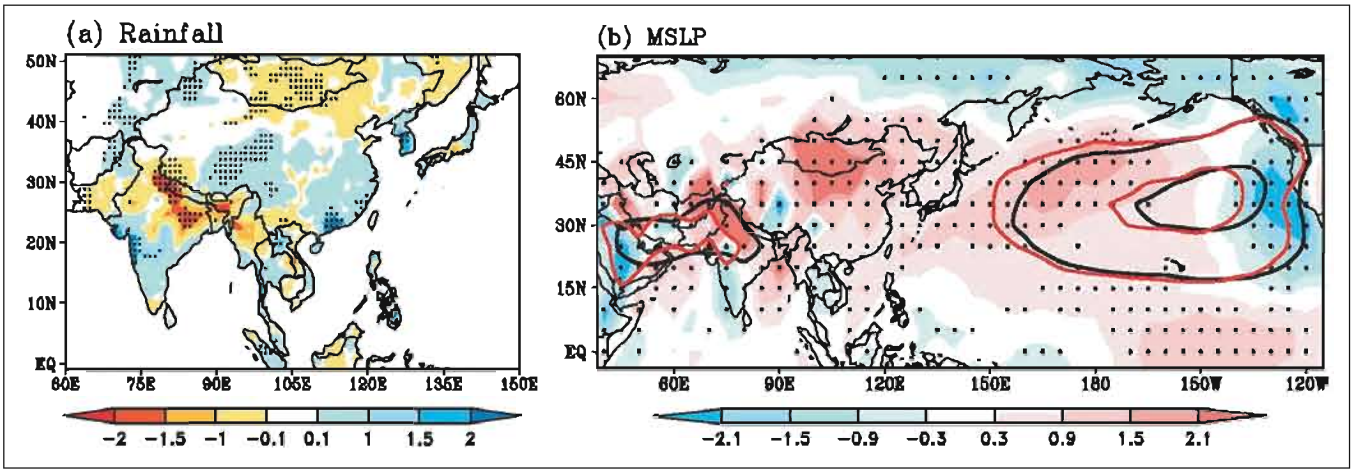


Fig. 2: *Linear trends in (a) rainfall (mm day^{-1}/45year) and (b) mean sea level pressure (mb/45year). Trends statistically significant at 90 % confidence level are shown in stippling. Black contours in (b) represent the position of monsoon trough and north Pacific sub-tropical high during the year 1970, whereas the red contours correspond to a 45-year trend in their respective positions with respect to 1970.*

Changes in Marine Biological Productivity in the Indian Ocean:

Biological Productivity and Ningaloo Niño/Niña events in the Indian Ocean: Ningaloo events have large impact on sea surface temperature (SST) in the southern subtropical Indian Ocean (SIO) with positive SST anomalies seen off the west coast of Australia during Ningaloo Niño and negative anomalies during Niña events. The ocean component of IITM-ESM is used to study the impact of these events on biological productivity in the SIO. The results from the study indicate that during Austral summer (DJF), the developing period of Ningaloo Niño, low chlorophyll anomaly appears near the southwest Australian coast concurrently with high SST anomaly (**Fig. 3a**) and vice-versa during Niña (**Fig. 3b**), which alter the seasonal cycle of biological productivity. During Austral winter (JJA), a high productivity is seen during Ningaloo Niño (**Fig. 3c**) and lesser productivity during Ningaloo Niña (**Fig. 3d**). The difference in the spatiotemporal response of chlorophyll during Niño/Niña events is due to the southward advection of Leeuwin current. Increased frequency of Ningaloo Niño events associated with cold phase of Pacific Decadal Oscillation (PDO) resulted in anomalous decrease in productivity over SIO during Austral summer in the recent decades. [***Narayanasetti S., Swapna P., Ashok K., Jadhav J., Krishnan R.,*** *Changes in biological productivity associated with Ningaloo Niño/Niña events in the southern subtropical Indian Ocean in recent decades,* ***Scientific Reports****, Online, June 2016, doi: 10.1038/srep27467*].

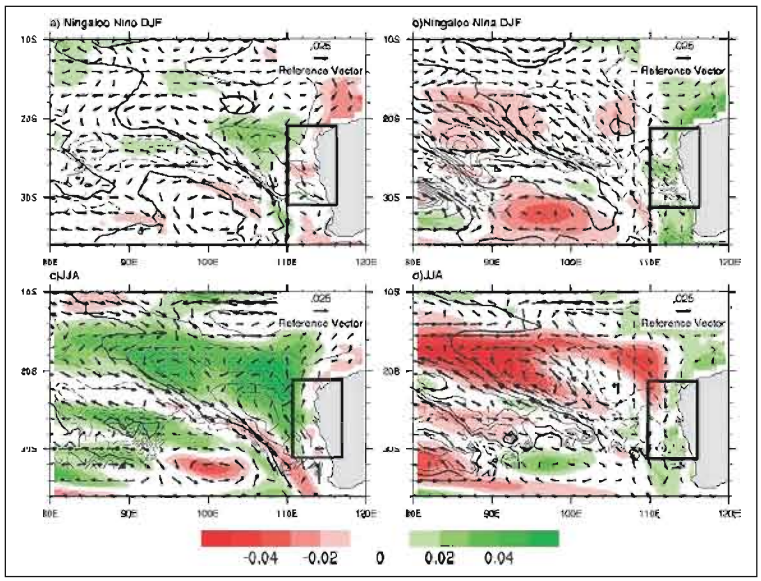


Fig. 3: *Composite plot showing chlorophyll anomalies (mg/m^3, shaded), thermocline (m, contour) and currents (m/s, vectors) for both Ningaloo events during two different seasons DJF and JJA from the model (a) Ningaloo Niño (DJF) and (b) Ningaloo Niña (DJF); (c) Ningaloo Niño (JJA) and (d) Ningaloo Niña (JJA). Stipplings denote 95% confidence regions.*

Sub-Project

Climate Change Science and Applications

Developmental Activities

Regional Climate Information for Application Studies - Updates on CORDEX South Asia: The ensemble of high resolution regional climate change projections upto 2100 for RCP4.5 and RCP8.5 scenarios at 50 km spatial resolution over the South Asian region generated at CCCR (IITM) by dynamical downscaling of six CMIP5 global climate model outputs using the ICTP regional climate model (RegCM4) are standardized, quality assured and disseminated by publishing on the Earth System Grid Federation (ESGF) CORDEX data node established on the CCCR-IITM Climate Data Portal (http://cccr.tropmet.res.in/home/cordexsa_datasets.jsp) to assist the science community in conducting studies of climate change impacts at regional scales.

Basic Research

Regional climate change scenarios

The downscaled climate over the Indian sub-continent, using regional climate models (RCMs) following the CO-ordinated Regional Climate Downscaling EXperiment (CORDEX) framework, is examined in this study. The results of the downscaled RCMs are compared to those of the driving atmosphere-ocean coupled-global climate models (AOGCMs) for the present climate period of 1976-2005, to investigate whether RCMs are able to show added value, at regional scale relative to the performances of their driving AOGCMs. The assessments of downscaled surface parameters are shown in **Fig. 4a-b**. It is found that the simulation of surface air temperature and seasonal precipitation are strongly affected by the choice of the RCM and driving AOGCMs. The RCMs are, however, able to improve the representation of the annual cycle of temperature in particular over the central India. Further, the climate change projections of four (AOGCMs) have been downscaled for the period 1950-2100. The CORDEX South Asia RCMs indicate significant increase in temperatures over India in the mid-term (2031-2060) future climate change projections with the RCP4.5 scenario (**Fig. 4c**). However, the magnitude and sign of the summer monsoon season precipitation change over India is uncertain (**Fig. 4d**). [***Sanjay J., Ramarao M.V.S., Mujumdar M., Krishnan R.,*** *Regional climate change scenarios, In:* ***Observed Climate Variability and Change over the Indian Region,*** *M.N. Rajeevan and Shailesh Nayak (Eds), Springer, 2017, ISBN: 978-981-10-2531-0, pp 285-304, doi: 10.1007/978-981-10-2531-0*]

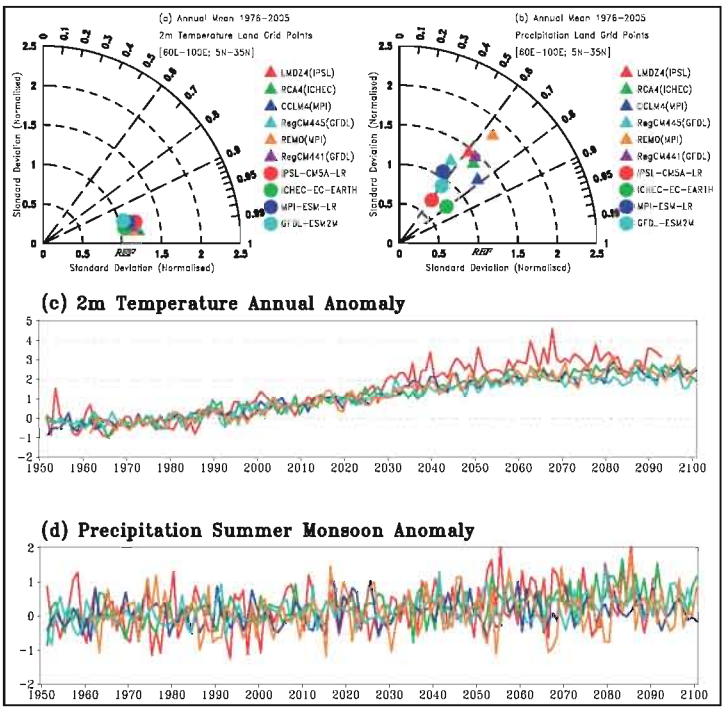


*Fig. 4: Taylor diagram for the annual mean (**a**) 2-m air temperature (°C) and (**b**) precipitation (mm day^{-1}) climatology (1976-2005) averaged over land grid points in South Asia (60-100°E, 5-35°N). Time series of relative change of South Asian (**c**) 2-m annual mean temperature (°C) and (**d**) summer monsoon precipitation (mm day^{-1}) for the period 1950 to 2100, with respect to 1976-2005.*

Projected changes in semi-permanent systems in CORDEX-SA framework

The semi-permanent systems such as seasonal heat low, monsoon trough, Tibetan anticyclone, tropical easterly jet and low level jet or Somali Jet play a vital role in defining the strength of the Indian summer monsoon rainfall as a whole. The study evaluates the ability of Consortium for Small-Scale Modeling

(COSMO) regional Climate Model (COSMO-CLM), a high resolution regional climate model within the CORDEX-SA framework, to simulate these semi-permanent systems of Indian monsoon. The historical simulations of the COSMO-CLM for the period 1951-2000 clearly show that the COSMO-CLM is able to simulate these components reasonably well, however with a dry bias over monsoon trough region and a wet bias over northeast India (**Fig. 5a-b**) along with a weakened monsoon trough (**Fig. 5d-e**). Further, possible changes in the position and the strength of the semi-permanent systems and their role in changing rainfall pattern over India are examined to assess the impact of global warming, under the RCP 4.5 simulations towards the end of the century (2051-2100). The study suggests that the semi permanent systems may not strengthen in the future as compared to the present climate, for example the monsoon trough (**Fig. 5e, f**). However, the summer monsoon rainfall does not show uniform changes over the region (**Fig. 5c**), with enhanced (reduction) rainfall over the southern parts (northern parts) of the country, under the global warming scenario. [***Patwardhan S., Kulkarni A., Sabade S.,*** *Projected Changes in Semi Permanent Systems of Indian Summer Monsoon in CORDEX-SA Framework,* ***American Journal of Climate Change****, 5, June 2016, 133-146, doi:10.4236/ajcc.2016.52013*]

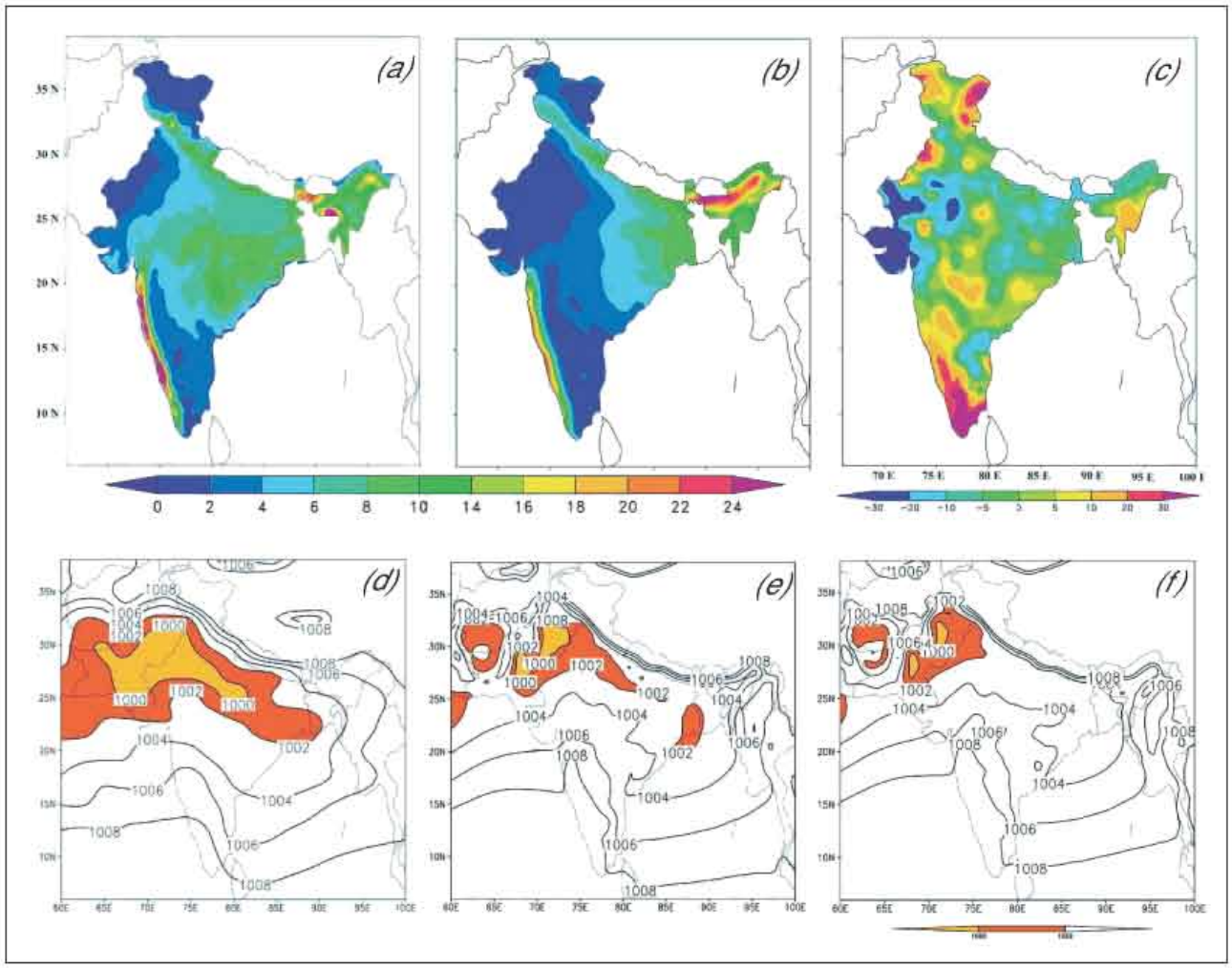


Fig. 5: Mean summer monsoon rainfall (June through September, mm day^{-1}) over India (a) Observed APHRODITE and (b) Historical simulation by COSMO-CLM, based on the period 1951-2000. (c) Percentage change in monsoon rainfall for 2051-2100 with respect to 1951-2000 under RCP4.5 scenario. Composite June to September mean Sea level pressure (hPa) pattern over monsoon trough region (d) Observation for 1951-2000, (e) Historical simulation for 1951-2000 and (f) RCP4.5 based on 2051-2100.

Sub-Project

Atmospheric Chemistry and Climate

Basic Research

Potential modulations of pre-monsoon aerosols during El Niño and its impact on Indian summer monsoon

The potential role of aerosol loading on the Indian summer monsoon rainfall during the El Niño years is examined using satellite-derived observations and a state of the art fully interactive aerosol-chemistry-climate model. The Aerosol Index (AI) from TOMS (1978-2005) and Aerosol Optical Depth (AOD) from MISR spectroradiometer (2000-10) indicate a higher-than-normal aerosol loading over the Indo-Gangetic plain (IGP) during the pre-monsoon season with a concurrent El Niño (**Fig. 6a-d**). The higher amount of AOD in El Niño year may be due to more (than climatology) transport of dust aerosols from west/northwest arid regions to the IGP and TP by stronger northerly winds in the lower troposphere and subtropical westerly winds in the upper troposphere. Model simulations reveal that these aerosols are mostly dust and BC (absorbing aerosols) since large amount of dust transported from West Asia and locally emitted BC piles up over the IGP. Sensitivity experiments using ECHAM5-HAMMOZ climate model suggest that this enhanced loading of pre-monsoon absorbing aerosols over the Indo-Gangetic plain can reduce the drought during El Niño years (**Fig. 6e-f**) by invoking the 'Elevated-Heat-Pump' mechanism through an anomalous aerosol-induced warm core over the Tibetan Plateau. This anomalous heating upshot the relative strengthening of the cross-equatorial moisture inflow associated with the monsoon and eventually reduces the severity of drought during El Niño years. [***Fadnavis S., Chaitri Roy, Sabin T.P., Ayantika D.C.,*** *Ashok K., Potential modulations of pre-monsoon aerosols during El Niño: Impact on Indian summer monsoon,* ***Climate Dynamics,*** *online, November 2016, doi:10.1007/s00382-016-3451-6*]

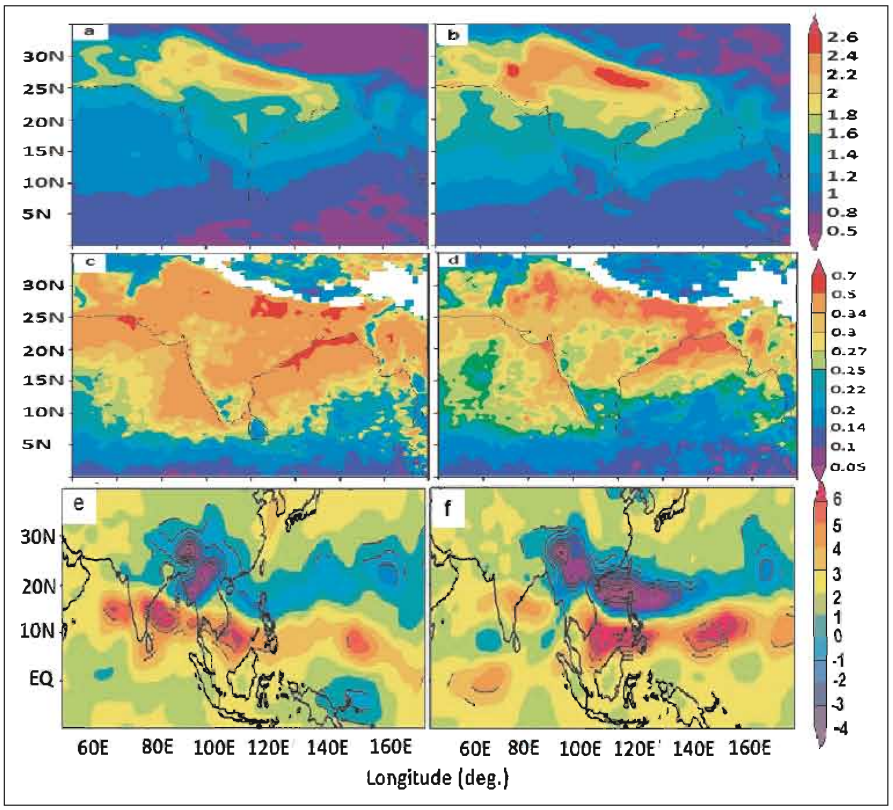


Fig. 6: *Longitude-latitude distribution of April-May average (a) TOMS aerosols index (AI) climatology of period 1978-2005, (b) TOMS aerosols index during El Niño years (1982, 1991, 1997, 2002, 2004), (c) Climatology (2000-2010) of MISR aerosols optical depth (AOD), (d) MISR AOD during El Niño years (2002, 2004, 2009), Aerosol-induced changes in seasonal mean precipitation as obtained from (e) difference between CTR_aero_pre-mon- and CTR_aeroOFF_pre-mon (f) difference between ElNiño_aero_pre-mon and ElNiño _aeroOFF_pre-mon experiments. Solid black line indicates the 95% Student's t-test confidence interval.*

Sub-Project

Paleoclimate

Basic Research

Heat index reconstruction based on tree-ring records of the western Himalayas in India

Tree ring-index chronology based on well replicated tree core samples (Cedrus deodara and Pinus roxburghii) of the western Himalayas has been prepared to study climate variability/change. The first principal component (PC1) prepared by using multiple-sites tree-ring chronologies of the western Himalayas is seen to be negatively correlated with heat index and positively with the Palmer Drought Severity Index (PDSI) and moisture index during February to May as representative of regional climate. The correlation coefficient of PC1 with heat index, PDSI and moisture index for the period 1901-88 is found to be -0.60, 0.37 and 0.59 respectively which are highly significant at 0.1% level. The results show that increasing heat index may enhance transpiration and evaporation over the western Himalayas, which may cause insufficient moisture at root zone of the trees. Based on the tree ring data, heat index of spring season (February to May) has been reconstructed back to AD 1839 (**Fig. 7**). The reconstructed heat index showed the widest warm periods during 1952-1963 and 1966-1976, in the 20th century. [***Somaru Ram, Borghaonkar H.P.,*** *Reconstruction of heat index based on tree-ring records of western Himalaya in India,* ***Dendrochronologia****, 40, December 2016, 64-71*].

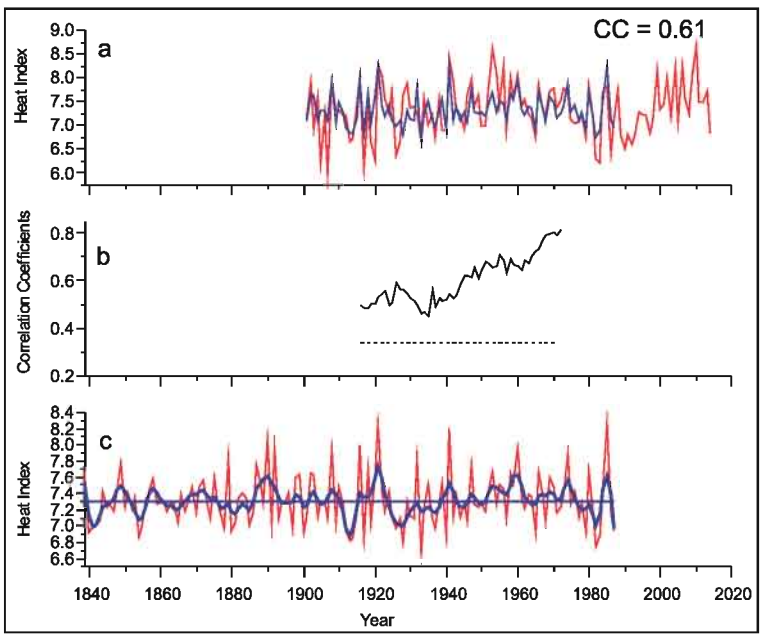


Fig. 7: *(**a**) Comparison between actual heat index for the period 1901-2014 (red line) and estimated heat index (blue line) for the period 1901-1988 during February to May. The A.D. 1901-1988 regression model was used for calibration; CC is the correlation coefficient in upper panel for the period 1901-1988. (**b**) A 31-year sliding correlation coefficients between actual and reconstructed heat index, correlation coefficients are plotted against the central year of the 31 years period, with level of significance at 5%. (**c**) February to May heat index reconstruction (A.D. 1839-1988). The smoothed blue line is a 10 years cubic spline fit in lower panel.*

Reconstruction of soil water oxygen isotope values from tree ring cellulose and its implications for paleoclimate studies

The rationale for estimating the soil water oxygen isotope values (δ_{sw}) from tree ring cellulose oxygen isotope data is presented and its efficacy as a tool to obtain paleoclimate information has been examined. Pre-dated tree ring cellulose samples collected from a site in the Western Himalayas were analyzed for oxygen isotopes. Additionally, similar datasets from 12 different locations across the world with overlapping time period were used to reconstruct δ_{sw} for the period of 1901 to 2004 Common Era. The reconstructed δ_{sw} data were compared with available observations and the implications of this technique were also examined. The study shows (i) good agreement in spatial ranges between observed and estimated δ_{sw} data suggesting its suitability as a representative parameter, and (ii) reconstructed δ_{sw} largely depend on soil moisture content modulated by regional evaporation regimes. Considering a growing importance of measurement of recycled soil moisture and its ensuing role in rainfall amount, this method to reconstruct soil moisture isotope will enable application of land hydrological models to the past. [***Bose T., Sengupta S., Chakraborty S., Borgaonkar H.P.,*** *Reconstruction of soil water oxygen isotope values from tree ring cellulose and its implications for paleoclimate studies,* ***Quaternary International****, 425, December 2016, 387-398*].

Sub-Project

Fluxnet Programme and Modeling

Basic Research

Variability of atmospheric CO_2 concentrations over India during summer monsoons

In a study based on a data assimilation product of the terrestrial biospheric fluxes of CO_2 over India, the subcontinent was hypothesized to be an anomalous source (sink) of CO_2 during the active (break) spells of rain in the summer monsoon from June to September. This hypothesis has been tested by investigating intra-seasonal variability in the atmospheric CO_2 concentrations over India by utilising a combination of ground-based and satellite observations along with model outputs. Results show that the atmospheric CO_2 concentration varies in synchrony with the active and break spells of rainfall with amplitude of ±2 ppm which is above the instrumental uncertainty of the present day techniques of atmospheric CO_2 measurements (**Fig. 8 & 9**). These results are also consistent with the signs of the Net Ecosystem Exchange (NEE) flux anomalies estimated earlier. The study offers the first observational affirmation of the above hypothesis although the data gap in the satellite measurements during monsoon season and the limited ground-based stations over India still leaves some uncertainty in the robust assertion of the hypothesis. The study highlights the need to capture these subtle variabilities and their responses to climate variability and change since it has implications for inverse estimates of terrestrial CO_2 fluxes. [***Ravi Kumar K., Valsala V., Tiwari Y.K., Revadekar J.V., Pillai P., Chakraborty S.,*** *Murtugudde R., Intra-seasonal variability of atmospheric CO_2 concentrations over India during summer monsoons,* ***Atmospheric Environment,*** *142, October 2016, doi:10.1016/j.atmosenv.2016.07.023, 229-237*].

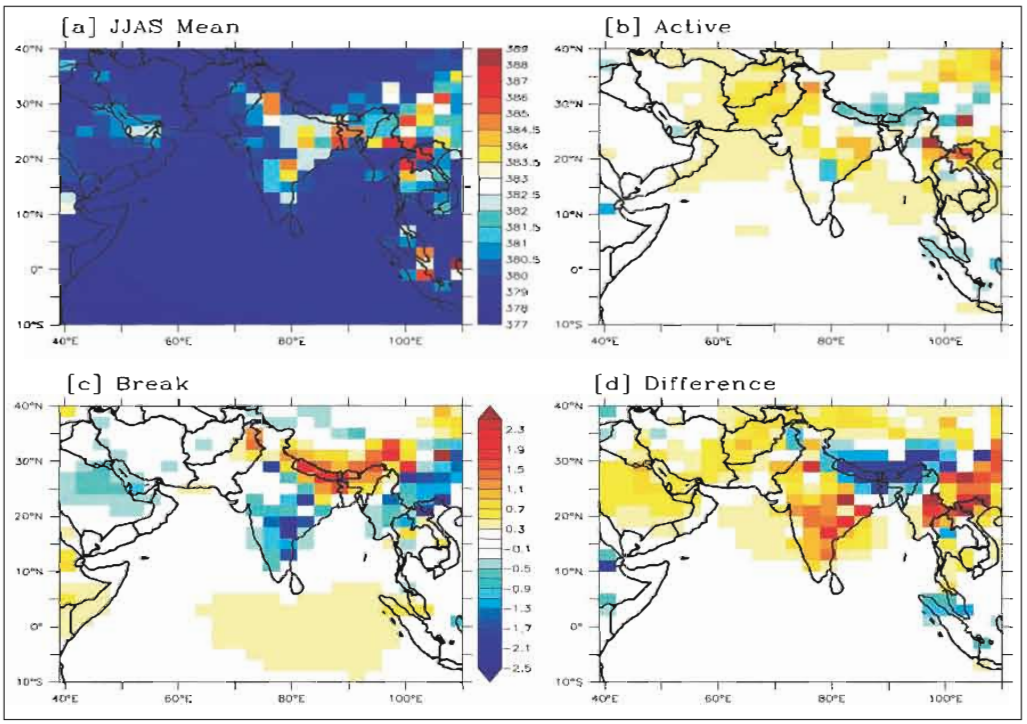


Fig. 8: *(a) June to September (JJAS) mean surface CO_2 concentrations from CT (average of 2000-2011). (b) Composite of surface CO_2 concentration anomalies during JJAS active days. (c) Same as (b), but for break days. (d) Difference between (b) and (c). Anomalies are calculated by de-trend and then de-seasonalized by removing first two harmonics of individual years. Units are in ppm.*

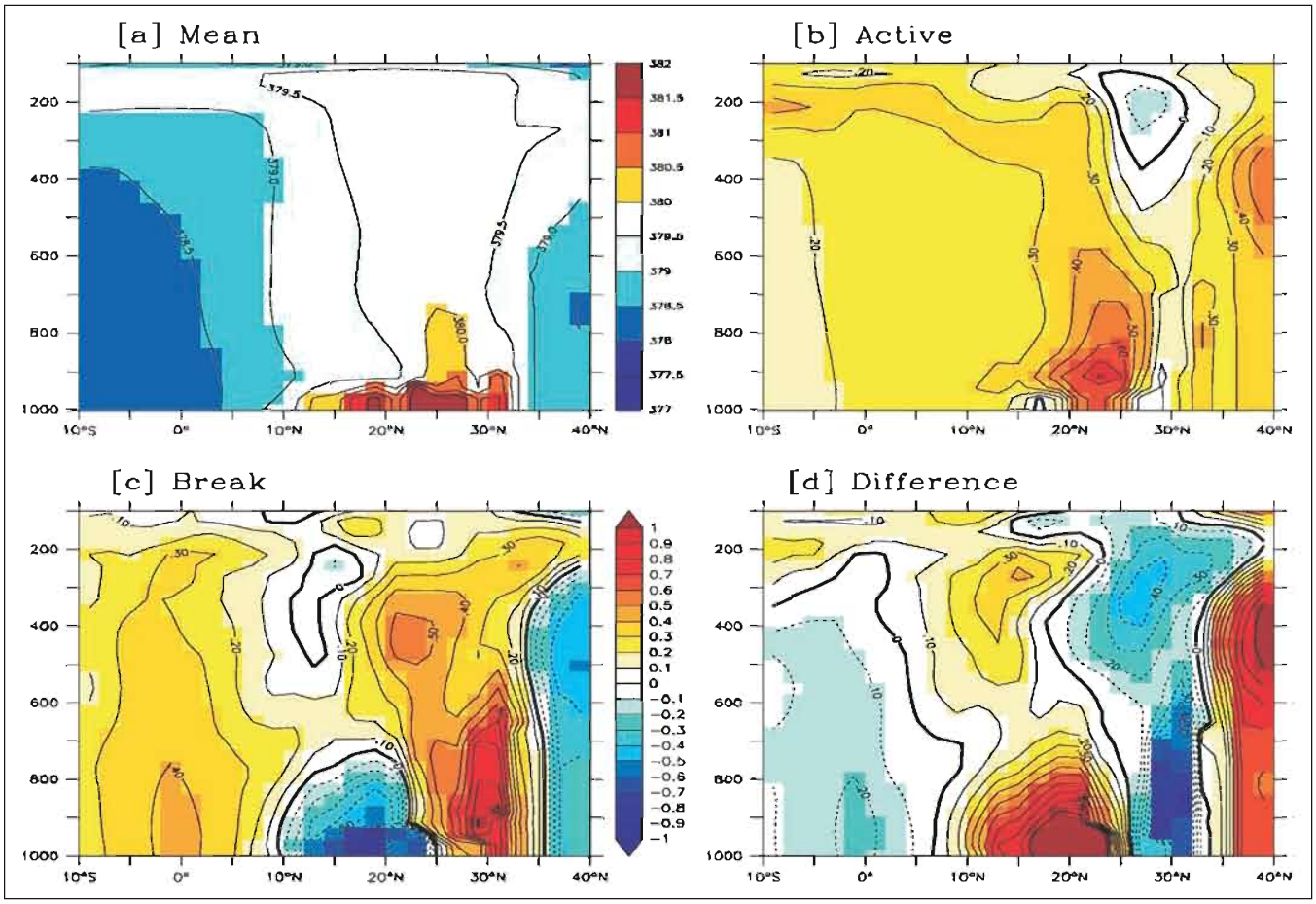


Fig. 9: Same as Fig. 8, but for vertical distribution of CO_2 as an average over a zonal section from 73E-82E over India and shown for 10S-40N and 1000 mb-200 mb.

Project

Short-Term Climate Variability and Prediction

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

Objectives

- To conduct basic research on Indian Summer Monsoon Rainfall (ISMR) variability and teleconnections.
- To continue ongoing efforts in identifying regional and global climate drivers for monsoon interannual variability.
- To develop regional climate data products for various stakeholders.
- To quantify the various aspects of climate change and climate variability over south Asian countries, with emphasis on the southwest and northeast monsoons.
- To develop different forecast models for climatic parameters over India.
- To study the impact of long term ocean variability on decadal monsoon variations.
- To investigate the processes associated with climate variability using observations and models.
- To understand the role of low-frequency feedbacks involving land-atmosphere interactions relevant to the Indian monsoon variability.
- To identify predictors for monsoon variability using both observations and models.

Sub-Projects

- **Climate Variability, Predictability and Applications**
- **Climate Variability and Data Assimilation Research**

Sub-Project

Climate Variability, Predictability and Applications

Developmental Activities

A web portal 'RAINFO and TEMPINFO' is being developed which will provide all the information on rainfall and temperature variability over a region in one click. The products are being prepared on the spatial scale of sub-divisions, cities and districts and on the time scale of daily, monthly and seasonal. The products are so designed to be used by general public as well as by farmers. These products would be very useful as inputs to impact assessment groups.

Basic Research

Monsoon variability, the 2015 Marathwada drought and rainfed agriculture

The impact of the drought of the summer monsoon of 2015 has been particularly large in the Marathwada region of Maharashtra which is facing unprecedented water scarcity and more than one thousand farmers have committed suicide. Substantial losses in the production of important crops such as pulses have been reported in Maharashtra. The large impact has been attributed to exceptionally large deficit in rainfall in two successive droughts in 2014 and 2015 by some, and some have considered the drought to be a manifestation of climate change. An analysis of the monsoon rainfall over Marathwada from 1871 onwards shows that the quantum of deficit rainfall in 2015 as well as the occurrence of two successive droughts is within the observed variability of the Marathwada rainfall and that the 2015 monsoon rainfall cannot be considered as a manifestation of climate change. Thus, the large impact of 2015 is a reflection of poor management of water resources and agriculture, despite the long experience of rainfall variability. The study shows that the prediction given by India Meteorological Department (IMD) of a high chance of below normal rainfall or a drought on the all-India scale and the occurrence of El Nino could have been used to anticipate large deficiency in Marathwada rainfall (**Fig 1**). It also suggests that the problem of lack of progress in the production of rainfed crops such as pulses has to be addressed by using the rich rainfall data sets in the country to generate information which can be used by farmers and agricultural scientists to identify strategies which are tailored to the entire spectrum of rainfall variability experienced. [***Kulkarni Ashwini***, *Gadgil S.*, ***Patwardhan S.***, *Monsoon variability, the 2015 Marathwada drought and rainfed agriculture,* ***Current Science****, 111, October 2016, 1182-1193*]

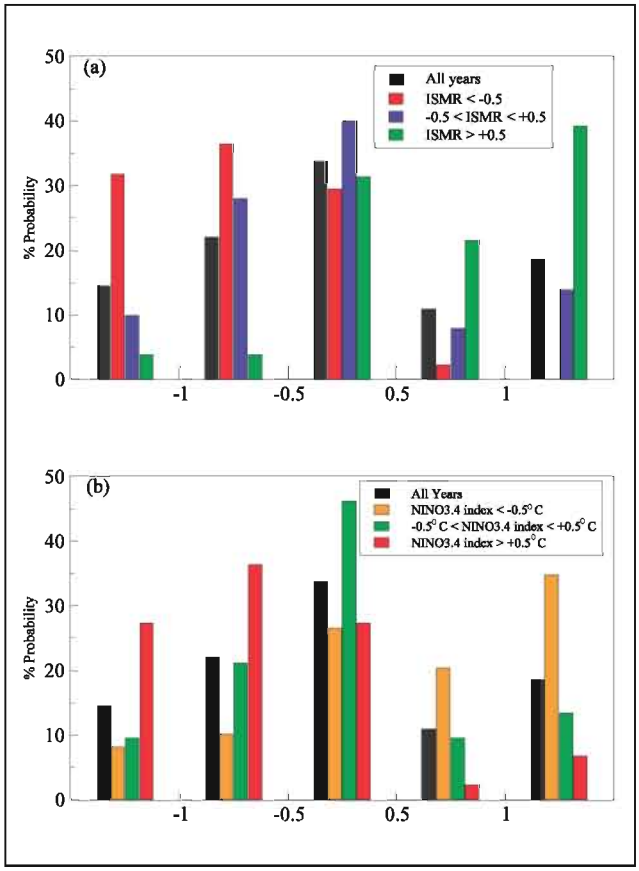


Fig. 1: *(a) The probability of Marathwada seasonal rainfall in the five categories viz. deficit (normalized anomaly < -1.0), below normal (-1.0 < normalized anomaly < -0.5), normal (-0.5 < normalized anomaly < +0.5), above normal (+0.5 < normalized anomaly < 1.0), excess (normalized anomaly > 1.0) for three categories of ISMR viz drought or below normal i.e. normalized anomaly < -0.5, normal (-0.5 < normalized anomaly < +0.5) and above normal or excess (normalized anomaly > +0.5), for the period 1871-2015. (**b**) same as (**a**) but for Nino 3.4 anomaly categories warm (anomaly > 0.5°C), normal (0.5°C > anomaly > -0.5°C) and cold (anomaly < -0.5°C).*

Projected changes in rainfall and temperature over homogeneous regions of India

The impact of climate change on the characteristics of seasonal maximum and minimum temperature and seasonal summer monsoon rainfall is assessed over five homogeneous regions of India using a high-resolution regional climate model. Providing Regional Climate for Climate Studies (PRECIS) is developed at Hadley Centre for Climate Prediction and Research, UK. The model simulations are carried out over South Asian domain for the continuous period of 1961- 2098 at 50 km horizontal resolution. Here, three simulations from a 17-member perturbed physics ensemble (PPE) produced using HadCM3 under the Quantifying Model Uncertainties in Model Predictions (QUMP) project of Hadley Centre, Met Office (UK) have been used as lateral boundary conditions (LBCs) for the 138-year simulations of the regional climate model under Intergovernmental Panel on Climate Change (IPCC) A1B scenario. The projections indicate the increase in the summer monsoon (June-September) rainfall over all the homogeneous regions (15-19%) except peninsular India (around 5%). There may be marginal change in the frequency of medium and heavy rainfall events (>20 mm) towards the end of the present century. The analysis over five homogeneous regions indicates that the mean maximum surface air temperature for the pre-monsoon season (March-April-May) as well as the mean minimum surface air temperature for winter season (January-February) may be warmer by around 4°C towards the end of the twenty-first century. [***Patwardhan S., Kulkarni Ashwini,*** *Koteswara Rao K., Projected changes in rainfall and temperature over homogeneous regions of India,* ***Theoretical and Applied Climatology,*** *online, November 2016, doi:10.1007/s00704-016-1999-z*]

Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975-2010

The Koshi river basin is a sub-basin of the Ganges shared among China, Nepal and India. The river system has a high potential for investment in hydropower development and for irrigation in downstream areas. The upper part of the basin contains a substantial reserve of freshwater in the form of snow and glaciers. Climate variability, climate change, and climate extremes might impact on these reserves, and in turn impact on systems that support livelihoods such as agriculture, biodiversity and related ecosystem services. Climatological variability and trends over the Koshi river basin were studied using RClimDex. Daily temperature data (20 stations) and precipitation data (50 stations) from 1975 to 2010 were used in the analysis. The results show that the frequency and intensity of weather extremes are increasing. The daily maximum temperature (TXx) increased by 0.1ºC per decade on average between 1975 and 2010 and the minimum (TNn) by 0.3ºC per decade. The number of warm nights increased at all stations. Most of the extreme temperature indices showed a consistently different pattern in the mountains than in the Indo-Gangetic plains, although not all results were statistically significant. The warm days (TX90p), warm nights (TN90p), warm spell duration (WSDI), and diurnal temperature range (DTR) increased at most of the mountain stations; whereas monthly maximum and minimum values of daily maximum temperature, TX90p, cool nights (TN10p), WSDI, cold spell duration indicator (CSDI), DTR decreased at the stations in the Indo-Gangetic plains, while the number of cold days increased. There was an increase in total annual rainfall and rainfall intensity, although no clear long-term linear trend was perceived, whereas the number of consecutive dry days increased at almost all stations. The results indicate that the risk of extreme climate events over the basin is increasing, which will increase people's vulnerability and has strong policy implications. [*Shrestha A.B., Bajaracharya S., Sharma A., Duo C.,* ***Kulkarni Ashwini,*** *Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975-2010,* ***International Journal of Climatology,*** *37, February 2017, 1066-1083, doi:10.1002/joc.4761*]

Progress of Indian summer monsoon onset and convective episodes over Indo-Pacific region observed during 2009-2014

Summer monsoon onset progress from the oceanic region of Southeast Bay of Bengal/Andaman Sea (Oceanr) up to extreme southwestern part of India (Kerala) for the years 2009 to 2014 was investigated. Synoptic weather information and INSAT/KALPANA-1 cloud imageries from IMD, METEOSAT/MTSAT cloud imageries from Dundee Satellite Receiving Station, tropical cyclone information from Co-operative Institute for Meteorological Satellite Studies, upper-air reanalyzed winds from NCEP (National Centre for

Environmental Prediction)/NCAR (National Climate Analysis Centre) and OLR data archived from NOAA satellites for the months of May and early June for these years were used in the study. It was found that during 2009-2014, the dates of onset over Ocean and Kerala have shown a variation from 17 to 29 May and from 23 May to 6 June against normal dates of 20 May and 1 June over these regions respectively. Also, the time required for the monsoon advance from Ocean to Kerala exhibited a large variation of 0-19 days against the long-term normal of 12 days. Analysis was carried out to investigate the reasons for the observed variation. It was found that intense disturbances, which formed over north Indian Ocean in 2009, 2010, 2013 and 2014 and over west-north Pacific Oceanic region in 2011 and 2012, contributed for the observed variation. The study brought out and discussed the role of these convective events in the variation of onset timing and progress by taking case to case review of these events, through synoptic analysis. The results showed that depending upon the location of formation, intensity and movement of the disturbances formed over Indo-Pacific region around the time of the monsoon onset, rapid advance or revival from stagnation or even stagnation occurred in the monsoon advance from Ocean to Kerala. The analysis revealed that synoptic developments occurring over the regions of southeast Bay of Bengal and southeast Arabian Sea are linked with those occurring over the tropical northwest Pacific Ocean. The study has brought out that the global prediction models which are presently used for the onset prediction can make a proper utilisation of synoptic analog based on the above information in improving their results. [***Ghanekar S.P., Narkhedkar S.G.,*** *Sikka D.R., Progress of Indian summer monsoon onset and convective episodes over Indo-Pacific region observed during 2009-2014,* ***Mausam****, 67, October 2016, 803-828*]

Assessment of TRMM Rainfall Data (2001-2015) over the Indian region

For the last fifteen years or so, there is predominant decrease in the rainfall activity over the Indian region resulting in severe drought conditions in the years 2002, 2009, 2012, 2014 and 2015. Even the remaining years have shown decrease in average annual rainfall. This caused depletion in surface as well as groundwater levels, whereas demand for water is continuously increasing with the increasing population. This increase in water demand also leads to water conflicts among different users. India being an agricultural country, accurate prediction of monsoon rainfall is essential for agricultural purpose *viz*. planning and management, from water resources point of view and in hydropower generation as well.

The most commonly used rainfall resources are rainfall data collected from rain gauge stations, ground based radar rainfall and satellite remote sensing devices. At present, a network of more than 5000 rain gauges all over India is collecting rainfall data during the monsoon season. Still rainfall data of some remote places (*e.g.*, eastern parts of Arunachal Pradesh, Assam, many places in Jharkhand, etc.) are questionable and also, are difficult to access due to administrative or technical reasons. Suc incomplete data sets can reduce the possibility of operational hydrological forecasting which needs real time data. Satellite-based rainfall products are a valuable alternative to overcome such situations.

To overcome the difficulty of availability of climatic data, especially on daily time scale, researchers prefer to use satellite data which has its wide applications in many fields *viz*. meteorology, hydrology, water resources models, climatic studies, etc. However, it is essential to verify these data for more consistency with the observed data. The study assessed the Tropical Rainfall Measuring Mission (TRMM) satellite data with that of observed rainfall data for the southwest monsoon season over the Indian region during 2001 to 2015. The results showed that there is high consistency between the estimates of these two data sets during 2008-15 than the earlier seven years period. [***Nandargi S.S.,*** *Mahto S., Assessment of TRMM Rainfall Data (2001-2015) Over the Indian Region,* ***Focus on Science****, 2, August 2016, 1-10*]

North equatorial Indian Ocean convection and Indian summer monsoon June progression: A case study of 2013 and 2014

The consecutive summer monsoons of 2013 and 2014 over Indian subcontinent saw very contrasting onsets and the progressions during the initial month. While 2013 monsoon saw the timely onset and one of the fastest progressions during the recent decades, 2014 had a delayed onset and a slower progression phase. The monthly rainfall of June 2013 was +34%, whereas in the year 2014 it was -43% of its long-period average. The progress/onset of monsoon in June is influenced by large-scale circulation and local feedback processes. But,

in the year 2013 (2014), one of the main reasons for timely onset and fastest progression (delayed onset and slower progression) was the persistent strong (weak) convection over north equatorial Indian Ocean during May (**Fig. 2**; OLR: grey shade). This resulted in a strong (weak) Hadley circulation with strong (weak) ascent and descent over the north equatorial Indian Ocean and the south Indian Ocean respectively. The strong (weak) descent over the south Indian Ocean had intensified (weakened) the Mascarene High (**Fig. 2**; MSLP: color shade) which in turn, strengthened (weakened) the cross equatorial flow (**Fig. 2**; 850-hPa wind: vectors) and hence the monsoonal circulation. [***Yadav R.K.*** *and* ***Singh B.B.****, North equatorial Indian Ocean convection and Indian summer monsoon June progression: A case study of 2013 and 2014,* ***Pure and Applied Geophysics****, 174, February 2017, 477-489, doi: 10.1007/s00024-016-1341-9*]

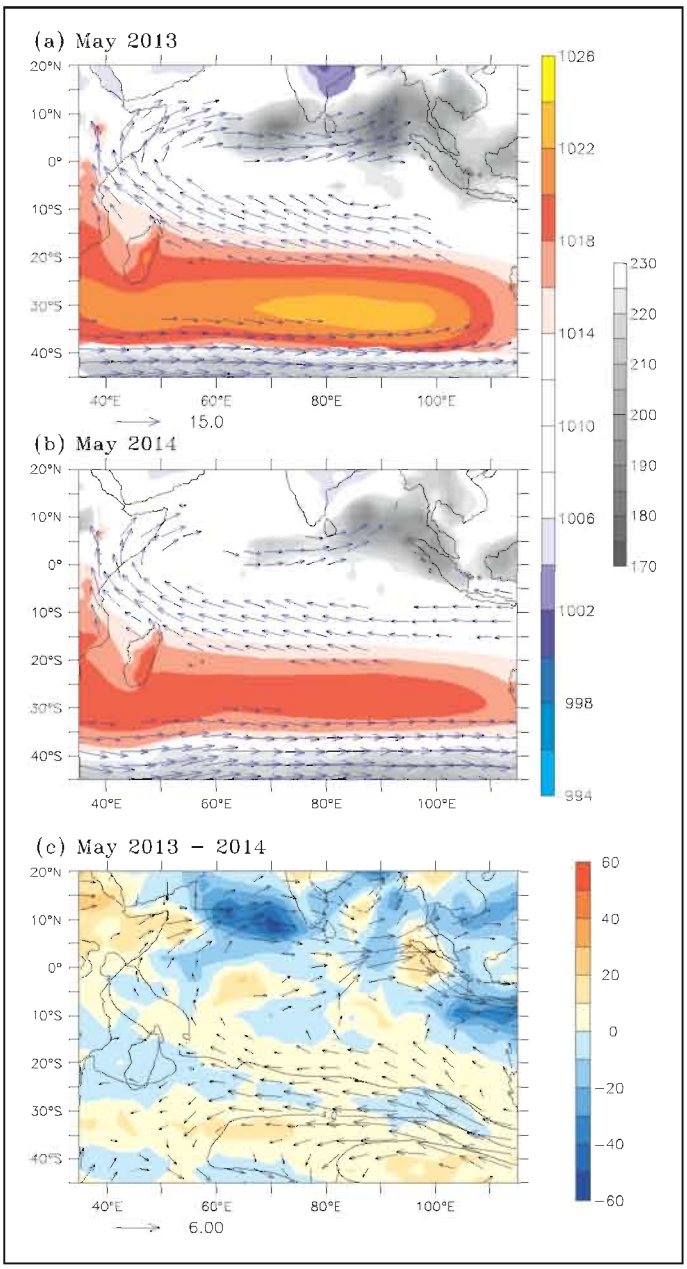


Fig. 2: *MSLP (color shade, hPa), 850 hPa winds (blue vectors, ms^{-1}), OLR (grey shade, Wm^{-2}) (**a**) May, 2013 and (**b**) May, 2014. (**c**) difference of May 2013 and May 2014 MSLP (contours), OLR (color shade) and 850-hPa wind (black vectors).*

Sub-Project

Climate Variability and Data Assimilation Research

Basic Research

Indian summer monsoon rainfall variability in response to differences in the decay phase of El Niño

For the first time, impact of large variations in decaying El Niño on the ISM rainfall has been brought out. It is found that ISM rainfall is above normal/excess during early-decay (ED; decay during spring) years, normal during mid-summer decay (MD; decay by mid-summer) and below normal/deficit no-decay (ND; no decay in summer), suggesting that the differences in El Niño decay phase display profound impact on the ISM rainfall. Schematic diagram (**Fig. 3**) illustrates the factors responsible for changes in ISM rainfall during ED, MD and ND years. During ED years, the seasonal rainfall over the Indian subcontinent is positive due to (1) establishment of La Nina like conditions over the central and eastern Pacific corroborated by enhanced Walker circulation with anomalous convection over the ISM and the Indo-western Pacific region, (2) anomalous TIO warming enhanced convection over ISM region, (3) increased cross equatorial flow and eastward shift in northwest Pacific anticyclone with the progress of summer monsoon supports ISM rainfall and (4) warm tropospheric temperature anomalies over the Indian subcontinent and enhanced low level convergence as shown by velocity potential from June to September further uphold positive rainfall anomalies over ISM region. [***Chowdary J.S., Harsha H.S., Gnanaseelan C., Srinivas G., Parekh A., Pillai P.,*** *Naidu C.V., Indian summer monsoon rainfall variability in response to differences in the decay phase of El Niño,* ***Climate Dynamics,*** *Online, June 2016, doi:10.1007/s00382-016-3233-1*]

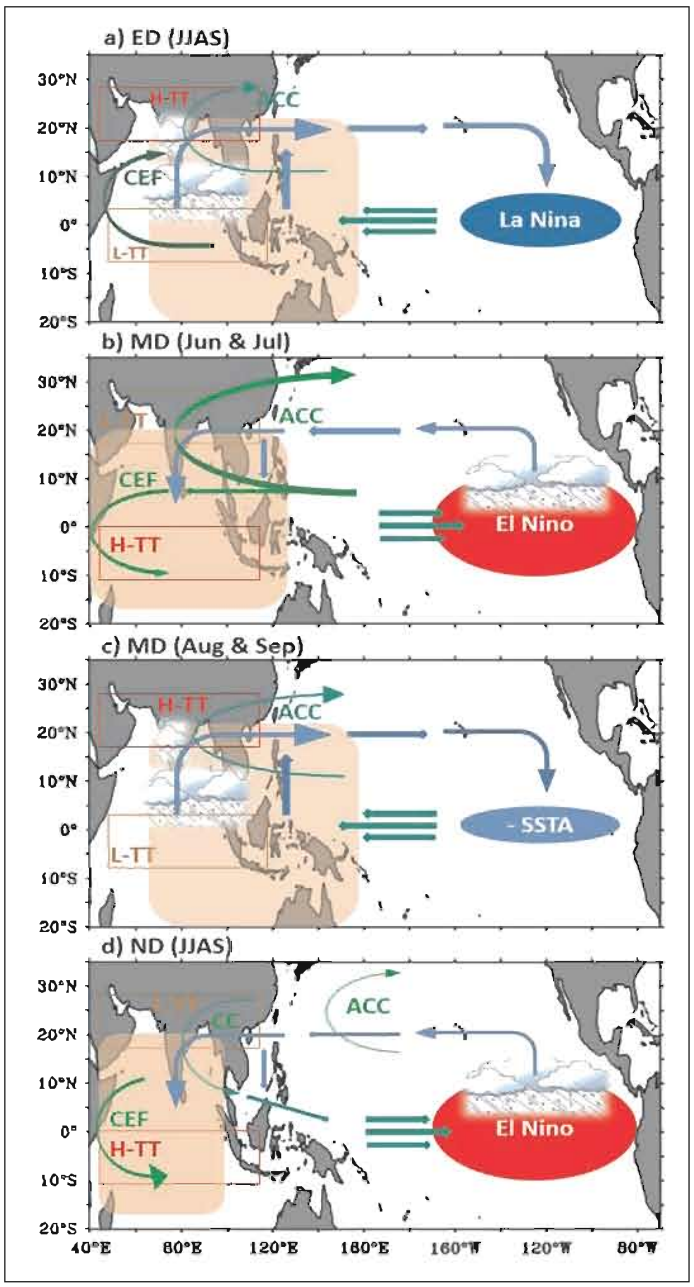


Fig. 3: Schematic diagram that shows factors responsible for changes in ISM rainfall during (a) ED seasonal mean, (b) June and July in MD years, (c) August and September in MD years and (d) ND seasonal mean. Green arrow represents low level circulation and blue arrows represent Walker circulation. Rectangular box dark red (light red) represents high (low) troposphere temperature (H-TT and L-TT). Thickness or brightness of color represents the intensity. ACC is anticyclone circulation, CC is cyclonic circulation and CEF is cross equatorial flow.

Processes associated with the tropical Indian Ocean subsurface temperature bias in a coupled model

Subsurface temperature biases in coupled models can seriously impair their capability in generating skilful seasonal forecasts. The National Centers for Environmental Prediction (NCEP) Climate Forecast System version 2 (CFSv2) coupled model, which is used for seasonal forecast in several countries including India, displays warm (cold) subsurface (surface) temperature bias in the tropical Indian Ocean (TIO), with deeper than observed mixed layer and thermocline. In the model, maximum warm bias is reported between 150-200 m depth. Detailed analysis reveals that the enhanced vertical mixing by strong vertical shear of horizontal currents is primarily responsible for TIO subsurface warming (**Fig. 4**). Weak upper ocean stability corroborated by surface cold and subsurface warm bias further strengthens the subsurface warm bias in the model. Excess inflow of warm subsurface water from Indonesian throughflow to TIO region is partially contributing to the warm bias mainly over the southern TIO region. Over the north Indian Ocean, Ekman convergence and downwelling due to wind stress bias deepen the thermocline, which favours subsurface warming. Further, upper ocean meridional and zonal cells are deeper in CFSv2 compared to the Ocean Reanalysis System data manifesting the deeper mixing. This study outlines the need for accurate representation of vertical structure in horizontal current and associated vertical gradients to simulate subsurface temperatures for skilful seasonal forecasts. [***Chowdary J.S., Parekh A., Srinivas G., Gnanaseelan C., Fousiya T.S., Khandekar R., Roxy M.K.,*** *Processes associated with the Tropical Indian Ocean subsurface temperature bias in a coupled model,* ***Journal of Physical Oceanography****, 46, September 2016, 2863-2875, doi: 10.1175/JPO-D-15-0245.1*]

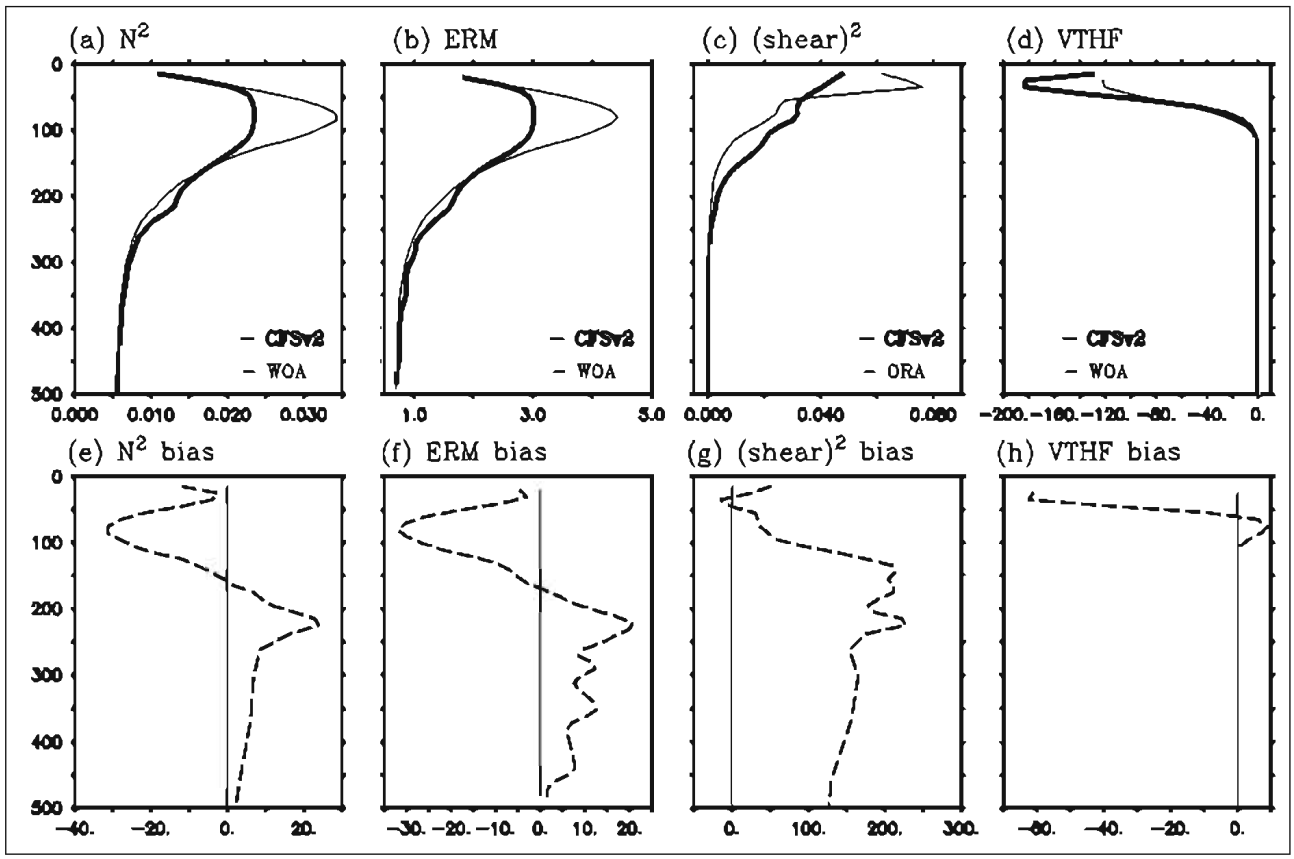


Fig. 4: Vertical profiles of [Annual mean area averaged in the TIO region] (a) Brunt-Vaisala frequency (N^2; 10^{-4} s^{-1}), (b) ERM (Jm^{-3}), (c) square of the vertical shear of horizontal currents (10^{-4} s^{-1}) and (d) vertical turbulent heat flux (Wm^{-1}). (e)-(h) are same as (a)-(d) but for bias. Bias in N^2 profiles and ERM of CFSv2 are calculated with respect to WOA13. In case of vertical shear CFSv2 bias is calculated with respect to ORAS4. Vertical turbulent heat flux bias is with respect to WOA13/MOM5. Note that biases are normalized with respect to observations and presented in percentage except for Vertical turbulent heat flux.

Project

Monsoon Mission

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

Objectives

The monsoon mission is planned with an overall objective to improve monsoon predication over India on all time scales. Specific objectives of the monsoon mission are:

- To build a working partnership between the academic and R&D organisations both national and international, and the MoES to improve the operational monsoon forecast skill over the country.
- To setup a state-of-the-art dynamical modelling framework for improving prediction skill of 'seasonal and extended range predictions' and 'short and medium range (up to two weeks) prediction'.

At IITM, the principle focus of the Monsoon Mission has been the development of seasonal and extended range prediction systems with the following objectives:

- To develop a fully coupled ocean-atmosphere-land modelling system for dynamical prediction on extended range and seasonal time scales and to improve the prediction skill.
- Development of data assimilation system for Climate Forecast System (CFS).
- To improve parameterization schemes in the coupled ocean-atmosphere models.
- To study and understand the monsoon variability over different spatio-temporal scales.
- To coordinate the working partnership amongst the ESSO-MoES organisations and various national and international R&D and academic institutions through the Monsoon Mission Directorate at IITM.

For facilitating the above objectives, the Monsoon Mission at IITM is divided into three sub-projects for better execution.

Sub-Projects

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

Sub-Project

Seasonal Prediction

Developmental Activities

Seasonal prediction and experiments using fully coupled General Circulation Model

The resolution of the CFSv2 model has been increased from original T126 spectral resolution (equivalent to about 110 km resolution) to T382 spectral resolution (equivalent to about 36 km horizontal resolution). T382 is the highest resolution used in Seasonal Prediction worldwide. Retrospective forecast (hindcast) experiments have been carried out by using the coupled model CFSv2 with this higher spectral resolution of T382 for 30 years, using various initial conditions (of different months) with six ensembles (using 06, 12, 18 UTC data). After acquiring the new HPC, model hindcast runs are completed with initial conditions from different months extending throughout the year.

Experimental dynamical seasonal prediction of 2016 South-West monsoon season rainfall by using high resolution CFSv2 model at IITM

The latest high resolution research version of the CFSv2 (with spectral resolution of T382 ~38 km in the horizontal) has been used to generate experimental forecast for the 2016 South-West Monsoon season rainfall by using the February initial conditions.

The experimental forecast based on the Monsoon Mission coupled dynamical model suggested that the monsoon rainfall during the 2016 monsoon season (June to September) averaged over the country as a whole is likely to be 111% ± 5% of long period model average (LPMA). However, the country as a whole received near normal rainfall with 97% of long period average rainfall. The probabilistic forecast provided a valuable guidance that the probability for this year's rainfall for below normal and deficit is zero.

Experimental forecasts for the 2016 South-West Monsoon season rainfall were also carried out by using initial conditions of March, April and May months. The same model was used to generate the experimental forecast for the 2016 North-East Monsoon season rainfall (over Indian region) by using the September initial conditions with 47 ensembles.

Hindcast Experiments: Long period hindcast experiments were carried out using fully coupled model CFSv2 at T382 resolution, with ensembles of various atmospheric and oceanic initial conditions.

Issuing ENSO/IOD Updates and Forecast Verification: ENSO/IOD Updates have been provided and forecast verification works have been carried out on routine basis.

Model development works: The impact of increasing atmospheric horizontal resolution of CFSv2 model from T126 spectral resolution (~100 km) to T382 spectral resolution (~38 km) has been studied. Several research works were carried out to improve model physics, especially new land surface model in CFSv2 and modified convective and microphysics schemes in CFSv2. New Land Surface Model, Multi-Layer Snow Scheme, and New Cloud Microphysics have been incorporated in CFSv2.

Basic Research

How distinct are the two flavours of El Niño in retrospective forecasts of Climate Forecast System version 2 (CFSv2)?

The El Niño Southern Oscillation (ENSO) is a prominent mode of climate variability at inter-annual time scale. Two different flavours of El Niño (canonical east Pacific El Niño and El Niño Modoki/central Pacific El Niño) are reported in the recent decades. These two flavours are found to influence the global climate in different ways. The success of a seasonal prediction system is dependent on its ability to capture these two flavours of El Niño accurately, together with associated teleconnections. Majority of the seasonal prediction models are not able to differentiate these two El Nino flavours and are found to have very less skill in the seasonal prediction of Indian summer monsoon rainfall (ISMR) in the recent decades. The ability of Climate Forecast System version 2 (CFSv2) in simulating these two El Niño flavours and their teleconnections are analysed to understand the seasonal prediction skill of the model. Two different resolutions of CFSv2, a low resolution T126 (~100 km resolution) and a high resolution T382 (~38 km resolution) hindcasts from February to May initial conditions (IC) are compared to study the evolution of El Nino flavours (**Fig. 1**). The

canonical El Niño pattern is captured faithfully by CFSv2 in both the resolutions as prominent mode. Even though the tri-pole structure of El Niño Modoki is produced as second EOF, it has some disagreement with observations. The canonical El Niño induced sea surface temperature (SST), rainfall and circulation in the tropical Pacific in summer and fall seasons are comparable with observations in both the resolutions at all lead time hindcasts from February to May. Meanwhile, the teleconnections in the tropical Indian Ocean and Indian monsoon region are close to observations in T382. Boreal summer teleconnections associated with El Niño Modoki are proper in higher resolution T382 February IC hindcasts only. Thus, February initial conditions (IC) hindcasts of T382 only can produce distinct effect of both the El Nino flavours in summer season. This distinction of El Niño flavours in summer is the major reason for the higher skill of CFSv2 T382 for seasonal prediction of Indian summer monsoon rainfall (acc = 0.55). However, teleconnections associated with two flavours of El Niño are not distinguishable in fall and winter, even in the higher resolution model. This is mainly related to the SST biases in the equatorial central Pacific in CFSv2. Equatorial central Pacific has strong cold bias in the model for all ICs except February ICs for summer and all ICs in spring, which will constrain the distinction of both the El Nino flavours in the model. Thus, in the CFSv2 model, the Pacific SST associated teleconnection and the prediction skill of summer seasonal rainfall is strictly related to the ability of the model in distinguishing the El Niño flavours and also higher resolution is required for distinguishing El Niño flavours of summer season at lead time of about four months. [***Pillai P.A., Rao S.A., George G., Rao D.N., Mahapatra S., Rajeevan M., Dhakate A., Salunke K.,*** *How distinct are the two flavors of El Niño in retrospective forecasts of Climate Forecast System version 2 (CFSv2)?* ***Climate Dynamics,*** *Online, August 2016, doi:10.1007/s00382-016-3305-2*]

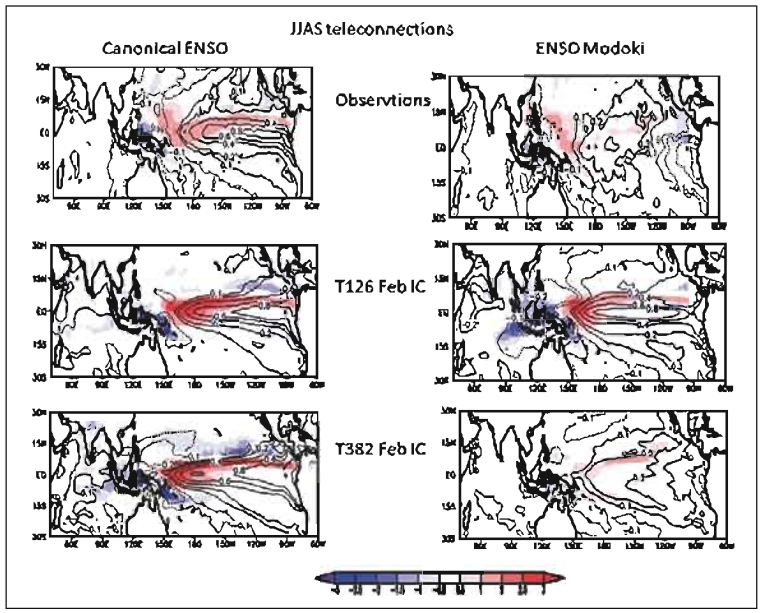


Fig. 1: *JJA SST (contour) and rainfall (shaded) obtained by regression of simultaneous Nino3.4 index from observations (top panel), T126 (middle panel) and T382 (bottom panel) on the left side and same regressed with EMI in the right side.*

Effects of Multi-Layer Snow Scheme on the Simulation of Snow: Offline Noah and Coupled with NCEP CFSv2

The Noah version 2.7.1 is a moderately complex land surface model (LSM), with a single layer snowpack, combined with vegetation and underlying soil layer. Many previous studies have pointed out biases in the simulation of snow, which may hinder the skill of a forecasting system coupled with the Noah. In order to improve the simulation of snow by the Noah, a multi-layer snow scheme (up to a maximum of six layers) is introduced. As Noah is the land surface component of the Climate Forecast System version 2 (CFSv2) of the National Centers for Environmental Prediction (NCEP), the modified Noah is also coupled with the CFSv2.

CFSv2 with the modified Noah reveals dramatic improvements in the simulation of snow depth and 2 m air temperature. As suggested in the previous diagnostic and sensitivity studies, improvements in the simulation of snow by CFSv2 have lead to the reduction in dry bias over the Indian subcontinent by a maximum of 2 mm/day. In general, the multi-layer snow scheme performs better than the previously used single layer snowpack in the LSM Noah. The offline LSM shows large improvements in the simulation of snow depth, snow water equivalent (SWE) and snow cover area during snow season (October to June). A much larger improvement in the snow

depth (Fig. 2) and SWE is evident in the simulations by CFSv2, where two-way land-atmosphere feedback exists (unlike in the offline LSM). The original and new snow schemes coupled with CFSv2 are termed as CFS_OSS and CFS_NSS respectively. The bias in snow depth (of the order of its mean) over the Eurasian region in the coupled model is now reduced considerably.

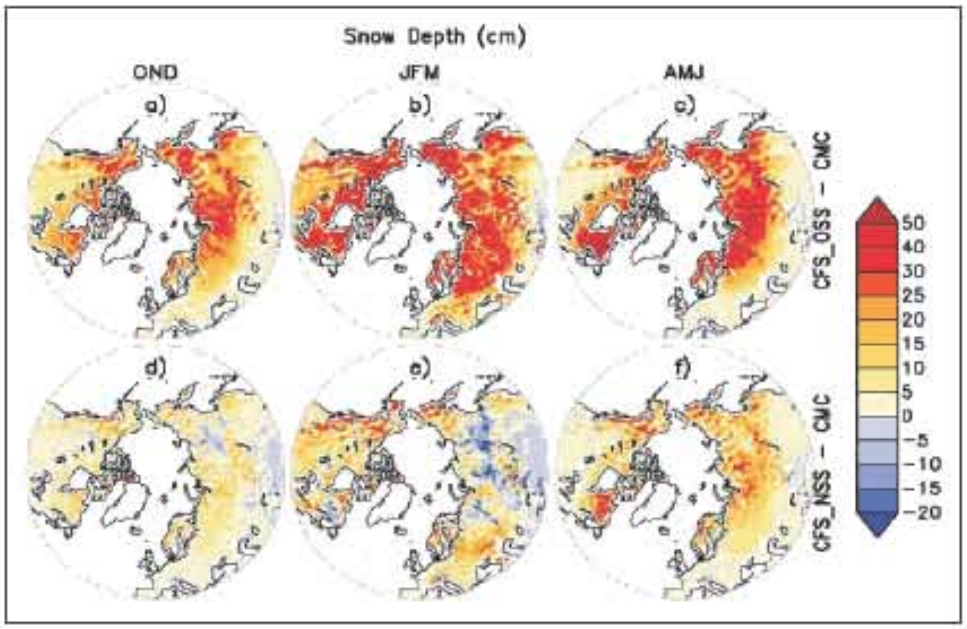


Fig. 2: Bias in the snow depth (against CMC analysis), simulated by CFSv2 coupled with (a, b, c) Noah with original snow scheme (CFS_OSS), (d, e, f) Noah with new snow scheme (CFS_NSS) in cm.

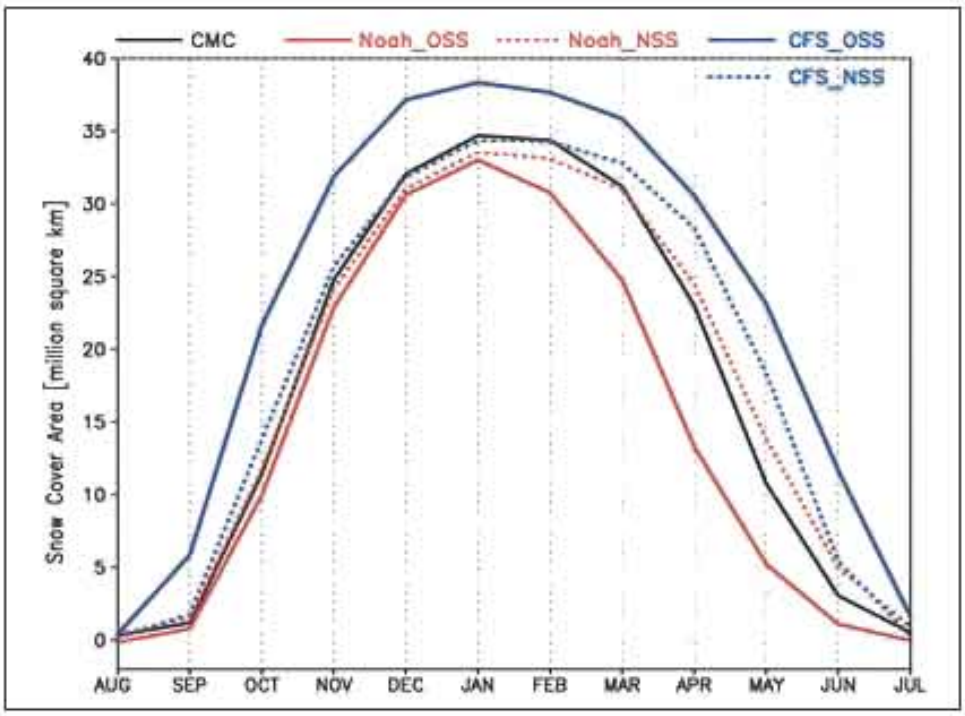


Fig. 3: Snow cover area in million square km, from CMC analysis, simulations by offline Noah_OSS, Noah_NSS, coupled simulation by CFSv2 using original Noah (CFS_OSS) and new/modified Noah (CFS_NSS). A grid box with snow depth >2 cm is assumed as fully covered area with snow (i.e., snow cover fraction 1).

Fig. 3 shows the monthly mean snow cover area (in million square km) from the month August to July in CMC analysis, and model simulations. The Noah_OSS underestimates snow cover area throughout the season, however the difference with observation becomes larger from the month December onward (underestimates by a maximum of about 10 million square km). On the other hand, snow cover area in Noah_NSS closely matches with the observation. The CFS_OSS overestimates the snow cover area throughout the snow season (from September to June by about 3.28 to 12.35 million square km). This bias is now reduced considerably in CFS_NSS.

Simulation by CFS_NSS indeed shows increase in seasonal mean monsoon rainfall (JJAS) by a maximum of 2 mm/day over the Indian subcontinent (**Fig. 4 c, e**). The rainfall zone in CFS_NSS is further propagated towards northwest over the Indian sub-continent, which is now closer to the observation as compared to that of CFS_OSS. Bias in the snow can also affect the north-south tropospheric gradient, which in turn may affect the Northern Hemispheric summer monsoon rainfall including ISMR. CFS_NSS indeed shows increase in the tropospheric temperature gradient by about 0.4-1.0°C (**Fig. 4 f**). The study shows promising results in the simulation of snow as well as ISMR, and it may be integrated in the future version of the CFS. [***Saha S.K., Sujith K., Pokhrel S., Chaudhari H.S., and Hazra A., Effects of multilayer snow scheme on the simulation of snow: Offline Noah and coupled with NCEP CFSv2, Journal of Advances in Modelling Earth Systems, 9, January 2017, doi:10.1002/2016MS000845***]

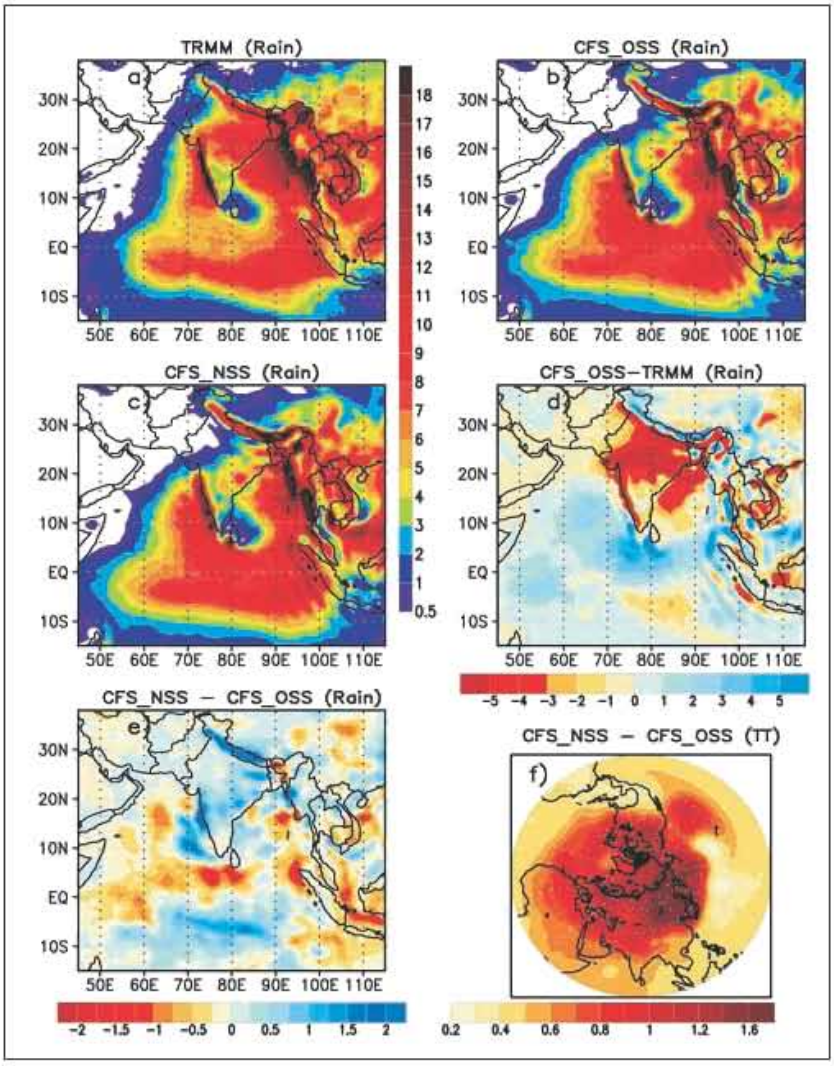


***Fig. 4:** Climatological mean seasonal (June-September) monsoon rainfall (in mm/day) from (a) TRMM, b) simulation by CFS_OSS, (c) simulation by CFS_NSS, (d) bias in the simulation by CFS_OSS with respect to TRMM. Change in seasonal (e) rainfall and (f) average of 600-200 hPa tropospheric temperature due to improvements in the simulation of snow (CFS_NSS – CFS_OSS).*

Prediction of seasonal summer monsoon rainfall over homogenous regions of India using dynamical prediction system

Seasonal prediction of Indian summer monsoon rainfall is a challenging task for the modelling community. Predicting seasonal mean rainfall at smaller regional scales is much more difficult than predicting seasonal mean average over the country. The regional scale prediction of summer monsoon mean rainfall at longer leads plays a vital role in planning hydrological and agriculture aspects of the society. Earlier attempts for predicting rainfall in homogenous regions over India have resulted in limited success (anomaly correlation coefficient, ACC ≈ 0.1 to 0.4) at zero month lead time. Earlier studies have shown that high resolution climate forecast system version 2 (CFSv2) T382 (~38 km) model can predict all

Indian summer monsoon rainfall at lead time of four months (ACC ≈ 0.55). By using the same model, an effort was made to investigate whether the seasonal mean rainfall over homogenous regions [NWI, WCI, CNEI, NEI and SPI are depicted as 1, 2, 3, 4, 5 respectively in **Fig. 5 e**] is predictable at four month lead time.]

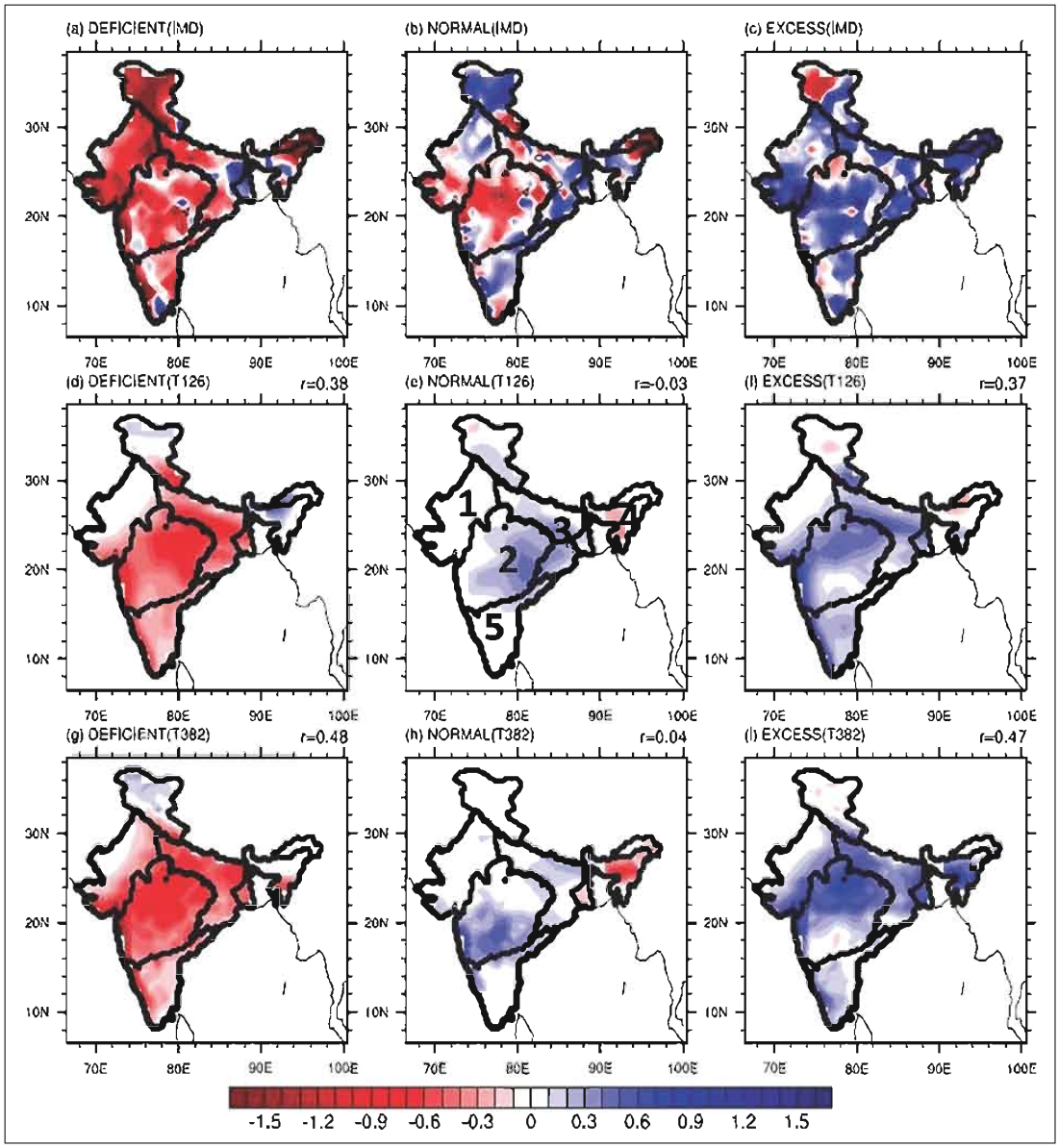


***Fig. 5:** Seasonal rainfall anomaly composites for deficit, excess and normal years for observations (a-c), T126 (d-f) and T382 (g-i). Geographical locations of 5 homogeneous regions of India are marked (e). Pattern correlation between model and observations is included in top of each model plots (d-i).*

It is noticed that, three homogeneous regions out of five have shown moderate prediction skill at four month lead (**Table-1**). Compared to lower resolution model, high resolution model has good skill for all the regions except south peninsular India. High resolution model is able to capture the extreme events and also, the teleconnections associated with large scale features at four month lead time and hence, it shows better skill (ACC ≈ 0.45). [***Ramu D.A., Suryachadra A. Rao, Pillai P., Pradhan M., George G., Nagarguna Rao D., Mahapatra S., Pai D.S., Rajeevan M., Prediction of seasonal summer monsoon rainfall over homogenous regions of India using dynamical prediction system, Journal of Hydrology**, 546, March 2017, 103-112*]

Table 1: Skill of JJAS rainfall over 5 homogenous regions of India for different initial conditions of model hindcasts. The values outside (inside) parenthesis represent the skill of T382 (T126). Bold colour indicates 95% significance level.

	FEB-IC	MAR-IC	APR-IC	MAY-IC
JJAS	0.55(0.49)	0.5(0.37)	0.4(0.39)	0.24(0.19)
CNEI	0.43(0.22)	0.35(0.15)	0.26(0.26)	0.37(0.42)
NEI	0.45(0.08)	0.08(0.03)	0.11(0.09)	-0.00(-0.16)
NWI	0.41(0.21)	0.29(0.23)	0.09(0.36)	0.13(0.17)
WCI	0.22(0.14)	0.18(0.21)	0.15(0.17)	-0.11(0.02)
SPI	0.26(0.43)	0.42(0.28)	0.34(0.19)	0.29(0.26)

Evaluation of energy fluxes in the NCEP climate forecast system version 2.0 (CFSv2)

The energy fluxes at the surface and the top of the atmosphere (TOA) from a long free run by the NCEP climate forecast system version 2.0 (CFSv2) are validated against several observation and reanalysis datasets. This study focuses on the annual mean energy fluxes and tries to link it with the systematic cold biases in the 2 m air temperature, particularly over the land regions (**Fig. 6a**). CFSv2 underestimates the net shortwave (SW) over the high latitudes of the Asian and European continents. The model overestimates surface albedo over mid and high latitudes of the Asian and European continents, eastern part of North America by about 20-30% (**Fig. 6b**). The largest albedo biases tend to occur over the snow covered region, highlighting the role of snow processes and representation of snow-albedo in the model. The regions with a large cold bias (by a maximum of 8°C) over mid and high latitudes of the Asian and European continents also happen to be the regions with large albedo bias. An overestimation of surface albedo generally results in negative temperature biases. On the other hand, surface albedo is highly underestimated over the coastal region around Antarctica and that may have contributed to the warm bias over that oceanic region. The imbalances in the long term mean global averaged energy fluxes are also evaluated. The global averaged imbalance at the surface and at the TOA is found to be 0.37 and 6.43 Wm^{-2} respectively (**Table 2** and **3**). This study highlights the need for improvements in the parameterization of snow/sea-ice albedo scheme for a realistic simulation of surface temperature and that may have implications on the global energy imbalance in the model. [***Rai A., Saha S.K.***, *Evaluation of energy fluxes in the NCEP climate forecast system version 2.0 (CFSv2),* ***Climate Dynamics****, online, March 2017, doi:10.1007/s00382-017-3587-z*]

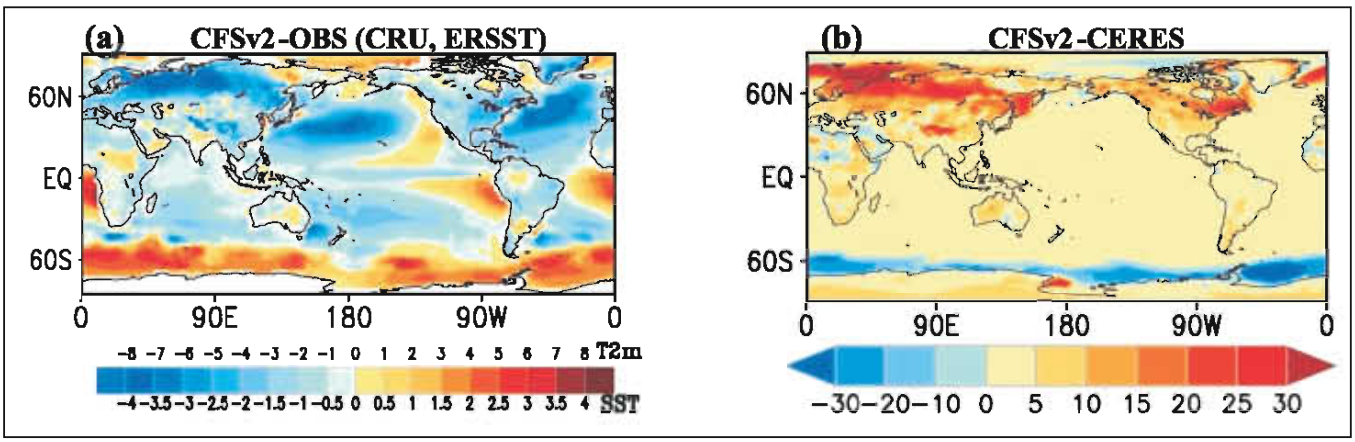


Fig. 6: (a) Climatological mean bias of annual 2m air temperature and sea surface temperature (°C) in CFSv2 with respect to observation (CRU over land and ERSST over ocean) (b) climatological mean bias of annual surface albedo in CFSv2 (%) with respect to observation (CERES).

Table 2: Statistics on global annual mean downward shortwave radiation (SW down), upward shortwave radiation (SW up), net shortwave (Net SW), downward longwave radiation (LW down), upward longwave radiation (LW up), net longwave (Net LW), sensible heat flux (SHF), latent heat flux (LHF), ground heat flux (GHF), and imbalance at the surface from observation (CERES), CFSv2, CFSR, NCEP2, and ERA Interim. The downward (upward) flux is indicted with positive (negative) sign. The signs of radiative terms are in line with their impact that positive (negative) value indicates gain (loss) of energy. Unit of heat fluxes is Wm^{-2}.

	SW down	SW up	Net SW	LW down	LW up	Net LW	SHF	LHF	GHF	Imbalance
CERES	186.69	-24.09	162.60	345.41	-398.59	-53.18	-	-	-	-
CFSv2	197.85	-28.69	169.16	327.69	-388.39	-60.70	-16.83	-88.85	-2.41	0.37
CFSR	192.92	-26.03	166.89	340.36	-397.41	-57.05	-16.44	-83.76	0.53	10.17
NCEP2	187.15	-26.86	160.29	339.98	-396.72	-56.74	-7.52	-91.28	-0.30	4.45
ERA Interim	187.58	-23.80	163.78	341.38	-397.60	-56.22	-17.48	-83.12	-	6.96

Table 3: Statistics on global annual mean downward shortwave radiation (SW down), upward shortwave radiation (SW up), net shortwave (Net SW), upward longwave radiation (LW up), and imbalance at the top of the atmosphere from observation (CERES), CFSv2, CFSR, NCEP2, and ERA Interim. The downward (upward) flux is indicated with positive (negative) sign. Unit of heat fluxes is Wm^{-2}.

	SW down	SW up	Net SW	LW up	Imbalance
CERES	340.17	-99.58	240.59	-239.71	0.88
CFSv2	341.68	-98.03	243.65	-237.22	6.43
CFSR	341.64	-97.78	243.86	-243.48	0.38
NCEP2	341.33	-105.25	236.08	-243.27	-7.19
ERA Interim	344.20	-100.32	243.88	-245.42	-1.54

Sub-Project

Extended Range Prediction

Developmental Activities

Developing a strategy for downscaled forecast: Starting of dynamical downscaling

Keeping in mind the need to improve the forecast at regional scale, IITM extended range products were downscaled to sub-divisional level based on statistical method. Statistical methods, however, can't downscale the extreme events to the fullest amplitude at very small (city, village) spatial scale. Dynamical downscaling is planned to be used in this regard. High resolution WRF runs based on CFS forecast boundary conditions are planned to be used for this purpose.

Implementation of multi resolution runs as a function of lead-time

Work is going on to implement extended range forecast at multiple resolutions as a function of lead-time. The aim is to start CFS forecast runs at high resolution and then, slowly reduce the resolution as the lead-time increases. The purpose of this forecast activity is to reduce the growth of error at larger lead-time.

Real-time prediction of 2016 monsoon season

Real-time extended range prediction of active/break spells of Indian summer monsoon for the 2016 monsoon season was prepared by using the newly developed CFS based Grand Ensemble Prediction System (CGEPS) and the forecasts are being updated in IITM website http://www.tropmet.res.in/erpas/. The CGEPS could predict the dominance of monsoon rainfall over west coast, east coast and northeast India and also, the delay in the progression of monsoon to central India till 20 June, reasonably well in advance. It could also predict the active phase of monsoon after 20 June, at least 10-15 days in advance.

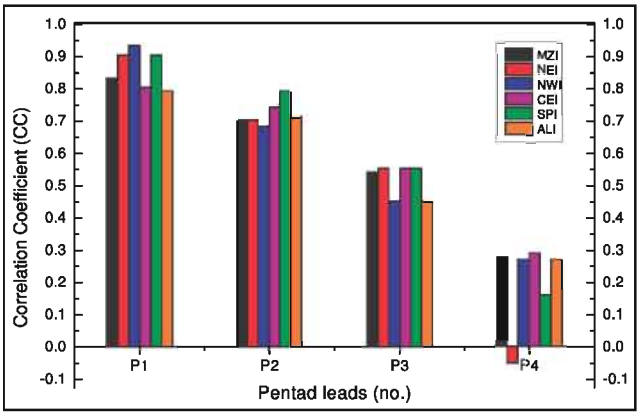


Fig. 7: Co-relation co-efficient between predicted and observed pentad-averaged rainfall anomaly over 5 homogeneous regions (MZI, CEI, NWI, NEI and SPI) of India and All over India (ALI).

Real-time prediction of extreme heat conditions

The extended range prediction for extreme heat conditions has been initiated from this year onwards. The predictions were given during April to June 2016. The extended range prediction system could reasonably provide guidance on the heat wave conditions experienced over various parts of the country during the summer of 2016.

Basic Research

A bias-correction and downscaling technique for operational extended range forecasts based on Self Organizing Map

If a coarse resolution dynamical model can well capture the large-scale patterns even if it has bias in smaller scales, the spatial information in smaller domains may also be retrievable. Based on this hypothesis, a method has been proposed to downscale the dynamical model forecasts of monsoon intra-seasonal oscillations in the extended range, and thus, to reduce the forecast spatial biases in smaller spatial scales. A hybrid of clustering and analog techniques, used in a Self Organizing Map (SOM)-based algorithm, is applied to correct the bias in the model predicted rainfall (**Fig. 8**). The novelty of this method is that the bias correction and downscaling could be done at any resolution in which observation/ reanalysis data are available and that the method is independent of the model resolution in which forecast is generated. A set of composite patterns of rainfall is identified by clustering the high resolution observed rainfall using SOM. These sets of composite patterns for the clustered days in each cluster centre or node are saved and the model forecasts for any day are compared with these patterns. The closest historical pattern is

identified by calculating the minimum Euclidean distance between the model rainfall forecast and the observed clustered pattern and is termed as the bias corrected SOM-based post-processed forecast. The bias-corrected and the SOM-based reconstructed forecasts are shown to improve the annual cycle and the skill of deterministic as well as probabilistic forecasts. Usage of the high resolution observational data improves the spatial pattern for smaller domain as seen from a case study for the Mahanadi basin flood during September 2011. Thus, downscaling and bias correction are both achieved by this technique. [***Sahai A.K., Borah N., Chattopadhyay R., Joseph S. and Abhilash S.**, A bias-correction and downscaling technique for operational extended range forecasts based on Self Organizing Map, **Climate Dynamics**, online, June 2016, doi:10.1007/s00382-016-3214-4*]

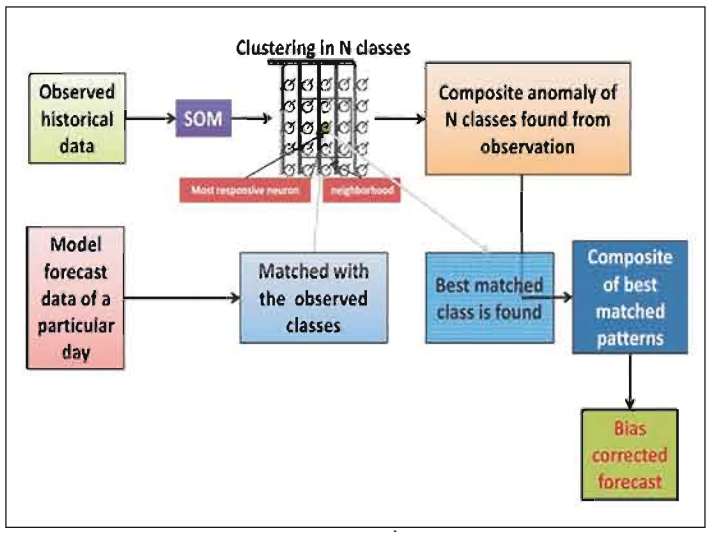


Fig. 8: Schematic representation of the SOM-based post processing from output of MME forecast.

Twin tropical cyclones in the Indian Ocean: The role of equatorial waves

An extensive area of active convection prevailing over wide-equatorial region, and the low-level westerly wind over near-equatorial region are major precursors to the two cases of twins. Convection and accompanying westerlies slowly strengthen, and the two sets of twins tend to emerge within it. The atmospheric equatorial convectively coupled Kelvin wave (CCKW) and convectively coupled equatorial Rossby (CCER) wave played key role in the formation of the two twins' events (**Fig. 9**). Wave-enhanced equatorial convection and low-level westerly anomalies produced by the combination of CCKW and CCER waves are crucial for the development of 'pair A' twins. CCKW prior to 'pair B' twins produced convection and westerly anomalies over equatorial region. The equatorial westerlies are further modulated by CCER wave favouring twins of 'pair B'. Moreover, convection reinforced by CCER wave in OLR aided occurrence of Northern Hemispheric cyclone of 'pair A' and Southern Hemispheric cyclone of 'pair B'. While the CCKW and CCER waves appear to be associated with the formation of the two twin cyclone cases, more thorough understanding of the mechanisms involved needs considerable attention in the forthcoming research. [***Mandke S.K. and Sahai A.K.**, Twin tropical cyclones in the Indian Ocean: The role of equatorial waves, **Natural Hazards**, 84, December 2016, 2211-2224, doi: 10.1007/s11069-016-2546-z*]

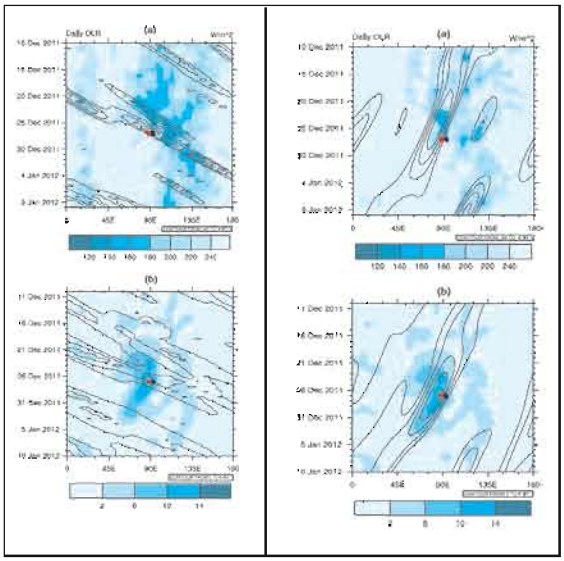


*Fig. 9: (**Left panel**) (a) A time-longitude plot averaging unfiltered OLR (shaded) and only negative Kelvin-wave filtered OLR anomalies (contour) averaged in the 5°S-5°N latitude belt overlaid with twin tropical cyclogenesis events for twins 'pair A'. (b) Same as in (a) except for unfiltered 850 hPa u-wind (shaded) and only positive Kelvin-wave filtered 850 hPa u-wind anomalies (contour). (**Right panel**) (a) A time-longitude plot averaging unfiltered OLR (shaded) and only negative Equatorial Rossby-wave filtered OLR anomalies (contour) averaged in the 2.5°N-15°N latitude belt overlaid with twin tropical cyclogenesis events for twins 'pair A'. (b) Same as in (a) except for unfiltered 850 hPa u-wind (shaded) and only positive Equatorial Rossby-wave filtered 850 hPa u-wind anomalies (contour).*

MJO diagnostics for extended range prediction and simulation in IITM CFSv2

A new method to track the smooth eastward propagation of Madden Julian Oscillation (MJO) is proposed in order to use it for real-time prediction **(Fig. 10)**. The new method essentially removes any requirement of pre-filtering of data and is based on the extended empirical orthogonal function (EEOF) analysis of the zonal wind at 850 hPa, 200 hPa and the velocity potential (chi) at 200 hPa. The lag used for creating the extended data matrix is 6 days (day 0 to day 5). The EEOF method not only captures the MJO but also smooths the temporal propagation in the phase space defined by first two principal components (PCs) of the EEOFs. Along with traditional tracking in a phase space, we extend the method to get the MJO-filtered spatial distribution of precipitation and other three dimensional variables associated with MJO. Examples of the TOGA-COARE and DYNAMO period are presented to compare the newly developed method with earlier ones. [***Sahai A.K., Chattopadhyay R., Dey A., Joseph S., Abhilash S., Phani M., Mandal Raju, Rajeevan M.*** *and Hendon H., MJO Diagnostics for Extended Range Prediction and Simulation in IITM CFSv2,* ***IITM Research Report****, RR 136, September 2016*].

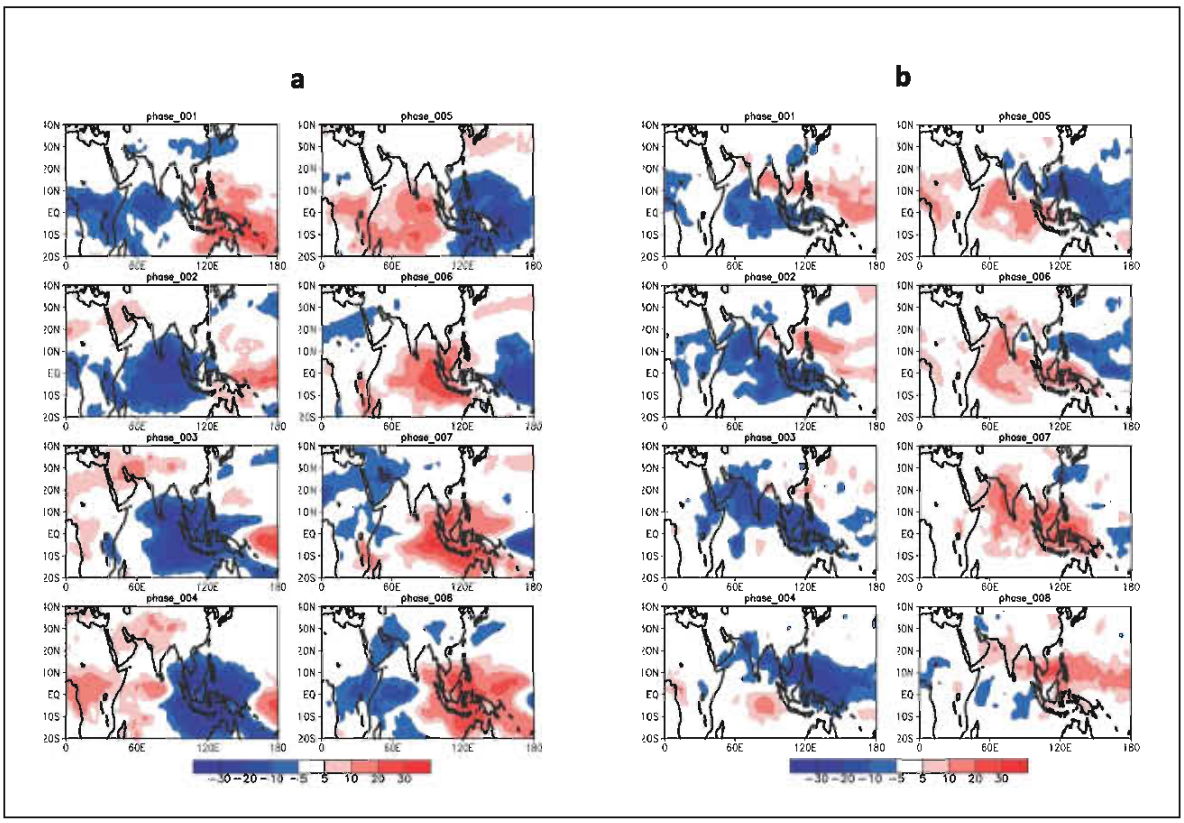


Fig. 10: *Spatial composite of OLR Anomalies for* ***(a)*** *15 January and* ***(b)*** *15 July.*

Sub-Project

Parameterization of Physical Processes and Analysis

Developmental Activities

Short range ensemble forecast system

Short Range Ensemble Forecast system based on Global Ensemble Forecast System (GEFS) with 21 ensemble members is developed. This modelling system is found to be highly useful for probabilistic forecasting. This modelling system will soon be handed over to IMD for operational application.

Real time short range deterministic forecasting system

The ongoing (experimental) real time short range deterministic forecasting system based on GFS T1534 has been established in IITM and 8 days forecast based on daily 0000 UTC initial condition provided by NCMRWF is being disseminated to IMD by 15:00 hours. High resolution Global Forecast System (GFS) model at T1534 (Global horizontal resolution ~12 km) has been run on real time daily (experimental basis) to generate deterministic forecast for 8 days. The forecast for 8 days is available at http://srf.tropmet.res.in/srf/files/archive_hires.php.

The T1534 GFS forecast is found to capture the location and intensity of extreme rains and also, the cyclogenesis with reasonably advance lead time. This modelling system is made operational in IMD since 16 January 2017. Presently, initiatives are being taken to use the GFS T1534 forecast output for block level agriculture forecasting.

Basic Research

Impact of revised simplified Arakawa-Schubert scheme on the simulation of mean and diurnal variability associated with active and break phases of Indian summer monsoon using CFSv2

The impact of revised simplified Arakawa-Schubert (RSAS) convective parameterization scheme in Climate Forecast System (CFS) version 2 (CFSv2) on the simulation of active and break phases of Indian summer monsoon (ISM) has been investigated. The results revealed that RSAS showed better fidelity in simulating monsoon features from diurnal to daily scales during active and break periods as compared to SAS simulation. Prominent improvement can be noted in simulating diurnal phase of precipitation in RSAS over central India (CI) (**Fig. 11**) and equatorial Indian Ocean (EIO) region during active periods. The spatial distribution of precipitation largely improved in RSAS simulation during active and break episodes. CFSv2 with SAS simulation has noticeable dry bias over CI and wet bias over EIO region which appeared to be largely reduced in RSAS simulation during both phases of the intra-seasonal oscillation (ISO). During active periods, RSAS simulates more realistic probability distribution function (PDF) is in good agreement with the observation. The relative improvements have been identified in outgoing longwave radiation, monsoon circulations, and vertical velocities in RSAS over SAS simulation. The improvement of rainfall distribution appears to be contributed by proper simulation of convective rainfall in RSAS. CFSv2 with RSAS simulation is able to simulate observed diurnal cycle of rainfall over CI. It correctly reproduces the time of maximum rainfall over CI. It is found that the improved feedback between moisture and convective processes (**Fig. 12**) in RSAS may be attributed to its improved simulation. However, RSAS could not reproduce proper tropospheric temperature, cloud hydrometeors over ISM domain which shows the scope for future development. [***Ganai M., Krishna R.P.M., Mukhopadhyay P.,*** *and* ***Mahakur M.,*** *The impact of revised simplified Arakawa-Schubert scheme on the simulation of mean and diurnal variability associated with active and break phases of Indian summer monsoon using CFSv2,* ***Journal of Geophysical Research: Atmosphere****, 121, August 2016, doi:10.1002/2016JD025393*]

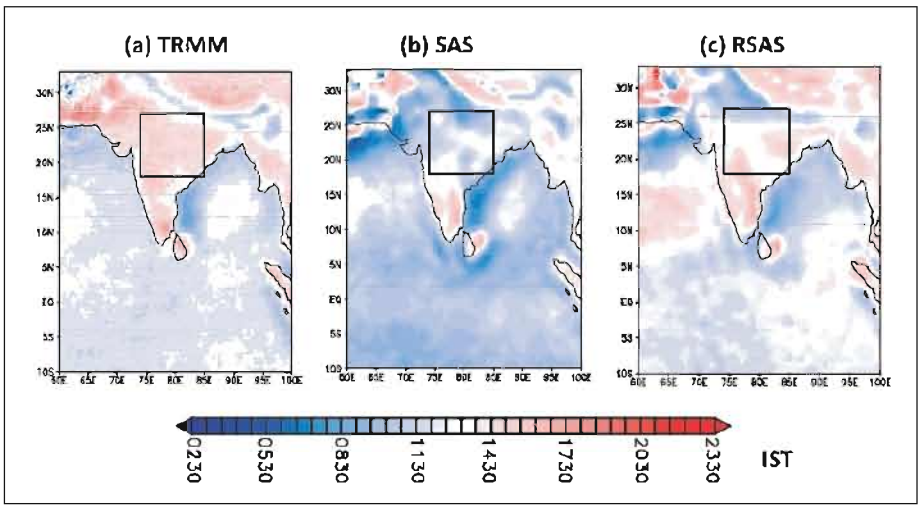


Fig. 11: Seasonal (JJAS) mean distribution of diurnal phase (IST (h)) when maximum precipitation occurs for (a) TRMM, CFSv2 with (b) SAS and (c) RSAS scheme. Black box represents central India (CI) (18°N–27°N, 74°E–85°E) region.

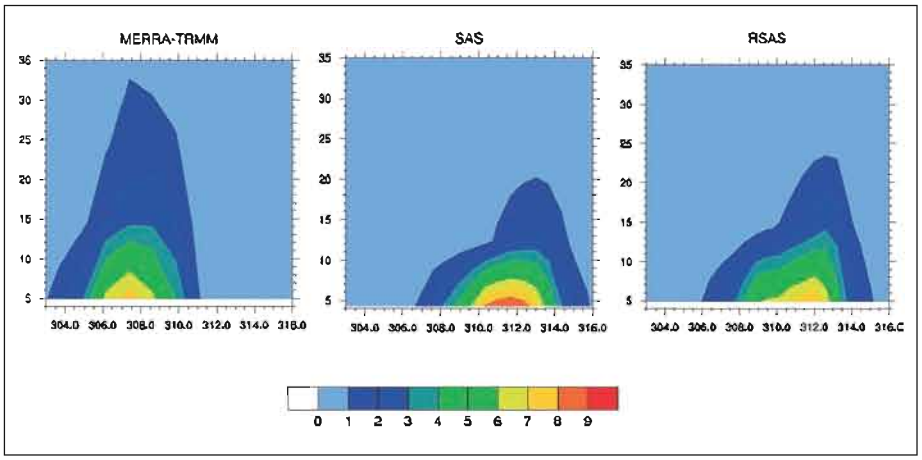


Fig. 12: Joint probability distribution function of rainfall (mm d^{-1}), along the y axis, and column integrated (surface to 100 hPa) MSE (× 107 Jm^{-2}), along the x axis, over CI region for (a) observation (TRMM and MERRA), CFSv2 with (b) SAS and (c) RSAS scheme during JJAS.

Revised cloud processes to improve the mean and intraseasonal variability of Indian summer monsoon in Climate Forecast System

The National Centre for Environmental Prediction (NCEP) Climate Forecast System (CFS) is being used for operational monsoon prediction over the Indian region. Recent studies indicate that the moist convective process in CFS is one of the major sources of uncertainty in monsoon predictions. In this study, the existing simple cloud microphysics of CFS is replaced by the six-class Weather Research Forecasting (WRF) single moment (WSM6) microphysical scheme. Additionally, a revised convective parameterization is employed to improve the performance of the model in simulating the boreal summer mean climate and intraseasonal variability over the Indian summer monsoon (ISM) region (**Fig. 13 a-e**). The revised version of the model (CFSCR) exhibits a potential to improve shortcomings in the seasonal mean precipitation distribution relative to the standard CFS (CTRL), especially over the ISM region. Consistently, notable improvements are also evident in other observed ISM characteristics. These improvements are found to be associated with a better simulation of spatial and vertical distributions of cloud hydrometeors in CFSCR. A reasonable representation of the sub-grid scale convective parameterization along with cloud hydrometeors helps to improve the convective and large-scale precipitation distribution in the model (**Fig. 13 c**). As a consequence, the simulated low frequency boreal summer intraseasonal oscillation (BSISO) exhibits realistic propagation and the observed northwest-southeast rainband is well reproduced in CFSCR. Additionally, both the high and low frequency BSISOs are better captured in CFSCR. The improvement of low and high frequency BSISOs in CFSCR is shown to be related to a realistic phase relationship of clouds. [***Abhik S., Krishna R.P.M., Mahakur M., Ganai M., Mukhopadhyay P. and Dudhia J., Revised cloud processes to improve the mean and intraseasonal variability of Indian summer monsoon in climate forecast system: Part-I. Journal of Advances in Modeling Earth Systems, Online, March 2017, doi:10.1002/2016MS000819***]

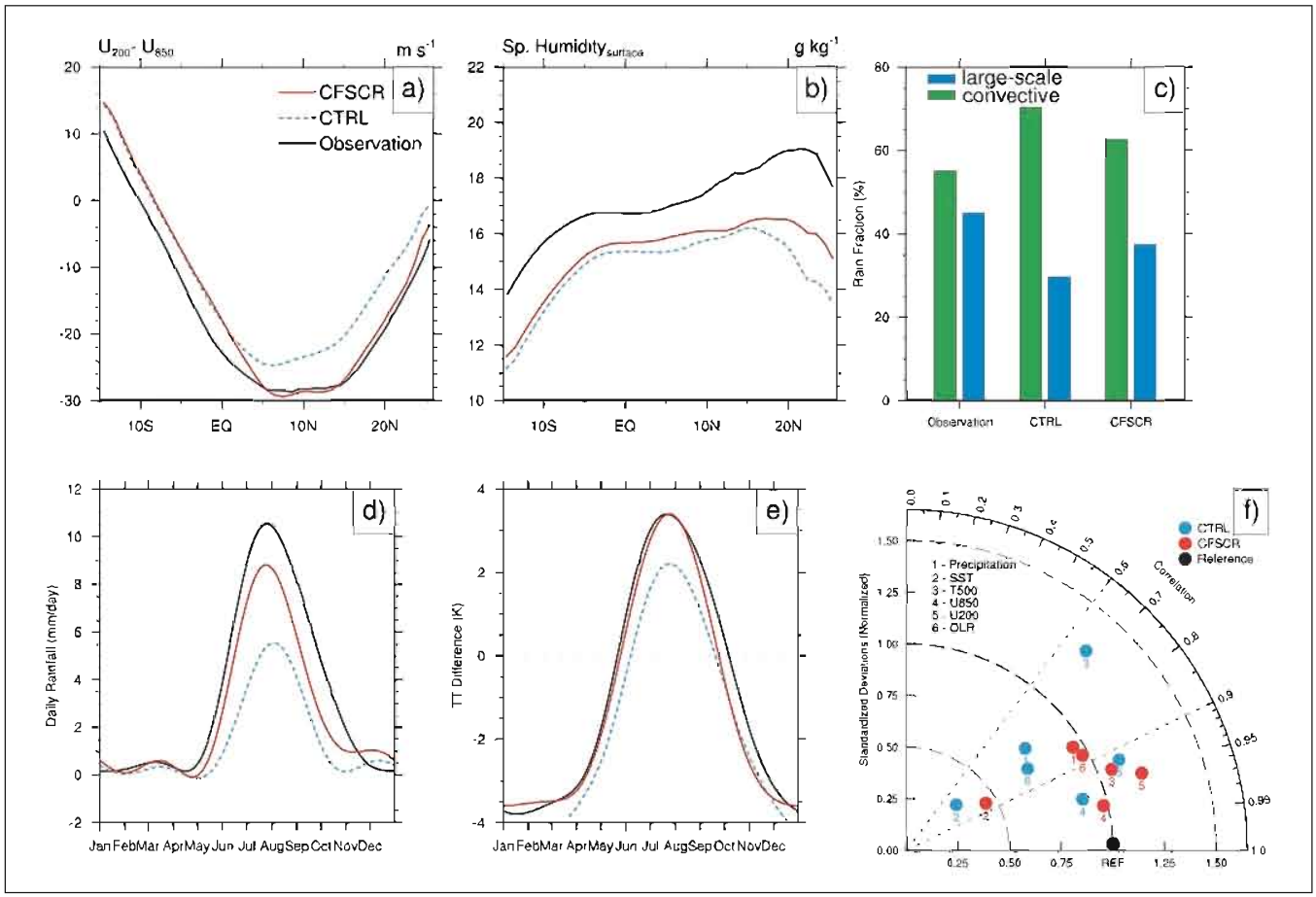


***Fig. 13:** Meridional distributions of boreal summer mean (a) U_{200}- U_{850}, (b) Surface specific humidity for observation, CTRL and CFSCR. All the datasets are averaged between 70°E and 90°E. (c) Convective and large-scale rain fraction (%) over the ISM region (40°-120°E, 15°S-30°N), (d) Climatological annual precipitation cycle over central India (73°-85°E, 15°-25°N), (e) same as (d), but for TT difference between a northern box (40°-100°E, 5°-35°N) and southern box (40°-100°E,15°S-5°N), (f) Taylor diagram for summarizing the relative skill of the simulations relative to the observed summertime mean meteorological fields over the same ISM region. Black dot denotes the reference point.*

Improving synoptic and intraseasonal variability in CFSv2 via stochastic representation of organized convection

To better represent organised convection in the Climate Forecast System version 2 (CFSv2), a stochastic multicloud model (SMCM) parameterization is adopted and a 15 year climate run is made. The last 10 years of simulations are analysed here. While retaining an equally good mean state (if not better) as the parent model, the CFS-SMCM simulation shows significant improvement in the synoptic and intraseasonal variability. The CFS-SMCM provides a better account of convectively coupled equatorial waves and the Madden-Julian oscillation (**Fig. 14**). The CFS-SMCM exhibits improvements in northward and eastward propagation of intraseasonal oscillation of convection including the MJO propagation beyond the maritime continent barrier, which is the Achilles Heel for coarse-resolution global climate models (GCMs). The distribution of precipitation events is better simulated in CFS-SMCM and spreads naturally toward high-precipitation events. Deterministic GCMs tend to simulate a narrow distribution with too much drizzling precipitation and too little high-precipitation events. [*Goswami B.B., Khouider B., **Phani R., Mukhopadhyay P.**, Majda A., Improving synoptic and intraseasonal variability in CFSv2 via stochastic representation of organized convection, **Geophysical Research Letters**, 44, January 2017, 1-10, doi:10.1002/2016GL071542*]

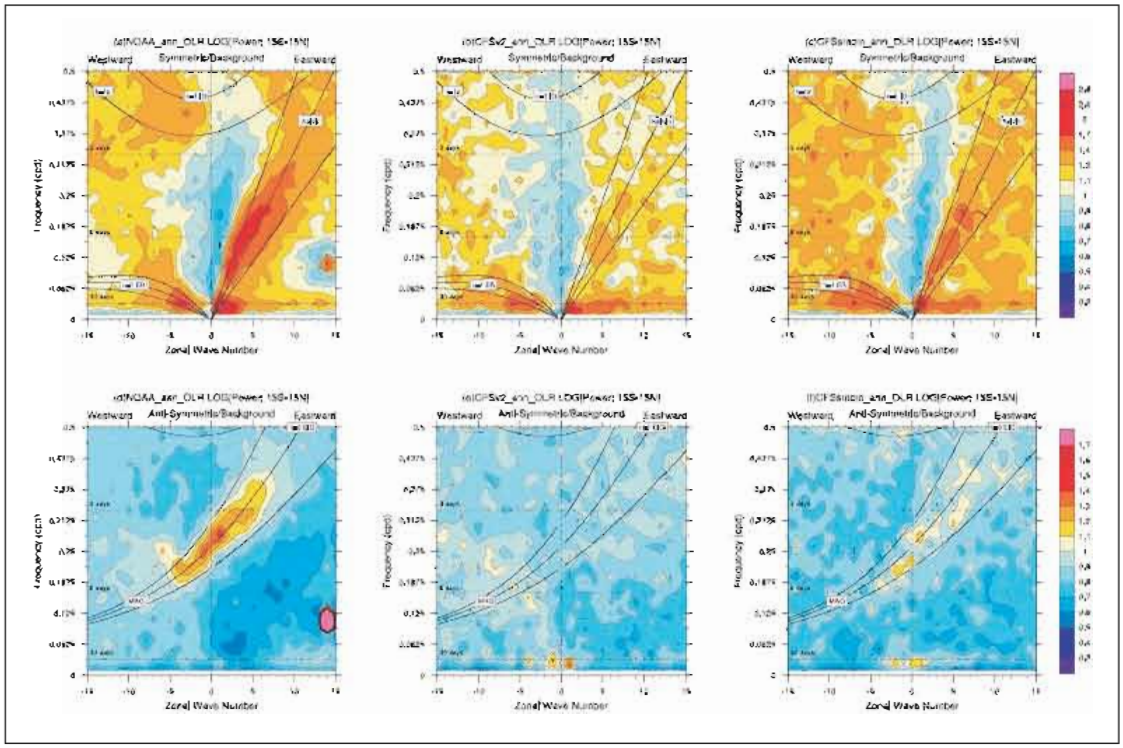


Fig. 14: Wheeler-Kiladis spectra of OLR from (a) NOAA, (b) CFSv2, and (c) CFSsmcm, for the symmetric component. (d-f) The corresponding antisymmetric spectra.

MoES-NERC Project Office at IITM

Under Monsoon Mission, the Ministry of Earth Sciences (MoES), Govt. of India and the Natural Environment Research Council (NERC), UK are working in partnership for understanding variability of the South Asian monsoon and the processes driving its variability, seasonality and predictability and for improving its prediction on all time scales. This MoES-NERC joint project has three major experimental components: SWAAMI (South West Asian Aerosol Monsoon Interactions), INCOMPASS (Interaction of Convective Organisation and Monsoon Precipitation, Atmosphere, Surface and Sea) and BoBBLE (Bay of Bengal Boundary Layer Experiment). An MoES-NERC Project Office is set up at IITM to liaise with NERC, MoES and other organisations for implementing these projects and for various clearances and smooth execution of observational campaigns. The Project Office at IITM is coordinated by Dr. R.S. Maheshkumar. During the period of this report, following campaigns were conducted:

Aircraft Campaign: BAe-146 Research Aircraft was operated in the country during 11 June to 11 July 2016 and about 100 hours of important data were collected over Indo-gangetic plains, parts of Rajasthan, west and east coastal regions and also some parts of the peninsular India. Observations over the Arabian Sea and also, over the Bay of Bengal were conducted in coordination with measurements on the Research Vessel Sindhu Sadhana over the Indian Ocean. A suite of instruments was used to measure a variety of atmospheric parameters such as: temperature, relative humidity, winds (3 components), SW radiation, LW radiation, turbulence, etc.; cloud microphysical parameters such as liquid water content, ice water content, total water content, updraft speed, cloud condensation nuclei, cloud droplet number and size, hydrometeor images, etc.; aerosol parameters such as aerosol number, size (all size ranges), black carbon aerosol concentration, aerosol scattering and absorption coefficients, etc.; chemical measurements such as Ozone, CO_2, CO, CH_4, NOx, SO_2 and chemical species in the aerosols, etc. Also, the aircraft was equipped with a weather radar, aerosol lidar and dropsonde facility.

RV Sindhu Sadhana Campaign: An observational campaign was undertaken in the Bay of Bengal during 23 June to 24 July 2016 along with the analysis of wider observational and reanalysis-based data sets, and a set of hierarchical modelling experiments. The measurements were conducted using CTD, gliders, uCTD, turbulence profiler, ARGO and drifting buoys, etc. All types of physical, chemical and bio-geo-chemical measurements apart from the atmospheric measurements were conducted on board the research vessel.

Photo: Research Aircraft BAe-146.

Photo: *Dr. M. Rajeevan, Secretary, MoES inaugurating the MoES-NERC Data Centre at IITM on 17 February 2017.*

Photo: *Dr. Harsh Vardhan, Union Minister for S&T and Earth Sciences along with Dr. M. Rajeevan Secretary, MoES visited the research aircraft facility at Lucknow on 11 July 2016.*

Project

Physics and Dynamics of Tropical Clouds

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

Objectives

- To study the cloud-aerosol-precipitation interactions using observations and simulations.
- To formulate a scientific basis and protocol to enhance rain formation and rain enhancement using the recent cloud seeding technologies and the state-of-the-art instrumentation.
- To carry out collocated airborne and integrated ground based observations to understand a) the microphysical changes in the clouds as a result of changes in aerosol particles, b) microphysical and dynamical controls on the rain formation, c) how physical and chemical properties of aerosols may impact radiative forcing and cloud formation, d) how direct and indirect effect of aerosols may be quantified, and e) utilization of observations in formulating process level parameterization for monsoon clouds, f) understand the fog layer microphysics and microscale processes to understand fog formation, evolution and dissipation.
- To Study the dynamical, microphysical and electrical characteristics of thunderstorms, and their interactions with each other over the Indian region (which can help in improving their prediction).
- To study the interaction of thunderclouds with environmental conditions.
- To understand the effect of electrical forces on microphysical characteristics of thunderstorm.
- To study boundary layer characteristics by making observation with micrometeorological tower.
- To establish India's first High-Altitude Cloud Physics Laboratory with state-of-the-art instrumentation to measure aerosol, cloud, precipitation and environmental parameters for studying the effect of aerosols on cloud microphysics and in-turn precipitation.
- To understand several of the micro physical and dynamical processes involved in aerosol-cloud-precipitation interactions by simultaneously observing them through long-term surface observations.
- To investigate a) secondary organic aerosol formation and their effect on cloud microphysics, and b) aerosol-CCN closure using aerosol chemistry and hygroscopicity measurements.
- To investigate the spatial distribution of cloud and precipitation systems over the Western Ghats and surrounding regions using polarimetric weather radars and to validate radar reflectivity and rainfall measurements using network of Optical Rain Gauge (ORG) and Disdrometer.
- Retrieval of cloud microphysical properties using polarimetric Ka-band radar.
- To study the impact of assimilation of Doppler and polarimetric radar products into numerical meso-scale models.
- To improve the understanding of cloud, precipitation systems and regional hydrological cycle through space borne observations.
- To contribute towards the national space programme in the areas of retrieval of scientific products, validation and through value addition.

Sub-Projects

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

Sub-Project

Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)

Developmental Activities

Preparations for CAIPEEX Phase-IV experiments: The site selection committee has identified Solapur as the possible site for radars and several other instruments for the campaign. Science plan for the seeding experiment at this site in 2017-2019 is developed and was reviewed by the CAIPEEX National Scientific Steering Committee (NSSC) in a meeting held on 22 July 2016. The committee has recommended: a) to install C-band radar at Solapur by June 2017, b) to develop a flare testing aerosol laboratory at IITM as part of CAIPEEX activities, c) conduct ground based observations from Solapur, d) to install 80 rain gauges in the seeding area, and e) to hire research and seeder aircraft and conduct airborne seeding in 2018-19.

Accordingly, a Memorandum of Understanding (MoU) between IITM and Savitribai Phule Shikshan Prasarak Mandal's N.B. Navale Sinhgad College of Engineering, Solapur (Maharashtra) was signed on 12 January 2017 for technical cooperation and establishment of an observational facility for C-band radar and other ground based instrumentation for CAIPEEX Phase-IV experiments during 2017-2020. C-band radar is being procured for installation at the College. The training and factory acceptance test for C-band radar are complete. Prior to its installation at the site, Radio Noise survey was conducted by SAMEER, Mumbai during 27-28 October 2016 to identify radio interference, if any, in the designated frequency band.

A rain gauge network is being established for evaluation of seeding and for calibration of radar in the rain shadow region for CAIPEEX Phase-IV campaign. So far, 20 rain gauges have been installed and more are being procured. Wind profilers are being procured for installation in the seeding area. Permissions from DGCA and AAI have been obtained for tethersonde and radiosonde flights from Solapur. Some instruments like microwave radiometer are already installed and others are being procured and installed to ready the site for the campaign.

Basic Research

Cloud-edge mixing: Direct numerical simulation and observations in Indian monsoon clouds

A direct numerical simulation (DNS) with the decaying turbulence setup has been carried out to study cloud-edge mixing and its impact on the droplet size distribution (DSD) applying thermodynamic conditions observed in monsoon convective clouds over Indian subcontinent during CAIPEEX. Mixing at the cloud-edge starts at small scales and gradually introduces larger scale fluctuations in temperature, moisture, and vertical velocity due to droplet evaporation (**Fig. 1**). The study focused on the early evolution of simulated fields that show intriguing similarities to the CAIPEEX cloud observations. A strong dilution at the cloud-edge, accompanied by significant spatial variations of the droplet concentration, mean radius, and spectral width, is found in both the DNS and in observations. In DNS, fluctuations of the mean radius and spectral width come from the impact of small-scale turbulence on the motion and evaporation of inertial droplets. These fluctuations decrease with the increase of the volume over which DNS data are averaged, as one might expect. In cloud observations, these fluctuations also come from other processes, such as entrainment/mixing below the observation level, secondary CCN activation, or variations of CCN activation at the cloud base. Despite large differences in the spatial and temporal scales, the mixing diagram often used in entrainment/mixing studies with aircraft data is remarkably similar for both DNS and cloud observations. It is argued that the similarity questions applicability of heuristic ideas based on mixing between two air parcels (that the mixing diagram is designed to properly represent) to the evolution of microphysical properties during turbulent mixing between a cloud and its environment. [***Kumar B., Bera S., Prabha T.V.*** *and Grabowski W.W., Cloud-edge mixing: Direct numerical simulation and observations in Indian monsoon clouds,* ***Journal of Advances in Modeling Earth Systems****, 9, February 2017, doi:10.1002/2016MS000731*]

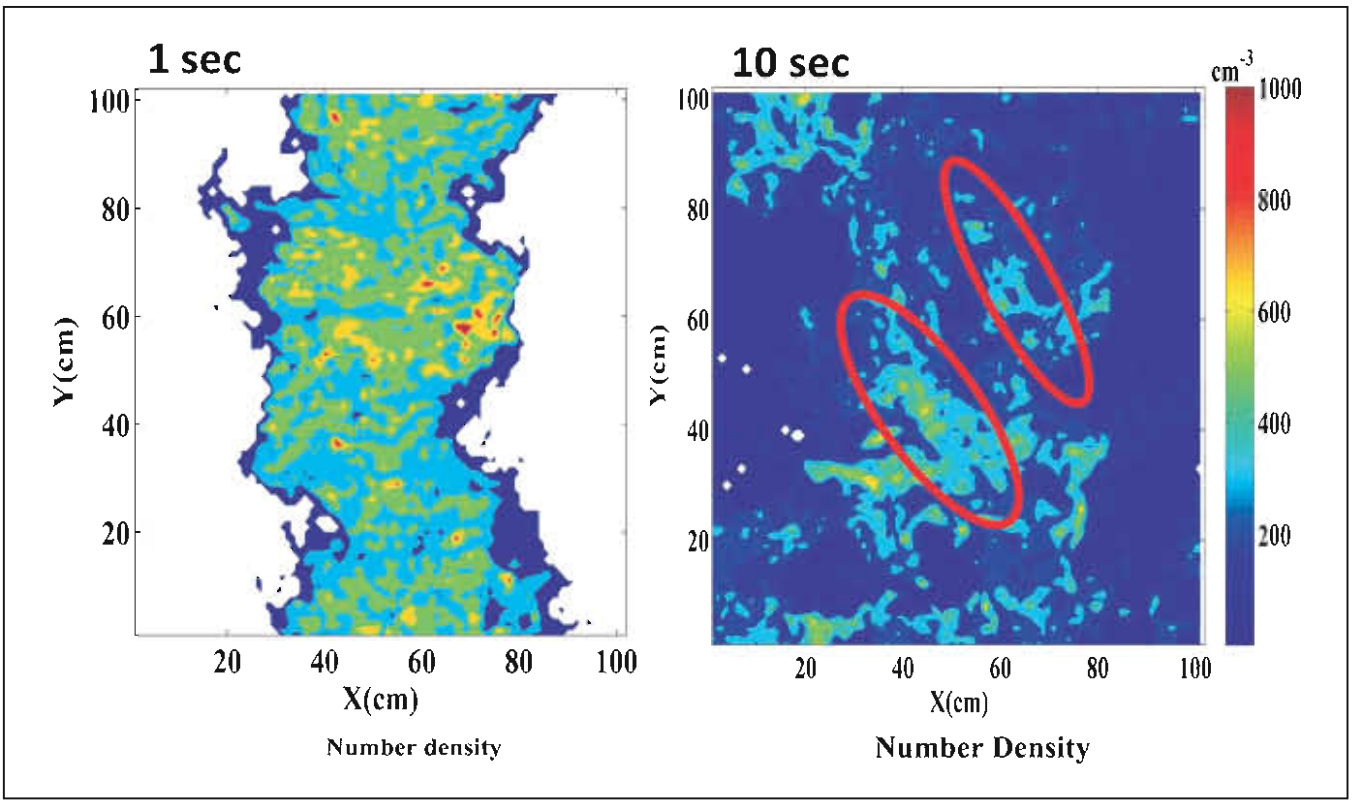


Fig. 1: Small scale motions in cloud accomplishing the mixing and evaporation of cloud droplets and coherent structures formed during the simulation (1s and 10s simulations): demonstrated with direct numerical simulation (DNS) of cloud-edge mixing in a small domain (1 m^3).

Observations of monsoon convective cloud microphysics over India and role of entrainment-mixing

Microphysical characteristics of pre-monsoon and monsoon deep cumuli over India observed by an instrumented aircraft are contrasted focusing on influences of environmental conditions and entrainment-mixing processes. Differences in the lower tropospheric temperature and moisture profiles lead to contrasting undiluted cloud buoyancy profiles around the cloud base, larger in the pre-monsoon case. It is argued that this affects the variation of the mean and maximum cloud droplet number concentrations and the droplet radius within the lowest several hundred metres above the cloud base. The conserved-variable thermodynamic diagram analysis suggests that entrained parcels originate from levels close to the observational level. Mixing processes and their impact on the droplet size distribution (DSD) are investigated contrasting 1 Hz and 10 Hz observations. In homogeneous-type mixing, likely because of unresolved small-scale structures associated with active turbulent stirring, is noted at cloud-edge volumes where dilution is significant and DSDs shift toward smaller sizes with reduced droplet number concentrations due to complete evaporation of smaller droplets and partial evaporation of larger droplets. DSDs within cloud core volumes suggest that the largest droplets are formed in the least diluted volumes where raindrops can form at higher levels; no super-adiabatic droplet growth is observed. The typical diluted parcel size is approximately 100-200 m for cloud-edge volumes, and it is much smaller, 10-20 m for cloud core volumes (**Fig. 2**). Time scale analysis indicates the possibility of inhomogeneous-type mixing within the diluted cloud-edge volumes at spatial scales of a 100 m or more. [***Bera, S., Prabha T.V.**, and Grabowski W.W., Observations of monsoon convective cloud microphysics over India and role of entrainment-mixing, **Journal of Geophysical Research**, 121, August 2016, doi:10.1002/2016JD025133*]

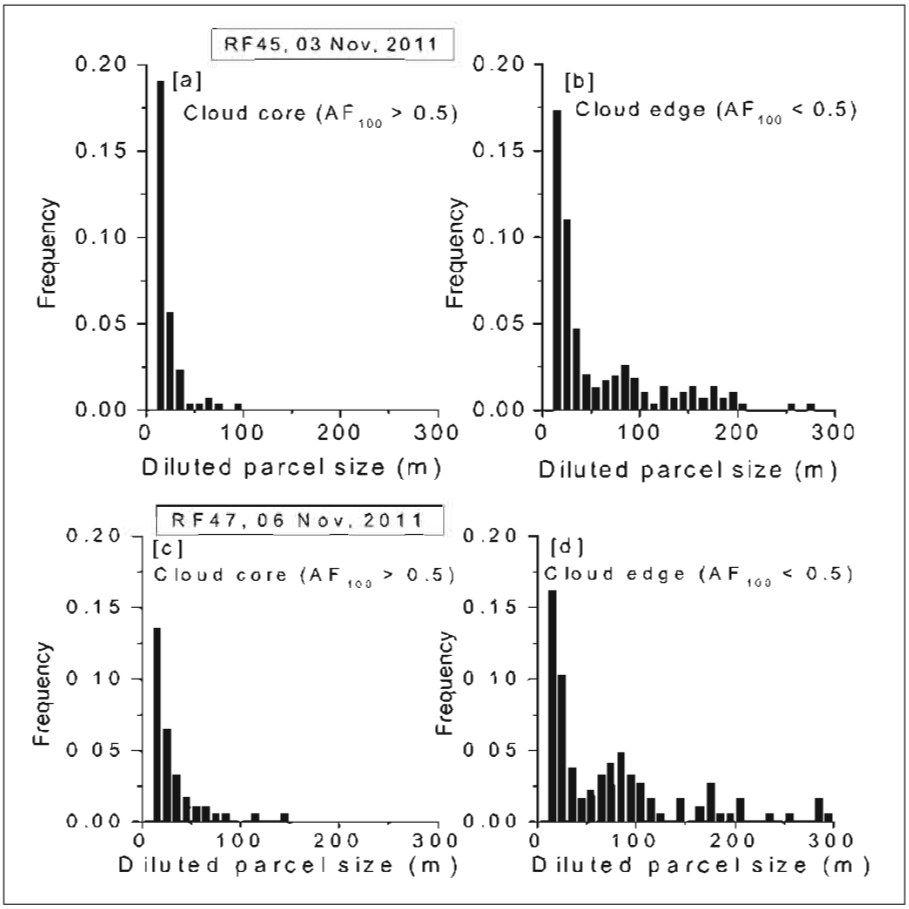


***Fig. 2:** Probability distribution function (PDF) of diluted parcel sizes for cloudy volume with (a and c) AF > 0.5 in 100 m segments and for cloudy volume with (b and d) AF < 0.5 in 100 m segments during two research flights, RF45 (a and b) and RF47 (c and d).*

Precipitable water as a predictor of LCL height

Based on precipitable water observations, easily available from *in-situ* and remote sensing sensors, a simple approach to define lifting condensation level (LCL) is proposed. High-resolution radiosonde and microwave radiometer observations over peninsular Indian region during the Cloud Aerosol Interaction and Precipitation Enhancement Experiment Integrated Ground Observational Campaign (CAIPEEX-IGOC) during the monsoon season of 2011 are used to illustrate the unique relationship. The inferences illustrate a linear relationship between precipitable water (PW) and LCL temperature. This relationship is especially valuable because PW is easily available as a derived parameter from various remote sensing and ground-based observations. Thus, it could be used to estimate LCL height and perhaps also, boundary layer height. LCL height and PW correlations are established from historical radiosonde data (1984-2012). This finding could be used to illustrate boundary layer-cloud interactions during monsoon, which is important for parameterization of boundary layer clouds in numerical models. The relationships are illustrated to be robust and seem promising to get reasonable estimates of LCL height over other locations as well using satellite observations of PW. [***Murugavel P., Malap N., Balaji B.,** Mehajan R.K., **Prabha T.V.,** Precipitable water as a predictor of LCL height, **Theoretical and Applied Climatology,** Online, August 2016, doi:10.1007/s00704-016-1872-0*]

Atmospheric heating due to black carbon aerosol during summer monsoon period over Ballia: A rural environment over Indo-Gangetic Plain

Black carbon (BC) aerosols are one of the most uncertain drivers of global climate change. The prevailing view is that BC mass concentrations are low in rural areas where industrialisation and vehicular emissions are at a minimum. As part of a national research programme called the 'Ganga Basin Ground Based Experiment-2014 under the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Phase-III' of Ministry of Earth Sciences, Government of India, continuous measurements of BC and particulate matter (PM) mass concentrations were conducted in a rural environment in the highly-polluted Indo-Gangetic Plain region during 16 June to 15 August 2014 (monsoon period). The mean mass concentration of BC was 4.03 (±0.85) μg m^{-3} with a daily variability between 2.4 and 5.64 μg m^{-3}, however, the mean mass PM concentrations [near ultrafine (PM1.0), fine (PM2.5) and inhalable (PM10)] were 29.1(±16.2), 34.7 (±19.9) and 43.7 (±28.3) μg m^{-3} respectively. The contribution of BC in PM1.0 was approximately 13%, which is one of the highest being

recorded. Diurnally, the BC mass concentrations were highest (mean: 5.89 μg m^{-3}) between 20:00 to 22:00 local time (LT) due to the burning of biofuels/biomass such as wood, dung, straw and crop residue mixed with dung by the local residents for cooking purposes. The atmospheric direct radiative forcing values due to the composite and BC aerosols were determined to be +78.3, +44.9, and +45.0 W m^{-2} and +42.2, +35.4 and +34.3 W m^{-2} during the months of June, July and August respectively. The corresponding atmospheric heating rates (AHR) for composite and BC aerosols were 2.21, 1.26 and 1.26; and 1.19, 0.99 and 0.96 K day^{-1} for the month of June, July and August respectively, with a mean of 1.57 and 1.05 K day^{-1} which was 33% lower AHR (BC) than for the composite particles during the study period. This high AHR underscores the importance of absorbing aerosols such as BC contributed by residential cooking using biofuels in India. The study demonstrates the need for immediate, effective regulations and policies that mitigate the emission of BC particles from domestic cooking in rural areas of India. [***Tiwari S.**, Dumka U.C., Hopke U.C., Tunved P., Atmospheric heating due to black carbon aerosol during the summer monsoon period over Ballia: A rural environment over Indo-Gangetic Plain, **Atmospheric Research**, 178-179, September 2016, 393-400, DOI:10.1016/j.atmosres.2016.04.008*]

Effects of agriculture crop residue burning on aerosol properties and long-range transport over northern India: A study using satellite data and model simulations

Agriculture crop residue burning in the tropics is a major source of the global atmospheric aerosols and monitoring their long-range transport is an important element in climate change studies. The effects of agriculture crop residue burning on aerosol properties and long-range transport over northern India were studied during a smoke event that occurred between 09 and 17 November 2013, with the help of satellite measurements and model simulation data. Satellite data observations on aerosol properties suggested transport of particles from agriculture crop residue burning in Indo-Gangetic Plains (IGP) over large regions. Additionally, ECMWF winds at 850 hPa have been used to trace the source, path and spatial extent of smoke events. Most of the smoke aerosols, during the study period, travel from a west-to-east pathway from the source-to-sink region. Furthermore, aerosol vertical profiles from CALIPSO show a layer of thick smoke extending from surface to an altitude of about 3 km. Smoke aerosols emitted from biomass burning activity from Punjab have been found to be a major contributor to the deterioration of local air quality over the NE Indian region due to their long range transport. [*Vijaykumar K., **Safai P.D.**, Devara P.C.S., Rao S.V.B., Jayasankar C.K., Effects of agriculture crop residue burning on aerosol properties and long-range transport over northern India: A study using satellite data and model simulations, **Atmospheric Research**, 178-179, September 2016, 155-163, doi:10.1016/j.atmosres.2016.04.003*]

Indirect forcing of black carbon on clouds over northeast India

Black carbon (BC) induced indirect radiative forcing and cloud albedo effect have been studied for the first time over northeast India. Measurements of BC and cloud microphysical parameters were carried out during Phase-I of CAIPEEX over northeast India (Guwahati) in 2009. Liquid water path (LWP) in the cloud layers coherent with BC on different experimental days was found to be 206-327 g m^{-2} over the region. Black carbon aerosol indirect effect (BCIE) for fixed LWP is found to be 0.32-0.48 on different days of observations. The indirect forcing corresponding to this BCIE has been estimated using a radiative transfer model for fixed LWP by altering the derived BC-AOD (aerosol optical depth from measured BC profiles) and cloud effective radius (Re) combinations. The estimated average BC-induced indirect forcing (BCIF) was –24 to –37.1 W m^{-2} at the surface and +2.5 to +14.8 W m^{-2} at the top of the atmosphere (TOA). The average albedo due to BCIF at TOA was 0.49-0.61. BCIF is found to reduce the cloud reflection by 1.5-2% over the region. The sensitivities of cloud parameters to BCIF and the albedo effect are illustrated. [***Panicker A.S., Pandithurai G., Safai P.D., Prabha T.V.**, Indirect forcing of black carbon on clouds over northeast India, **Quarterly Journal of Royal Meteorological Society**, 142, October 2016, 2968-2973, doi:10.1002/qj. 2878*]

Sub-Project

High Altitude Cloud Physics Laboratory (HACPL)

Basic Research

Aerosol indirect effects on monsoon clouds

The effect of aerosols on cloud droplet number concentration and droplet effective radius is investigated from ground-based measurements over a high-altitude site where clouds pass over the surface. First aerosol indirect effect (AIE) estimat2es were made using (i) relative changes in cloud droplet number concentration (AIEn) and (ii) relative changes in droplet effective radius (AIEs) with relative changes in aerosol for different cloud liquid water contents (LWCs). AIE estimates from two different methods reveal that there is systematic overestimation in AIEn as compared to that of AIEs. Aerosol indirect effects (AIEn and AIEs) and dispersion effect (DE) at different LWC regimes ranging from 0.05 to 0.50 gm^{-3} were estimated. The analysis demonstrates that there is overestimation of AIEn as compared to AIEs, which is mainly due to DE. Aerosol effects on spectral dispersion in droplet size distribution play an important role in altering Twomey's cooling effect and thereby changes in climate. This study shows that the higher DE in the medium LWC regime offsets the AIE by 30%. [***Anil Kumar V., Pandithurai G., Leena P.P., Dani K.K., Murugavel P., Sonbawne S.M., Patil R.D., Maheskumar R.S.,*** *Investigation of aerosol indirect effects on monsoon clouds using ground-based measurements over a high-altitude site in Western Ghats,* ***Atmospheric Chemistry and Physics****, 16, July 2016, 8423-8430, doi:10.5194/acp-16-8423-2016*]

Raindrop size distribution of different cloud types over the Western Ghats

Investigating the raindrop size distributions (DSDs) for different cloud types is essential for the rain characterisation and understanding different microphysical processes within the cloud system. In this study, the simultaneous measurements from the Micro-Rain Radar (MRR) and Joss-Waldvogel Disdrometer (JWD) were used to investigate the DSDs of different precipitation categories during the Indian Summer Monsoon (ISM) season (June-September) for the period 2012-15. Both the instruments were deployed at Mahabaleshwar in the Western Ghats. From the MRR reflectivity factor and fall-velocity profiles, the observed precipitation systems are classified into four categories: shallow-convective, convective, stratiform and mixed convective-stratiform. In terms of rain occurrence frequency, it is found that rain over Mahabaleshwar is mostly contributed by the shallow-convective (~89%) system while the stratiform system contributes about 9% and the convective and the mixed convective-stratiform systems contribute <2%. For different precipitation categories, the rain microphysical parameters such as median volume diameter, rain liquid water content and normalised intercept parameter are estimated using the moment method (second, third and fourth moment) of the observed DSDs. The reflectivity-rainfall (Z-R) relation of the form $Z = aR^b$ is estimated for each precipitation category. Study of systematic and comprehensive classification of precipitation types in terms of their rain microphysical parameters and Z-R relationships over a region is important as it would improve the understanding on rain microphysics and rainfall estimation from active and passive remote sensing devices. [***Das S.K., Konwar M., Chakravarty K.,*** *and* ***Deshpande S.M.,*** *Raindrop size distribution of different cloud types over the Western Ghats using simultaneous measurements from Micro-Rain Radar and disdrometer,* ***Atmospheric Research****, Online, November 2016, doi:10.1016/j.atmosres.2016.11.003*]

Role of organic aerosols in CCN activation and closure

A cloud condensation nuclei (CCN) closure study was performed to exemplify the effect of aerosol chemical composition on the CCN activity of aerosols at Mahabaleshwar, a high altitude background site in the Western Ghats in India. For this study, collocated aerosol, CCN, Elemental Carbon (EC), Organic Carbon (OC) and sub-micron aerosol chemical speciation for the period 03-19 June 2015 were used. CCN concentrations were predicted using Köhler theory on the basis of measured aerosol particle number size distribution, size independent chemical composition and calculated

hygroscopicity. The CCN closure study was evaluated for three scenarios, B-I (all soluble inorganics), B-IO (all soluble organics and inorganics) and B-IOOA (all soluble inorganic and soluble oxygenated organic aerosol, OOA). OOA component was derived from the positive matrix factorisation analysis of organic aerosol mass spectra. Considering the bulk composition as internal mixture, CCN closure study was underestimated by 16-39% for B-I and overestimated by 47-62% for B-IO. The CCN closure result was appreciably improved for B-IOOA where the knowledge of OOA fraction was introduced and uncertainty reduced to within 8-10%. [***Singla V., Mukherjee S., Safai P.D., Meena G.S., Dani K.K., Pandithurai G.***, *Role of organic aerosols in CCN activation and closure over a rural background site in Western Ghats, India,* ***Atmospheric Environment****, Online, March 2017, doi:10.1016/j.atmosenv.2017.03.037*]

Sub-Project

Radar and Satellite Meteorology

Developmental Activities

Radars observational campaign using collocated X- and Ka- band radars was conducted during 07 June – 15 October 2016 at Mandhardev. GPS-RS/RW flights were also conducted during 08-10 July 2016 from the radar site at Mandardev to capture two diurnal cycles under the challenging local wind conditions. Microrain radar is installed and tested at Mandhardev in collocation with other radars for its operation in the forthcoming monsoon campaign.

Basic Research

Cloud vertical properties over the Northern Hemisphere monsoon regions

The combined CloudSat-CALIPSO data products were used for the summer season (June-August) of 2006-10 to present the statistics of cloud macrophysical (such as cloud occurrence, frequency, distribution of cloud top and base heights, geometrical thickness and cloud types base on occurrence height), and microphysical (such as ice water content, ice water path, and ice effective radius) properties of the Northern Hemisphere (NH) monsoon region. The monsoon regions considered in this work are the North American (NAM), North African (NAF), Indian (IND), East Asian (EAS), and Western North Pacific (WNP). The total cloud fraction over IND (mostly multiple-layered cloud) appeared to be more frequent as compared to other monsoon regions. Three distinctive modes of cloud top height distribution are observed over all the monsoon regions. The high-level cloud fraction is comparatively high over WNP and IND. The ice water content and ice water path over the Indian region showed maxima compared to the other monsoon regions. It is found that ice water content has little variations over NAM, NAF, IND, and WNP as compared to their macro-physical properties, giving an impression that the regional differences in dynamical and thermodynamical properties primarily cause changes in cloud frequency or coverage and are only secondary in cloud ice properties. The background atmospheric dynamics using wind and relative humidity from the ERA-Interim reanalysis data was also investigated which helped in understanding the variability of cloud properties over different monsoon regions. [***Das S.K.**, Golhait R. and Uma K.N., Clouds vertical properties over the Northern Hemisphere monsoon regions from CloudSat-CALIPSO measurements, **Atmospheric Research**, 183, January 2017, 73-83, doi:10.1016/j.atmosres.2016.08.011*]

Summer monsoon rainfall variability over North East regions of India and its association with Eurasian snow, Atlantic Sea surface temperature and Arctic Oscillation

An observational study during the 29-year period from 1979 to 2007 evaluates the potential role of Eurasian snow in modulating the North East Indian Summer Monsoon Rainfall with a lead time of almost six months. This link is manifested by the changes in high-latitude atmospheric winter snow variability over Eurasia associated with Arctic Oscillation (AO). Excessive winter time Eurasian snow leads to an anomalous cooling of the overlying atmosphere and is associated with the negative mode of AO, inducing a meridional wave-train descending over the tropical north Atlantic and is associated with cooling of this region. Once the cold anomalies are established over the tropical Atlantic, it persists up to the following summer leading to an anomalous zonal wave-train further inducing a descending branch over NE-India resulting in weak summer monsoon rainfall. [***Prabhu A.**, Oh J., Kim I-w, **Kripalani R.H.**, Mitra A.K., **Pandithurai G.**, Summer monsoon rainfall variability over North East regions of India and its association with Eurasian snow, Atlantic Sea Surface temperature and Arctic Oscillation, **Climate Dynamics**, online, November 2016, doi:10.1007/s00382-016-3445-4*]

Sub-Project

Thunderstorm Dynamics

Basic Research

Role of aerosols in formation of inverted polarity thunderstorms

The electric field and Maxwell current density measured below 32 small isolated thunderstorms over Pune during the period 1996-2008 are analysed as a function of dew-point depression (DPD), aerosol optical depth (AOD) measured on that day and peak flash rate (**Fig. 3**). It is seen that on days when inverted polarity thunderstorms were observed, AOD remained above 0.45. The average AOD values on inverted polarity thunderstorm days were 0.57 whereas on normal days, the average AOD values were 0.38. Further, no relation between peak flash rate and occurrence of inverted thunderstorms or dew point depressions and occurrence of inverted polarity thunderstorms was observed. These observations led us to propose that high aerosol concentration with high ice nuclei fraction is one of the dominant factors responsible for the occurrence of inverted polarity charge structure in ordinary (non-severe) thunderstorms. However, as there are no records on ice-nuclei concentration available and in view of the high DPD on some of the days when inverted polarity thunderstorms occurred, one cannot entirely rule out the role of high DPD in producing inverted polarity charge structure in thunderclouds. [***Pawar S.D., Gopalakrishnan V., Murugavel P.,*** *Veremey N.E., Sinkevich A.A., Possible role of aerosols in the charge structure of isolated thunderstorms,* ***Atmospheric Research****, Online, September 2016, doi:10.1016/j.atmosres.2016.09.016*]

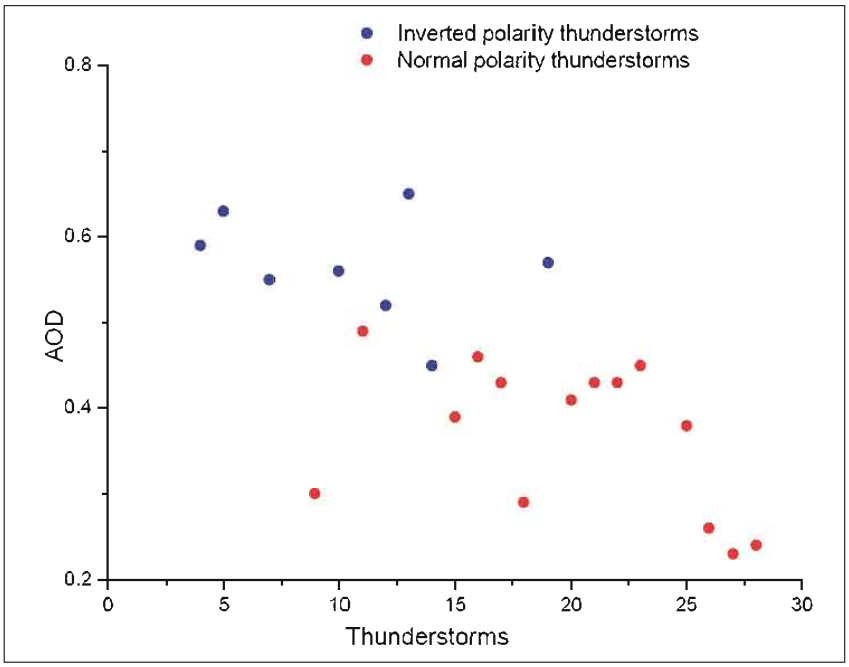


Fig. 3: *Daily values of AOD as observed from MODIS on thunderstorm days over Pune (India).*

Association of lightning with CAPE and AOD

Association of lightning with long-term distribution of convective available potential energy (CAPE), convective rain, vegetation cover and aerosol optical depth (AOD) over India has been studied using satellite data. It is seen that lightning is positively correlated to CAPE, convective rain and AOD and negatively to vegetation cover. These correlations help in understanding the definite entity that is responsible for changing the lightning activity in different parts of India. It is shown that the upper tropospheric water vapour possesses a significant linkage with lightning occurrences associated with convective activities and strong updraft over India. Future projections through CMIP5-based CCSM4 and CESM1-CAM5 models have shown that enhancement of AOD, convective rain and specific humidity may result in regional changes in lightning activity over the Indian sub-continent (**Fig. 4**). [*Saha U.,* ***Singh D., Kamra A.K.,*** *Galanaki E., Maitra A., Singh R.P., Singh A.K., Chakraborty Swastika, Singh Rajesh, On the association of lightning activity and projected change in climate over the Indian sub-continent,* ***Atmospheric Research****, online, January 2017, doi:10.1016/j.atmosres.2016.09.001*]

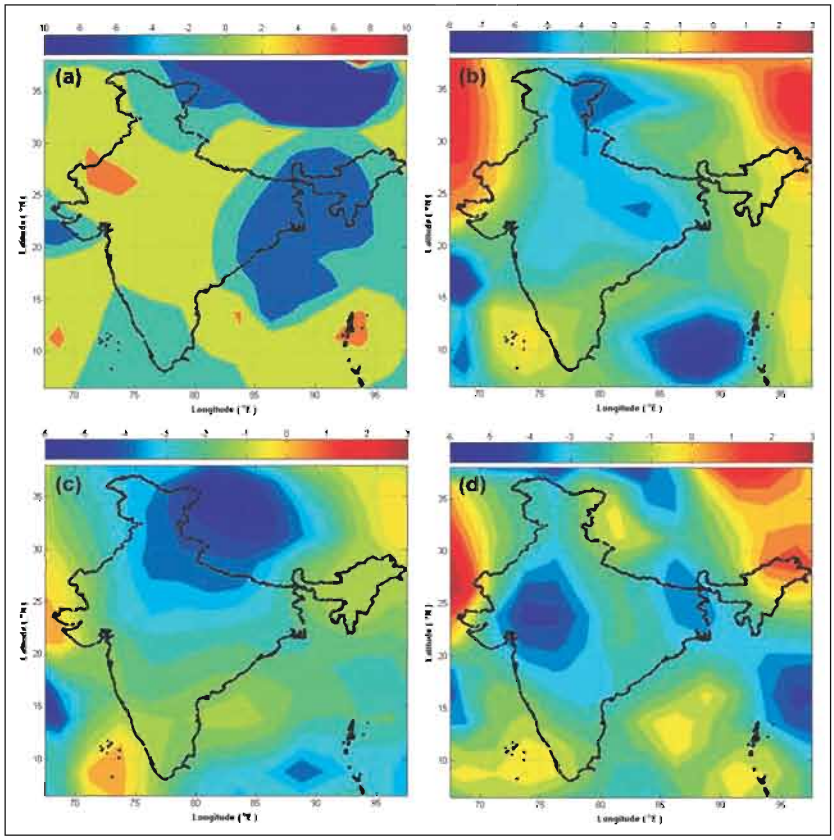


Fig. 4: Trend Maps of lightning flash rate (units in %) during (a) January-February, (b) March-May, (c) June-September and (d) October-December, for the period 2000-2014 over the Indian sub-continent.

Effect of horizontal electric field on deformation and breakup characteristics of waterdrops

The influence of strong horizontal electric field (E_H) on different stages of deformation and eventual breakup of large water drops of 6.6, 7.0, and 7.25 mm diameter has been observed in a vertical wind tunnel using high-speed photography. Dumbbell, filament, and bag modes of drop breakup are observed when E_H = 0. However, drops elongate in horizontal direction, mostly develop sharp curvature at their ends, eject a fine jet spray of tiny droplets, and ultimately break up into several droplets in E_H = 500 kVm^{-1}. Extreme elongation up to 29 mm is observed for a 7.0 mm diameter drop (**Fig. 5**). Results suggest that the effect of E_H in final oscillation before breakup overcomes the effect of hydrodynamic and aerodynamic forces in elongating the drop. Also, no breakup of bag type is observed in E_H = 500 kVm^{-1}. Moreover, the fragments formed after the drop breakup and tiny droplets ejected by their fragments carry electrical charges of polarity determined by the induced charge on the parent drop in E_H. The significance of the results is discussed in modifying the drop growth and the radar echo-precipitation relationships in thunderclouds. [***Bhalwankar R., Deshpande C.G., Kamra A.K.,*** *Breakup modes of the drops suspended in a vertical wind tunnel in presence of the horizontal electric field,* ***Journal of Geophysical Research: Atmospheres,*** *122, February 2017, 1838-1849, doi:10.1002/2016JD025805*]

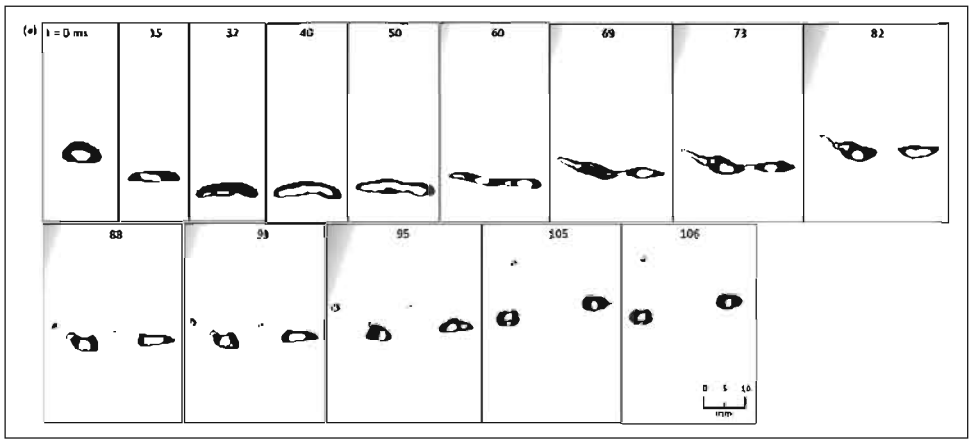


Fig. 5: Photographs illustrating the occurrence of extreme elongation followed by the breakup of a drop of 7.0 mm diameter in the presence of horizontal electric field of 500 kVm^{-1}. Time shown in each frame indicates the evolution of breakup in milliseconds.

Lightning characteristics over Indo-Gangetic Plains

Indicators for lightning activity over Indo-Gangetic Plains (IGP) are investigated by analysing the data of surface heat flux, Bowen ratio (ratio of sensible to latent heats) and cloud base height. Lightning activity varies with the surface heat flux, Bowen ratio and cloud base height over India. Total heat flux (sensible + latent) and lightning flash counts show a strong correlation coefficient of 0.75 for Indian land and 0.73 for IGP relative to that of Bowen ratio with lightning flash count (0.63 for Indian land and 0.19 for IGP). Hence, the total heat flux represents the best parameter for describing lightning activity over IGP and Indian land. Bowen ratio ≥ 1 in pre-monsoon increases lightning flash counts over IGP and Indian land. Cloudbase height (a measure of moisture) and lightning flash counts show values in the order as Indian land > Indian seas > IGP. Geographic asymmetry of Indian land, IGP and Indian seas drives the continental and sea surface-atmosphere interactive processes that corroborate: (1) asymmetric synoptic scale delivery of moisture to Indian land and IGP from Indian seas revises the Bowen ratio, cloud base height and lightning activity, (2) increase in lightning activity with the total heat flux over Indian land and (3) enhance the lightning activity with the cloud base height/liquid condensation level. [***Chate D.M., Tinmaker M.I.R., Aslam M.Y., Ghude S.D.,*** *Climate indicators for lightning over sea, sea-land mixed and land-only surfaces in India,* ***International Journal of Climatology****, 37, March 2017, 1672-1679, doi:10.1002/joc.4802*]

Project

National Facility for Airborne Research (NFAR) including UAV

Project Director: Dr. C.G. Deshpande

Objectives

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

Overview

The Ministry of Earth Sciences (MoES) is determined to establish the National Facility for Airborne Research (NFAR) to facilitate the atmospheric research community for conducting airborne research on atmospheric processes. A need for long term airborne measurements in respect of aerosol sampling, measurement of cloud properties, cloud physics, Convective Tropical Convergence Zone (CTCZ), atmospheric chemistry, etc. is strongly felt by the research community in this country to address all relevant scientific issues for improving the treatment of rain making processes in the monsoon environment in particular and other cloud-aerosol-radiative feedback mechanisms associated with the climate variability and change over India. Having an airborne platform is a need of time to meet the challenges of the expanding subject and to be at par with other atmospheric research communities in the world.

A medium sized twin engine turboprop pressurised aircraft is being procured with service ceiling limit of 30,000 feet and minimum lowest operating altitude of 500-1,000 feet over sea, operating range of 2,500 km and endurance of about five hours. The aircraft will carry scientific payload of 900-1,200 kg with four scientists.

The research aircraft is planned to be positioned at Aurangabad and will be managed by IITM, Pune. This aircraft can be used for all airborne atmospheric research in the country. Depending on the research objectives, the aircraft operations will be conducted from different bases in the country. The facilities for maintenance and repair of aircraft, development, installation, calibration and modifications of scientific instruments onboard will be available at the hangar to be located at Aurangabad airport.

The airborne platform is projected as national facility, which will cater the scientific need of several national research and educational institutions in the country. Following research activities/problems will be addressed at local/regional/national level:

- Cloud Aerosol Interaction studies
- Direct-Indirect aerosol effect
- Air Pollution studies - Mega cities/Urban
- Radiation studies Coastal pollution studies
- Urban visibility studies Flood/Forestry/City modeling
- Cloud microphysics and precipitation process studies

Utilisation of Unmanned Aerial Vehicle (UAV) is also being explored to understand the atmospheric processes in the lower atmosphere. The process of procurement of a single UAV instrumented with aerosol, radiation and meteorological parameters is initiated. In future, it is also planned to equip different UAVs with different sets of instruments for aerosols, radiation, clouds, fluxes and trace gases. This will be an institutional activity under NFAR.

Project

Metropolitan Air Quality and Weather Services

Project Director: Dr. Gufran Beig
Deputy Project Director: Dr. D.M. Chate

Objectives

- Development of an early warning system to predict air quality and weather for Indian metropolitan cities called SAFAR (System of Air quality and Weather Forecasting And Research). To investigate the role of air pollution and its impact on human health and crop yield.
- Development of chemical-transport modelling capability to understand the linkages of atmospheric chemistry with weather and climate.
- Development of improved high-resolution gridded national emission inventories.
- Establishment of MAPAN (Modeling Air Pollution And Networking) – a national monitoring network for atmospheric chemical parameters.
- Investigating the role of carbonaceous species (black carbon, organic carbon, brown carbon, etc.).

Basic Research

The Big smog: Delhi's worst air quality crisis

Indian capital New Delhi hit a 'record-high' air pollution of the century during 30 October to 07 November 2016. The smog engulfed the city for more than a week and levels of toxic fine particulate matter PM2.5 (≤2.5 micron in diameter) rose to unprecedented level (10-13 times higher than Indian National Standards, NAAQS of 60 $\mu g/m^3$). The System of Air quality and weather Forecasting and Research (SAFAR), consisting of dense network of 10 automatic online air quality and weather monitoring stations across Delhi coupled with online chemistry-transport (CT) model, tracked the air quality of Delhi on a day-to-day basis and unfolded scientific processes responsible for such an extreme event. Onset of winter in the last week of October in Delhi usually keeps the PM2.5 level about 2-3 times higher than NAAQS. However, the firecracker festival Diwali on 30 October followed by the unusual upper wind pattern originating from the bio-mass burning regions of Northern India, combined with cool and calm wind (near zero ventilation coefficient) increased PM2.5 levels to unprecedented high (10-13 times than NAAQS) for more than a week, triggering emergency conditions. Here, the share of bio-mass transport emissions from stubble burning in PM2.5 is quantified by using interactive online chemical model which reveals that the contribution rose from ~1.8% on 01 November to 38.6% on 02 November, with a peak of 68% on 06 November, before it started to retreat. While extreme weather and changing climate patterns taking heavier toll on the planet, emerging extreme pollution events are taking toll at regional scale thus threatening health and food security.

Quantifying the sectorial contribution of pollution transport from South Asia

Results on distribution of tropospheric ozone (O_3) and carbon monoxide (CO) and nitrogen dioxide (NO_2) over South Asia are presented with the Model for Ozone and Related chemical Tracers (MOZART-4) and Hemispheric Transport of Air Pollution version-2 (HTAP-v2) emission inventory. The model simulated O_3, CO and NO_2 are validated with ground-based, balloon-borne and satellite (MOPITT and OMI) observations. Model overestimates surface O_3 mixing ratios (range of mean bias about: 1-30 ppbv). Observed vertical profiles of ozone show a positive bias from the surface up to 600 hPa and a negative bias above 600 hPa. The seasonal variation of simulated CO mixing ratio is consistent with observations with a negative bias of about 50-200 ppb. Nevertheless, model simulations show a high bias of about 15-20 X 10^{17} molecules/cm^2 over South Asia when compared to satellite derived CO columns from the MOPITT instrument. Also, model overestimates OMI retrieved tropospheric column NO_2 abundance by about 100-250 X 10^{13} molecules/cm^2. A response to 20% reduction in all anthropogenic emissions over South Asia

shows a decrease in the annual mean O_3 mixing ratios by about 3-12 ppb, CO by about 10-80 ppb and NO_x by about 3-6 ppb at the surface level. During summer monsoon, O_3 mixing ratios at 200 hPa show a decrease of about 6-12 ppb over South Asia and about 1-4 ppb over the remote northern hemispheric western Pacific region (Fig. 1). [***Surendran D.E., Ghude S.D., Beig G., Jena C., Chate D.M.,*** *Quantifying the sectoral contribution of pollution transport from South Asia during summer and winter monsoon seasons in support of HTAP-2 experiment,* ***Atmospheric Environment****, 145, November 2016, 60-71, doi:10.1016/j.atmosenv.2016.09.011*]

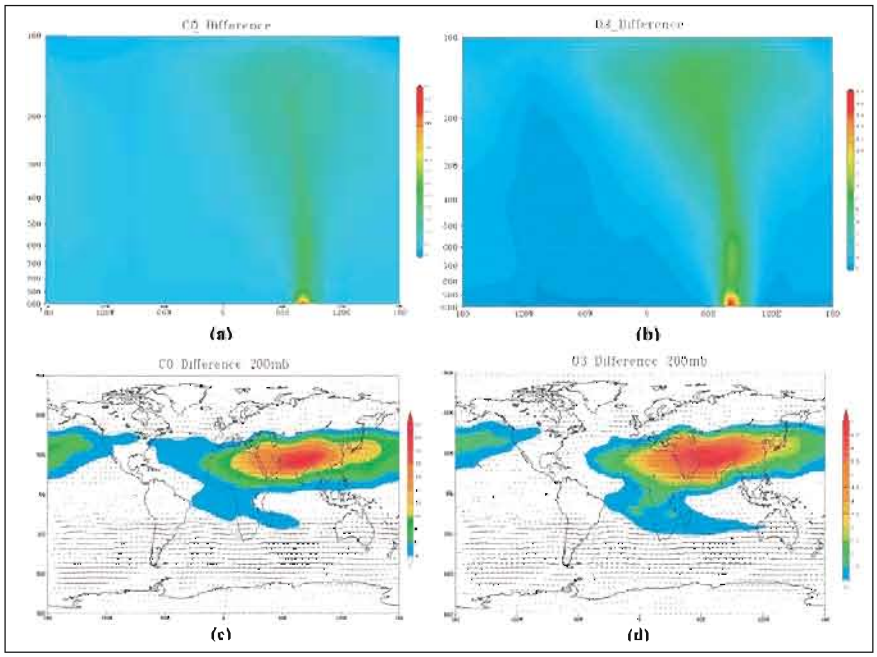


Fig. 1: *Pressure longitude cross-section (zonal averaged over the 5° – 35° N) of change in (a) CO mixing ratio (ppbv) and (b) O_3 mixing ratio (ppbv) during summer season, and horizontal structure of change in (c) CO mixing ratios and (d) O_3 mixing ratios at 200mb during summer season due to 20% reduction in all anthropogenic emissions over South Asia.*

Impact of ozone and its precursors on agriculture

Impact of anthropogenic NOx mitigation action shows relatively 93% (98% for Rice and 90% for wheat) decrease in O_3-induced crop yield losses compared to baseline scenario. On the other hand, impact of anthropogenic VOCs emissions mitigation action results in small changes of about 24% (97% for Rice and 89% for wheat) decrease in O_3 induced crop yield losses with respect to baseline scenario. Widespread ozone pollution under present emission scenario has considerable impact on productivity of crops important for food security under the provision of the recently implemented National Food Security Bill (2013) by the Government of India. The present-day ozone-induced damage to wheat (3.5± 0.8 Mt) and rice (2.1 ± 0.8 Mt) is sufficient to feed about 35% (94 million poor people) of 270 million below poverty line population in India. Response of NOx and VOC's mitigation action are also quantified on the basis of ground level O_3 simulations with individual reduction in anthropogenic NOx and VOC's emissions over the Indian domain. The combined effects of ozone pollution and climate change on agricultural crop yields can enrich the scientific evidence for emission mitigation measures to be implemented for ozone-induced wheat and rice damage in India. Results clearly deliver the societal and economic benefits, including cost savings in agricultural crop yields which directly or indirectly get affected by air quality and weather and also, it serves as the scientific framework for food policy analysis for air pollution control and prevention in India. [***Ghude S.D., Jena C.K., Kumar R., Kulkarni S.H., Chate D.M.,*** *Impact of emission mitigation on ozone-induced wheat and rice damage in India,* ***Current Science****, 110, April 2016, 1452-1458, doi:10.18520/cs/v110/i8/1452-1458*]

Absorbing aerosols, possible implication to crop yield in IGB region

The current study compares black carbon radiative effects at the densely populated plain station, Varanasi and the lesser populated plateau station Ranchi which has large forest cover but with numerous open coal mines. While the measured average black carbon mass density (BC) reduces from February to March in Ranchi following an increase in convective mixing, it is observed to increase by 150% from February to March in Varanasi, as transport from northeast forest fires increases. It is observed that absorption due to black carbon of non-fossil fuel origin is prevalent throughout the day in Varanasi, while this contribution is most significant during post sunset hours in Ranchi. Radiative forcing, estimated hourly using chemical model (to derive BC-aod) and radiative transfer model, indicates

that at least 5% of the incoming radiation is always cutoff during any time of the day in Varanasi while this is about 4% in Ranchi. BC effectively causes an apparent delayed sunrise by reducing the incoming radiation on the plains of Indo Gangetic Basin (IGB) by up to 25% at the daybreak. An estimate of crop loss due to cut off in radiation, using an empirical formula for crop yield as a function of radiation, indicates a possible loss of more than a quintal per hectare considering anthesis (February) and maturity (March) periods for the winter wheat in both the IGB stations with consistently higher losses in Varanasi. [***Latha R., Murthy B.S.**, Lipi K., Srivastava Manoj K., Kumar Manoj, Absorbing aerosols, possible implication to crop yield - a comparison between IGB stations, **Aerosol and Air Quality Research**, 17, March 2017, 693-705, doi:10.4209/aaqr.2016.02.0554*]

Transport, Elevated CO levels and Monsoon over Delhi

Carbon monoxide (CO) concentration over Delhi during the unusual onset of monsoon 2013 was dramatically elevated and crossed the permissible limit (1.7 ppmv) for about a month long-period as against normal onset of monsoon where CO concentration reduces. In this study, concentration of CO in 2013 with normal monsoon year 2012 is compared. The study provides a hypothesis to interpret this high concentration CO episode and validate using interactive high resolution WRF-Chem model. The model results indicate that the high CO episode was caused by an unusually active Bay of Bengal branch of monsoon which bounces off from the east and transports CO rich air from the eastern part of the Indo-Gangetic Plains to Delhi (**Fig. 2**). [***Srinivas R., Beig G.**, Peshin S.K., Role of transport in elevated CO levels over Delhi during onset phase of monsoon, **Atmospheric Environment**, 140, September 2016, 234-241, doi:10.1016/j.atmosenv.2016.06.003*

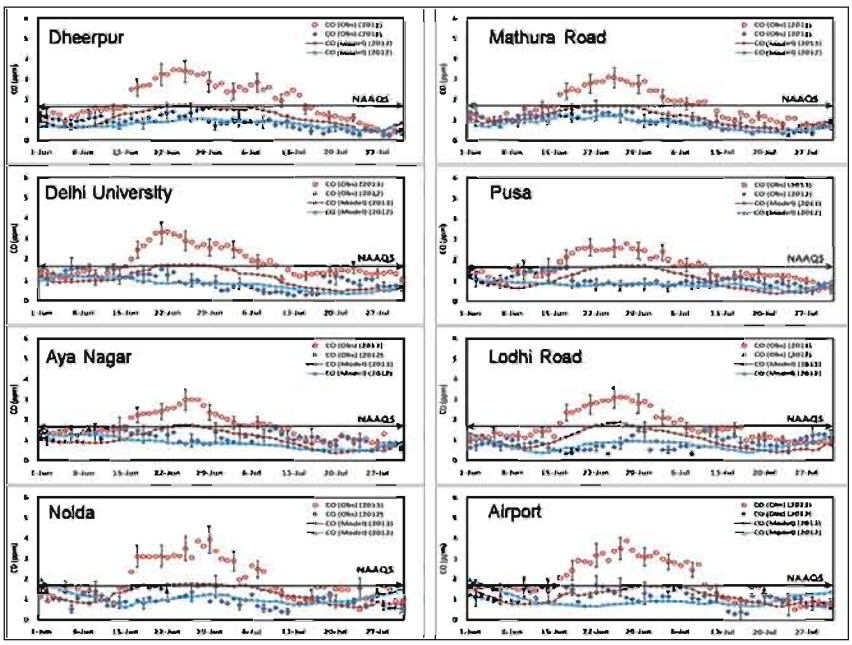


***Fig. 2:** Distribution of CO volume mixing ratio (8 h average) as observed during the onset of monsoon period in 2012 and 2013 at various locations in Delhi. The model simulated results for scenario C where impact of only emissions (without long range transport) is shown.*

Developmental Activities

Development of high resolution emission inventory for Ahmedabad

As part of SAFAR-Ahmedabad, Emission Inventory Campaign was organised during May to July 2016 to generate a unique region specific primary data on the emissions of major air pollution sources classified in five major sectors *viz*. transport, industrial, residential cooking, windblown dust and bio-mass burning in Ahmedabad and Gandhinagar city area. In addition, available secondary data have also been collected and whenever required, updated and validated.

During the Emission Inventory Campaign, the required data on fuel consumption pattern in different sectors, hours of cooking, vehicle kilometer travelled, vehicular density on different major and minor roads were collected with the involvement of around 150-200 students. To train the students on data collection methodology, a one-day training-cum-orientation workshop was organised at St. Xavier's College, Ahmedabad. Emission inventory campaign was successfully completed with more than 100,000 samples collected; the detailed analysis for quality control and quality check for the same has been accomplished. The GIS based statistical model has been applied using above-mentioned data bank to develop the gridded emission inventory, which provides an important input to air quality forecasting model for Ahmedabad.

Setting up SAFAR-Ahmedabad high resolution AQ forecasting model

Atmospheric chemistry transport model is used for air quality

forecasting. To forecast the air quality of various pollutants along with weather parameters for Ahmedabad and surrounding regions, WRF-Chem model with four-nested domain has been set-up. The domain starts from near global to the local city level. The inner most domain covering Ahmedabad and Gandhinagar cities and the surrounding areas has a resolution of 1.67 km x 1.67 km. The other three domains have resolution of 45 km, 15 km and 5 km. All these four domains run interactively and feedback of meteorology to chemistry and vice-versa has been accounted. This model requires several key inputs for accurate forecasting. Major among them are: emission inventory, weather parameter, topographical data, land use/land cover data, initial and lateral boundary conditions, etc. The initial and lateral boundary conditions for the outermost domain in meteorological model have been taken either from NCEP reanalysis or from internally generated GFS of NCMRWF, Noida whereas for the chemical forecast model, these have been taken from MACC (Monitoring Atmospheric Composition and Climate), a project of European union under MoU between IITM and EU project partners. All surface libraries have been prepared. Dummy runs are being made and it is kept ready for final runs.

Air quality and weather monitoring stations in Ahmedabad

Under the project SAFAR-Ahmedabad, a network of 10 Air Quality Monitoring Stations (AQMS) is established across Ahmedabad Region (**Table 1**). AQMS covers residential, industrial, commercial, tourist place, urban complex, traffic junction, slum and background environments. Parameters monitored round the clock are: PM_{10}, $PM_{2.5}$, PM_{1}, Ozone, CO, NOx ($NO+NO_2$), BTX, SO_2, mercury and temperature, rainfall, humidity, wind speed, wind direction and UV radiation dose. Considering the benefits of the Metropolitan Air Quality Information Services to citizens of Ahmedabad, AMC has agreed to be a potential and active partner in providing the required space and electricity for installation of 10 AQMS, 10 AWS and 12 DDS across Ahmedabad city area. To ensure wide spread of stations in different parts of Ahmedabad and Gandhinagar city area, collaboration has also been made with educational and state agencies.

To establish a dense network of AQMS across Ahmedabad Metropolitan Region, extensive field survey was done during 2015-16. Ten sites have been selected which are spread across Ahmedabad and Gandhinagar city area (**Fig. 3**). These strategically selected locations represent various micro-environments of the region including urban, downtown area, industrial area, background/clean area, residential area, etc. The list of selected sites is given in **Table 1**. The basic foundation work is done at all the ten sites.]

Table 1: List of selected locations for installation of AQMS in Ahmedabad Region.

S. No.	Area	Location
1	Navrangpura	Sardar Patel Stadium, AMC
2	Pirana	Gyaspur Forestry Plantation Nursery, AMC
3	Rakhial	Shraminkranti Garden, AMC
4	Raikhad	Victoria Garden, AMC
5	Chandlodiya	Kali cultural centre, AMC
6	Bopal	SAC, ISRO
7	Satellite	SAC, ISRO
8	Ahmedabad Airport	India Meteorological Department (IMD)-Ahmedabad
9	Gandhinagar	Indian Institute of Public Health, Gandhinagar
10	GIFT City	Gujarat International Finance Tec-City

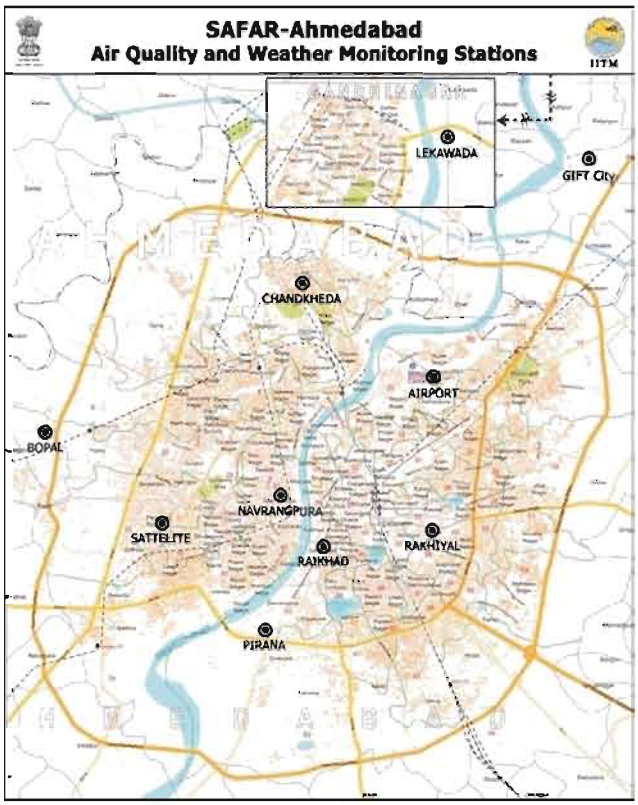


Fig. 3: Map of selected locations for installation of AQMS in Ahmedabad Region.

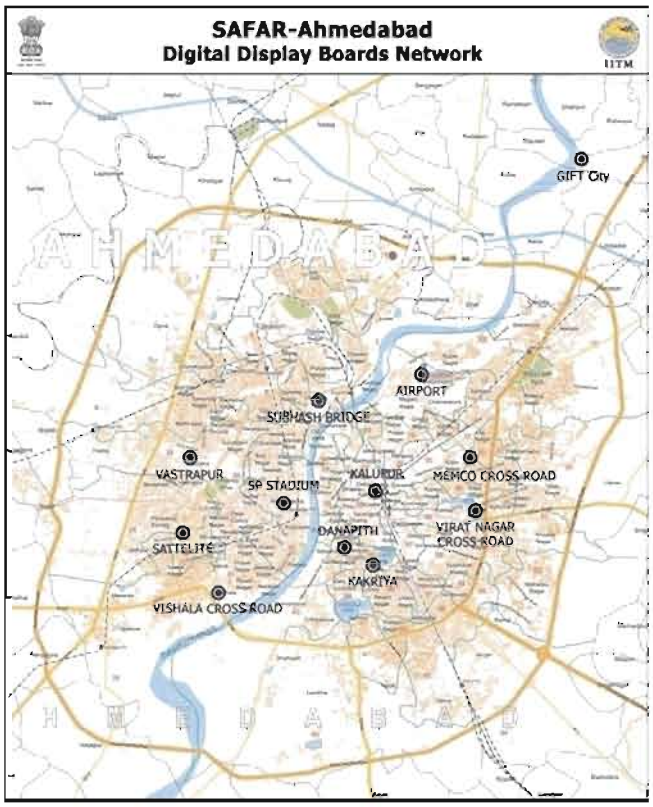


Fig. 4: Map of selected locations for installation of DDS in Ahmedabad Region.

Establishment of digital display system (DDS) network: To display the information of Air Quality Now, Air Quality Tomorrow, Weather Now, Weather Tomorrow and UV Index, 12 sites have been selected, after extensive field survey, for installation of Digital Display System **(Fig. 4; Table 2)**.

Table 2: List of selected locations for installation of DDS in Ahmedabad Region.

S. No.	Area	S. No.	Area
1	AMC Main Building, Danapith	7	Virat Nagar Cross Road
2	SP Stadium Six Road	8	Kalupur Railway Station
3	Vastrapur Lake	9	RTO Circle, Subhash Bridge
4	Kakriya Lake	10	Ahmedabad Airport
5	Memco Cross Road	11	SAC, ISRO, Satellite
6	Vishala Cross Road	12	GIFT City

Connecting to the Society: Dissemination of information for the benefit of society is the backbone of this project. It involves translating data to information *i.e.,* Air Quality Index (AQI), UV Index (UVI) and associated health and skin advisories. It also ensures wide dissemination of this information in an easy to understand format. SAFAR-Ahmedabad system products include Air Quality-Now, Air Quality-Tomorrow, Weather-Now, Weather-Tomorrow, UV Index-Skin Advisory, AQI-Health Advisory and City Pollution Maps. Before putting information in public domain, major focus has been given to the good data quality. For various stakeholders, following dissemination tools are available for easy access of data/information:

1. SAFAR-AIR Mobile App (can be downloaded from Play Store and Apple Store)
2. SAFAR-INDIA website: http://safar.tropmet.res.in/
3. Digital Display Board System (DDS)
4. SAFAR toll free No., an IVRS Service: 1800 180 1717
5. SMS and E-mail Alert Services (safar@tropmet.res.in)

In India, the major beneficiaries of the projects are disaster management units, environment departments of corporations, health sector, agricultural sector, aviation sector, urban planning/ town planning, etc. The system products are useful for protecting human health and planning of agricultural crop yield and can be used by policy makers to implement short term and long-term mitigation strategies. It is creating awareness on air quality and its impact on the human health and environment among the public.

Memoranda of Understanding (MoU): MoUs have been signed with the Space Application Centre (SAC), Ahmedabad Municipal Corporation (AMC) and Indian Institute of Public Health (IIPHG), Gandhinagar for scientific cooperation for SAFAR-Ahmadabad. Installation of air quality monitoring stations (AQMS), automatic weather stations (AWS) and public display LED boards at suitable locations in Ahmedabad metropolitan area (AMR) has been accomplished under the above agreement.

India-UK Water Centre

The Ministry of Earth Sciences (MoES), Govt. of India and the National Environment Research Council (NERC), UK have established a virtual India-UK Water Centre (IUKWC) in 2016. This virtual joint centre aims to promote cooperation and collaboration between India and UK on water security research through long-term partnerships and dialogue among water researchers, water policy-makers and water businesses in the two countries.

On behalf of MoES-NERC, the Centre is hosted jointly by the Indian Institute of Tropical Meteorology (IITM) in India and the Centre for Ecology & Hydrology (CEH) in the UK. From the Indian side, the Centre is coordinated by Dr. A.K. Sahai (IITM) and on the UK side, by Dr. H. Dixon (CEH). The centre coordinators are further supported by a team of experienced project managers, stakeholder engagement experts, administrators and web developers.

The IUKWC undertakes various activities to facilitate partnerships between scientists and other stakeholders in the water security sector of the two countries. These activities include: Science Workshops, User Interaction Initiatives, Pump Priming Projects and Researcher Exchanges. The Centre also maintains an **Open Network of India-UK Water Scientists**. Launched in September 2016, the network is an online database of individuals and institutions keen on water security in India and the UK. It has over 350 registered members. Efforts are being made to engage the wider community of stakeholders.

The IUKWC organises **Science Workshops** are on priority areas of water security research for knowledge sharing, identifying future requirements/ideas for joint research, and training purposes. These workshops are commissioned to be held either in the UK or India through open calls inviting proposals from the community. The Centre organised its first workshop on 'Developing hydro-climatic services for water security' during 29 November – 01 December 2016 in Pune. A report on the key findings from the workshop is prepared and made available on the Centre's website. Arrangements are being made for organising another science workshop on 'Enhancing Freshwater Monitoring through Earth Observation' during 19-21 June 2017 in Stirling, UK.

The IUKWC's **User Engagement Initiatives** focus on translating the results of India-UK science into policy/operational practice. These initiatives are designed to bring together different stakeholders to take the India-UK water security science to users, and/or to collect inputs on stakeholders' needs for future research and innovation. Based on the feedback received from its network members through an online survey, IUKWC is designing its first User Engagement Initiative.

Pump Priming Projects are typically small projects of short duration (upto three months) on specific topics and are designed to take forward new ideas or provide preparatory groundwork for future IUKWC activities. The Centre funds a small number of such projects to help develop early ideas into future collaborations. Based on the ideas that emerged during the first science workshop in Pune, the Centre has funded two Pump Priming Projects: 1) Ways of optimising new hydro-climatic services for stakeholders, and 2) Current opportunities and challenges in developing hydro-climatic services in the Himalayas.

Researcher Exchanges is another scheme offered by the Centre providing opportunities to Indian (UK) experts to visit the UK (India) for exploring research ideas, building capacity or training in research methods, or exchanging latest findings. The Centre aims to hold at least one exchange per year in both the countries. The exchanges are offered under Senior and Junior categories. Seeing the huge response to the first call for application under these schemes, the UKWC Management Board has decided to fund five exchanges, instead of the originally envisaged two, which are expected to take place in May-June 2017.

More details about the activities of the Centre are available at: www.iukwc.org. The Centre also engages actively with different stakeholders through online communication platforms like social media (LinkedIn, Facebook and Twitter **@IndiaUKWater).**

Winter Fog Experiment 2016-17

The winter fog experiment (WIFEX) is a multi-institutional initiative of the Ministry of Earth Sciences (MoES) to understand different physical, dynamical and chemical features of fog and the factors responsible for its genesis, intensity and duration. The observational campaign is being led by IITM in collaboration with India Meteorological Department (IMD), New Delhi and with full cooperation and support from Airport Authority of India (AAI), GMR Group, Indira Gandhi International Airport (IGIA), National Centre for Medium Range Weather Forecast (NCMRWF) and Indian Institute of Science Education and Research (IISER), Mohali.

WIFEX tries to explore the characteristics and variability of fog events and associated dynamics, thermodynamics and fog microphysics, to achieve better understanding of fog life cycle and ultimately, to improve capability in fog prediction on various temporal and spatial scales. Such capability can help reduce the adverse impact of fog on aviation, transportation and economy, and loss of human life due to accidents.

Extensive sets of comprehensive ground-based measurements include micro meteorological, radiation, fog droplet and aerosol microphysics, aerosol optical properties, and aerosol and fog water chemistry to describe the complete environmental conditions in which fog develops. These measurements form the basis for understanding some of the key questions on fog formation and dissipation and for tuning the fog forecast model. It is planned to introduce this model for operational forecasts of fog during the winter season of 2017-18.

During the winter of 2016-17, WIFEX was conducted at Indira Gandhi International Airport (IGIA), New Delhi and Hissar Agricultural University (HAU), Haryana. At IGIA, the campaign was conducted during 28 November 2016 to 15 February 2017 with the recording of 26 fog (15 dense fog) events. At HAU, a 10 m meteorological tower was erected which started taking some observations from 02 December 2016. The main objective of the campaign was to study the characteristics and variability of fog events over polluted places like Delhi and less polluted places like Hissar, the associated dynamics and thermodynamics and cloud microphysics.

IITM is also issuing experimental fog forecast using IITM-WRF model with initial and boundary conditions from IITM 12.5 km GEFS and NCMRWF NCUM global forecast. Preliminary analysis of these experimental fog forecasts reveals that GEFS with 00 UTC initial conditions shows relatively good skill compared to NCUM in capturing fog events in terms of liquid water content. On the other hand, NCUM has more false alarm, but is good in simulating spatial distribution of fog over the IGP region as compared to GEFS.

The campaign is coordinated by Dr. Sachin D. Ghude from IITM and Dr. R. Jenamani from IMD. From IITM, different research groups including Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX), High Altitude Cloud Physics Laboratory (HACPL), Metropolitan Air Quality and Weather Services (MAQWS) and IITM New Delhi Branch Office participated in the campaign through personal involvement or by deploying their scientific equipments. Different equipments and the instrumented tower were installed at IGI Airport in New Delhi and Hissar Agricultural University, Haryana for the campaign. The majority of instruments installed during the campaign were from the CAIPEEX group at IITM: microwave radiometer, wind profiler, and tower instruments such as all weather sensors, eddy covariance sensors, net radiometers, soil temperature and moisture sensors, aethalometer, fog collector, cloud droplet probe with an aspirator, condensation particle counter and photo acoustic extinctiometer. Filter samples were collected for chemical and physical analysis.

Basic Research

Winter fog experiment over the Indo-Gangetic plains of India

The objectives of the Winter Fog Experiment (WIFEX) over the Indo-Gangetic Plains of India are to develop better now-casting and forecasting of winter fog on various time and spatial scales. Maximum fog

occurrence over northwest India is about 48 days (visibility <1000 m) per year, and it occurs mostly during December-February period. The physical and chemical characteristics of fog, meteorological factors responsible for its genesis, sustenance, intensity and dissipation are poorly understood. Improved understanding on the above aspects is required to develop reliable forecasting models and observational techniques for accurate prediction of fog events. Extensive sets of comprehensive ground based instrumentation were deployed at the Indira Gandhi International Airport, New Delhi. Major *in-situ* sensors were deployed to measure surface micro-meteorological conditions, radiation balance, turbulence, thermodynamical structure of the surface layer, fog droplet and aerosol microphysics, aerosol optical properties, and aerosol and fog water chemistry to describe the complete environmental conditions under which fog develops. In addition, Weather Forecasting Model coupled with chemistry is planned for fog prediction at a spatial resolution of 2 km. The present study provides an introductory overview of the winter fog field campaign with its unique instrumentation (**Fig. 1**). [***Ghude S.D. et.al., Winter fog experiment over the Indo-Gangetic plains of India, Current Science, 112, February 2017, 767-784***]

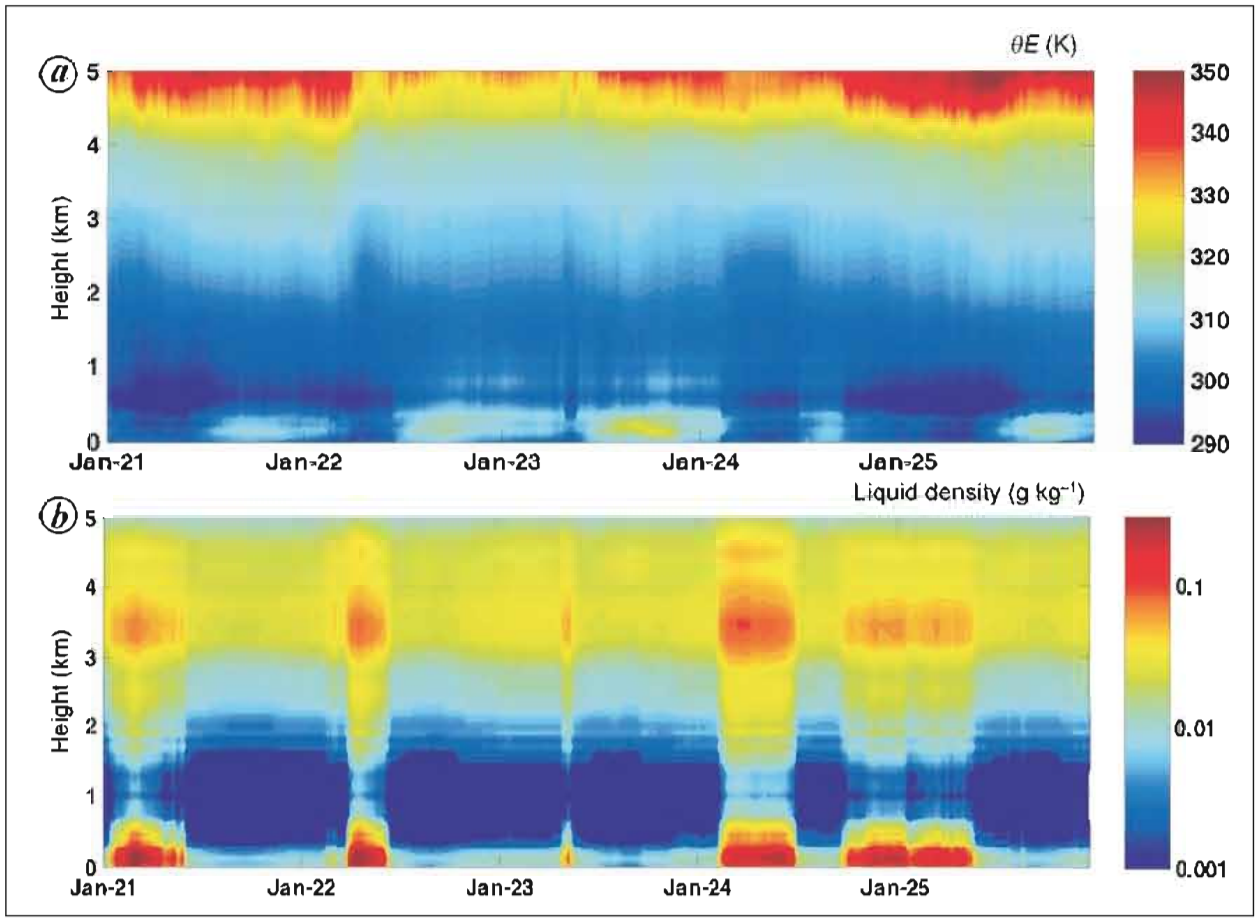


***Fig. 1:** Time height distribution of radiometer derived potential temperature and liquid water content during 21-25 January 2016, a dense fog event.*

International CLIVAR Monsoon Project Office (ICMPO)

Executive Director: Dr. Rokkam R. Rao

Overview

The International CLIVAR Project Office (ICPO) has established its International CLIVAR Monsoon Project Office (ICMPO) at IITM. The ICPO operates through its two offices and contract staff. One of its offices *i.e.*, ICMPO is hosted by IITM and the other is the International CLIVAR Global Project Office (ICGPO) hosted by First Institute of Oceanography (FIO), Qingdao, China. The responsibilities of the ICMPO include support to CLIVAR/GEWEX Monsoon Panel, CLIVAR/IOC-GOOS Indian Ocean Region Panel and co-ordinate and arrange teleconference meetings for the Working Groups of the Asian-Australian Monsoons, The African Monsoons and the American Monsoons. The ICMPO is also responsible for providing support to CLIVAR research focus on intra-seasonal, seasonal and inter-annual variability and predictability of monsoon systems, in close operation with the WCRP grand challenges on regional climate information and other activities. The activities of ICMPO also include production of CLIVAR Exchanges, development of Monsoon Web Portal, which catalogues current monsoon research initiatives, information and resources relevant for the international monsoon community. The establishment of ICMPO at IITM has been approved by the Union Cabinet on 12 August 2015.

Major Activities

CLIVAR Exchanges: During the period, ICMPO published and distributed three special issues of the CLIVAR Exchanges newsletter. These special issues are:

- CLIVAR Exchanges No. 69 (Kuroshio Current and Extension System).
- CLIVAR Exchanges No. 70 (CLIVAR's 20th Anniversary Publication).
- CLIVAR Exchanges No. 71 (CLIVAR Open Science Conference Award Winners).

CLIVAR Open Science Conference (OSC): CLIVAR's OSC was held at Qingdao during 17-25 September 2016. ICMPO contributed to the success of the OSC by preparing documents like the abstract volume and the booklet of technical sessions and submitted these to ICPO, Qingdao.

GEWEX-CLIVAR Monsoons Panel Meeting: ICMPO organised Monsoons Panel Meeting at the OSC, Qingdao, China during 17-18 September 2016. Prepared the proceedings of the meeting with action points and submitted the report to Co-Chairs of the Panel and ICPO, Qingdao. All the presentations of the meeting were uploaded on the web pages of the Monsoon Panel. Also, ICMPO has initiated planning for the next CLIVAR/GEWEX Monsoons Panel Meeting along with Sixth WMO International Workshops on Monsoons to be held in Singapore during 13-17 November 2017.

Teleconferences with Working Groups: ICMPO organised several teleconferences by using GoToMeeting software for the Working Groups of the GEWEX-CLIVAR Monsoons Panel (Americas Monsoon, Asian-Australian Monsoon, Indian Ocean-Monsoon and Africa Monsoon), Asian-Australian Working Group, and ICPO. Also, participated in the 'IndOOS Review' White Paper meeting with ICPO and 14 Scientists across the globe on 13 March 2017.

Development of Web Pages for Monsoon Panel: ICMPO is regularly posting monsoon news, events, calendar events, and training/jobs/studentships notifications on the web pages for the Monsoon Panel.

Photo: *Participants of the CLIVAR-GEWEX Monsoons Panel Meeting held at Qingdao during 17-18 September 2016.*

Photo: *Participants of the CLIVAR/IOC-GOOS Indian Ocean Region Panel Meeting held at Perth on 01 February 2017.*

Project

Centre for Advanced Training

Project Director: Dr. Vinu Valsala

Overview

In order to cater to the huge requirement of skilled manpower in the field of Climate and Earth System Sciences and to bridge the gap between knowledge acquired at university level and that required for working in the MoES units, the Centre for Advanced Training (CAT) was established at IITM. The main objective of the centre is to create large pool of trained and dedicated multidisciplinary climate and earth system scientists with in-depth hands-on expertise on individual physical processes of the land, ocean, atmosphere, biosphere and cryosphere with special emphasis on climate modeling. Since its inception in 2010, the centre has successfully run three batches of job-linked training programme producing 56 scientists who were absorbed in the MoES institutions.

Presently, the job-linked training programme is temporarily put on hold due to some administrative reasons. However, the Centre is contributing in human resource development and capacity building by running pre-PhD coursework for IITM JRFs. It is also conducting short-term training programmes/workshops for junior and mid-level scientists.

Pre-PhD coursework

IITM runs a PhD programme in Atmospheric Sciences in collaboration with S.P. Pune University. The semester-II coursework for the IITM JRFs 2015-16 Batch was conducted by CAT and after completion of the coursework, students were allotted to respective guides for PhD work in May 2016. The following IITM JRFs of the 2015-16 Batch successfully completed the pre-PhD coursework:

Sr. No.	Name of Candidate	Qualification
1	Abhishek Gupta	M.Sc. (Physics)
2	Manpreet Kaur	M.Sc. (Physics)
3	Deepak Suryavanshi	Integrated BS-MS
4	Sandeep K	M.Sc. (Tech) Photonics with Physics
5	Panini Dasgupta	M.Sc., M.Tech (Atmospheric Sciences)
6	Soumya Samanta	M.Sc. (Atmospheric Science)
7	Sandeep Mohapatra	M.Sc. (Maths)
8	Dipti Hingmire	B.E. (Civil Engg.), M.Tech. (Atmospheric Science)
9	Piyush Garg	M.Sc. (Atmospheric Science)
10	Kumar Roy	M.Sc. (Physics)
11	Anju M.	M.Sc. (Oceanography)
12	Anju S.	B.Tech. (Electronics & Communication), M.Tech. (Atmospheric Science)
13	Swaleha Inamdar	M.Sc. (Physics)
14	Sneha Sunil	M.Sc. (Meteorology)

CAT undertook the admission process for the IITM JRFs 2016-17 Batch. Applications were collected, shortlisted and interviews were conducted by CAT. Details of 12 students admitted to the PhD programme are given in the following table. Coursework for Semester-I was started in September 2016 with the semester-I final exams conducted in February 2017. Semester-II classes were started in March 2017. Also, the guide allotment exercise for this batch was carried out.

S.No.	Name of Candidate	Qualification
1	Sreyashi Debnath	M.Sc. (Atmospheric Science)
2	Reddy P. Annapureddy	M.Tech. (Oceanic Sciences)
3	Ushnanshu Dutta	M.Sc. (Physics)
4	Abirlal Metya	M.Sc. (Atmospheric Science)
5	Santanu Halder	M.Sc. (Physics)
6	Roja Chaluvadi	M.Sc. (Atmospheric Science) M.Tech. (Atmospheric Science)
7	Chinta Veeranjaneyulu	M.Sc. (Oceanic Sciences)
8	Vineet Kumar Singh	M.Sc. (Atmospheric Science)
9	Lois Thomas	M.Tech. (Atmospheric Science)
10	Mahesh Kalshetti	M.Tech. (Atmsopheric Science)
11	Narendra Dhangar	M.Tech. (Atmospheric Science)
12	Naresh Ganeshi	M.Sc. (Mathematics)

Short-Term Training Activities

Several areas or topics were identified for short-term

Academic Cell

Coordinator: Dr. P. Mukhopadhyay

Objectives

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

M.Tech. (Atmospheric Science) programme

M.Tech. (Atmospheric Science) is a joint academic programme of IITM and the Department of Atmospheric and Space Sciences (DASS) of S.P. Pune University. Five students were admitted in this programme for the academic session 2016-18 (28th Batch). Courses on Mathematical and Statistical Methods, Data Assimilation and Parameterisation, and Radar Meteorology for M.Tech. were conducted at IITM.

M.Sc. (Atmospheric Science) programme

Under this IITM and Department of Atmospheric and Space Science (DASS) of S.P. Pune University collaborative M.Sc. (Atmospheric Science) Programme, 10 students were admitted for the academic session 2016-18. The M.Sc. second year students (05) of the batch 2015-17 are doing their project work at IITM. Following courses for this programme were conducted at IITM: Mathematical methods, Statistical methods, Numerical Methods, Dynamic Meteorology, Satellite and Radar Meteorology, Data Assimilation and Parameterisation.

Faculty for M.Tech. and M.Sc. programmes

Following IITM scientists were awarded Adjunct Professorship by Savitribai Phule Pune University for the academic year 2016-17. They worked as faculty for the above mentioned M.Tech. and M.Sc. courses.

Name, Designation	Professorship Awarded
Dr. C. Gnanaseelan, Scientist-F	Adjunct Professor
Dr. (Mrs.) Ashwini Kulkarni, Scientist-E	Adjunct Professor
Dr. P. Mukhopadhyay, Scientist-E	Adjunct Associate Professor
Dr. Madhuchandra Reddy, Scientist-D	Adjunct Associate Professor
Dr. S.A. Dixit, Scientist-D	Adjunct Assistant Professor
Mr. M. Mahakur, Scientist-C	Adjunct Assistant Professor
Mrs. Rashmi Khandekar, Scientist-B	Adjunct Assistant Professor
Ms. J.S. Deepa, Scientist-B	Adjunct Assistant Professor

PhD Awarded by Savitribai Phule Pune University, Pune

Student	Thesis Title	Guide(s)
Mrs. Tanusri Chakraborty	Intercontinental Transport and Distribution of Air Pollutants over South Asia	Dr. G. Beig
Mr. Nagaraju Chilukoti	Decadal Changes in the Relationship between Indian and Australian Summer Monsoons	Dr. K. Ashok
Mr. Ramarao Mandavilli V.S.	Land Surface Hydrological Response over the Indian Monsoon Region under Changing Climate	Dr. Sanjay J. Dr. R. Krishnan
Mr. Gibies George	Role of Ocean-Atmosphere Coupling in the Seasonal Prediction of South Asia Monsoon	Dr. A. Suryachandra Rao
Mrs. Preethi Bhaskar	Variability and Teleconnections of South and East Asian Summer Monsoons in a Warming Environment	Dr. R.H. Kripalani Dr. M. Mujumdar
Mr. S.G. Pathade	A New Parameterization for Ice Nucleation in Indian Monsoon Clouds Based on CAIPEEX Observation	Dr. Thara Prabhakaran Dr. P. Pradeep Kumar
Mrs. S.M. Marathe	Linear and Non-Linear Evolution and International Variability of Sea Surface Temperature in the Tropical Pacific	Dr. K. Ashok Dr. Swapna P.

PhD Awarded by Andhra University, Visakhapatnam

Mr. S.D. Sanap	Study on Aerosol-Monsoon Interactions over Indian Subcontinent and CMIP-5 Simulations	Dr. G. Pandithurai Dr. K. Niranjan

PhD Awarded by Rani Durgavati Vishwavidyalaya, Jabalpur

Ms. Kalpana Sagar	Diurnal and seasonal variabilities of Particulate pollutant and air quality in Jabalpur	Dr. G. Beig
Mrs. Shampa Sarkar	Distribution of Ozone and its Precursors over the Tropical Station, Jabalpur	Dr. R.K. Srivastava Dr. G. Beig

Thesis submitted to Savitribai Phule Pune University, Pune for the Award of PhD

Mr. D. Nagarjuna Rao	Interactions Between the Synoptic Variability and Seasonal Mean Monsoon: Role of Ocean-Atmosphere Coupling	Dr. A. Suryachandra Rao
Mr. Harikishan Gandham	Study of the Cloud Macro and Micro Physical Properties and their Response to Aerosol from Insitu and Remote Sensing Techniques	Dr. B. Padmakumari
Mrs. M.H. Kane	High Resolution Modeling of Winter-Time Weather and Climate Process over Western Himalayas under a Changing Climate	Dr. R. Krishnan Prof. B.N. Goswami
Mrs. Priya P.	Modeling Studies on Hydro- meteorological Response of Indus River Basin to Heavy Monsoon Rain Events under Changing Climate	Dr. R. Krishnan Dr. M. Mujumdar

Research guidance to students for project work

IITM is committed to offer its expertise in Weather and Climate Sciences and extend its state-of-the-art facilities to aspirants seeking knowledge or a career and hands-on experience in these areas of expertise. Therefore, IITM generously admits meritorious under-graduate (UG) and post-graduate (PG) students for their internship/course work. During the year 2016-17, about 100 students of different UG/PG courses in science and engineering from various colleges, universities and institutions from across the country have completed or are working for their short-term project/internship under the guidance of IITM scientists. IITM has also started receiving National Post Doctoral Fellows of DST-SERB programme from 2017 onwards.

Important Events and Activities

Important Events

CORDEX Science Advisory Team Meeting: The CCCR at IITM leads the South Asia component of CORDEX. CCCR Scientists represented CORDEX South Asia in the CORDEX science advisory team meeting held on 20 May 2016 during the International Conference on Regional Climate (ICRC)-CORDEX 2016 in Stockholm, Sweden. The analyses of the regional climate scenarios developed using multiple high-resolution regional climate models for the historical period and the future scenarios available over South Asia in the framework of CORDEX were presented during the ICRC-CORDEX 2016.

SAFAR 'RAJVAYU' Mobile-App Launch: System of Air Quality and Weather Forecasting Research (SAFAR) provided scientific and technical assistance to Rajasthan Government in developing air quality mobile app 'RajVayu' that was dedicated to the nation at the hands of the Hon'ble Chief Minister of Rajasthan, Mrs. Vasundhara Raje on 05 June 2016 (the World Environmental Day). The App provides information about current air quality index and weather of Jaipur, Jodhpur and Udaipur.

Targeted Training Activity (TTA): In accordance with the agreement of cooperation between IITM and ICTP, the ICTP-IITM-COLA Targeted Training Activity (TTA) on 'Towards Improved Monsoon Simulations' was held at ICTP, Trieste, Italy during 13-17 June 2016. It was jointly organised by Dr. Jagdish Shukla, Centre for Ocean, Land, Atmosphere Studies (COLA), George Mason University, USA; Dr. M. Rajeevan and Dr. A.S. Rao, Indian Institute of Tropical Meteorology (IITM); Dr. H. Annamalai, University of Hawaii; and Dr. F. Kucharski, ICTP. About 30 participants from different countries including 10 participants from IITM attended the Targeted Training Activity at ICTP. More than 10 experts from different parts of the world including IITM scientists were invited as resource persons for the training.

Celebration of International Yoga Day: IITM celebrated the International Yoga Day on 21 June 2016. On this occasion, a Yoga Workshop for IITM employees was organised at the Institute.

Inauguration of IITM-IMD Hostel: MoES has constructed a hostel facility in Pune with a vision to cater and support students, trainees, researchers and scientists from various parts of India and abroad who would be visiting for research activities. The facility named as 'PRITHVI - The Hall of Residence' was inaugurated on 23 June 2016 by Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences (MoES) in the presence of Dr. B. Mukhopadhyay, ADGM, IMD, Pune and Dr. R. Krishnan, Director, IITM. Former Directors of IITM, Prof. B.N. Goswami and Dr. G.B. Pant were also present. PRITHVI is a 10-story building well-equipped accommodation facility comprising of 215 single occupancy rooms for students and researchers and 12 guest rooms. The facility is located at IMD Colony, Pashan, Pune and will be used by IITM and IMD.

Dr. Harsh Vardhan visits the IITM Monsoon Observational Campaign: As part of MoES and UK's Natural Environmental Research Council (NERC) joint project under the Monsoon Mission, aircraft observations with sophisticated scientific instruments were carried out in the main field phase of the project during May-July 2016. These observations were taken by operating the atmospheric research aircraft (ARA) from Lucknow and Bengaluru airbases. These airborne observations were carried out over Indo-gangetic plains, Northwestern India, East coast, Bay of Bengal, Arabian Sea and Western Ghats during this period and a wealth of data was collected. The aircraft observations will be augmented by special observational programmes over the land using boundary layer flux towers, radars, microwave radiometers, etc. Dr. Harsh Vardhan, the Union Minister for Science & Technology and Earth Sciences, Govt. of India along with Dr. M. Rajeevan Secretary, MoES visited the campaign site in Lucknow on 11 July 2016 and also, participated in a research flight of 1.20 hours duration.

Advanced School on Earth System Modelling and Workshop on Climate Change and Regional Impacts over South Asia: IITM and ICTP (Italy) jointly organised an Advanced School on Earth System Modelling (ESM) during 18-27 July 2016, followed by a Workshop on Climate Change and Regional Impacts over South Asia during 28-29 July 2016 at IITM. The ESM School was inaugurated by Dr. M. Rajeevan, Secretary, MoES on 18 July 2016. Prof. V.K. Gaur, Chairman, Governing Council, IITM was the Guest of Honour at the event. The summer school with an international faculty provided training on different components of the Earth System *i.e.*,

atmosphere, ocean, land, cryosphere, atmospheric chemistry and aerosols, ocean biogeochemistry, etc. The newly developed IITM Earth System Model was the focus of the School. The school was attended by 41 national and international participants. The workshop was inaugurated by Dr. S.S.C. Shenoi, Director, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad.

IITM Corporate Film Released: A 16 minutes film on the institute's R&D activities and achievements for the last 10 years (since the inception of MoES) was produced. The film was released on 27 July 2016, as part of the 10th anniversary celebrations of the Ministry of Earth Sciences at Vigyan Bhawan, New Delhi. The film was also screened at the National Science Film Festival (NSFF) - 2017 in Kolkata during 14-18 February 2107.

IITM Wins Bid to Host ICCP-2020 Conference: IITM has successfully won the bid to host the forthcoming quadrennial 18th International Conference on Clouds and Precipitation (ICCP 2020) in 2020. This can be seen as an international recognition to India, especially IITM in the area of understanding clouds and precipitation. Hosting the event will bring more visibility to IITM as a global leader in this area. The International Commission on Clouds and Precipitation (ICCP) conducts International Conference on Clouds and Precipitation (ICCP) after every four years which is attended by about 500-600 scientists working specifically on cloud and precipitation from around the globe. The bidding was organised by the ICCP Commission during the 17th ICCP Conference held at the University of Manchester, Manchester (UK) during 25-29 July 2016.

Establishment of India-UK Water Security Centre (IUKWC) As an outcome of collaborative efforts and funding by the Ministry of Earth Sciences (MoES), India and the Natural Environment Research Council (NERC), UK; a virtual India-UK Water Centre (IUKWC) was officially launched on 27 September 2016. This virtual centre builds on recent and ongoing collaborative water research programmes between India and the UK. The Centre is fully functional and is coordinated by Dr. A.K. Sahai (Indian Institute of Tropical Meteorology, Pune) and Dr. H. Dixon (Centre for Ecology and hydrology, UK). The centre aims to promote cooperation and collaboration for NERC-MoES water security research in order to establish a platform for, and legacy of, long-term partnerships and dialogue between Indian and UK water researchers, water policy-makers and water businesses.

Website for Short Range Deterministic Forecast: The website for high resolution IITM short range deterministic forecast with GFS at T1534 (12 km horizontal resolution) was launched by Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences, Govt. of India on 03 October 2016. The experimental forecast is made available at http://srf.tropmet.res.in/srf/files/archive_hires.php.

WMO Workshop: A WMO Workshop on 'Enhancing Climate Indices for Sector-specific Applications in South Asia region' was held at IITM during 03-07 October 2016. The workshop was organised by World Meteorological Organization (WMO) under the guidance of the Expert Team on Sector-specific Climate Indices (ET-SCI) and as a part of the Canada-funded programme on the implementation of the Global Framework for Climate Services (GFCS) at the regional and national scales. It was hosted by IITM. The workshop was aimed at enhancing the use of climate information in climate-sensitive sectors for climate risk management and adaptation through interdisciplinary analysis and interpretation of sector-specific climate indices. The workshop brought together experts from National Meteorological and Hydrological Services (NMHSs) and representatives of priority areas (agriculture and food security, water health energy and disaster risk reduction) from nine South Asian countries including India and also, experts from across the globe.

Short Course on Eddy Covariance and GHG Flux Estimation: A workshop on 'Eddy Covariance and GHG Flux Estimation' was organised at IITM during 07-12 November 2016. The workshop was aimed to train young people involved in different aspects of green house gases (GHGs) research in India. About twenty Junior Research Fellows and early career scientists having diverse background ranging from greenhouse gas emission in crops, agro-forestry, net ecosystem exchange, surface energy flux, etc. from across the country participated in the workshop. Two eminent scientists specialised in micro and boundary layer meteorology, Prof. K.T. Paw, University of California at Davis and Dr. George Burba, Licor Biosciences, USA participated as resource persons. Dr. Anand Karipot, Savitibai Phule Pune University (SPPU) also delivered lectures and demonstrated the use of various micro-meteorological sensors and data-loggers to the participants.

Foundation Day Celebrations: IITM celebrated its 55th Foundation Day on 17 November 2016 at its premises. On this occasion, Prof. S.K. Dube, Vice Chancellor, Amity University, Jaipur was the Chief Guest and Prof. P.C. Joshi, Retired Scientist, SAC, Ahmedabad was the Guest of Honour. In addition to the main function, the celebration included the presentation of various awards *viz*. Biennial Golden Jubilee Award, Annual Silver Jubilee Award, Best Student Research Paper Award, Excellent Performance Awards for the Scientific Support, Administrative, Technical and Multi Tasking Staff and Prof. R. Ananthakrishnan Best Thesis Award were presented. From this year onward, IITM has started an award comprising a citation and a reward of relevant books worth Rs. 7500/- for top two research fellows for their performance in the pre-PhD course work. The programme also included the Foundation Day Lecture, and the Silver Jubilee Award Lecture, the Best Student Paper Award Lecture and Prof. R. Ananthakrishnan Best Thesis Award Lecture by the respective award winners. Also, in association with Indian Meteorological Society, Pune Chapter (IMSP), Prof. P.R. Pisharoty Distinguished Lecture on the topic 'Improved Estimates of 20th and early 21st century global sea level rise' by Prof. C.K. Shum, Ohio State University was organised. The celebrations concluded with a cultural programme in the evening. Several ex-employees and special invitees, in addition to the existing employees and their families, attended the function.

- Presentation of the 3rd biennial IITM Golden Jubilee Award for the year 2016 to Dr. A. K. Sahai and Dr. C. Gnanaseelan for their outstanding contributions in the field of Atmosphere, Weather and Climate Science.
- Presentation of the 28th annual IITM Silver Jubilee Award for the year 2015 to a paper entitled 'Tropical Indian Ocean subsurface temperature variability and the forcing mechanisms' by Sayantani Ojha and C. Gnanaseelan published in the international journal Climate Dynamics, 44, May 2015, 2447-2462.
- Presentation of the Annual Excellent Performance Award for the year 2015 to Mrs. S.B. Patankar, Mr. S.M. Thorat, Mr. K.D. Barne and Mr. V.V. Bamble for the Scientific Support, Technical, Administrative and Multi-Tasking Staff categories respectively.
- Presentation of the Best Student Paper Award for the year 2015 to the paper entitled 'Impacts of Indo-Pacific sea surface temperature anomalies on the summer monsoon circulation and heavy precipitation over Northwest India-Pakistan region during 2010' by P. Priya, M. Mujumdar, T.P. Sabin, P. Terray and R. Krishnan published in the international Journal of Climate, 28, May 2015, 3714-3730.
- Prof. R. Ananthakrishnan Best Thesis Award for the year 2015 was presented to Dr. C.K. Jena for his PhD thesis entitled 'High resolution NO_x emission estimates for India based on satellite measurements and regional chemistry transport model'.
- IITM Pre-PhD Coursework Award 2017 carrying a citation and a reward of relevant books worth Rs. 7500/- to top two research fellows Mrs. Dipti Hingmire and Mr. Abhishek Gupta for their performance in the pre-PhD coursework.
- A special Foundation Day Lecture on the topic 'Five decades of satellite: Satellite meteorology in India and way-forward' by Prof. P. C. Joshi.

Workshop on Developing Hydro-Climate Services for Water Security: Under the India-UK Water Centre (IUKWC), this workshop was organised by IITM in collaboration with the Centre for Ecology and hydrology (UK) at IITM, Pune during 29 November to 01 December 2016. The workshop explored the opportunities for future research collaborations in hydro-climatic services between the two countries. It was attended by about fifty delegates from the two countries, and included researchers, government officials, policy makers and NGO representatives. Current research and management measures in the water sector were discussed. The need for formulation of better research decimation measures, increasing technological capacity, sharing of data and research along with significance of stakeholder engagement initiatives was highlighted. The workshop was inaugurated by the Chief Guest, Prof. V.K. Gaur (Distinguished Scientist, CSIR Fourth Paradigm Institute, Bengaluru) and the Guests of Honour, Prof. Alan Jenkins (Deputy Director, Center for Ecology and Hydrology, NERC) in the presence of Dr. A.K. Sahai (IUKWC Coordinator, IITM, India) and Dr. Harry Dixon (IUKWC Coordinator, Center for Ecology and Hydrology, UK).

Tree Census Activity at IITM: A tree census activity was organised at IITM on 04 December 2016. The tree census was based on GIS+GPS method of measuring 14 parameters of individual trees. This event was organised by the Swachh and Green IITM Campus Committee (SGICC) with support from the NGO Disha-Parivar's student volunteers and Pune Municipal Corporation (PMC) authorised agency M/s Sar IT Resources Pvt. Ltd., Mumbai.

National Workshop on 'NWP on Probabilistic Forecast' was organised by Centre for Advanced Training, IITM during 06-08 December 2016 at IITM. All the 40 participants were from IMD and most of them were field forecasters at various meteorological centres of IMD. Eight resource persons were involved in the workshop.

Workshop on Development and Applications of Downscaling Climate Projections: As part of the INDO-US Partnership for Climate Resilience, IITM is working with the U.S. Department of State and the NOAA National Centers for Environmental Information for capacity-building in climate adaptation planning in India through a series of workshops and other collaborative activities. The first in a series of workshops is focused on techniques for downscaling climate information and opportunities for sharing available downscaled information to local planners in India. The workshop was organised by Centre for Climate Change Research at IITM during 07-09 March 2017.

The workshop focused on sharing expertise in climate modeling and downscaling among the experts of the two countries. Downscaled international climate model data for the Indian sub-continent, including NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) and IITM Coordinated Regional Downscaling Experiment (CORDEX) programme for South Asia, were presented. This will help to promote discussions on the State Action Plan Development and to identify collaborative research opportunities for developing additional high-resolution climate datasets for the Indian sub-continent and the approaches for their use in climate adaptation planning.

INTROSPECT 2017: An International Workshop on Representation of Physical Processes in Weather and Climate Models (INTROSPECT 2017) was organised at IITM during 13-16 February 2017. The workshop emphasised on the debate of cloud resolving approach or hybrid approach (with parameterized convection and grid scale cloud microphysics) and its impact on model fidelity. The workshop addressed the major challenge areas to numerical prediction models *viz*., a) need of scale aware parameterizations schemes, b) stochastic and multiscale nature of schemes and c) unified scheme of physical processes. The workshop provided a platform to bring together world renowned experts from all over the globe to meet, discuss and do hands-on and deliver lectures to Indian participants/students. About 20 experts from various premier research institutes such as ECMWF (UK), NCAR (USA), GSFC and JPL of NASA (USA), Seoul National University (South Korea), University of Victoria (Canada), Center for Ocean-Land-Atmosphere Studies (COLA) at Gorger Manson University (USA), University of Tokyo (Japan), KNMI (Netherlands), NCEP (USA), Purdue University (USA), IISc Bengaluru, IITs, IMD, NCMRWF and IITM. About 73 participants from different parts of the country participated in the workshop. The webcasting of the talks was arranged which benefited the students and faculty who could not attend the workshop. As an outcome of the workshop, it is recommended by the experts to constitute a consortium where all the researchers working in the field of parameterization can discuss issues related to parameterization in the country. This workshop has worked as a facilitator motivating students and researchers in taking up cutting edge research in the field of parameterization.

Important Meetings

- **A Joint-working Group meeting** was held at IITM on 11 April 2016 to discuss the possibility of using lightning information available from IITM's Lightning Location Network in IMD's Nowcast product. The meeting was attended by scientists from IMD, IITM and NCMRWF.
- **Preparation of MOES Strategic Vision Document:** The Ministry of Earth Sciences (MoES) is preparing its Strategic Vision Document for the next 5-10 years. In this regard, two national level brainstorming meetings were held at IITM on 01 April 2016 and 09 May 2016.
- **Meeting regarding NOAA-IITM Partnership for Climate Resilience:** A meeting on NOAA-IITM Partnership for Climate Resilience between IITM and the U.S. Delegation was held during11-12 April 2016

at IITM. The US Delegation was represented by Dr. A. Luers, Assistant Director, Climate Resilience and Information, White House Office of Science & Technology Policy; Dr. D. Easterling, Chief, Global Climate Applications Division, NOAA National Climatic Data Center; Dr. K. E. Kunkel, Research Professor & Lead Scientist for Assessments, NOAA National Climatic Data Center/North Carolina State University; Dr. F. Akhtar, Foreign Affairs Officer, Office of Global Change, U. S. Department of State; and Dr. Trisha Chilimbi, Economic Specialist, American Consulate General, Mumbai. From IITM, Dr. R. Krishnan, IITM Director and other IITM scientists participated in the meeting. Dr. Amir Bazaz, IIHS, Bengaluru, and Mr. C. Lobo and Mr. Shilke from WOTR, Pune also attended the meeting.

- **Meeting for formulating New Hydrometeorology Research Group:** With the idea of formulating a long term scientific programme on some of key hydro-meteorological issues that require effective linkage between hydrologists and climate/weather scientists, a meeting was called for scientific discussions to start a Hydrometeorology Research Group at IITM. The meeting was held at IITM on 03 May 2016. Dr. R. Krishnan, Director, IITM; other scientists of IITM; Prof. V.K. Gaur, CSIR Fourth Paradigm Institute (C4PI), Bengaluru; Prof. P.P. Mujumdar, Indian Institute of Science (IISc), Bengaluru; Prof. M. Sekhar, IISc, Bengaluru; Dr. Sharad K. Jain, National Institute of Hydrology (NIH), Roorkee and Dr. Dipankar Saha, Central Ground Water Board (CGWB) attended the meeting.

- **Meeting on Extended Range Prediction (ERP):** A meeting was held at IMD, New Delhi during 27-29 May 2016 to discuss the scientific aspects of the Extended Range Prediction (ERP) to be operationally issued by IMD throughout the year. In this regard, it was decided that IITM Pune will transfer the modeling system to IMD after the hindcast analysis is computed based on the atmospheric initial conditions prepared by NCMRWF, Noida and the oceanic initial conditions being prepared by INCOIS, Hyderabad. From IITM, Dr. A.K. Sahai participated in the meeting.

- **A Brainstorming Meeting on Lightning Location Network** was held at IITM on 30 June 2016 to discuss the need for expanding the present lightning location network over Maharashtra to other parts of the country. Scientists from IMD, IITM, INCOIS and Savitribai Phule Pune University participated in the meeting. It was recommended that the network should be expanded to the whole country in a phased manner and in the first phase, the network should be established over lightning prone regions of East and North-east India.

- **CAIPEEX National Scientific Steering Committee Meeting:** A meeting of the National Steering Committee (NSC) of CAIPEEX was held at IITM on 22 August 2016 under the chairmanship of Prof. G.S. Bhatt, Centre for Atmospheric and Oceanic Sciences (CAOS) of Indian Institute of Science (IISc), Bengaluru. During the meeting, CAIPEEX results and the gap areas were discussed. Also, cloud seeding plan was finalised for the upcoming CAIPEEX phase during 2017-2019. NSC members Dr. K. Krishnamoorthy, Director, Space Physics Laboratory (SPL); Capt. R.K. Mehajan, Scientist, Science and Engineering Research Board (SERB); Prof. P. Pradeep Kumar, Professor, Savitribai Phule Pune University; Dr. J.R. Kulkarni, Retd. Scientist (IITM) and Dr. R. Krishnan, Director, IITM attended the meeting.

- **Meetings for Climate Reference Stations**: It is proposed to set up a network of climate reference stations in the country. Climate reference stations will provide long-term, accurate, and unbiased observations that are essential to define the state of the global integrated earth system, its history, and its future variability and change. In this direction, a discussion meeting on setting up of Climate Reference Stations over India was held at IITM on 09 September 2016. The meeting was conducted to draw the plan on: i) framing the technical specifications of planned equipments, and ii) constitution of a committee for the selection of sites. Another meeting was held at IMD, Pune on 20 October 2016 to discuss site selection for these stations. The meetings were attended by scientists from IITM and IMD, Pune.

- A meeting was held at IITM on 14 September 2016 to initiate documentation on the project **'Urban Meteorology-Meso-Networks, Urban Modelling and Prediction of Urban Floods'** under Modernisation of Weather and Climate Services. Mr. S. C. Bhan, India Meteorological Department

(IMD), Delhi; Dr. Raghvendra Ashrit, National Centre for Medium Range Weather Forecasting (NCMRWF), Delhi; Dr. (Mrs.) Saideepa Kumar, Indian Institute for Human Settlements (*IIHS*), Bengaluru; Dr. Prashant Srivastava, Banaras Hindu University (BHU), Varanasi and IITM scientists attended the meeting.

- A meeting on **Meteorological Support for Floods (Hydrological Information System, Flood Warning System)** was held at IITM on 15 September 2016. Dr. S.C Kar, National Centre for Medium Range Weather Forecasting (NCMRWF); Dr. Prashant Srivastava, Banaras Hindu University (BHU); Dr. Vimal Mishra, Indian Institute of Technology (IIT), Gandhinagar; Dr. Subimal Ghosh, Indian Institute of Technology (IIT), Bombay; Dr. (Mrs.) Saideepa Kumar, Indian Institute for Human Settlements (*IIHS*), Bengaluru; Dr. Rahul Saxena and Dr. A.K. Das from India Meteorological Department (IMD) Delhi and IITM scientists attended the meeting.
- **CAIPEEX PHASE-IV Technical Evaluation Committee (TEC) Meeting** was held at IITM on 16 September 2016. Dr. Vidyadhar Y. Mudkavi, CSIR Fourth Paradigm Institute (CSIR-4PI), Bengaluru chaired the meeting to formulate the technical specifications for the procurement of aircrafts and instruments. IITM scientists presented the specifications of the proposed instruments and aircrafts for the upcoming CAIPEEX phase.
- **Independent Review Committee (IRC) Meeting:** The Ministry of Earth Sciences (MoES), Govt. of India constituted an Independent Review Committee (IRC) chaired by Prof. Sulochana Gadgil to assess the performance of all the IITM programmes being executed during 12th Five Year Plan period and to finalise the projects to be continued beyond 12th Plan till 31 March 2024. The other members of the Committee included:Dr. V.K. Dadhwal, Prof. K. Mohan Kumar, Prof. S.K. Sateesh, Prof. G.S. Bhat, Dr. D. Shankar, Dr. M. Mohapatra and Dr. Parvinder Maini. The Committee met on 30 September 2016 at IITM, Pune.
- **Independent Peer Review Committee (IPRC) Meeting:** The Ministry of Earth Sciences (MoES), Govt. of India constituted an Independent Peer Review Committee (IPRC) chaired by Prof. R. Narasimha to review the performance of IITM as an autonomous institute. The other members of the Committee included: Prof. Sulochana Gadgil, Prof. J. Srinivasan, Dr. S.K. Dube and Dr. Parvinder Maini. The Committee met on 22 November 2016 at Indian Institute of Science (IISc), Bengaluru. Director, IITM presented Institute's work since its inception to the Committee. Senior IITM officials and scientists were also present.
- **Meeting Regarding Jalyukt Shivar Abhiyan (JSA):** Under the Maharashtra Government's ambitious project 'Jalyukt Shivar Abhiyaan' to make Maharashtra a drought-free state by 2019, a team led by Dr. Krishna Lavekar, IAS (Retd.) and former Commissioner of Agriculture is conducting a technical study on climate proofing of Jalyukt Shivar Abhiyan. In this regard, the team visited IITM on 30 January 2017 to discuss with CCCR scientists about climate change issues, future climate projections for Maharashtra, impacts on water resources and adaptation measures.
- **Meeting Regarding the Impact of Climate Change on Indian Armed Forces**: The National Security Council Secretariat (NSCS), New Delhi and the College of Defence Management (CDM), Secunderabad are jointly studying the impact of climate change on Indian Armed Forces. A joint team of officers from NSCS and CDM visited IITM on 13 February 2017 to meet CCCR scientists for discussion on seeking some specific research inputs from IITM on various topics (such as global temperature change and its impact on different sectors) needed for their study.

Observational Programmes/Field Campaigns

- **Observations at Antarctica:** IITM scientists participated in a campaign for atmospheric data collection using Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) instrument at Maitri and Bharati Stations in Antarctica during 17 December 2016 to 02 April 2017. The campaign was part of the 36th Indian Scientific Expedition to Antarctica (36-ISEA) organised by National Centre for Antarctic and Ocean Research (NCAOR), Goa.
- **Emission Inventory Campaign for SAFAR-Ahmedabad:** A campaign for developing an Emission Inventory for Ahmedabad city was launched on 15 May 2016. The campaign for SAFAR-Ahmedabad was conducted in collaboration with Indian Institute of

Public Health, Gandhinagar (IIPHG) and St. Xavier's College, Ahmedabad. Around 150-200 students from various colleges participated in the campaign. The campaign was conducted for a period of one month in which local emission sources were identified and quantitative unique datasets were generated. The sources included: vehicular activity, vehicular density on different roads, cooking activity in slum and non slum areas which involve bio-fuel burning, industrial sector, waste burning, etc. A field survey was carried out by IITM scientists during 09-16 April 2016 in and around Ahmedabad city to identify suitable locations for installation of Air Quality Monitoring Stations and Automatic Weather Stations in collaboration with the members of Ahmedabad Municipal Corporation (AMC). In this initial survey, localities with different micro-environments were selected.

- **Indo-Gangetic Rain Chemistry Study during Monsoon 2016:** To understand the rain chemistry over the entire Indo-Gangetic basin, rain gadgets for collection of rainwater samples at various stations *viz*., New Delhi, Patna, Lucknow, Srinagar, Hisar, Varanasi, Jaipur and Dhanbad were installed by IITM scientists. Rain samples were collected for the complete monsoon season *i.e*., June to October 2016.

- **High-Altitude Balloonsode Campaign in July-August 2016:** Under an MoU between MoES and German Helmholtz Association (HGF), a project entitled 'Influence of Asian Summer Monsoon (ASM) on the upper troposphere-lower stratosphere (UTLS): Feedback on monsoon circulation' is being carried out by IITM for understanding processes related to Asian summer monsoon circulation and its impact on the UTLS. As part of this project, a balloon campaign was conducted at Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, Uttarakhand during Monsoon (July-August-2016) and post-Monsoon (November 2016) periods. Special sensors were flown on high altitude (stratosphere) through balloon flights. High frequency measurements of water vapour, aerosol back scatter, ozone and relative humidity along with meteorological parameters were obtained at the centre of the monsoon anticyclone. These data show events of wave braking and eddy shedding from the monsoon anticyclone. Observations along with model simulations are being analysed. Similar experiments are proposed to be conducted during monsoon season in 2017, 2018 and 2019 to understand inter annual variability.

- **Mobile Air Quality Campaign in Jaipur:** A campaign was conducted to assess the air quality at strategically important and unique locations in Jaipur (Rajasthan) during May to July 2016. The campaign was conducted by using a mobile van equipped with several air quality and weather monitoring sophisticated instruments in association with Rajasthan State Pollution Control Board (RSPCB) and UNICEF, Rajasthan. A SAFAR Technical Report on 'Assessment of summer air quality of Jaipur in different micro-environments' was prepared. It was released during the Air Quality Monitoring, Impact and Action Plan Workshop held in Jaipur on 09 September 2016.

- **Mobile Air Quality Campaign in Northern India:** To understand the medium range transport of air pollutants (to and from Delhi) and quantify the share of stubble burning, a mobile air quality campaign in northern India was organised from 25 October 2016 onwards. Several sophisticated instruments for monitoring air quality and weather parameters were deployed in the mobile van. The campaign was conducted in the cities: Chandigarh, Amritsar, Bhatinda, Rohtak, Fatehpur and Hissar.

- **9th Indian Scientific Expedition to Southern Ocean:** IITM participated in this expedition during 20 December 2016 to 24 February 2017.

- **Speleothem samples** from Hyderabad and nearby regions were collected during 22-27 June 2016.

- **Tree ring samples** of teak for dendroclimatological study were collected from Nagarhole and Bhadra Wildlife Sanctuaries in Karnataka during 16 February to 02 March 2017.

Collaborative Programmes

- A multi-institutional national project entitled **'National Carbonaceous Aerosols Programme (NCAP) Working Group III'** under the Climate Change Action Plan (CCAP) of the Ministry of Environment, Forest and Climate Change (MoEFCC), New Delhi was recently approved and sanctioned for funding by MoEFCC for a period of five years (*i.e*., 2016-21). The

project is led by Indian Institute of Technology, Mumbai. IITM is one of the 17 participating institutes. A budget of around one crore is provided to IITM for this period. Under this project, aerosol measurements will be carried out at HACPL, Mahabaleshwar.

- **An MoU has been signed with the Space Application Centre (SAC)** for scientific cooperation in the project SAFAR-Ahmadabad.
- **MoU between IITM and Hari Singh Gour University, Sagar:** An MoU was signed between IITM and Hari Singh Gour University, Sagar, Madhya Pradesh for establishing an atmospheric test bed site on 12 June 2016 in Bhopal. The MoU was signed in the presence of Dr. M. Rajeevan, Secretary, MoES and Prof. Raghavendra Tiwari, Vice Chancellor, Hari Singh Gour University.
- **Collaborative projects of MoES and Belmont Forum:** Under an MoU between MoES and the Belmont Forum countries, international research collaboration under the theme of Climate Predictability and Inter-regional Linkages has been approved by Belmont Forum. Under this framework, two scientific proposals from Centre for Climate Change Research (CCCR) at IITM have been approved: (1) Globally Observed Teleconnections and Their Role and Representation in Hierarchies of Atmospheric Models (GOTHAM), and (2) PAleo-Constraints on Monsoon Evolution and DYnamics (PACMEDY).
- The Memorandum of Understanding (MoU) with Indian Institute for Human Settlements (IIHS), Bengaluru for knowledge partnership on climate science and its applications in rural and urban adaptation is extended from 1 January 2017 to 31 October 2018.
- **COSMOS-India Network:** Under NERC-MoES research collaboration, a network of field-scale soil moisture monitoring stations across India (COSMOS-India) is being developed using cosmic-ray soil moisture sensors (CRS). Centre for Ecology and Hydrology (CEH), UK; Indian Institute of Science (IISc), Bengaluru; Indian Institute of Technology (IIT), Kanpur; IITM, Pune and University of Agricultural Sciences (UAS), Dharwad are working in partnership on this project. Recently, a tower with CRS was erected at IITM under the COSMOS-India network. The IITM CRS was inaugurated by Prof. V.K. Gaur, Distinguished Scientist, CSIR Fourth Paradigm Institute, Bengaluru and Chairman, Governing Council, IITM on 31 January 2017. IITM has set up a dedicated Hydrometeorology Research Unit (HMRU) at CCCR to coordinate for the development and implementation of observational and modeling activities under this project. While engaging climate scientists and hydrologists, the COSMOS-India project is expected to enhance the knowledge base on water balance components (*e.g.*, precipitation, evapotranspiration, soil moisture and runoff etc.), and to develop a national hydrological outlook for India.

Computer and IT Services

- Ninety eight desktops and seven centralised printers were procured in bulk for replacement of old ones.
- Integrated Office Automation Systems: Est, SBU, Security and Transport modules are completed and implemented.

Infrastructure Development

Work completed

- Renovation of one block of type-II Quarters, IITM Colony.
- Site development works for installation of de-ionization plant and foundation of water tunnel in fluid dynamics lab at IITM.
- Renovation of Chemistry Lab room no. 305 and making cubicals in room no. 303 and 307 at Second Floor in PM&A Division.
- Renovation of committee room No.F-127 at Phase-II Office Building.
- Application of Heat Shield Coating at various roof tops (Phase-I, Phase-II, LIP and CCCR Building) in the campus.
- Construction of the 'Prithvi – the Hall of Residence' at IMD Colony, Pune premises.
- Solar water heating systems installed at two buildings at IITM Colony and at the Prithvi Hostel.
- Water flow metres installed at various positions in the office for measuring water usage.

- Wireless fire alarm and detection system installed at the Prithvi Hostel.
- Fire extinguishers and proper signage were fitted.

Work in progress

- Repair of roads in the office and colony campus.

Special Days/Weeks Observed

- **Anti Terrorism Day** was observed on 20 May 2016 at IITM. A pledge was administered to the employees of the institute by the Director of the institute.
- **Vigilance Awareness Week** was observed during 31 October - 05 November 2016. On this occasion, a pledge was administered by the Director, IITM to the employees on 31 October 2016. A lecture on vigilance awareness by Mrs. Sangeeta Upadhaye, Assistant Director (E), All India Radio, Pune was arranged on 04 November 2016. As per the Central Vigilance Commission guidelines, slogan and essay writing competitions were arranged on the theme 'Public participation in promoting integrity and eradicating Corruption'. Prizes to the winners of the slogan and essay competitions were distributed.
- **Rashtriya Ekta Diwas (National Unity Day):** Commemorating the birth anniversary of Shri Sardar Vallabhbhai Patel, a pledge was administered to the employees of the institute by the Director on 31 October 2016.
- **International Women's Day** was celebrated at IITM on 03 March 2017. On this occasion, a special lecture by Mrs. Rashmi Shukla, IPS, Commissioner of Police, Pune was organised.

Science Popularisation Programmes

- **National Science Day Celebrations:** The Institute celebrated the National Science Day on 28 February 2017 at its premises in a befitting manner. On this occasion, an open day for students, general public and the media persons was observed. Students and other visitors were taken around the Institute, in groups, to see the working of scientific instruments and experimental activities at the various laboratories and to have interactions with scientists. IITM scientists and researchers demonstrated and explained different aspects of weather and climate sciences to the visitors. An introductory presentation about the Institute was also given. Students were also guided about the various career opportunities available in the field. Refreshments were distributed among the visitors.
- **National Science Day Celebrations at GMRT, Narayangaon:** On invitation, IITM participated in the National Science Day Celebrations of the Giant Metrewave Radio Telescope (GMRT) at Narayangaon during 28 February – 01 March 2017. During this period, a big science exhibition is organised by GMRT where IITM participates regularly. The exhibition attracts huge crowd of inquisitive visitors, especially from the rural areas. A big stall was set up where IITM's popular scientific exhibits and specimens were displayed for the general public and students. The visitors to the stall were apprised about the various research activities and projects being carried out by IITM and their relevance to the society. Many school and college students and faculty and the general public visited the exhibition stall. Availing this opportunity, an effort was made to popularise Atmospheric Sciences and to sensitise students for opting a career in the same. For this, Institute's information and career flyers were distributed among the interested students and faculty. The visitors were explained science through exhibits and demonstrations.
- **World Meteorological Day Celebrations:** The Institute celebrated the World Meteorological Day on 23 March 2017 at its premises in a befitting manner. This year, the theme of the day was 'Understanding Clouds'. As a part of the celebration, a public lecture on the topic 'Understanding Clouds' by Dr. J.R. Kulkarni (Ex-Scientist and Ex-Prog. Manager of CAIPEEX at IITM) was arranged. About 100 Students from New English School & Junior College, Hadapsar visited the institute on this occasion. Visitors were taken on guided tour to different laboratories and facilities at the Institute. IITM scientists and researchers demonstrated and explained different aspects of weather and climate sciences to these visitors.
- **Celebration of Earth Day and *Swachh Pakhawada* at IITM:** As per the guidelines received from MoES, *Swachh Pakhawada* under the Swachh Bharat Mission was observed at IITM during 14-29 April 2016. As part of the *Swachh Pakhawada*, 'Earth Day'

was celebrated on 22 April 2016. On this occasion, various activities/competitions like drawing/poster, quiz, essay, best out of waste were conducted on the theme 'Caring Mother Earth' at IITM. Students from many schools participated in these competitions. 'Swachh Dorumentary' was screened. Also, there was a street play show organised by Pune Municipal Corporation (PMC) employees. Swachh employees and street play participants were felicitated on this occasion. An exhibition of the drawings and best out of waste models was arranged. Winners and runner ups of all competitions were given prizes.

- **Celebration of Ten Years of MoES:** IITM celebrated 10-years of Ministry of Earth Sciences (MoES) by organizing an exhibition event during 1-5 August 2016. As part of this week-long event, students and teachers from different schools and colleges in Pune were allowed to visit IITM labs and to interact with scientists. The students were shown a film on IITM's progress. The students were also introduced about the R&D activities of IITM and the recent achievements. They were taken on a guided tour showing them different labs, meteorological equipments and meteorological balloon ascent with an opportunity to interact with scientists.

- **India International Science Festival 2016 (IISF-2016):** IITM participated in the MoES science exhibition at the India International Science Festival 2016 held at National Physical laboratory (NPL), New Delhi during 7-11 December 2016. Various R&D activities of IITM including SAFAR with its mobile van and display board, dendro paleoclimatology, etc.

- **24th National Children Science Congress (NCSC-2016)**: IITM participated in the science exhibition at the 24th National Children Science Congress held at VIIT Baramati, Maharashtra during 27-31 December 2016. A big stall was set at the exhibition to showcase the R&D activities of the Institute and to popularize weather and climate sciences among students and the general public. On the spot quizzes were organised at the stall and token gifts were given to students.

- **Pride of India Expo at Indian Science Congress**: IITM participated in the MoES pavilion at the Pride of India Expo at the 104th Indian Science Congress held at SV University, Tirupati during 03-07 January 2017. Various R&D activities of the Institute were showcased there while popularising weather and climate sciences among students and the general public.

- **Celebration of National Forest Conservation Day:** IITM organised an environmental awareness event on the occasion of National Forest Conservation Day on 16 January 2017. On this occasion, a public lecture on 'Forest Conservation and Sustainable Development' by eminent scientist Dr. Rahul Mungikar, Senior Research Consultant, Maharashtra State Biodiversity Board, Pune was arranged. Various competitions such as drawing, best out of waste, essay writing and elocution for school students (5th-11th standard) were arranged. The event was coordinated by the ENVIS centre at IITM.

- **School, College and Public Visits Throughout the Year:** IITM receives a lot of requests from the different walks of life to visit the Institute and to see the science in action in the laboratories and to interact with scientists. Many groups visited the Institute throughout the year. Such visits were coordinated by Mr. S.P. Ghanekar and Mrs. Usha Iyer. The visitors are shown the laboratories, equipments, etc. used for the research purpose. They are given presentations about the R&D activities at the Institute. They are also allowed to interact with scientists and researchers. Mr. S. Mahapatra was also involved in apprising the visitors about the activities of the Institute by giving introductory talks and presentations.

Library, Information and Publication Services

The Library, Information and Publication Division serves as the National Information System in Meteorology and Atmospheric Sciences. The information resources have been strengthened by adding a good number of international scientific journals in Meteorology and Oceanography with online access and purchasing latest books. IITM subscribed to 70 journals (61 foreign and 09 Indian) with online access to 61 foreign and 3 Indian journals for the year 2016 (costing approx. Rs. 64.23 lakhs). Subscription to 61 journals (52 foreign and 09 Indian) with online access to 52 foreign and 03 Indian journals for the year 2017 (costing approx. Rs. 57.24 lakhs) has been processed. In addition to this, access to 129 foreign journals and the SCOPUS database, which

were earlier subscribed to individually by IITM, is available under the MoES Consortium from Science Direct. The Web of Science database is accessible through the MoES Consortium. Access to 24 journals (11 Indian and 13 foreign) is available either complimentary/free online or against life membership. Online IP based institutional access to the Earth and Environment Sciences Package of the E-book resources of Springer for the copy right years 2005-13 is working satisfactorily. Online IP based institutional access to 56 titles of Cambridge e-books is available. Thirty three (33) books covering majority of the Institute's research areas (costing approx. Rs. 2.06 lakhs) were purchased. Payments for paper publications charges/page charges/article processing charges/excess length fee for ten papers of the Institute scientists were approx. Rs. 4.57 lakhs. A good number of scientific and technical reports of leading institutions from various countries have also been received on exchange and gratis basis.

The division has maintained liaison with institutions, universities and ministries. A number of reports on the research activities of the Institute were compiled and sent to the Ministry of Earth Sciences, India Meteorological Department, universities and research institutes. English and Hindi Version of the Institute's Annual Report for 2015-16, Director's Reports for the Meetings of the Governing Council and Research Advisory Committee, Institute's input for Annual Report of the Ministry of Earth Sciences, etc. were compiled. Various reports in respect of 12th Five Year Plan schemes were compiled and provided to the MoES.

Institute's website is being regularly updated. Latest information on various activities, achievements, tenders, jobs, etc. is being uploaded from time to time. Access to library catalogue, subscribed to and open access journals, papers and research reports of the Institute's scientists, annual reports, meteorological data, scientists' profiles, etc. has been made available at the Institute's website.

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

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

Management

Governing Council

As per the Notification No. O.M. No. 25/10/2006 dated 19 July 2006 from the President of India, the Indian Institute of Tropical Meteorology (IITM), Pune has been transferred from the Department of Science and Technology (Ministry of Science and Technology) to the Ministry of Earth Sciences, Government of India with effect from 12 July 2006. The management of the Institute vests with its Governing Council at the apex level comprising of a Chairman and twelve Members, consisting seven outside senior scientists, Director General of Meteorology, three Senior Representatives of the Ministry of Earth Sciences including Financial Advisor, and Director, IITM as the Member Secretary. Administrative Officer (*now* Senior Manager), IITM is the Non-Member Secretary. Prof. V.K. Gaur is the Chairman of the Council w.e.f. 22 July 2014. The Governing Council meets twice a year. During the year 2016-17, the Governing Council had its 93rd and 94th meetings on 30 August 2016 and 01 February 2017 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

Chairman is nominated by the Governing Council. The senior most scientist of the Institute is the Member Secretary. The roles and functions of the Research Advisory Committee are (i) to advice and recommend thrust areas and research programs of the Institute and to monitor and evaluate its programs from time to time, (ii) to recommend in general the allocation of funds to various activities of the Institute to enable it to achieve academic excellence, (iii) to recommend new areas of research to be undertaken by the Institute, and (iv) to advice upon and recommend the creation of posts for priority areas of research. The 11th meeting of the Research Advisory Committee was held during 19-20 January 2017 under the Chairmanship of Prof. J. Srinivasan. Director of IITM and all the Chief Project Scientists made presentations on the achievements and the future plans of their respective research and development projects.

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 2017

Category	No. of Posts
Research	147
Scientific Support Staff	15
Technical Support Staff	06
Admin. Support Staff	39
MTS	19
Total	**226**

Staff Changes

Appointments: Research Staff

- Prof. Ravi Shankar Nanjundiah, Director, 02 March 2017.

Appointments: Administrative Staff

- Mr. Ajit Prasad P., Administrative Officer Grade-III, 01 March 2017.

Relieved: Administrative Staff

- Mr. V.R. Patil, Senior Manager, 01 February 2017 (Deputation period ended).

Retirement on Superannuation

- Dr. H.P. Borgaonkar, Scientist-E, 30 April 2016.
- Mr. A.L. Sagar, Scientific Assistant Grade-B, 31 May 2016.
- Mr. U.R. Kashid, MTS, 31 May 2016.
- Mr. P.S. Jagtap, Technician Grade-D, 31 May 2016.
- Mrs. D.J. Titkare, MTS, 30 June 2016.
- Mrs. A. R. Seshagiri, Scientific Officer Grade-II, 31 July 2016.
- Mr. A.B. Sikder, Scientist-E, 31 October 2016.
- Mr. Birendra Singh Bhandari, MTS, 31 January 2017.

Resignation

- Mr. M.A. Shinde, Junior Scientific Officer, 25 November 2016.
- Mr. Amit Kumar Verma , Scientist-B, 12 January 2017.

Temporary Transfer

- Mr. B. Balaji, Scientist-C to INCOIS, Hyderabad, 04 May 2016 (one year).

Resignation after Lien Period

- Mr. Alok Sagar Gautam, Scientific Assistant Grade-A, 26 June 2013 (vide Office Order No. 2/236/2016 dated 29.11.2016).

Status of SC/ST/OBC/ Reservation as on 31 March 2017:

Category	SC	ST	OBC	Total
Research	12	06	23	41
Scientific Support Staff	03	05	01	09
Technical Support Staff	03	00	00	03
Isolated Staff	00	00	00	00
Administrative Support Staff	04	05	05	14
MTS	07	02	02	11
Total	**29**	**18**	**31**	**78**

Employment of Ex-servicemen

Reservation for Ex-servicemen is made at 10% in Group-C and MTS posts of the Institute. The percentage of Ex-servicemen at the Institute via-a-vis total number of employees in group of 'A', 'B', 'C' and MTS is: Nil, Nil, 33.33% and 5.26% respectively.

Finance

Finance Committee

Finance Committee constituted by the Governing Council meets twice in a year and reviews the financial performance of the Institute and provides guidance for improvement of the performance. The Finance Committee held its 31st and 32nd meetings at IITM, Pune on 29 August 2016 and 31 January 2017 respectively. The present Finance Committee is chaired by Prof. V.K. Gaur.

Budget

The grant received and the actual expenditure incurred for the period 2016-17 are as follows (In Crores):

Sr. No.	Schemes	Opening Balance	Funds received	Other Receipts	Total Funds	Total Expenditure	Closing Balance
1	Advanced Training in Earth System Science & Climate	8.25	0.00	0.66	8.91	4.09	4.82
2	Centre for Climate Change Research	0.43	7.66	0.62	8.71	1.74	6.97
3	High Performance Computer System	38.93	170.48	3.57	212.98	155.68	57.30
4	IITM Operations & Maintenance	1.13	21.00	0.59	22.72	21.78	0.94
5	Metropolitan Air Quality & Weather Services	0.52	8.57	0.74	9.83	7.22	2.61
6	Monsoon Mission	6.18	11.66	0.60	18.44	18.91	-0.47
7	Physics and Dynamics of Tropical Clouds	-3.74	30.98	1.08	28.32	20.15	8.17
8	Short Term Climate Prediction & Variability	3.59	6.76	0.62	10.97	4.42	6.55
9	National Facility for Airborne Research (NFAR)	7.86	0.00	0.74	8.60	0.05	8.55
	Total	**63.15**	**257.11**	**9.22**	**329.48**	**234.04**	**95.44**
	Non-Plan	2.56	32.85	1.91	37.32	33.54	3.78
	Sponsored Projects	0.33	0.94	0.00	1.27	0.68	0.59
	Net Total	**66.04**	**290.90**	**11.13**	**368.07**	**268.26**	**99.81**

The Auditors appointed by the Governing Council M/s C.R. SAGDEO & Co., Pune conducted the audit for the year 2016-17. The abstract of the report is enclosed at the end of this report.

Purchase and Stores

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

During the period, the following purchases were made:

	Institute Funds (in Rs.)	Project Funds (in Rs.)	Total (in Rs.)
Equipment	**542,475,891.50**	**55,125.00**	**542,531,016.50**
Consumable	**774,000.00**	**39,247.50**	**813,247.50**
Dead Stock	**150,910.00**	**0.00**	**150,910.00**
Total	**543,400,801.50**	**94,372.50**	**543,495,174.00**

Official Language Implementation

- Continuous efforts are being made for compliance of Official Language Policy of the Union.
- Four Official Language Implementation Committee (OLIC) meetings were held on 14 June 2016, 25 August 2016, 26 December 2016 and 14 March 2017.
- Eleventh edition of the in-house Hindi magazine '*Indradhanush*' was released at the hands of Dr. A.K. Sahai, Executive Director and Chairman, Hindi Advisory Committee of IITM in the OLIC meeting held on 14 June 2016.
- A one day Hindi workshop was organised at IITM on 24 June 2016 where Mrs. Swati Chaddha, Hindi Officer, NCL, Pune; Dr. D.M. Chate, Scientist-E and Mr. D.K. Trivedi, Scientist-C delivered lectures. Dr. O.N. Shukla, Deputy Manager (Hindi) organized other Hindi workshops on 'Noting and Drafting', and 'Official Language Policy and Different Forms of Writing' on 16 September 2016 and 16 December 2016 respectively.
- A one day Hindi workshop on 'Use of Technology in the Progress of Official Language' was organized on 15 March 2017 by Mr. R.P. Verma, Assistant Director (Typing and Stenography), Hindi Teaching Scheme, Department of Official Language, Govt. of India.
- **Hindi Week Celebrations**: IITM celebrated Hindi Week during 14-21 September 2016. Different competitions such as essay writing, *antakshari*, solo song, noting and drafting were organised during the week. Many employees participated in these competitions. *Akhil Bharatiya Kavi Sammelan* was organised on 14 September 2016 as part of the celebrations. Renowned poets of national repute participated in the programme. Hindi week celebrations concluded with distribution of prizes on 21 September 2016. The prizes to the winners were distributed at the hands of Dr. A.K. Sahai, Scientist-G and Chairman of IITM Hindi Advisory Committee and Mr. V.R. Patil, Senior Manager. Also, certificates were distributed to 30 employees who passed the Praveen and Pragya examinations under Hindi Teaching Scheme.
- Quarterly Progress Reports for progressive use of Hindi in the Institute for the quarters ending on 30 June 2016, 30 September 2016 and 31 December 2016 were prepared and sent to the Ministry of Earth Sciences and the Department of Official Language.
- Two half yearly meetings of the Town Official Language Implementation Committee-2, Pune were conducted on 21 June 2016 and 25 November 2016.
- Maintenance of Hindi Library is being done and the issue and receipt of books is being made regularly.
- Hindi version of the IITM website is being updated regularly.

Awards and Honours

Dr. R. Krishnan

- Elected as Fellow of the Indian Academy of Sciences 2017.
- Chair, Session on 'Remote Sensing and Climate-II', 10th SPIE Asia-Pacific Remote Sensing Symposium, New Delhi, 04-07 April 2016.
- Invited as Coordinating Lead Author (CLA) - Climate Change in the Hindu Kush Himalayan Region (HKH) in the Hindu Kush Himalayan Monitoring and Assessment Program (HIMAP) Writeshop, International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, 11-13 June 2016.
- Chair, Panel Discussion on 'Framing the 1.5°C Climate Challenge: Integrating SDGs, climate policy and climate action', and a technical session on 'Dynamics of Ecosystem Services and Climate Science', Third National Consultation on Climate Change Responses of the ASSAR consortia of the CARIAA project organised by Indian Institute for Human Settlements (IIHS), Bengaluru at the India International Centre, New Delhi on 23 March 2017.

Dr. G. Beig

- Member, WCRP Core-Project for Stratosphere-Troposphere Processes and their Role in Climate (SPARC) for an initial term of three years (January 2016 onwards).
- Honorary Professor, Amity University, Rajasthan (awarded on 21 January 2017).

Dr. A.K. Sahai

- Assumed additional charge as Head, Office of Climate Research and Services, India Meteorological Department, Pune w.e.f. 01 January 2017.

Dr. A. Suryachandra Rao and **Dr. Bipin Kumar**

- Member, Applications Group of the National Super Computing Mission, India.

Dr. C. Gnanaseelan

- Adjunct Faculty, Indian Institute of Technology, Bhubaneswar.
- Visiting Scholar, University of Hyderabad.

Dr. (Mrs.) Ashwini Kulkarni

- Expert Member, Committee on Environment and Climate Change to evaluate planned schemes of the MOEF&CC.
- Nominated to 'Empirical Statistical Downscaling Group-Asia'.

Dr. Thara Prabhakaran

- Chaired two sessions on Satellite Data Assimilation, 10th SPIE Asia-Pacific Remote Sensing Symposium, New Delhi, 04-07 April 2016.
- Member, Programme Advisory and Monitoring Committee (PAMC) on Atmospheric Science, MoES.
- Invited as Resource Person, Technologies for Rural Development and their Commercialization (ITRDC-2017) Mega Event organised by Sinhgad Institute, Solapur and BARC Mumbai at Centre for Research and Technology Development, Sinhgad Institute, Solapur, 20 February 2017.
- Chief Guest, World Meteorological Day Celebrations, RMC Chennai on 23 March 2017.

Dr. S. Chakraborty

- Resource Person, International Earth Science Olympiad School, Department of Geology, Anna University, Chennai, 10-30 May 2016.
- Silver Jubilee Member, American Geophysical Union, 15 December 2016.

Dr. (Mrs.) S.S. Fadnavis

- Member-Secretary, Project Appraisal and Monitoring Committee for National Programme in Atmospheric Chemistry (PAMC-NAPC).

Dr. G. Pandithurai

- Invited as an Expert to review and recommend the atmospheric science proposals to Arctic Campaign by NCAOR, Goa during 27-28 April 2016.
- Chaired a session on 'Aerosol remote sensing', IASTA-2016, PRL, Ahmedabad, 06-08 December 2016.
- Chaired a session on 'Radar data assimilation', IRAD-2017, IIT-Kharagpur, during 08-11 January 2017.

- Elected as a Treasurer, India Radar Meteorological Society.

Dr. J. Sanjay

- Member, CORDEX Science Advisory Team (SAT) for a period of three years w.e.f. 01 January 2017.
- Lead Author, Climate Change in the Hindu Kush Himalayan Region (HKH) in the Hindu Kush Himalayan Monitoring and Assessment Program (HIMAP) Writeshop, International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, 11-13 June 2016.

Dr. P. Mukhopadhyay

- Member, International CLIVAR-GEWEX Working Group on Asian-Australian Monsoon (WG-AAM).

Dr. Vinu Valsala

- Nominated as Group Programme Coordinator/National Contact Point for the Belmont forum by Ministry of Earth Sciences (MoES).
- Elected as Indian National Young Academy of Science (INYAS) Member of Indian National Science Academy (INSA) for the period of 2016-2021.

Mr. S. Mahapatra

- Elected as Member, Executive Council, Indian Meteorological Society, Pune Chapter for the period 2016-2018.

Dr. (Mrs.) Swapna P.

- Member, Working Group on Coupled Modeling (WGCM), World Climate Research Programme (WCRP).
- Awarded the Ministry of Earth Sciences (MoES) Certificate of Merit for the year 2016 for her outstanding contribution in the field of Atmospheric Science and Technology.

Dr. Roxy Mathew Koll

- Chair, session on 'Scientific drivers: Indian Ocean coupled modes of variability', Indian Ocean Observing System (IndOOS) Review workshop, Perth, Australia, 30 January - 04 February 2017.
- Chief Guest, National Science Day Celebrations Programme/Exhibition, Acharya Sree Vijay Vallabh School, Pune, 28 February, 2017.

Dr. Sreenivas Pentakota

- Member, Board of Studies, Department of Meteorology and Oceanography, Andhra University, Visakhapatnam.

Dr. A. K. Srivastava

- Rapporteur for Panel Discussion on 'Linking Observations and Modeling for Air Quality and Climate', International Brainstorming Meeting on Air Quality and Climate Impacts, New Delhi, 04-07 October 2016.

Mrs. R.S. Salunke, Mr. R.D. Nair, Mr. S.A. Sayyad and **Mr. E.M. Botla**

- MoES Annual Award for Best Employees for the year 2016 under the category 'Group B', 'Group B', 'Group C' and 'Multi Tasking Staff' respectively.

Ms. Chaitri Roy

- Best Presentation Award, Advanced School on Earth System Modeling & Workshop on Climate Change and Regional Impacts over South Asia, IITM, Pune, 18-29 July 2016.

Dr. R.H. Kripalani

- Chair, session on 'Climate Change: Monsoons and Extreme Weather Events' and Main convener, session 'Tele-connections: Monsoons over South and East Asia', 13th Annual Meeting of the Asia Oceania Geosciences Society (AOGS2016), Beijing, China, 31 July – 05 August 2016.

Ms. Neelam Malap and Ms. Rohini P.

- Best Paper Award (Poster) in TROPMET, 15-22 December 2016.

Mr. U. Bhowmik

- First Prize (Oral Presentation) in IRAD-2017, IIT-Kharagpur, 08-11 January 2017.

Indian Meteorological Society (IMS) Awards

- **Indian Meteorological Society (IMS) Award 2016 for the best paper on 'Monsoon Research'** was conferred during TROPMET-2016, Bhubaneswar (Odisha) on 18 December 2016 to the paper entitled 'Mechanism of high rainfall over the Indian west coast region during the monsoon season' by Maheskumar R.S., Narkhedkar S.G., Morwal S.B., Padmakumari B., Kothawale D.R., Joshi R.R., Deshpande C.G., Bhalwankar R.V. and Kulkarni J.R. published in the journal Climate Dynamics,

43, September 2014, 1513-1529, DOI:10.1007/s00382-013-1972-9.

- **Indian Meteorological Society (IMS) Award 2016 for the best paper on 'Application of Satellite Data in Meteorology and Remote Sensing'** was conferred during TROPMET-2016, Bhubaneswar (Odisha) on 18 December 2016 to the paper entitled 'High-resolution outgoing longwave radiation dataset from Kalpana-1 satellite during 2004–2012' by Mahakur M., Prabhu A., Sharma A.K., Rao V.R., Senroy S., Singh R. and Goswami B.N. published in the journal Current Science, 105, October 2013, 1124-1133.

- **Indian Meteorological Society (IMS) Award 2016 for the best paper on** 'Tropical Meteorology' was conferred during TROPMET-2016, Bhubaneswar (Odisha) on 18 December 2016 to the paper entitled 'Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient' by Roxy M., Kapoor R., Terray P., Murtugudde R., Ashok K. and Goswami B.N. published in the journal Nature Communications, 6:7423, June 2015, DOI:10.1038/ncomms8423.

VISITORS

International

- **Dr. Harry Dixon**, Centre for Ecology & Hydrology (CEH), **UK**, 04 April 2016.
- **Dr. Hannah Nissan**, Columbia University, New York, **USA**, 19-24 April 2016 and 13-16 November 2016.
- **Prof. Phil Dickerson,** Group Leader, United States Environmental Protection Agency (US-EPA), Office of Air Quality Planning & Standards, North Carolina State University, **USA**, 22 April 2016.
- **Dr. J. Vivekanandan**, Senior Scientist, NCAR, **USA**, 24-28 May 2016.
- **Dr. Matt Handbury**, Executive Chairman, Australian Rain Technologies, **Australia**, 09 June 2016.
- **Ms. Kriti Bhargava**, Graduate Research Assistant of Prof. Eugenia Kalnay, Department of Atmospheric & Oceanic science, University of Maryland, **USA**, 10 June 2016.
- **Prof. Subrahmanyam Bulusu**, Professor of Satellite Oceanography & Physical Oceanography, School of Earth, Ocean and Environment, University of South Carolina, Columbia, **USA**, 17 June 2016.
- **Prof. S. Lakshmivarahan**, George Lynn Cross Research Professor, University of Oklahoma, Norman, **USA**, 18 June 2016.
- **Prof. Mark Sutton**, Chairman, International Nitrogen Initiative (INI) and Environmental Physicist, CEH, **UK**, 21 June 2016.
- **Dr. Martijn Lammers**, Liaison for Science, Technology & Innovation, and Consulate-General, **Kingdom of the Netherlands**, 08 July 2016.
- **Prof. Jun Matsumoto, Dr. Shoichi Shige, Prof. Taichi Hayashi, Prof. Toru Terao, Dr Hamada Jun-Ichi** and **Dr. Inoue**, Tokyo Metropolitan University, **Japan**, 08-12 August 2016.
- **Dr. Antonio Caetano Caltabiano**, Acting Executive Director, International CLIVAR Project Office Southampton, **UK**, 8-19 August 2016.
- **Dr. Nico Caltabiano,** Deputy Executive Director, International CLIVAR Project Office, 17 August 2016.
- **Prof. Thomas Peter**, Institute of Atmosphere and Climate (IAC), Zürich, **Switzerland**, 26 August 2016.
- **Prof. K.T. Paw**, University of California, Davis, **USA**, 04 November 2016.
- **Dr. George Burba**, Licor Biosciences, **USA**, 09 November 2016.
- **Dr. Harry Dixon**, Senior Hydrologist, Centre for Ecology & Hydrology (CEH), **UK**, 04 April and 13-16 November 2016.
- **Dr. Georgina Cundill Kemp**, Senior Program Officer, Adaptation at Scale in Semi-Arid Regions - Collaborative Adaptation Research Initiative in Africa and Asia (ASSAR-CARIAA), International Development Research Centre (IDRC) **Canada**, 18 November 2016.
- **Ms. Lucia Scodanibbio**, ASSAR Project Manager, ACDI, University of Cape Town (UCT) **South Africa**, 18 November 2016.
- **Prof. Raghu Murtugudde**, CBFS Executive Director, CMNS-Atmospheric & Oceanic Science, Earth System Science Interdisciplinary Center, University of Maryland, **USA**, 24 November 2016.
- **Dr. Andre Prevot**, Paul Scherrer Institute, **Switzerland**, 30 November - 01 December 2016.
- **Mr. Fredrick J. Brechtel**, BMI, **USA**, 05 December 2016.
- **Prof. Jun Matsumoto, Dr. Tomoshige Inoue** and **Prof. Taici Hayashi,** Tokyo Metropolitan University, Japan and **Prof Toru Terao** from Faculty of Education, Kagawa University, Kagawa, **Japan**, 19-24 December 2016.
- **Prof. Wojciech Grabowski**, Senior Scientist and Distinguished Professor, NCAR, **USA**, 29 December 2016 to 10 January 2017.
- **Prof. Atul Jain**, Professor, Department of Atmospheric Sciences, University of Illinois, Urbana-Champagne, **USA**, 12-15 January 2017.
- **Dr. Ibrahim Hoteit**, Physical Sciences and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, **Saudi Arabia**, 01 February 2017.
- **Dr. Andrew Turner**, NCAS-Climate & Department of Meteorology, Lecturer in Monsoon Systems, Dept. of Meteorology, University of Reading, **UK**, 18 February 2017.

- **Dr. H. Annamalai**, Senior Researcher, Affiliate Researcher, Meteorology International Pacific Research Center School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, **Hawaii**, 27 July 2016 and 18 February 2017.
- **Prof. Marianne T. Lund** and **Dr. Bjørn H. Samset**, Research Directors, CICERO Center for International Climate and Environmental Research, Oslo, **Norway**, 07 March 2017.
- **Dr. Alexandru Rap,** School of Earth and Environment, University of Leeds, **UK**, 24 March 2017.

National

- **Dr. R.V. Sharma**, Consultant, Maharashtra state government, 11 April 2016.
- **Ms. Jisha Joseph**, PhD Scholar, IIT Bombay, Mumbai, 11-14 May 2016.
- **Dr. Kunal Chakraborty**, Scientist, INCOIS, Hyderabad, 16 June 2016.
- **Dr. Arun Srivastava**, Assistant Professor, Jawaharlal Nehru University (JNU), New Delhi, 24 June 2016.
- **Dr. Srinivasa Ramanujam Kannan**, Assistant Professor, School of Mechanical Sciences, IIT Bhubaneswar, 28 June 2016.
- **Dr Abhilash S.**, Assistant Professor, Cochin University of Science and Technology, Kochi, 05-11 July 2016.
- **Prof. Sreedhar Balasubrahmanyam**, Department of Mechanical Engineering, Interdisciplinary Program on Climate Change, IIT Bombay, 11 July 2016.
- **Prof. Swaroop Sahoo** and 3 other faculty members, Amrita University, Coimbatore, 22-23 July 2016. They also visited radar facility and HACPL.
- **Prof. M. Sarin,** Member of National Scientific Steering Committee, CAIPEEX, 19 August 2016.
- **Mr. Kalyan Chakravarthy**, Indian Administrative Service (IAS), Director General, Environment Protection Training and Research Institute, Hyderabad, 09 September 2016.
- **Dr. Vidyadhar Mudkavi**, CSIR-4PI, Bengaluru, 15-16 September 2016.
- **Dr. Amir Bashir Bazaz**, Senior Consultant-Practice, Indian Institute for Human Settlements (IIHS) Bengaluru, 18 November 2016.
- **Dr. Y.S. Mayya, Prof. R.M. Thaokar** and coworkers, IIT, Mumbai, 06 March 2017.

Visitors to HACPL, Mahabaleshwar/RADAR Site, Mandhardev

- **Mr. B. Mukhopadhyay**, ADGM and **Dr. R. R. Mali**, DDGM, IMD, Pune, 10 December 2016.
- **Dr. Jagvir Singh**, Scientist-F, MoES, New Delhi, 17 December 2016.
- **Prof. Jai Oh**, Professor, Dept. of Env. & Atmos. Sci. and Director of PKNU Supercomputer Center, Pukyong National University, Busan, South Korea, 11 February 2017.
- **Prof. D. Sengupta**, IISc, Bengaluru, **Dr. M. Ravichandran**, NCAOR, Goa and others, 02 July 2016.
- **Prof. Sudhir Agashe** and his colleagues from Department of Instrumentation and Control, College of Engineering, Pune, 18 November 2016.

SEMINARS

By Visitors

Prof. Phil Dickerson, Group Leader, United States Environmental Protection Agency (US-EPA), Office of Air Quality Planning & Standards, North Carolina State University, USA

- US EPA Air Now System - History, Purpose, and Future, 22 April 2016.

Dr. Matt Handbury, Executive Chairman, Australian Rain Technologies

- Statistical methodologies for rain enhancement with high confidence, 09 June 2016.

Ms. Kriti Bhargava, Graduate Research Assistant of Prof. Eugenia Kalnay, Department of Atmospheric & Oceanic science, University of Maryland

- Estimation and correction of systematic model errors in GFS, 10 June 2016.

Dr. Kunal Chakraborty, Scientist, INCOIS, Hyderabad

- Efforts of setting up biogeochemical model configuration using ROMS at high resolutions in the Indian Ocean, 16 June 2016.

Prof. Subrahmanyam Bulusu, Professor of Satellite Oceanography & Physical Oceanography, School of Earth, Ocean and Environment, University of South Carolina, Columbia, USA

- Role of ocean dynamics in the MJO initiation over the Indian Ocean, 17 June 2016.

Prof. S. Lakshmivarahan, George Lynn Cross Research Professor, University of Oklahoma, Norman, USA

- Unscented Kalman Filters, 18 June 2016.

Dr. Arun Srivastava, Assistant Professor, Jawaharlal Nehru University (JNU), New Delhi

- Quantifying enhancement in aerosol radiative forcing during 'extreme aerosol days' in summer at Delhi National Capital Region, India, 24 June 2016.

Dr. Srinivasa Ramanujam Kannan, Assistant Professor, School of Mechanical Sciences, IIT Bhubaneswar

- Information theoretic approach for model-observation synergy, 28 June 2016.

Prof. Sreedhar Balasubrahmanyam, Dept. of Mechanical Engineering, Interdisciplinary Program on Climate Change, IIT Bombay

- Using experimentation to study bulk and local mixing dynamics in stratified fluids, 11 July 2016.

Dr. Nico Caltabiano, Deputy Executive Director, International CLIVAR Project Office,

- An overview of CLIVAR activities - Role of India, 17 August 2016.

Prof. Thomas Peter, Institute of Atmosphere and Climate (IAC), Zürich, Switzerland

- Accuracy of upper tropospheric humidity measurements and the 2016 balloon campaign in Nainital, India, 26 August 2016.

Prof. K.T. Paw, University of California, Davis, USA

- Evapotranspiration measurements and modelling with biomicrometeorological methods at UC Davis, 04 November 2016.

Dr. George Burba, Licor Biosciences, USA

- Review: Novel use of high-speed open path technology in various applications for mobile methane measurements by research organizations and regulatory agencies, 09 November 2016.

Prof. Raghu Murtugudde, CBFS Executive Director, CMNS-Atmospheric & Oceanic Science, Earth System Science Interdisciplinary Center, University of Maryland, USA

- ITCZ, Tropical Atlantic and the Indian monsoon, 24 November 2016.

Dr. Andre Prevot, Paul Scherrer Institute, Switzerland

- Organic aerosols: Source apportionment and aging studies, 01 December 2016.

Dr. Pranav Khawale, National Institute of Naturopathy (NIN), Pune

- A special lecture on Naturopathy, 02 December 2016.

Dr. Fred Bretchel, BMI, USA

- Advanced Aerosol Technology for Aerosol and Cloud Research, 05 December 2016.

Prof. Wojciech W. Grabowski, Senior Scientist and Distinguished Professor, NCAR, USA

- Modeling condensation in cloud-scale models, 09 January 2017.

Prof. Atul Jain, Professor, Department of Atmospheric Sciences, University of Illinois, Urbana-Champagne, USA

- The implications of growing bioenergy crops on water resources, carbon and nitrogen dynamics in the United States, 12 January 2017.
- (1) The influence of man on climate and (2) Global biogeochemical cycles and climate change, 14 January 2017.

Dr. Ibrahim Hoteit, Physical Sciences and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

- A data-driven modelling system for studying and forecasting the circulation and climate of the Red Sea, 01 February 2017.

Prof. Marianne T. Lund and **Dr. Bjørn H. Samset**, Research Directors, CICERO Center for International Climate and Environmental Research - Oslo, Norway

- Precipitation and response model inter-comparision Project (PDRMIR)-Climate Research at CICERO, 07 March 2017.

Dr. Venkata Ratnam Jayanthi, Senior Scientist, Japan Agency for Marine-Earth-Science and Technology (JAMSTEC), Japan

- Improvements to SINTEX-F2 CGCM seasonal forecasts using dynamical downscaling, 10 March 2017.

Dr. Alexandru Rap, School of Earth and Environment, University of Leeds, UK

- Aerosol and ozone radiative effects, 24 March 2017.

Internal Discussions Seminars

Dr. P. Mukhopadhyay

- Short-range prediction, IITM Monsoon Discussion Forum, 22 June 2016.

Dr. Susmitha Joseph

- Extended-range prediction, IITM Monsoon Discussion Forum, 22 June 2016.

Mr. Ankur Srivastava

- Seasonal prediction of the onset and initial progression phase of 2016 monsoon, IITM Monsoon Discussion Forum, 22 June 2016.

Dr. J.R. Kulkarni

- Brief on observational features, IITM Monsoon Discussion Forum, 22 June 2016.

Seminar on PhD proposal

Ms. Pallavi Buchunde

- Carbonaceous aerosols and particulate matter pollutants over high altitude: Temporal variation and their role in the new particle formation and associated cloud condensation nuclei, 19 May 2016.

Seminar on PhD Synopsis

Ms. Fousiya T.S.

- Seasonal and intra-seasonal variability of surface and subsurface processes in the Bay of Bengal from observations and model, 08 November 2016.

Ms. Divya Surendran

- Impact of Emission Scenarios and associated transport processes over India using Global Chemical Transport Model- MOZART-4, 27 December 2016.

Lectures Delivered Outside

Dr. A. Suryachandra Rao

- Lectures on Ocean Dynamics, M.Sc. Students of University Centre for Earth and Space Sciences (UCESS), University of Hyderabad, 05-09 April 2016.
- Lectures on Ocean-Atmosphere Interactions, M.Sc. Students of University Centre for Earth and Space Sciences (UCESS), University of Hyderabad, 08-09 and 12 November 2016.

Dr. S. Chakraborty

- Lectures on Oceanography, International Earth Science Olympiad School, Department of Geology, Anna University, Chennai, 11-13 May 2016.

Dr (Mrs) Ashwini Kulkarni

- Applications of Statistics in Atmospheric Science, World Statistics Day Lecture, Modern College, Pune, 02 July 2016.

Dr. P. Mukhopadhyay

- Monsoon ISO and related moist processes In Model and observation, CAOS, IISc, Bengaluru, 20-21 September 2016.

Dr. J. Sanjay

- ESGF for CORDEX, Advanced School on Earth System Modelling (ESM), IITM, Pune, 26 July 2016.

Dr. Suvarna Fadnavis

- Atmospheric Chemistry and UTLS, Advanced School on Earth System Modelling (ESM), IITM, Pune, 28 July 2016.

Dr. Vinu Valsala

- Turbulence and Physical Oceanography, Meteorologist Grade-II trainees, Advanced course, IMD, Pune, May-June 2016. (*Lecture series*)

Mr. S. Mahapatra

- i) Meteorological prediction and warning systems and ii) ICT systems using modern equipment, Emergency Operation Centers (EOCs) in Disaster Management (Monsoon preparedness) training, YASHADA, Pune, 16 May 2016.
- Prediction and warning systems for severe weather conditions, Incident Response System in Disaster Management training, YASHADA, Pune, 23 May 2016.

Dr. Roxy Mathew Koll

- Climate science, Meteorologist Grade-II Trainee Scientists of Meteorological Training Institute, IMD, Pune, April-May 2016.
- i) Data Analysis, Model Diagnostics and Visualization using CDO and Ferret, and ii) Modeling Ocean Biogeochemistry using IITM-ESM and biophysical feedbacks in the Indian Ocean, Advanced School on Earth System Modelling (ESM), IITM, Pune, 25-27 July 2016.
- i) Interaction of Asian Monsoon and global oceans, and ii) Seasonal to subseasonal modeling and monsoon prediction, Training School on Monsoon Variability in Changing Climate, Jeju National University, South Korea, 16-21 January 2017.

Dr. Hamza Varikoden

- i) Fundamentals of Climate Modelling, and ii) An Introduction to downscaling, Faculty Development Programme, National Institute of Technology, Calicut, Kerala, 29-30 August 2016.

Dr. (Mrs.) Medha Deshpande

- Performance of GFS-1534 and GEFS-574 during 2016 summer monsoon and post-monsoon Cyclones, RMC, IMD, Nagpur, 19-20 January 2017.

Dr. R.H. Kripalani

- Statistical Applications in oceanic and atmospheric sciences, Meteorologist Grade-II Trainees Batch 21 and 22, India Meteorological Department, May 2016 - January 2017.
- Multi-decadal variability in the Indian summer monsoon rainfall using proxy data, Global Modeling Climate Laboratory, Pusan National University, Busan, South Korea, 23 December 2016.

DEPUTATIONS ABROAD

Dr. R. Krishnan

- To participate as Coordinating Lead Author (CLA) in the Hindu Kush Himalayan Monitoring and Assessment Program (HIMAP) Writeshop, Kathmandu, **Nepal**, 11-13 June 2016.
- WCRP CLIVAR Open Conference-2016 and related events, Qingdao, **China**, 18-25 September 2016.
- As part of the delegation headed by Secretary, MoES to participate in a scientific workshop followed by a symposium on 'Past, Present, Future of Predicting Ocean and Climate Variability' held at JAMSTEC Yokohama Institute and at Hongo Campus, University of Tokyo, Tokyo, **Japan**, 25-26 January 2017.

Dr. G. Beig

- 9th International Workshop on long term changes and trends in the atmosphere, Kuhlungsborn, **Germany**, 19-23 September 2016.
- SPARC SSG-24 Meeting and Local Workshop, Berlin, **Germany**, 31 October – 04 November 2016.
- As a member of Advisory Group of GURME, WMO workshop Urban Health and Short Leave Climate Pollutants Reduction Project, Accra, **Ghana**, 27-30 November 2016.

Dr. A.K. Sahai

- Eighth Session of the 'South Asian Climate Outlook Forum (SASCOF-8) and Climate Services User Forums for the Water Sector (CSUF-Water) and the Health Sector (CSUF-Health)', Department of Meteorology of Sri Lanka, Colombo, **Sri Lanka**, 26-28 April 2016.
- South Asian Climate Outlook Forum (SASCOF-9), Nay Pyi Taw, **Myanmar**, 27-28 September 2016.

Dr. A. Suryachandra Rao

- To participate and to serve as an expert in the Eighth Session of the South Asian Climate Outlook Forum (SASCOF-8) and Training Workshop, Colombo, **Sri Lanka**, 22-26 April 2016.
- To deliver lectures at ICTP-IITM-COLA Targeted Training Activity (TTA) on 'Towards Improved Monsoon Simulations', The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 13-17 June 2016.
- To attend the programme committee of HPC to deliver a short talk on 'Status Report from India' as a part of programme 'Status Report from Asian HPC' in the International Supercomputing Conference (ISC), Frankfurt, **Germany**, 19-22 June 2016.

Dr. H.P. Borgaonkar

- Asia-Pacific Network (APN) 21st Inter-Governmental Meeting (IGM)/Scientific Planning Group (SPG) Meeting, Zhengzhou, **China**, 18-21 April 2016.

Dr. S.D. Pawar and **Dr. V. Gopalakrishnan**

- To conduct experiment in cloud chamber and to discuss problems involving aerosol effects in electrified cloud using models at A.I. Voeikov Main Geophysical Observatory (MGO), St. Petersburg, **Russia**, 15-30 April 2016.

Dr. V. Gopalakrishnan

- Batsheva de Rothschild Seminar on the Atmospheric Global Electric Circuit (GEC), Tel Aviv, Mitzpe Ramon, **Israel**, 05-10 February 2017.

Dr. (Mrs.) Thara Prabhakaran

- Pre-meeting on data analysis and software workshop for airborne observations and the 17th International Conference on clouds and precipitation ICCP meeting at University of Manchester, **UK**, 23-29 July 2016.

Dr. S. Chakraborty and **Dr. T.P. Sabin**

- American Geophysical Union (AGU) Fall Meeting, San Francisco, **USA**, 12-16 December 2016.

Dr. (Mrs.) Ashwini Kulkarni

- APN South Asia Collaborative Approach Workshop, Paro, **Bhutan**, 12-13 December 2016.

Dr. J. Sanjay

- International Conference on Regional Climate (ICRC)-CORDEX 2016, Stockholm, **Sweden**, 17-20 May 2016.
- ICIMOD Himalayan Monitoring and Assessment Programme (HIMAP) Editing Writeshop, Kavrepalanchowk, **Nepal**, 26-30 September 2016.

Dr. Suresh Tiwari

- 7th International Conference on Fog, Fog collection and Dew, Wroclaw, **Poland**, 24-29 July 2016.
- American Geophysical Union (AGU) Fall Meeting, San Francisco, **USA**, 12-16 December 2016.

Dr. (Mrs.) S.S. Fadnavis

- ISSI Team Meeting on Stratospheric Sulfur and its Role in Climate (SSiRC) at International Space Science Institute, Bern, **Switzerland**, 30 January – 02 February 2017.

Dr. P. Mukhopadhyay

- Max-Planck Institute for Meteorology, Hamburg, **Germany**, 08-10 June 2016.
- To deliver invited lectures in the workshop 'Grand Challenges in monsoon modeling: representation of processes in climate models' during 12-13 June 2016 and to deliver lectures at ICTP-IITM-COLA Targeted Training Activity (TTA): Towards Improved Monsoon Simulations, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 13-17 June 2016.

Dr. Vinu Valsala

- National Institute of Environmental Studies (NIES), Tsukuba, **Japan**, 21-29 January 2017.

Dr. Ramesh Vellore

- CARIAA workshop on 1.5 Degrees: Meeting the challenges of the Paris Climate Agreement, and Collaborative work on aerosol impacts on the Indian monsoons using the IITM Earth System Model (ESM) developed at IITM, University of Edinburgn, **UK**, 22-25 September 2016.
- Belmont Forum JPI Climate Funded GOTHAM Project Meeting at the University of Oxford, Oxford, **UK**, 26-30 September 2016.

Dr. H.S. Chaudhari

- Climate Modeling perspective of Asia Monsoon Workshop, Busan, **South Korea**, 09-16 August 2016.

Mr. P. Murugavel

- Collaboration with NCAR – short Time Scholar in the Visiting Scientist Programme. The main aim is to investigate the characteristics of Cloud Population during DYNAMO Experiment & during the Intra-seasonal phases of India Summer Monsoon at National Center for Atmospheric Research (NCAR), Boulder, Colorado, **USA**, 05 September - 05 November 2016.
- C - Band Radar Training and Factory Acceptance Test, Neuss, **Germany**, 01 March – 03 April 2017.

Dr. Anoop Mahajan

- Second International Young Scholars Zhuhai Forum of Sun Yat-Sen University (SYSU), Zhuhai, **China**, 16-20 June 2016.
- Participation in the Southern Ocean Expedition at Mauritius, Southern Ocean, 20 December 2016 – 06 March 2017.

Dr. (Mrs.) Swapna P.

- 20th session of Working Group on Coupled Modeling (WGCM) and the Modeling Hierarchies Workshop at Princeton University, New jersey, **USA**, 01-04 November 2016.
- IPCC WCRP workshop on Connecting Climate Model Evaluation to Fitness-for-Purpose at Max Planck Institute for Meteorology, Hamburg, **Germany**, 23-24 February 2017.

Dr. Roxy Mathew Koll

- GEWEX-CLIVAR (World Climate Research Programme) Monsoon Panel Meeting and poster presentation at the WCRP CLIVAR Open Science Conference-2016, Qingdao, **China**, 17-25 September 2016.
- ICTP Workshop on Teleconnections in the Present and Future Climate and the Euro-Mediterranean Centre on Climate Change (CMCC) Climate Lecture Series at the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 24 October – 01 November 2016.
- Training School on Monsoon Variability in Changing Climate organized by the World Climate Research Program (WCRP) at Jeju National University, **South Korea**, 15-21 January 2017.
- International Indian Ocean science conference organized by CLIVAR-UNESCO Intergovernmental Oceanograhic Commission, Perth, **Australia**, 30 January – 04 February 2017.

Dr. Bipin Kumar

- 17th International Conference on Clouds & Precipitation (ICCP), University of Manchester, **UK** and interactions to establish collaboration on the topic related to particle tracing, collision and interaction for one day at Dublin City University (DCU), **Ireland**, 25-29 July 2016.

Dr. R.K. Yadav, Dr. M.K. Joshi and **Mr. Vineet Kumar Singh**

- ICTP Workshop on Teleconnections in the Present and Future Climate, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 24-28 October 2016.

Dr. Kaustav Chakravarty

- Collaboration with NCAR – short Time Scholar in the Visiting Scientist Programme and to investigate the characteristics of Cloud Population during DYNAMO Experiment & during the Intra-seasonal phases of India Summer Monsoon at National Center for Atmospheric Research (NCAR), Boulder and to visit and have discussions with the scientists of Pacific Northwest Laboratory (PNNL), Colorado, USA and Richland, **USA**, 05 September - 05 November 2016.

Dr. Y.K. Tiwari

- 8th Asia Pacific GAW workshop on greenhouse gases and 3rd GAW Asia Pacific Training and Education course, Seoul, **South Korea**, 17-21 October 2016.

Dr. J.S. Chowdary

- Visiting scholar to the State Key Laboratory of Tropical Oceanography (LTO), South China Sea Institute of Oceanology (SCSIO), Chinese Academy of Science, Guangzhou, **China**, 25 July – 25 August 2016.
- 13th Annual Meeting of the Asian Oceania Geosciences Society (AOGS 2016), Beijing, **China,** 31 July – 05 August 2016.

Dr. Naveen Gandhi

- APN South Asia Proposal Development Training Workshop (PDTW), Paro, **Bhutan**, 14-16 December 2016.

Dr. Abhilash S. Panicker

- Collaborative research with International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 12 October – 15 November 2016.

Mrs. Rohini Bhalwankar

- 17th International Conference on Clouds & Precipitation (ICCP), University of Manchester, **UK**, 25-29 July 2016.

Dr. A.K. Srivastava

- Participation in the 22nd European Aerosol Conference at Tours, **France**, 04-09 September 2016.

Dr. (Mrs.) Medha Deshpande

- Seventh NCEP Ensemble User Workshop, 13-15 June 2016, Eighth NAEFS Workshop, 15-17 June 2016, Discussion with NCEP on GEFS System, National Center for Climate and Weather Prediction, College Park, Maryland, **USA**, 13 June – 01 July 2016.

Mr. Sunil Sonbawne

- Training on sensors, sondes interfacing and scientific exchange, Lindenberg, **Germany**, 11-14 April 2016.

Mr. G.R. Chinthalu

- 13th Pan Ocean Remote Sensing Conference (PORSEC 2016), Fortaleza, Ceara State, **Brazil**, 08-11 November 2016.

Mr. Bhupendra Bahadur Singh

- Fifth Annual ARC Centre of Excellence for Climate System Science Winter School, School of Earth Atmosphere and Environment, Monash University (Clayton Campus), **Australia**, 20-24 June 2016.

Mr. Subharthi Chowdhuri

- Australian Meteorology and Oceanographic Conference, Australian National University, Canberra, **Australia**, 07-10 February 2017.

Mr. Sudarshan Bera, Mr. Harikrishna Gandham and **Mr. Soumya Samanta**

- Summer School on Aerosol Cloud Interactions and the International CFMIP Conference on Clouds, Circulation and Climate Sensitivity, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 27 June - 07 July 2016.

Mr. Sandeep Narayanasetti, Mr. Manmeet Singh, Mr. Maheswar Pradhan, Mr. Avijit Dey, Mr. Kumar Roy, Mr. Abhishek Gupta, Mr. Panini Dasgupta and **Ms. Dipti Hingmire**

- ICTP-IITM-COLA Targeted Training Activity (TTA) on

Towards Improved Monsoon Simulations, The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, **Italy**, 13-17 June 2016.

Mr. Mriganka Biswas

- Participation in the 36th Indian Scientific Expedition to Antarctica for atmospheric data collection using MAX-DOAS instrument at Maitri and Bharati Stations, **Antarctica**, 17 December 2016 - 02 April 2017.

Mr. Sahadat Sarkar and **Ms. Aditi Modi**

- WCRP CLIVAR Open Science Conference-2016 and CLIVAR Early Career Scientist Symposium (ECSS), Qingdao, **China**, 17-25 September 2016.

Mr. Subrata Mukherjee

- SOFI (Source Finder) workshop and participated in ACSM data analysis training, Paul Scherer Institute, **Switzerland**, 11-22 April 2016.

Ms. Snehlata Tirkey and **Mr. Srinivas Gangiredla**

- WCRP-JNU Training School on Monsoon Variability in Changing Climate, Jeju National University (JNU), **Republic of Korea**, 16-20 January 2017.

Mrs. V.V. Sapre

- 7th Asian-Pacific Conference on Library and Information Education and Practice (A-LIEP-2016) and present poster paper in the conference, Nanjing, **China**, 03-04 November 2016.

Dr. R.H. Kripalani

- 13th Annual Meeting of the Asia Oceania Geosciences Society (AOGS2016), Beijing, **China**, 31 July – 05 August 2016.
- Visiting Scientist to Pukyong National University, Busan, **South Korea**, 06-15 August 2016.
- WCRP CLIVAR Open Science Conference (OSC) and its associated meetings, Qingdao, **China**, 17-25 September 2016.
- Discussion on model simulation and talks on monsoon variability over South and East Asia, Busan, **South Korea**, 12-30 December 2016.

Dr. R.R. Rao

- GEWEX-CILVAR (World Climate Research Programme) Monsoon Panel Meeting, Cross-Panel Meetings, WCRP CLIVAR Open Science Conference-2016 and SSG Meeting, Qingdao, **China**, 17-25 September 2016.
- Integrated Meetings of IOGOOS, IOP, SIBER, IRF, IIOE-2 Steering Committee and a Bio-Agro Related Technical Workshop of the AISFR, Perth, **Australia**, 30 January – 04 February 2017.

Mr. S.P. Ingle

- Regional Climate Change and Renewable Energy, Research Center, Ramkhamhaeng University, Bangkok, **Thailand**, 24-26 October 2016.

Mr. Anil Kumar Pandey and **Ms. Priya Joshi**

- Exposure and discussion visit for India UK Water Centre at Centre For Ecology and Hydrology, Wallingford, **UK**, 04-19 March 2017.

Mr. Dinesh N. Gurnule

- C-Band Radar Training and Factory Acceptance Test, Neuss, **Germany**, 01-29 March 2017.

Dr. Reka Srinivas

- Meeting at International Space Science Institute (ISSI), Bern, **Switzerland**, 17-20 May 2016.

Mr. Nitesh Sinha

- European Geosciences Union (EGU) – 2016 Meeting, Vienna, **Austria**, 17-22 April 2016.

Mr. Utsav Bhowmik

- 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), Antalya, **Turkey**, 10-14 October 2016.

Ms. Swaleha Indamdar

- Participation in the Southern Ocean Expedition at Mauritius, Southern Ocean, 20 December 2016 – 06 March 2017.

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Dr. Jagat Bisht, Project Scientist-C (CCCR)	Mr. Uppara Umakanth, Project Scientist-C (CCCR)

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Dr. R.R. Rao, Executive Director	Dr. R.H. Kriplani, Senior Scientist	Mr. Harish Borse, D.T.P. Operator

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Ms. Roja Chaluvadi	Mr. Veeranjaneyulu Chinta	Mr. Santanu Halder
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Mr. Utsav Bhowmik	Ms. Rohini P.	

Working under SAFAR Project

Mr. M.Y. Aslam, SRF	Mr. Karumuri LNBR Krishna, SRF	Ms. Vrinda Anand, SRF
Mr. Nikhil Anil Korhale, SRF		

Working under ENVIS Project

Ms. Neha S. Parkhi, Senior Programme Officer	Mr. Gaurav Prabhakar Shinde, I.T. Assistant	Ms. Aishwarya Dhananjay Purwant, Information Officer

CSIR Research Fellow

Mr. Boragapu Raja

Publications

1. **Abhik S., Krishna R.P.M., Mahakur M., Ganai M., Mukhopadhyay P.**, Dudhia J., Revised cloud processes to improve the mean and intraseasonal variability of Indian summer monsoon in climate forecast system: Part 1, **Journal of Advances in Modeling Earth Systems**, Online, March 2017, doi:10.1002/2016MS000819 **(Impact Factor 6.417)**

2. **Ali K., Trivedi D.K.,** Sahu S.K., Surface ozone characterization at Larsemann Hills and Maitri, Antarctica, **Science of the Total Environment**, Online, January 2017, 1130-1137, doi:10.1016/j.scitotenv.2017.01.173 **(Impact Factor 3.976)**

3. Anil Kumar V., **Pandithurai G., Leena P.P., Dani K.K., Murugavel P., Sonbawne S.M.,** Patil R.D., **Maheskumar R.S.,** Investigation of aerosol indirect effects on monsoon clouds using ground-based measurements over a high-altitude site in Western Ghats, **Atmospheric Chemistry and Physics**, 16, July 2016, 8423-8430, doi:10.5194/acp-16-8423-2016 **(Impact Factor 5.053)**

4. **Arora A., Suryachandra A. Rao, Chattopadhyay R., Goswami T., George G.**, Sabeerali C.T., Role of Indian Ocean SST variability on the recent global warming hiatus, **Global and Planetary Change**, 143, August 2016, 21-30 **(Impact Factor 2.766)**

5. Attri S.D., Soni V.K., **Tiwari S., Srivastava A.K.**, Tiwari S.hani, Taneja K., High aerosol loading over mega city Delhi in the western Indo-Gangetic plain: Optical characteristics. **Mausam**, 67(3), July 2016, 609-618 **(Impact Factor 0.181)**

6. **Bera S., Prabha T.V.,** Grabowski W.W., Observations of monsoon convective cloud microphysics over India and role of entrainment-mixing, **Journal of Geophysical Research**, 121, August 2016, 1-22, doi:10.1002/2016JD025133 **(Impact Factor 3.426)**

7. **Bhalwankar R., Deshpande C.G., Kamra A.K.,** Breakup modes of the drops suspended in a vertical wind tunnel in presence of the horizontal electric field, **Journal of Geophysical Research**, 122, February 2017, 1838-1849, DOI:10.1002/2016JD025805 **(Impact Factor 3.318)**

8. Bhawar R.L., Lee W-S, **Rahul R.P.C.,** Aerosol types and radiative forcing estimates over East Asia, **Atmospheric Environment**, 141, September 2016, 532-541, doi:10.1016/j.atmosenv.2016.07.028 **(Impact Factor 3.281)**

9. **Bipin Kumar, Bera S., Prabha T.V.,** Grabowski W., Cloud-edge mixing: Direct numerical simulation and observations in Indian Monsoon clouds, **Journal of Advances in Modeling Earth Systems**, 9, February 2017, 1-22, doi:10.1002/2016MS000731 **(Impact Factor 6.417)**

10. **Bisht D.S., Srivastava A.K.,** Joshi H., Ram K., Singh N., Naja M., Srivastava M.K., **Tiwari S,** Chemical characterization of rainwater at a high-altitude site Nainital in the central Himalayas, India, **Environmental Science and Pollution Research**, 24, February 2017, 3959-3969, doi:10.1007/s11356-016-8093-z **(Impact Factor 2.760)**

11. **Bisht D.S., Tiwari Suresh**, Dumka U.C., **Srivastava A.K., Safai P.D., Ghude S.D., Chate D.M., Rao P.S.P., Ali K., Prabha T.V., Panickar A.S.,** Soni V.K., Attri S.D., Tunved P., Chakrabarty R.K., Hopke P.K., Tethered balloon-born and ground-based measurements of black carbon and particulate profiles within the lower troposphere during the foggy period in Delhi, India, **Science of the Total Environment**, 573, December 2016, 894-905, doi:10.1016/j.scitotenv.2016.08.185 **(Impact Factor 4.099)**

12. **Bose T., Sengupta S., Chakraborty S., Borgaonkar H.,** Reconstruction of soil water oxygen isotope values from tree ring cellulose and its implications for paleoclimate studies, **Quaternary International**, 425, December 2016, 387-398, doi:10.1016/j.quaint.2016.07.052 **(Impact Factor 2.062)**

13. Budhavant K.B., **Rao P.S.P., Safai P.D.,** Size distribution and chemical composition of summer aerosols over Southern Ocean and the Antarctic region, **Journal of atmospheric Chemistry**, Online, December 2016, 1-13, doi:10.1007/s10874-016-9356-2 **(Impact Factor 1.950)**

14. Chanrion O., Neubert T., Mogensen A., Yair Y., Stendel M., Singh Rajesh, **Siingh D.,** Profuse activity of blue electrical discharges at the tops of thunderstorms, **Geophysical Research Letters**, 44, January 2017, 1-8, doi:10.1002/2016GL071311 **(Impact Factor 4.212)**

15. **Chate D.M., Tinmaker M.I.R., Aslam M.Y., Ghude S.D.,** Climate indicators for lightning over sea, sea-land mixed and land-only surfaces in India, **International Journal of Climatology**, 37, March 2017, 1672-1679, doi:10.1002/joc.4802 **(Impact Factor 3.609)**

16. **Chaudhari H.S., Hazra A., Pokhrel S.,** Chakrabarty Chandrima, **Saha Subodh K., Sreenivas P.,** SST and OLR relationship during Indian summer monsoon: a coupled climate modelling perspective, **Meteorology and Atmospheric Physics**, Online, March 2017, 1-15, doi:10.1007/s00703-017-0514-0 **(Impact Factor 1.172)**

17. **Chinthalu G.R., Dharmaraj T., Patil M.N., Dhakate A.R., Siingh D.,** Cloud aerosol interactions and its influence on cloud microphysical parameters during dry and wet spells of Indian summer monsoon using CAIPEEX data, **Journal of Indian Geophysical Union**, 20, November 2016, 596-605 **(Impact Factor 0.000)**

18. **Chowdary J.S, Harsha H.S., Gnanaseelan C., Srinivas G., Parekh A., Pillai P.A.** and Naidu C.V., Indian summer monsoon rainfall variability in response to differences in the decay phase of El Niño, **Climate Dynamics**, Online, June 2016, doi:10.1007/s00382-016-3233-1 **(Impact Factor 4.673)**

19. **Chowdary J.S., Parekh A., Srinivas G., Gnanaseelan C., Fousiya T.S., Khandekar R., Roxy M.K.,** Processes associated with the Tropical Indian Ocean subsurface temperature bias in a Coupled Model, **Journal of Physical Oceanography**, 46, September 2016, 2863-2875, doi:10.1175/JPO-D-15-0245.1 **(Impact Factor 2.856)**

20. **Chowdary J.S., Srinivas G., Fousiya T.S., Parekh A., Gnanaseelan C.,** Seo H., MacKinnon J.A., Representation of Bay of Bengal upper-ocean salinity in general circulation models, **Oceanography**, 29, June 2016, doi:10.5670/oceanog.2016.37 **(Impact Factor 2.935)**

21. Crétat J., Terry P., Masson S., **Sooraj K.P., Roxy M.K.,** Indian Ocean and Indian summer monsoon: relationships without ENSO in ocean-atmosphere coupled simulations, **Climate Dynamics**, Online, October 2016, 1-20, doi:10.1007/s00382-016-3387-x **(Impact Factor 4.673)**

22. **Das S.K., Konwar M., Chakravarty K., Deshpande S.M.,** Raindrop size distribution of different cloud types over the Western Ghats using simultaneous measurements from Micro-Rain Radar and disdrometer, **Atmospheric Research**, Online, November 2016, 72-82, doi:10.1016/j.atmosres.2016.11.003 **(Impact Factor 2.844)**

23. **Das Subrata Kumar,** Golhait R.B., Uma K.N., Clouds vertical properties over the Northern Hemisphere monsoon regions from CloudSat-CALIPSO measurements, **Atmospheric Research**, 183, January 2017, 73-83, doi:10.1016/j.atmosres.2016.08.011 **(Impact Factor 3.377)**

24. **Deshpande A., Gnanaseelan C., Chowdary J.S., Rahul S.,** Interannual spring Wyrtki jet variability and its regional impacts, **Dynamics of Atmosphere and Ocean**, Online, February 2017, doi:10.1016/j.dynatmoce.2017.02.001 **(Impact Factor 1.439)**

25. Dumka U.C., **Tiwari Suresh,** Kaskaoutis D.G. , Hopke P.K., Singh Jagvir, **Srivastava A.K., Bisht D.S.,** Attri S.D., Tyagi S., Misra A., Pasha M.G.S., Assessment of PM2.5 chemical compositions in Delhi: primary vs secondary emissions and contribution to light extinction coefficient and visibility degradation, **Journal of Atmospheric Chemistry**, Online, November 2016, 1-28, doi:10.1007/s10874-016-9350-8 **(Impact Factor 1.950)**

26. **Fadnavis S.,** Feng W., Shepherd G.G., Plane J.M.C., **Sonbawne S., Roy C.,** Dhomse S., **Ghude S.D.,** Preliminary observations and simulation of nocturnal variations of airglow temperature and emission rates at Pune (18.5°N), India, **Journal of Atmospheric and Solar Terrestrial Physics**, 149, November 2016, 59-68, doi:10.1016/j.jastp.2016.10.002 **(Impact Factor 1.474)**

27. **Fadnavis S., Roy C., Sabin T.P., Ayantika D.C.,** Ashok K., Potential modulations of pre monsoon aerosols during El Niño: impact on Indian summer monsoon, **Climate Dynamics**, Online, November 2016, 1-12, doi:10.1007/s00382-016-3451-6 **(Impact Factor 4.673)**

28. **Fousiya A.A., Chakraborty S.,** Achyuthan H., **Gandhi N., Sinha N., Datye A.,** Stable isotopic investigation of Porites coral from the Minicoy Island, **Indian Journal of Geo-Marine Science**, 45, November 2016, 1465-1470 **(Impact Factor 0.294)**

29. **Ganai M., Krishna R.P.M., Mukhopadhyay P., Mahakur M.,** Impact of revised simplified Arakawa-Schubert scheme on the simulation of mean and diurnal variability associated with active and break phases of Indian Summer Monsoon using CFSv2, **Journal of Geophysical Research**, 121, August 2016, 1-50, doi:10.1002/2016JD025393 **(Impact Factor 3.426)**

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Publications in books, reports, proceedings, magazines, newsletters, etc.

1. **Phani Murali Krishna R.,** S. Abhik, Bidyut B. Goswami, **Malay Ganai, M. Mahakur, Medha Deshpande, P. Mukhopadhyay, Renu S Das**, Marat Khairoutdinonv, Jimy Dudhia and B.N. Goswami, Improvement of cloud and convective Parameterizations in Climate Forecast System Version 2 (CFSv2): Indian Summer Monsoon perspective, **IITM Research Report**, RR 136, ISSN 0252-1075, August 2016, ESSO/IITM/SERP/ SR/01(2016)/186.

2. **Sahai A.K., Chattopadhyay Rajib, Dey Avijit, Joseph Susmitha, Abhilash S., Phani M., Mandal Raju,** Rajeevan M.N. and Hendon H., MJO Diagnostics for Extended Range Prediction and Simulation in IITM CFSv2, **IITM Research Report**, ISSN 0252-1075, September 2016, ESSO/IITM/ SERP/SR/02(2016)/187.

3. **Kulkarni A.,** Gadgil S., **Patwardhan S.,** Dushkal Tumacha Pawasachya Mathi Ka Marta? Marathi bi-monthly magazine **Bhawataal**, July-August 2016, pp 06-09.

4. **Karmakar A., Parekh A. and Gnanaseelan C.,** Status of Bay of Bengal upper ocean mean state in different Reanalysis Products, **Ocean Digest**, ISSN 2394-1928, 3(3), November 2016, pp 08-09.

5. **Chakraborty S.**, ORV Isotope, **Ocean Digest**, ISSN 2394-1928, 4(1), February 2017, pp 06-08.

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9. **Gufran Beig**, Parkhi N.S. and Purwant A., Assessment of Summer Air Quality of Jaipur in Different Micro-Environments, SAFAR Technical Report No. 8, Publisher: IITM, Rajasthan State Pollution Control Board and UNICEF-Rajasthan, 2016.

10. Sharma S., Rehman I.H., Ramanathan V., Balakrishnan K., **Beig G.**, et al., Breathing Cleaner Air – Ten Scalable Solutions for Indian Cities, Task Force report for World Sustainable Development Summit, TERI and UC San Diego, 2016.

11. **Sapre V.V., Das S.**, Institutional Repository in a Research Institute: Pathway towards progress. **Proceedings of the National Conference on Creativity, Innovation and Transformation in Libraries SALIS 2016**, pp.305-309, Tiruchengode, Tamilnadu, 08-09 July 2016.

Book Chapters

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12. Guhathakurta Pulak and **Revadekar Jayashree,** Observed Variability and Long-Term Trends of Rainfall Over India, pp 1-16.

13. Srivastava A.K., **Kothawale D.R.** and Rajeevan M.N., Variability and Long-Term Changes in Surface Air Temperatures Over the Indian Subcontinent, pp 17-35.

14. Pai D.S., Guhathakurta Pulak, **Kulkarni Ashwini** and Rajeevan M.N., Variability of Meteorological Droughts Over India, pp 73-87.

15. **Mukhopadhyay P.**, Jaswal A.K. and **Deshpande M.,** Variability and Trends of Atmospheric Moisture over the Indian Region, pp 129-144.

16. **Padmakumari B.**, Soni Vijay Kumar and Rajeevan M.N., Trends in Radiative Fluxes Over the Indian Region, pp 145-163.

17. **Gnanaseelan C., Roxy M.K.** and Deshpande Aditi, Variability and Trends of Sea Surface Temperature and Circulation in the Indian Ocean, pp 165-179.

18. **Parekh Anant, Gnanaseelan C., Deepa J.S., Karmakar Ananya and Chowdary J.S.**, Sea Level Variability and Trends in the North Indian Ocean, pp 181-192.

19. Satheesh S.K., Babu S. Suresh, **Padmakumari B., Pandithurai G.** and Soni V.K., Variability of Atmospheric Aerosols Over India, pp 221-248.

20. Ramesh R., **Boragaonkar H.**, Band S. and Yadava M.G., Proxy Climatic Records of Past Monsoons, pp 271-284.

21. **Sanjay J., Ramarao M.V.S., Mujumdar M.** and **Krishnan R.**, Regional Climate Change Scenarios, pp 285-304.

Publications

Papers published in journals	:	**149**
Cumulative Impact Factor	:	**425.890**
Average Impact Factor		**2.858**
Publications in books, reports, proceedings, etc.	:	**21**

C.R. SAGDEO & Co.

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INDEPENDENT AUDITORS' REPORT

To
The Director
Indian Institute of Tropical Meteorology

Report on the Standalone Financial Statements

We have audited the standalone financial statements of the Indian Institute of Tropical Meteorology ("the Institute"), which comprises the Balance Sheet as at March 31, 2017, 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.

Management's Responsibility for the standalone Financial Statements

The Institute's management is responsible for the preparation of these standalone financial statements that give a true and fair view of the financial position, financial performance of the Institute in accordance with the accounting principles generally accepted in India. This responsibility also includes maintenance of adequate accounting records in accordance with the bye-laws for safeguarding the assets of the Institute and for preventing and detecting frauds and other irregularities; selection and application of appropriate accounting policies; making judgments and estimates that are reasonable and prudent; and design, implementation and maintenance of adequate internal financial controls, that were operating effectively for ensuring the accuracy and completeness of the accounting records, 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.

Auditor's Responsibility for the Audit of the Financial Statements

Our responsibility is to express an opinion on these standalone financial statements based on our audit.

We have taken into account the provisions of the bye-laws governing the Institute, the accounting and auditing standards and matters which are required to be included in the audit report under the provisions and the Rules made there under. An audit involves performing procedures to obtain audit evidence about the amounts and the disclosures in the financial statements.

The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal financial control relevant to the Institute's management for the preparation of the financial statements that give a true and fair view in order to design audit procedures that are appropriate in the circumstances. An audit also includes evaluating the appropriateness of the accounting policies used and the reasonableness of the accounting estimates made by the Institute's management, as well as evaluating the overall presentation of the financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion on the standalone financial statements.

Basis for Qualified Opinions

a) Fixed Assets held by the Institute were not physically verified by the Institute's management and no report in this regard was available for our verification.

   Further the Fixed Asset Register was not updated as on 31st March 2017 and due to which the Physical Verification Process was not completed.

b) The employee benefits are accounted on the basis of cash system of accounting and not on the basis of any actuarial valuation as required under "Accounting Standard (AS) 15 - Employee Benefits (revised 2005)" issued by ICAI.

c) Land Dispute with National Chemical Laboratory (NCL), Pune, has not been resolved.

Cumulative impact of all these on Income / Expenditure and Assets and Liabilities of the Institute could not be ascertained.

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 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.

Qualified Opinion

In our opinion and to the best of our information and according to the explanations given to us, except for the effects of the matter described in the Basis for Qualified Opinions section of our report, 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 31st March, 2017 and the Statement of Income and Expenditure for the year ended on that date.

For **C.R. SAGDEO & Co.**
Chartered Accountants
(Firm's Registration No.108959W)

Sd/-
(CA AJAY S JOSHI)
(Partner)
(Membership No.110708)

Pune
July 25, 2017

COMPLIANCE TO AUDIT OBSERVATIONS

OBSERVATIONS	COMPLIANCE
1. Physical Verification Fixed Assets and maintenance of register –	
Fixed Assets held by the Institute were not physically verified by the Institute's management and no report in this regard was available for our verification.	The physical verification for the year 2013-14 has been completed. The reconciliation of the physical verification report for 2013-14 is under process. As soon as the reconciliation is completed the physical verification for the next year will be started.
Further the Fixed Asset Register was not updated as on 31st March 2017 and due to which the Physical Verification Process was not completed.	The assets acquired are entered in Dead Stock Register maintained by the Purchase and Stores Unit. Also, the same is reflected in the books of accounts maintained by the Institute. In addition, the fixed asset register is being maintained by the concerned division. As soon as assets are acquired, entry would be made in the asset register.
2. Provision for employees benefits	
The employee's benefits are accounted on the basis of cash system of accounting and not on the basis of actuarial valuation as required under Accounting Standard (AS) 15 – Employee Benefits (revised 2005) issued by ICAI.	The provision for the Leave Encashment & Gratuity is made under the budget of every year.
3. Land dispute with National Chemical Laboratory (NCL), Pune.	
Land Dispute with National Chemical Laboratory (NCL), Pune has not been resolved.	Both IITM and NCL have constituted a committee regarding final settlement of land issue between IITM and CSIR-NCL. The joint committee has taken up this issue.

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE-8
BALANCE SHEET AS AT 31-03-2017

1. CORPUS/ CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
CORPUS/ CAPITAL FUND	1	7407246393.22	5513871135.25
RESERVES AND SURPLUS	2	11530788.49	11349143.37
EARMARKED/ ENDOWMENT FUNDS	3	5952365.51	3284574.91
SECURED LOANS AND BORROWINGS			
UNSECURED LOANS AND BORROWINGS			
DEFERRED CREDIT LIABILITIES			
CURRENT LIABILITIES AND PROVISIONS	4	309034338.12	150019968.20
INTEREST TO BE ADJUSTED AGAINST FUTURE GRANTS (PLAN)	15	92183928.00	74987269.00
INTEREST TO BE ADJUSTED AGAINST FUTURE GRANTS (NON-PLAN)	15	16394623.62	4616637.00
2. TOTAL		**7842342436.96**	**5758128727.73**
1. ASSETS			
FIXED ASSETS	5	4670785880.19	4452004985.84
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUNDS			
INVESTMENTS - OTHERS			
CURRENT ASSETS LOANS ADVANCES ETC.	6	3171556556.77	1306123741.89
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)			
3. TOTAL		**7842342436.96**	**5758128727.73**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS		**0.00**	**0.00**

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD/YEAR ENDED 31-03-2017

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services			
Grants/Subsidiser	7	759600000.00	873630500.00
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	2722397.90	2446111.87
Increase/(decrease) in stock of Finished goods and works-in-progress			
TOTAL (A)		**762322397.90**	**876076611.87**
EXPENDITURE			
Establishment Expenses	11	335414614.50	311528986.42
Other Administrative Expenses etc.			
Expenditure on Schemes	13 A	509858374.87	601610529.84
Interest			
Depreciation during the year	14	241171306.56	216684677.00
TOTAL (B)		**1086444295.93**	**1129824193.26**
TOTAL (C) - Prior Period Expenses (Exp. Incurred before 01.04.2015, but payment made in the F.Y. 2015-16	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		**-324121898.03**	**-253747581.39**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS			

RECEIPTS AND PAYMENTS
FOR THE PERIOD/YEAR ENDED 31-3-2017

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
I. Opening Balances			**I. Establishment expenses**		**335414614.50**
a) Cash in hand		**153815.00**	**II. Payment made against various project funds**		**6755236.40**
b) Bank Balances					
i) In current account - Linked with CLTD (SBI)		**574156804.67**	**III. Advances to Others than project**		**745023.00**
ii) In Saving account - (PNB)		**275551751.55**	**IV. Advance to staff**		**6354386.00**
iii) In current account - Linked with CLTD Project (SBI)		**7402308.93**	**V. Deposits with**		**0.00**
			VI. Overheads		**218294.00**
			VII. Funds Retained from suppliers		**83277668.50**
iv) In deposit accounts		**13726781.00**	**VIII. Statutory Liability**		**294345383.00**
II. Grants Received		**2899600000.00**	**IX. Short Term Climate Prediction**		**44215324.50**
1) High Performance Computing (HPC)	1704800000.00		Recurring	42786932.50	
2) Centre for Climate Change Research (CCCR)	76600000.00		Non-Recurring	1534325.00	
3) IITM - Operations & Maintenance	210000000.00		Advance	2288771.00	
4) Metropolitan Air Quality and Weather Services	85700000.00		Total	46610028.50	
5) Monsoon Mission	116600000.00		Less: Advance adjusted	2394704.00	
6) Physics & Dynamics of Tropical Clouds	309800000.00		**X. Centre for Climate Change Research**		**17442759.92**
7) Short Term Climate Prediction and Variability	67600000.00		Recurring	17176341.00	
8) Non-Plan	328500000.00		Non-Recurring	920593.92	
III. Interest Received			Advance	6626633.00	
Non-Plan Interest (to be adjusted against future grants)		**16394623.62**	Total	24723567.92	
1) On Bank deposits	16347863.62		Less: Advance adjusted	7280808.00	
2) Penal Interest	3449.00		**XI. Advance Training in Earth System Science & Climate**		**40919452.46**
3) Interest on Scooter Advance	13200.00		Recurring	9334765.99	
4) Interest on Car Advance	6913.00		Non-Recurring	32029117.46	
5) Interest on Computer Advance	23198.00		Advance	2219026.00	
			Total	43582909.45	
b) Plan Interest - On Schemes (to be adjusted against future grants)		**92183928.00**	Less: Advance adjusted	2663456.99	
1) Advanced Training in Earth System Science and Climate	6610414.00		**XII. IITM Operations & Maintenance**		**217763741.00**
2) Centre for Climate Change Research	6160416.00		Recurring	180703619.00	
3) HPC	35678492.00		Non-Recurring	19546809.00	
4) IITM O&M	5943277.00		Advance	20291499.00	
5) Metropolitan Air Quality & Weather System	7368878.00		Total	220541927.00	
6) Monsoon Mission	5997461.00		Less: Advance adjusted	2778186.00	
7) PDTC	10806120.00		**XIII. Monsoon Mission**		**189121006.75**
8) Short Term Climate Prediction	6197934.00		Recurring	196334026.75	
9) NFAR	7420936.00		Non-Recurring	0.00	
			Advance	1874633.00	
			Total	198208659.75	
			Less: Advance adjusted	9087653.00	
			XIV. Metropolitan Air Quality and Weather Services		**72152917.88**
			Recurring	9517150.00	
			Non-Recurring	120334571.88	
			Advance	43174161.00	
			Total	173025882.88	
			Less: Advance adjusted	100872965.00	

RECEIPTS AND PAYMENTS
FOR THE PERIOD/YEAR ENDED 31-3-2017

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
IV. Other Income		**2722397.90**	**XV. HPC - 2**		**1556780500.65**
1) Contribution to Pensioners Medical Sch.	350400.00		Recurring	36608845.85	
2) Fees from Student	273794.00		Non-Recurring	194943947.65	
3) Guest House charges	465125.00		Advance	1519321872.00	
4) Licence Fees	807816.00		Total	1750874665.50	
5) Maint of Colony Welfare	52541.00		Less: Advance adjusted	194094164.85	
6) Misc. Receipts	687517.90		**XVI Physics & Dynamics of Tropical Clouds**		**201504650.78**
7) Water charges	53514.00		Recurring	17082920.78	
8) Library Charges	50.00		Non-Recurring	88006854.00	
9) Prithvi Hall Hostel Charges	31640.00		Advance	206806040.00	
V. Any other receipts		**573674399.12**	Total	311895814.78	
1) Receipts from various project	9423027.00		Less: Advance adjusted	110391164.00	
2) Funds Retained from suppliers	1310905.00		**XVII. National Facility for Airborne Research**		**539757.00**
3) Claims Receivable	1412772.00		Recurring	313773.00	
4) Statutory liabilities	335098507.00		Non-Recurring	2635982.00	
5) Deposits with	0.00		Advance	895175.00	
6) Advance to others than project	622193.00		Total	3844930.00	
7) Overheads	399939.12		Less: Advance adjusted	33051373.00	
8) Deposits from creditors	218990666.00		**XVIII. IOAS**		**2106750.00**
9) Adv. to staff	6416390.00		**XIX. Claims Receivable**		**1948014.00**
VI. Accrued Interest		**360237.00**	**XX. Deposits From Creditors**		**18762656.58**
			XXI. Accrued Interest		**362284.00**
			XXII. Closing Balance		
			a) Cash in hand		**65899.00**
			b) Bank Balances		
			i) In current account - Linked with CLTD (SBI)		**1257821087.31**
			ii) In Saving account - (PNB)		**85685115.41**
			iii) In current account - Linked with CLTD Project (SBI)		**10182702.15**
			iv) In deposit accounts		**11441822.00**
TOTAL		**4455927046.79**	**TOTAL**		**4455927046.79**

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 accrual method 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.	Furniture & Fixtures	6.33%
3.	Plant & Machinery, Scientific Equipments and Office Equipments	4.75%
4.	Computer and Workstations, Furniture and Fixtures Under Schemes	16.21%
5.	Vehicle	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

Sd/-
(DR. RAVI S. NANJUNDIAH)
(Director)

Pune
July 25, 2017

As per our Report on even date
For & on behalf of
C.R. SAGDEO & CO.
Chartered Accountants
(Firm's Registration No.108959W)

Sd/-
(AJAY S JOSHI)
(Partner, Membership No. 110708)

ईएसएसओ–भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
(पृथ्वी विज्ञान मंत्रालय, भारत सरकार का एक स्वायत्त संस्थान)
डॉ. होमी भाभा मार्ग, पाषाण, पुणे – 411 008, महाराष्ट्र, भारत

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