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ईएसएसओ–भारतीय उष्णदेशीय मौसम विज्ञान संस्थान

ESSO-INDIAN INSTITUTE OF TROPICAL METEOROLOGY



Annual Report
2015-16

Meetings



Research Advisory Committee 12 January 2016





Finance Committee 11 August 2015 and 29 January 2016





Governing Council 12 August 2015 and 29 January 2016

Annual Report
2015-16

ESSO-Indian Institute of Tropical Meteorology

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

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India Meteorological Department, Pune - 411 005

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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
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Director
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Pune – 411008



Organizational Flow Chart of R&D Activities

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Foreword



The Indian Institute of Tropical Meteorology (IITM), Pune is a premier research institution to generate scientific knowledge in Meteorology and Atmospheric Sciences with the vision of creating a World Centre of Excellence in Weather and Climate Sciences. The Institute is consistently aspiring for the better predictions of weather and climate with the national priority of developing a better prediction system for the Indian Summer Monsoon – the lifeline of the agriculture-based Indian society and economy. With continuous efforts over the years, IITM is now one of the foremost research institutes working on weather and climate sciences globally.

In 2015-16, the Institute achieved remarkable progress in all its mission mode R- D projects and brought out high quality research publications in the reputed national and international journals. During this year, IITM scientists published a record number of 149 papers in peer-reviewed journals with a cumulative Impact Factor (IF) of 468.451 and the average IF of 3.144.

Under the Monsoon Mission, consistent efforts are being made to improve the skill of dynamical prediction systems of the Indian monsoon rainfall on extended range and seasonal time scales. The experimental dynamical seasonal prediction for 2015 Summer Monsoon rainfall prepared by using the latest T382 spectral resolution version of CFSv2 was 88 ± 5 of long period model average (LPMA) which was very close to the actually realized rainfall, i.e., 86 of long period average (LPA) over the country. The real time prediction of 2015 monsoon season over the extended range (10-15 days in advance) was prepared by using the newly developed CFS based Grand Ensemble Prediction System (CGEPS). During the 2015 monsoon season, both the seasonal and extended range prediction systems demonstrated significant precision in the prediction skills. The IITM Global Ocean Data Assimilation (IITM-GODAS) was successful in tracking the evolution of the 2015-16 El Niño. Ocean data assimilation experiments show improvements in ocean initial conditions by assimilation of temperature and salinity profiles in the upper ocean from ARGO, sea surface salinity estimates from satellites (AQUARIUS) and sea-level variations from satellite altimeter. In an effort to reduce model biases in simulating monsoon variability in CFSv2, a stochastic multi-cloud model parameterization is developed and successfully tested in CFSv2 in collaboration with the University of Victoria.

At the Centre for Climate Change Research (CCCR), major improvements were incorporated in the IITM Earth System Model (IITM-ESM) to obtain a radiatively balanced global modelling framework for studying long-term climate variability and change. These include the (1) Implementation of the effects of tropospheric and volcanic aerosols on climate, (2) Implementation of the effects of ozone-mixing ratios on the climate, and (3) Improvements in ocean bio-geo-chemistry (BGC) processes. CCCR-IITM has developed an Earth System Grid Federation (ESGF) data node for archival, management, retrieval and dissemination of CORDEX South Asia and CMIP6 datasets. In addition to model developments, several basic research studies were carried out at CCCR,

including (a) Response of ocean biological productivity to Ningaloo Niño/Niña events in the southern subtropical Indian Ocean, (b) Recent changes in large-scale climate patterns over the Indo-Pacific region, (c) Role of the Asian summer monsoon in influencing the upper troposphere and lower stratosphere, (d) Trace gas observations and reactive species in the Southern Indian Ocean and Antarctica, and (e) Role of cloud microphysics on rain amount-isotope correlation across the Western Ghats and its implication to paleoclimate studies.

The Metropolitan Air Quality and Weather Services Group has successfully implemented SAFAR-Mumbai which was inaugurated by Dr. Harsh Vardhan, Hon'ble Union Minister for Science - Technology and Earth Sciences (Govt. of India) and Mr. Devendra Fadnavis, Hon'ble Chief Minister of Maharashtra on 23 June 2015. Efforts are being made to initialize SAFAR-Ahmedabad for providing air quality weather services to the citizens of Ahmedabad.

Extensive observations were successfully conducted during the CAIPEEX ground campaign in Varanasi. Aircraft based observations were conducted in the triangular area of Kolhapur, Mahabaleshwar and Solapur in Maharashtra. A new research group is constituted to work in the area of Radar and Satellite Meteorology. Lightning Location Network established in Maharashtra is further strengthened by installing sensors at Mahabaleshwar, Nanded and Phalghar. The network has been successful in capturing thunderstorms with great accuracy.

CAT Trainee Scientists of the Batch-III who successfully completed the training in 2014 have been placed as scientists at different MoES Institutes. Eighteen students/employees of the institute were awarded PhD degrees and four others have submitted their theses for award of PhD during the period.

The Union Cabinet has formally approved the establishment of the International CLIVAR Monsoon Project Office (ICMPO) of the World Climate Research Programme (WCRP) at the institute.

IITM organized various training programs, seminars, conferences and workshops. I am happy to inform that many IITM scientists have received prestigious awards, honours, memberships and fellowships in recognition of their outstanding contributions. IITM has been engaged in collaborative activities with National R- D, Operational and Academic Institutions such as IMD, NCMRWF, NCAOR, INCOIS, IISc, IITs and universities.

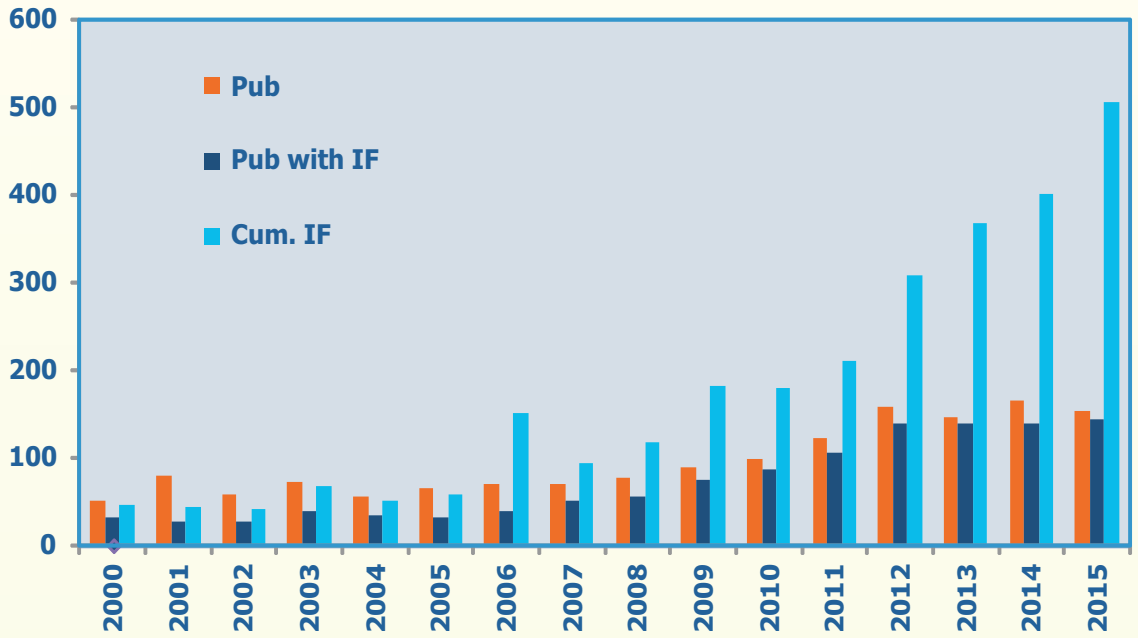
This annual report presents some glimpses of the success and growth achieved by IITM during the year 2015-16. Hard work and dedicated support from the Scientific Research and Development programs, technical, scientific and engineering support and the administrative staff has been vital for the success and growth of IITM. The success and growth story of IITM would not have been possible without the advisory and funding support of the Earth System Science Organization (ESSO) and the Ministry of Earth Sciences, and without the constant support and guidance of the Governing Council, the Finance Committee and the Research Advisory Committee. I also thank the Ministry of Science - Technology, the Ministry of Environment, Forests and Climate Change and the Indian Space Research Organization for their continuing support and for sponsoring some important scientific projects. Our international collaborators are also acknowledged for their scientific and technical cooperation.

IITM's research work is increasingly becoming relevant in terms of improved operational forecast for societal benefits. I do hope that the progress of IITM would further continue towards making the Institute a Global Leader in Weather and Climate Sciences and to bring the fruits of high end research to the service of the Nation and the world at large.

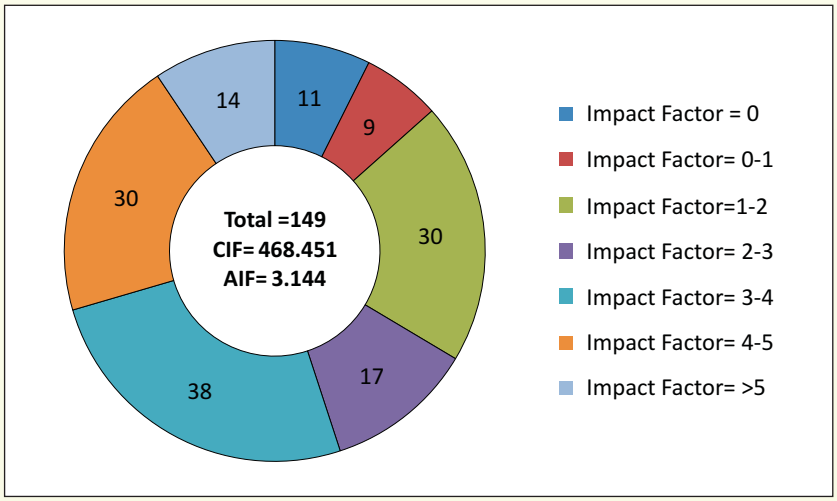


R. Krishnan
Director

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 2015-16

Details of Publications during the year 2015-16	
Total No. of papers published in journals	149
Papers with Impact Factor	138
Papers without Impact Factor	11
Cumulative Impact Factor	468.451
Average Impact Factor	3.144

Visit of Dr. Harsh Vardhan
Hon'ble Union Minister of Science & Technology and Earth Sciences, Govt. of India



Dignitaries on dias (L-R): Dr. R. Krishnan, Dr. Shailesh Nayak, Dr. Harsh Vardhan and Dr. M. Rajeevan



Welcome Address by
Dr. R. Krishnan



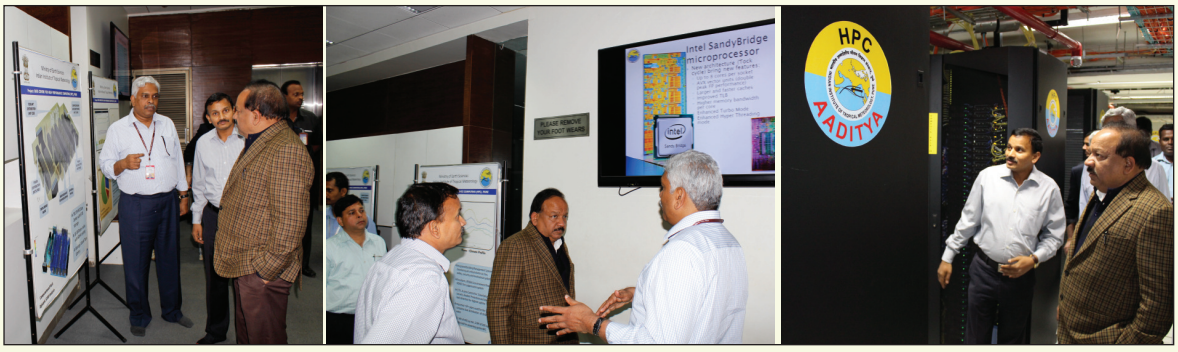
Brief about IITM by
Dr. M. Rajeevan



Address by
Dr. Shailesh Nayak



Address by
Dr. Harsh Vardhan



Visit to High Performance Computer (HPC) 'Aaditya'



Interaction with Media Persons

System of Air Quality and Weather Forecasting And Research (SAFAR)





Lamp Lighting



Dignitaries on dias (L-R): Dr. M. Rajeevan, Dr. Harsh Vardhan, Mr. Devendra Fadnavis and Dr. G. Beig



Welcome Address by Dr. M. Rajeevan



Brief about SAFAR by Dr. G. Beig



Dr. Harsh Vardhan
Inaugurating 'SAFAR-Mumbai'



Dr. Harsh Vardhan
releasing 'Mumbai-Air'



Mr. Devendra Fadnavis
launching 'SAFAR-App'



Address by Mr. Devendra Fadnavis
Hon'ble Chief Minister, Maharashtra State

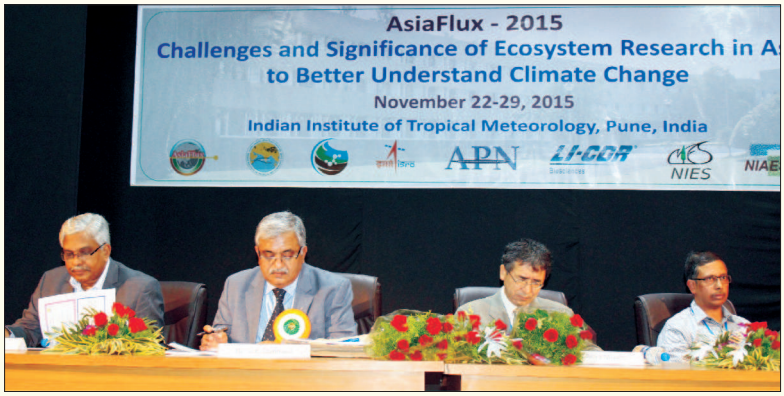


Address by Dr. Harsh Vardhan
Hon'ble Union Minister of Science - Technology and Earth Sciences, Govt. of India



MoU signed between
IITM and ISRO's Space Application Centre (SAC), Ahmedabad
for 'SAFAR-Ahmedabad'

AsiaFlux 2015



Dignitaries on dias (L-R): Dr. M. Rajeevan, Dr. V.K. Dadhwal, Dr. Akira Miyata and Dr. S. Chakraborty



Lamp Lighting



Welcome Address by Dr. M. Rajeevan



Lecture by Dr. V.K. Dadhwal



Lecture by Dr. Akira Miyata



Vote of thanks by Dr. S. Chakraborty



Participants

54th Foundation Day Celebrations



Dignitaries on dias (L-R): Dr. M. Rajeevan, Dr. A.S. Kiran Kumar, Prof V.K. Gaur, Prof. Rajat Moona and Dr. C. Gnanaseelan



Lamp Lighting



Welcome Address by Dr. M. Rajeevan



Address by Prof V.K. Gaur



Dr. C.T. Sabeerali receiving 'Prof. Ananthakrishnan Best Thesis Award - 2014'



Mr. Siddharth Kumar and Dr. Anupam Hazra receiving '27th Annual IITM Silver Jubilee Award'



Ms. Aditi Deshpande and Mr. R.D. Ruchit receiving 'Best Student Paper Award'



Presentation of 'IITM Excellent Performance Award' to (L-R): Mr. S.G. Purandare, Mr. Kiran Salunke, Mr. R.N. Kulkarni and Mr. E.M. Botla



Dr. A.S. Kiran Kumar releasing 'IITM Research Report on Monsoon 2015'



Special Lecture by
Dr. A.S. Kiran Kumar



Foundation Day Lecture by
Prof. Rajat Moona









(L-R): 'Prof. Ananthakrishnan Best Thesis Award' Lecture by Dr. C.T. Sabeerali, '27th Annual IITM Silver Jubilee Award' Lecture by Mr. Siddharth Kumar, 'Best Student Paper Award Lecture' by Ms. Aditi Deshpande and Mr. R.D. Ruchit



Cultural activities on the occasion of the 54th Foundation Day Celebrations

First WMO Workshop on Operational Climate Prediction



Welcome Address by
Dr. M. Rajeevan



Address by Chief Guest
Prof. Sulochana Gadgil





Sessions in Progress







Discussions

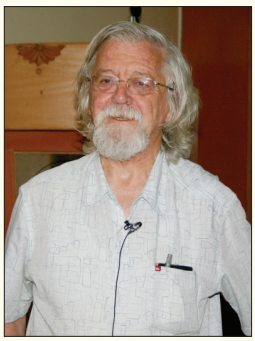


Participants

Visitors



Dr. Chulkyu Lee
South Korea



Dr. John McGregor
Australia



Dr. A.A. Sinkevich
Russia



Dr. Martin Schultz
Germany



Prof. Olivier Pauluis
Abu Dhabi



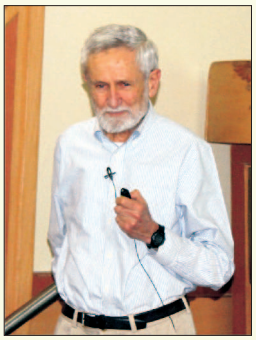
Dr. Yushi Morioka
Japan



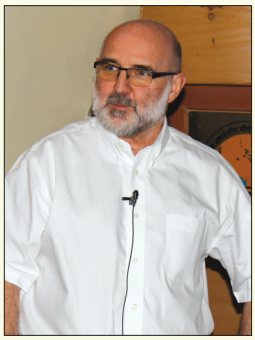
Dr. Holger Mahlke
Germany



Dr. Harry Hendon
Australia



Prof. Mike Wallace
USA



Prof. Wojciech Grabowski
USA



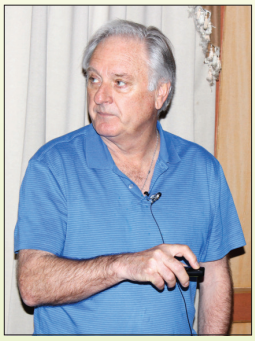
Prof. Jun Matsumoto
Japan



Dr. Tomoshige Inoue
Japan



Dr. Toru Terao
Japan



Dr. Mitchell Moncrieff
USA



Dr. Jun-Ichi Hamada
Japan



Dr. Taichi Hayashi
Japan



Dr. P. Mukhopadhyay receiving the 'Certificate of Merit 2015' of Ministry of Earth Sciences, Govt. of India









(Top L-R): Dr. O.N. Shukla, Mr. Deewan Singh Bisht, (Bottom L-R): Mr. D.E. Shinde - Mr. G.E. Dhongade receiving the 'Best Employee Award 2014 of Ministry of Earth Sciences, Govt. of India for Group B, Group C and Multi Tasking Staff Category respectively

Hindi Week Celebrations



Dignitaries on Dias (L-R): Dr. O.N. Shukla, Dr. M. Rajeevan, Dr. Rajkishor Pandey, Dr. A.K. Sahai and Mr. K.K. Dani



Lamp Lighting



Welcome Address by Dr. M. Rajeevan



Address by Dr. Rajkishor Pandey

Vigilance Awareness Week



Pledge administered to the IITM Employees



Address by Mr. C.G. Kumbhar

Observation of Special Days / Weeks

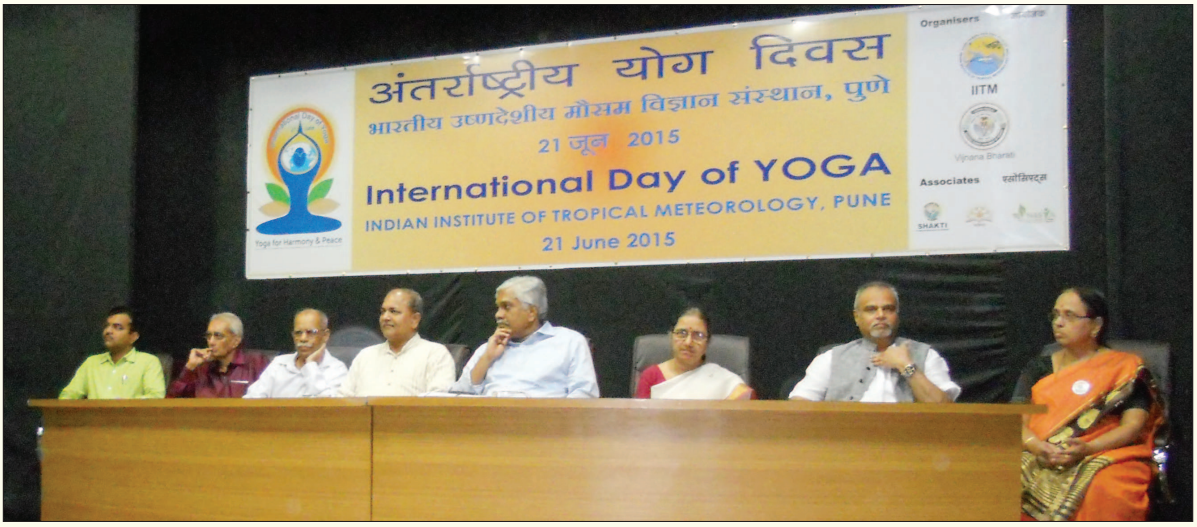




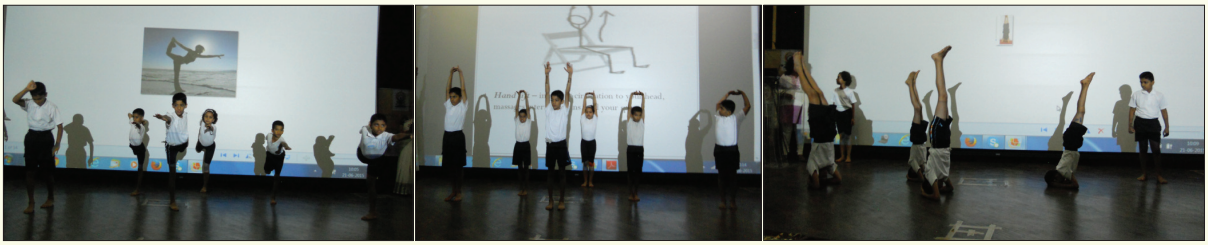


Pledge administered on the occasion of
(Top L-R): 'Anti Terrorism Day', 'Sadbhavana Diwas'
(Bottom) 'Quami Ekta Week'

Yoga Day Celebrations



Dignitaries on dias





▲
◄ Yoga performance by Students

▼ Yoga performance by Audience





Dr. M. Rajeevan releasing a book on Yoga

Dr. M. Rajeevan felicitating the student performers

National Pollution Control Day Celebrations



Welcome Address by
Dr. G. Beig



Address by
Dr. M. Rajeevan



Lecture by
Ms. Sanskriti R. Menon





Participants of 'Drawing' and 'Best from the Waste' Competitions



Prize Distribution

World Meteorological Day Celebrations



Participants of Drawing Competition

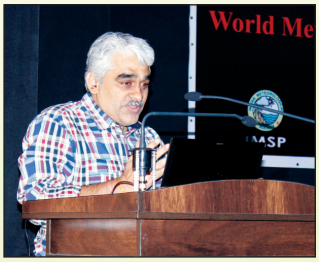




Participants of Model Presentations



Dignitaries on Dias (L-R):
Dr. R. Krishnan, Mr. B. Mukhopadhyay
and Dr. C. Gnanaseelan



Welcome Address by
Dr. R. Krishnan



WMO Day Lecture by
Mr. B. Mukhopadhyay



Prize Distribution

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



Institute's participation in Indian International Science Festival (IISF-2015), New Delhi

Visitors on Open Days



Project

Centre for Climate Change Research (CCCR)

Project Director: Dr. R. Krishnan
Project Deputy Director: Dr. H.P. Borgaonkar

Objectives

- To identify and explore new areas of research that will contribute to the fundamental understanding of the Earth's climate system.
- To enhance 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 vapour 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.
- To build 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
- GHG, Fluxnet program and Modeling

Sub-Project

Earth System Modeling (ESM)

Developmental Activities

Updates on IITM ESM: In 2014, the first version of the IITM ESM was developed by incorporating the MOM4p1 ocean model (with interactive biogeochemistry) in the Climate Forecast System (CFSv2), and by transforming the CFS seasonal prediction model into a long-term climate model. The simulation of sea surface temperature, South Asian monsoon rainfall, dominant modes of climate variability and ENSO-Monsoon teleconnections were captured in the ESM1.0. Since January 2015, further improvements have been incorporated to obtain a radiatively balanced global climate modeling framework required for making reliable long-term climate projections. In the new version (ESM2.0), the net energy imbalance at the top of the atmosphere is less than 1 Wm^{-2} and it compares with the state-of-the-art CMIP models.

One of the important developments in ESM2.0 is the incorporation of aerosol optical properties based on the MACv1 dataset (Max-Planck-Institute Aerosol Climatology version-1). At present, only aerosol direct effects are considered. The MACv1 aerosols cover both natural and anthropogenic components. A spatial map of the column integrated annual mean aerosol optical depth (AOD) at 550 nm is shown in **(Fig. 1)**. One can see larger AOD values over China, South Asia, Central Asia and northern Africa. Aerosol sensitivity switch on/off test simulations of the IITM-ESM2.0 indicate dominance of negative values of the clear sky aerosol radiative forcing (ARF) and show that the global mean magnitudes of ARF at the top of the atmosphere and surface are about -3.4 Wm^{-2} and -6.4 Wm^{-2} respectively. The associated surface temperature response shows cooling over most of the northern hemisphere continents **(Fig.1)**. Given the complexity of interaction of different aerosol species, the background large-scale conditions and feedback mechanisms, further experiments and

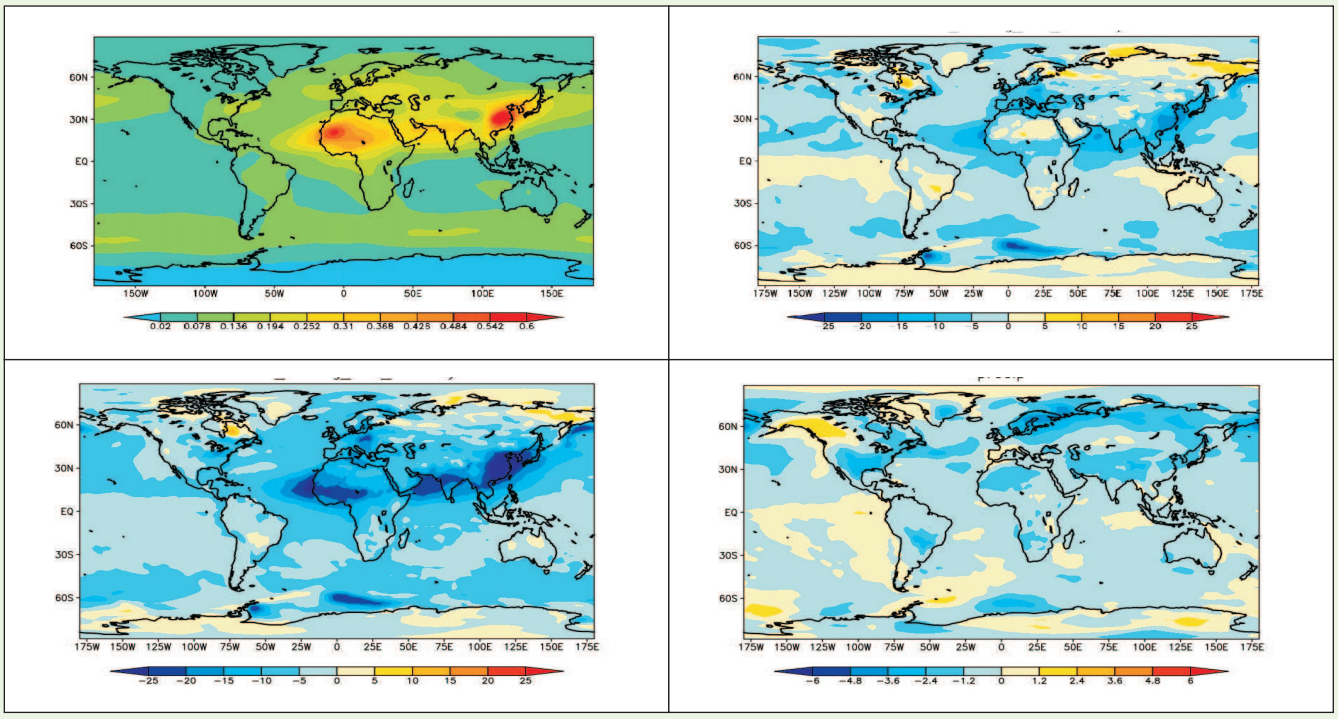


Fig. 1: *Annual mean fields for (**a**) 2005 Macv1 AOD at 550nm (**b**) Clear sky ARF (Wm^{-2}) at TOA simulated by IITM ESM2.0 (**c**) same as (**b**) but for surface (**d**) Surface temperature anomaly (°C) (Aerosol minus No Aerosol).*

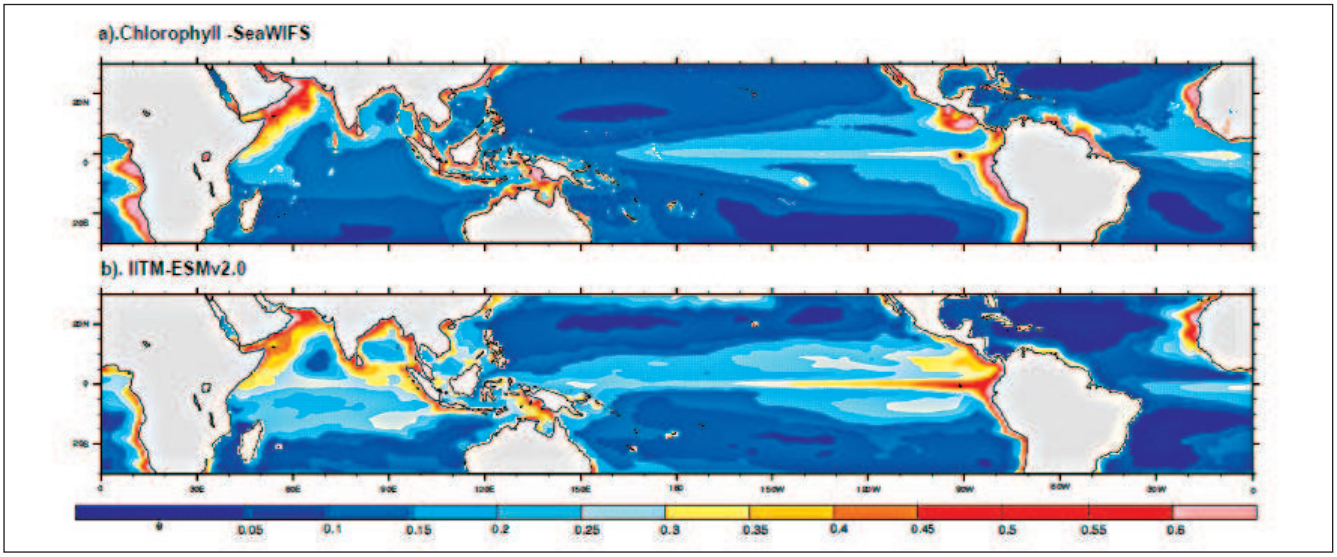


Fig. 2: *The spatial distribution of annual mean chlorophyll concentration (Mg m^{-3}) from (**a**) SeaWiFS and (**b**) IITM-ESM2.0.*

analysis will be carried out to better understand and quantify the impact of aerosols on South Asian climate. For the CMIP6/IPCC experiments, the IITM-ESM2.0 simulations will also include interactive ocean biogeochemistry. The spatial distribution of Chlorophyll (Chl) concentration (Mg m^{-3}) during June-September in ESM2.0 shows Chl blooms associated with upwelling near the coast of Somalia in the Arabian Sea, Sumatra in the eastern equatorial Indian Ocean and eastern equatorial Pacific, which correspond to Chl patterns derived from the satellite SeaWiFS data **(Fig. 2).**

Basic Research

Climate Change and tropical Indo-Pacific variability: The study addresses the triggering mechanism for different flavours of El Niño in the recent decades. The time evolution of SST and thermocline anomalies during different El Niño types is shown in **Fig. 3**. The results show that stronger boreal spring (Mar-May) through summer (June-September) westerly wind anomalies (WWA), with relatively stronger ocean pre-conditioning result in canonical El Niño, weaker ocean pre-conditioning and weaker WWA generate El Niño Modoki or central Pacific El Niño, stronger ocean preconditioning and weaker WWA lead to a basin wide warming pattern. The strength of the WWA is crucial in determining the strength of the ocean dynamic response and the thermocline displacements in the Pacific. The study has important implications for understanding the nature of El Niño in advance. **[*Jadhav J., Swapna P., Marathe S., Ashok K., On the possible cause of distinct El Niño types in the recent decades,* Scientific Reports, *5, November 2015, DOI:10.1038/srep17009*]**

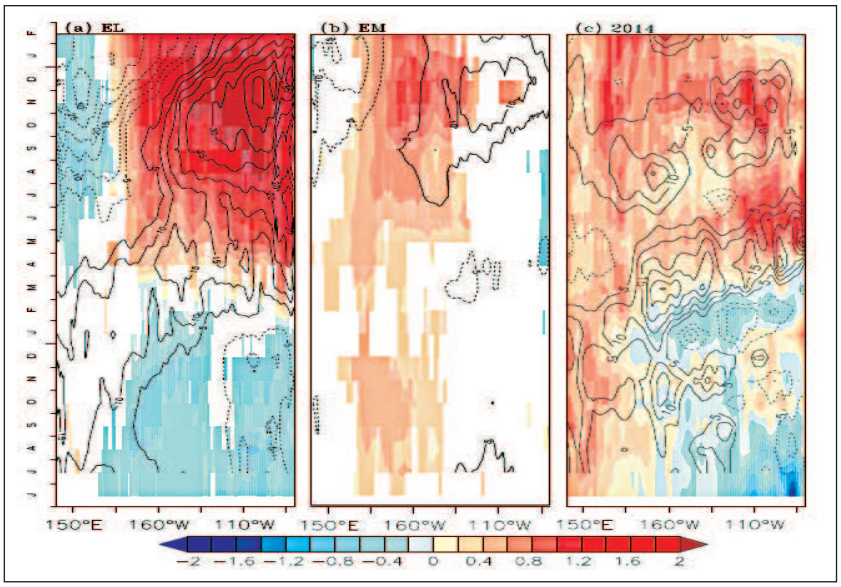


Fig. 3: *Time-longitude plot showing composite anomalies of sea surface temperature (°C, shaded) and 20°C isotherm depth (m, contour) averaged between 5°S-5°N for (**a**) canonical El Niño (**b**) El Niño Modoki and (**c**) 2014. Significance values above 90% confidence level from two-tailed student's t-test are shaded in (**a**) and (**b**).*

Revisiting El Niño Modokis: The distinct evolution of El Niño Modoki from canonical El Niño is studied using various linear and non-linear approaches and composite analysis technique. The results indicate that dynamic feedback intensity is stronger for El Niño Modoki (canonical El Niño) during boreal summer (winter); though the air-sea coupling strength, a major contributor to Bjerknes feedback, is maximum for Modokis during the developing stages and it decreases thereafter. In the case of thermodynamic feedback intensity, SST-wind-evaporation feedback is dominant for El Niño's while SST-SHF feedback is important during El Niño Modokis. Dynamics and thermodynamic feedback intensities during El Niño evolution are shown in **Fig. 4**. The results reveal that two types of El Niño have different driving mechanisms leading to different spatial patterns of SST anomalies and teleconnections. [***Marathe S., Ashok K., Swapna P., Sabin T.P.**, Revisiting El Niño Modokis, **Climate Dynamics**, 45, December 2015, DOI:10.1007/s00382-015-2555-8, 3527-3545*]

Tropical Indo-Pacific climate drivers and African rainfall: The study diagnoses the relative impacts of the four known Indo-Pacific drivers namely, El Niño Southern Oscillation (ENSO), ENSO Modoki, Indian Ocean Dipole (IOD), and Indian Ocean Basin-wide mode (IOBM) on the entire regional and seasonal spectrum of African rainfall variability using multiple datasets. The Indo-Pacific drivers significantly and distinctly affect the seasonal rainfall of Africa (**Fig. 5**), and a simultaneous occurrence of Indian Ocean events and Pacific Ocean events results in interference of individual impacts. Using observed/reanalysed datasets and through AGCM sensitivity experiments, the study further demonstrates that, in addition to the Walker circulation changes, the Indo-Pacific drivers influence the African rainfall through modulating jet streams. [***Preethi B., Sabin T.P.**, Adedoyin J.A., **Ashok K.**, Impacts of the ENSO Modoki and other tropical Indo-Pacific climate-drivers on African rainfall, **Scientific Reports**, 5, November 2015, DOI: 10.1038/srep16653*]

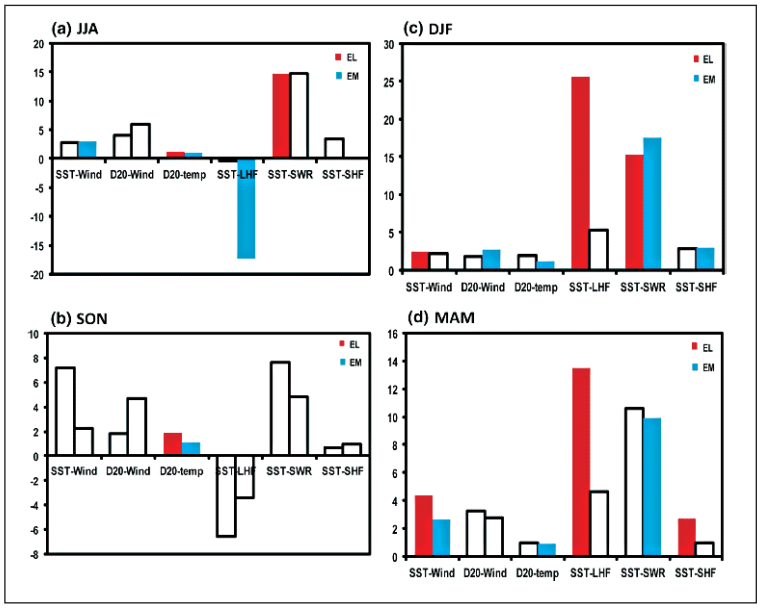


Fig. 4: *The histogram showing the slope values of dynamic and thermodynamic coupling strength for (**a**) boreal summer (June-August) (**b**) fall (September-November) (**c**) winter (December-February) and (**d**) spring (March-May).*

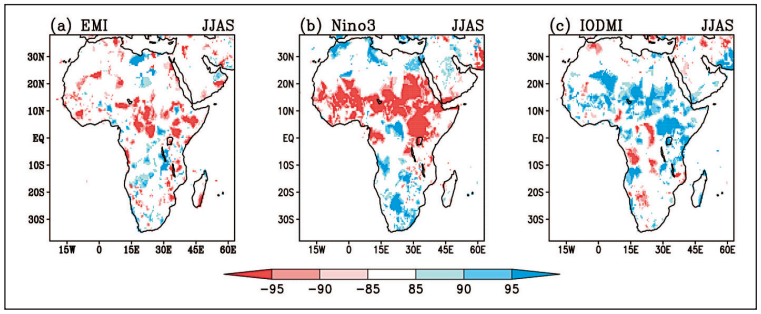


Fig. 5: *Partial correlations between CRU seasonal rainfall and SST indices. (**a**) with ENSO Modoki Index (EMI), (**b**) with ENSO (Niño3) index, and (**c**) with Indian Ocean Dipole Mode Index (IODMI), for the boreal summer (JJAS) season. Correlations significant at 85%, 90% and 95% confidence level, based on Student's t-test are shown.*

Climate Change Science and Applications

Developmental Activities

Regional Climate Information for Application Studies - Updates on CORDEX South Asia: During the past one year, the ensemble of dynamically downscaled regional climate scenarios developed for CORDEX South Asia using multiple high-resolution (50 km horizontal resolution) regional climate models (RCMs) forced by lateral boundary and initial conditions generated by the CMIP5 AOGCMs for the historical period and the future RCP scenarios has increased. SMHI, Sweden has contributed by publishing on Earth System Grid Federation (ESGF) simulations based on RCA4 RCM driven with ten CMIP5 AOGCMs. CCCR, IITM has completed simulations based on ICTP RegCM4 RCM driven with five CMIP5 AOGCMs. These new datasets will be useful for exploring the uncertainties due to large-scale forcing and RCM formulation on regional climate over South Asia.

Basic Research

On the recent declining trend of the South Asian monsoon rainfall

South Asian monsoon response to forcing elements: Rising propensity of precipitation extremes and concomitant decline of summer monsoon rains are amongst the most distinctive hydroclimatic signals that have emerged over South Asia since 1950s. A clear understanding of the underlying causes driving these monsoon hydroclimatic signals has remained elusive. Using a state-of-the-art global climate model with high-resolution zooming over South Asia, it is demonstrated that a juxtaposition of regional land-use changes, anthropogenic-aerosol forcing and the rapid warming signal of the equatorial Indian Ocean is crucial to produce the observed monsoon weakening in the recent decades. The findings also show that this monsoonal weakening significantly enhances occurrence of localised intense precipitation events as compared to the global-warming response. A 21st century climate projection using the same high-resolution model indicates persistent decrease of monsoonal rains and prolongation of soil drying. Critical value additions from this study include (a) realistic simulation of the mean and long-term historical trends in the Indian monsoon rainfall, (b) robust attributions of changes in moderate and heavy precipitation events over Central India, and (c) a 21st century projection of drying trend of the South Asian monsoon. The present findings have profound bearing on the regional water-security which is already under severe hydrological-stress. (**Fig.6**) [***Krishnan R., Sabin T.P., Vellore R., Mujumdar M., Sanjay J., Goswami B.N.***, *F. Hourdin, J.-L. Dufresne,* ***P. Terray****, Deciphering the desiccation trend of the South Asian monsoon hydroclimate in a warming world,* ***Climate Dynamics****, online, October 2015, DOI:10.1007/s00382-015-2886-5*]

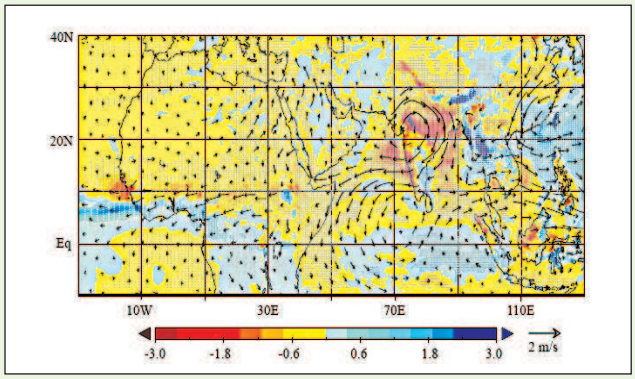


Fig. 6: *Attributing the monsoon weakening to anthropogenic influence. Map showing the difference in June-September mean precipitation (mm day^{-1}) and 850 hPa winds (vectors: ms^{-1}) between the HIST1 and HISTNAT1 simulations for the period (1951-2005). Grey dots correspond to mean precipitation differences (HIST1 minus HISTNAT1) which exceed 95% confidence level based on a two-tailed student's t-test.*

Land surface response to decreasing monsoon rains over India: Simulation experiments are performed using a variable grid high-resolution model (LMDZ) coupled to a sophisticated land surface scheme (ORCHIDEE) having consistent surface water balance over the South Asian region to understand the regional hydrological response to monsoonal changes (Ramarao *et al*. 2015). Results

show that post-1950s, drying in summer monsoon precipitation over the Indian region is accompanied by a 5% decrease of soil moisture during 1951-2005, a reduction in evapotranspiration ~9.5% (**Fig. 7**). A future climate projection using medium scenario (RCP4.5) indicates likely continuation of the drying trend in monsoon rainfall and noticeable decrease of soil moisture till the end of the 21st century. [***Ramarao M.V.S., Krishnan, R., Sanjay J., Sabin, T.P.***, *Understanding land surface response to changing South Asian monsoon in a warming climate,* ***Earth System Dynamics****, 6, September 2015, DOI:10.5194/esd-6-569-2015, 569-582*]

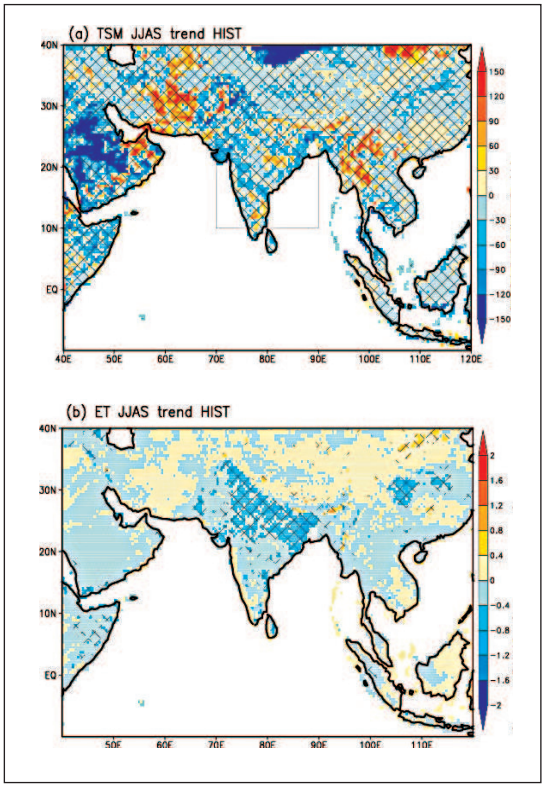


Fig. 7*: Spatial distribution of linear trends in JJAS mean (**a**) total soil moisture (TSM) and (**b**) evapotranspiration (ET) from HIST (all forcing) simulation of LMDZ. Units are mm and mmd^{-1} change over the period 1951-2005 for TSM and ET respectively. Trend values exceeding the 95% level of statistical significance based on Student's t-test are hatched.*

The Indian Ocean has been warming for more than a century at a rate and magnitude larger than what was thought before. The surface warming is the largest in the west-central Indian Ocean with up to 1.2°C in summer SSTs during the past century. Consequences of this rapid warming of Indian Ocean are large, especially on the physical and biological dynamics over the South Asian domain, and eventually, on the socio-economic livelihood of the countries bordering it. Previous studies suggested that the land in the northern hemisphere is warming much faster than the oceans, which implies that the monsoon driver should be getting stronger. Also, the rising ocean surface temperatures entail increased moisture availability in the atmosphere due to increase in evaporation and moisture holding capacity of air. Hence, increased land-sea temperature contrast and moisture availability should ideally increase the monsoon rainfall. However, the current analysis using multiple observed datasets demonstrates a significant weakening trend in summer rainfall during 1901-2012 over the central-east and northern regions of India (**Fig. 8**), where agriculture is still largely rain-fed. The study finds that this is because the land-sea thermal gradient over South Asia has been decreasing due to rapid warming in the Indian Ocean and a relatively subdued warming over the subcontinent. Long-term observations and coupled model experiments used in the study provide compelling evidence that the enhanced Indian Ocean warming potentially weakens the land-sea thermal contrast, dampens the summer monsoon Hadley circulation, and thereby, reduces the rainfall over parts of South Asia.

It is also found that a warmer Indian Ocean dampens the magnitude of ENSO and also, shortens its lifecycle. This involves modulations of the surface winds in the western equatorial Pacific, which trigger eastward-propagating oceanic Kelvin waves responsible for the turnabout of ENSO, through changes in the thermocline.

The rapid ocean warming has also resulted in increased surface stratification over the western Indian Ocean. The western Indian Ocean is one of the most biologically productive regions among the tropical oceans, supporting the second largest share of the most economically valuable tuna catch. It is found that these increasingly stratified ocean waters have suppressed the upwelling of nutrients from the subsurface waters, and have resulted in a reduction of up to 30% in the marine primary production (**Fig. 9**). Future climate projections suggest that the Indian Ocean will continue to warm, leading to further reduction in marine productivity, which combined with the fishing pressure, can drive this productive region into an ecological desert. Altogether, the Indian Ocean warming is a factor to be vigilant of, while assessing long-term changes in the monsoon, the marine productivity, and the global climate. *[**Roxy M., Kapoor R., Terray P.**, Murtugudde R., **Ashok K., Goswami B.N.**, Drying of Indian subcontinent by rapid Indian Ocean warming*

and a weakening land-sea thermal gradient, ***Nature Communications****, 6:7423, June 2015, DOI:10.1038/ncomms8423;* ***Terray P.****, Masson S., Prodhomme C.,* ***Roxy M., Sooraj K.P.****, Impacts of Indian and Atlantic oceans on ENSO in a comprehensive modeling framework,* ***Climate Dynamics****, Online, July 2015, DOI:10.1007/s00382-015-2715-x;* ***Roxy M.K., Modi A.****, Murtugudde R.,* ***Valsala V., Panickal S.,*** *Prasanna Kumar S., Ravichandran M., Vichi M., Levy M., A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean,* ***Geophysical Research Letters****, 43, January 2016, DOI:10.1002/2015GL066979]*

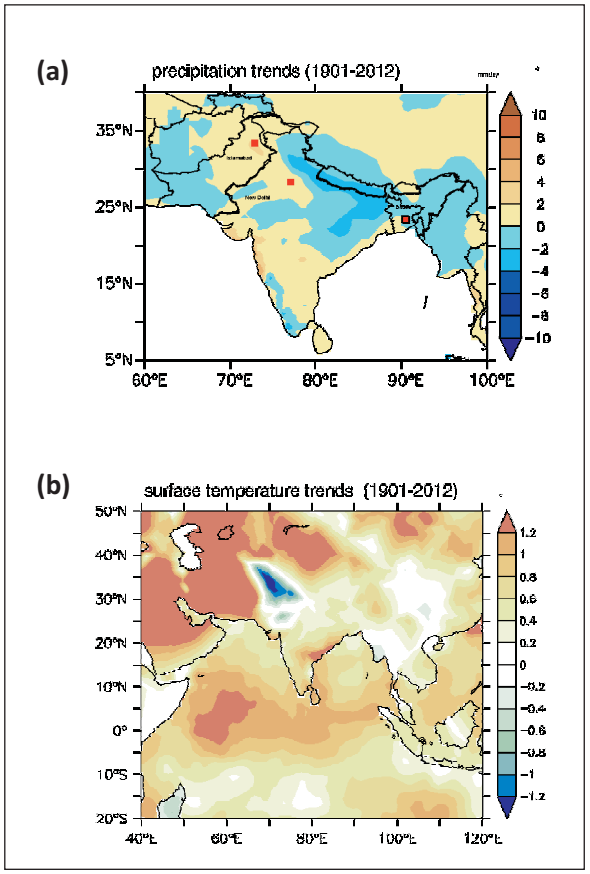


Fig. 8: *(**a**) Precipitation and (**b**) surface temperature trends in the South Asian domain, during summer (June-September), 1901-2012.*

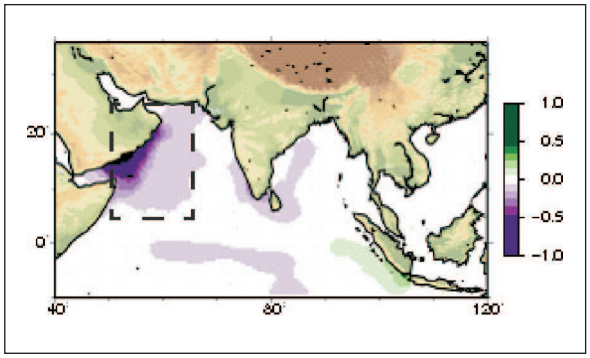


Fig. 9: *Declining trend in marine phytoplankton during June-September, 1998-2013. Blue color indicates significant decline.*

Heavy precipitation events during the Indian summer monsoon

Dynamics of extreme precipitation events over Western Himalayas: A comprehensive analysis of 34 extreme precipitation events (daily rainfall >200 mm) over the Western Himalayas, including the infamous Uttarakhand heavy precipitation event of 17 June 2013, was performed. Results indicate that these extreme precipitation events arise from a common large-scale pattern of monsoon and mid-latitude circulation interactions. The key elements of this interaction include (i) mid-latitude Rossby wave breaking, (ii) west-northwest propagation of monsoon low-pressure system from the Bay of Bengal across the Indian subcontinent, (iii) shedding of the Tibetan anticyclone, (iv) generation of new jet streaks, and (v) mesoscale ageostrophic motions and transverse circulation across the Himalayas in concert with orographic lifting and strong moist convection over the Himalayan foothills (**Fig.10**).

Impact of tropical Indo-Pacific SST anomalies on floods in the Indo-Pakistan region: Flood producing heavy precipitation events over the northwest Indo-Pakistan region (*e.g.*, recent events in 2010, 2011, 2012) during boreal summer have been traditionally linked to mid-latitude influences, while little is known about the impact of slowly varying tropical SST boundary forcing on these flow-dependent precipitation extremes. By conducting a suite of numerical simulations using a high-resolution global atmospheric model, it is noted that warm tropical SST anomalies in the Indo-Pacific basin during La Nina episodes are highly effective in promoting heavy precipitation over the Indo-Pakistan region through pronounced westward shifts in the Pacific subtropical anticyclone and enhanced northward moisture transport from the western Indian Ocean by the monsoonal winds. (**Fig.11**) [***Priya P., Mujumdar M., Sabin T.P., Terry P., Krishnan R.****, Impacts of Indo-Pacific sea surface temperature anomalies on the summer monsoon circulation and heavy precipitation over Northwest India-Pakistan region during 2010,* ***Journal of Climate****, 28, May 2015, DOI:10.1175/JCLI-D-14-00595.1, 3714-3730*]

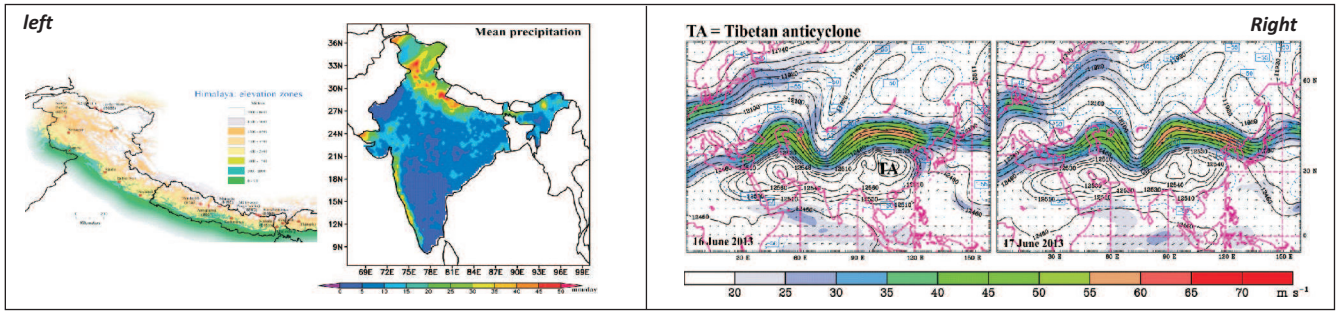


Fig. 10: ***(left)*** *Elevation map of the Himalayas and a composite map of observed mean precipitation (mm day^{-1}) from the 34 precipitation events over the Indian subcontinent (Source: India Meteorological Department).* ***(right)*** *200 hPa horizontal winds (vectors; ≥20 m s^{-1} is shaded), geopotential height (contour interval = 60 m), and air temperature (blue-dashed contour; contour interval = 3ºC) during a heavy precipitation which occurred in the Uttarakhand region during the period 14-17 June 2013 (source: ERA-Interim reanalysis).*

Attribution of recent increase in heavy precipitation events over Central India: Daily rainfall observations over Central India suggest that the frequency of occurrence of heavy rainfall events (intensity >100 mm day^{-1}) has increased since 1950s at the expense of low and moderate rain events. Long climate change simulations were conducted using a variable grid high-resolution model (LMDZ) to understanding the contrasting change in the frequency counts of heavy and moderate rain events over Central India. Results show that the historical simulation (HIST), which includes both the natural and anthropogenic forcing (GHG, aerosols, land-cover/land-use change), captures the contrasting change of the frequency-counts between the moderate and heavy precipitation types over Central India, whereas both categories of precipitation are found to increase in the GHG-only forcing experiment (HIST_GHG). Note that HIST displays an opposite change for the moderate (-) and heavy (+) precipitation categories, but HIST1_GHG shows positive changes for both categories. For changes in the heavy-precipitation category, the third quartile in HIST is also significantly higher by 10□ as compared to HIST_GHG (**Fig.12**).

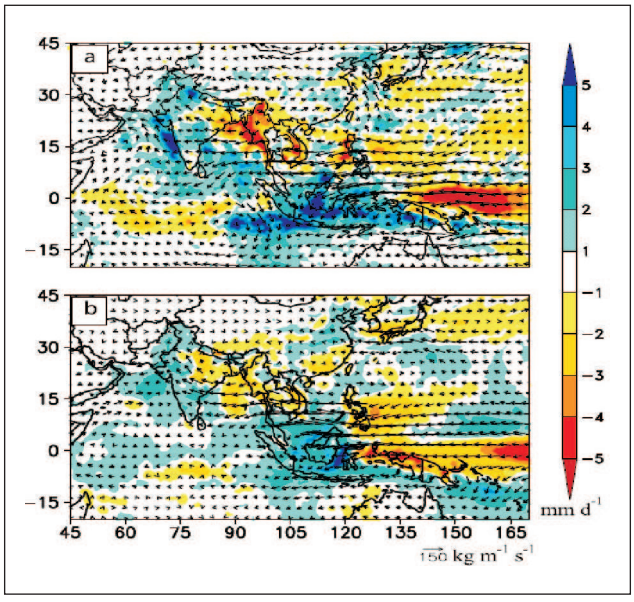


*Fig. 11: TRMM rainfall (mm day^{-1}; shaded) and vertically integrated moisture transport NCEP (vector; Kg m^{-1} s^{-1}); (**b**) Model simulations with real-time SST runs. The rainfall and vertically integrated moisture transport anomalies are relative to the climatology estimated from the Climatological SST runs.*

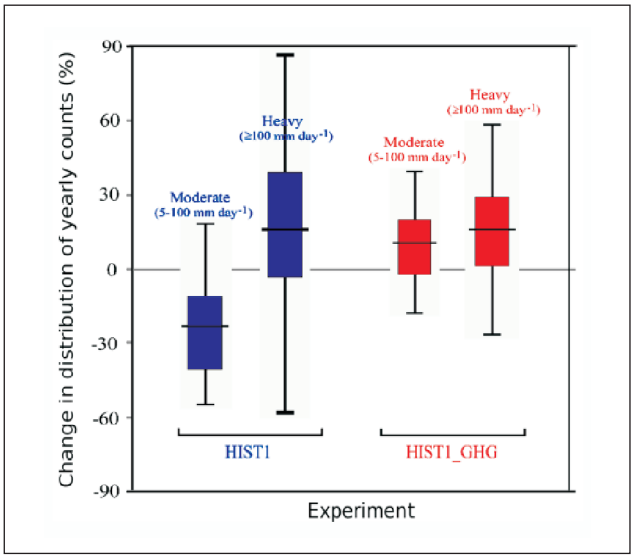


Fig. 12: Attributing changes in moderate and heavy precipitation categories to global and regional forcing. Box-whisker plot showing the distributions of yearly count of moderate (5 mm day^{-1} ≤ precipitation intensity <100 mm day^{-1}) and heavy (precipitation intensity ≥100 mm day^{-1}) events over Central India (74.5°E-86.5°E, 16.5°N-26.5°N) during the period (1951-2000) from HIST1 and HIST1_GHG, expressed as percentage departure relative to HISTNAT1. Note that, for each year the events are counted over 750 grid-cells in the Central India domain and 122 days of the JJAS season. Year-wise departures in the frequency counts are first calculated for both precipitation categories relative to the mean frequency count from HISTNAT1. The quartiles are then computed from the year-wise counts for the two precipitation categories in HIST1 and HIST1_GHG.

Basic Research

Transport of trace gases from North America and West Africa to Asia during monsoon season and its impact on the Asian UTLS

The Asian summer monsoon involves complex transport patterns with large-scale redistribution of trace gases in the upper troposphere and lower stratosphere (UTLS). The model simulations and MIPAS-E satellite measurements show that there are three regions which contribute substantial pollution to the South Asian UTLS: the Asian summer monsoon (ASM), the North American monsoon (NAM) and the West African monsoon (WAM). However, penetration due to ASM convection reaches deeper into the UTLS compared to NAM and WAM outflow (**Fig. 13**). In the lower stratosphere, the injected pollutants are transported westward by easterly winds. Sensitivity experiments with ECHAM5-HAMMOZ for simultaneous NOx and non-methane volatile organic compounds (NMVOCs) emission change (−10) over ASM, NAM and WAM confirm similar transport. Simulations with and without lightning show an increase in the concentrations of PAN (~40), HNO_3 (75), NOx (70) and ozone (30) over the regions of convective transport. Lightning-induced production of these species is higher over equatorial Africa and America compared to the ASM region. This indicates that the contribution of anthropogenic emissions to PAN in the UTLS over the ASM is higher than that of lightning. [***Fadnavis S.***, *Semeniuk K., Schultz M.G., Kiefer M.,* ***Mahajan A.***, *Pozzoli L.,* ***Sonbawane S.***, *Transport pathways of peroxyacetyl nitrate in the upper troposphere and lower stratosphere from different monsoon systems during the summer monsoon season,* ***Atmospheric Chemistry and Physics****, 15, October 2015, DOI:10.5194/acp-15-11477-2015, 11477-11499*]

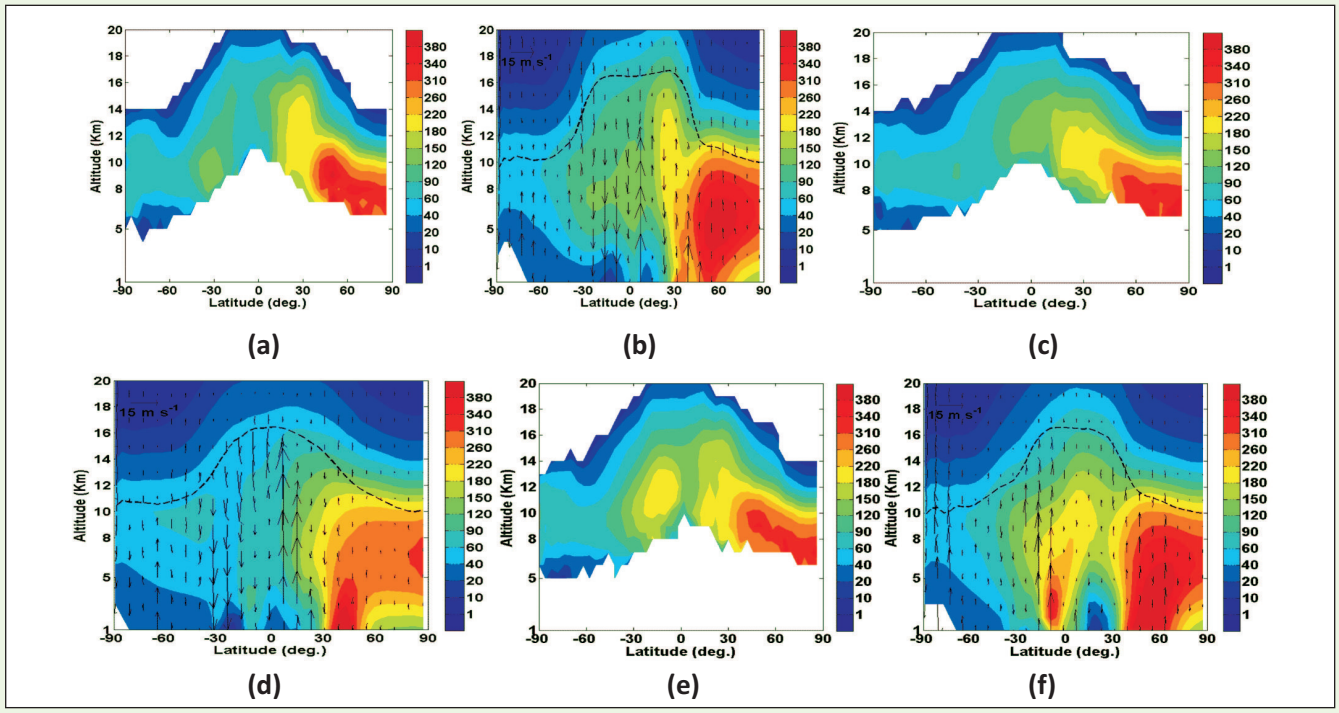


Fig. 13: *Latitude-altitude cross section of PAN (ppt) (**a**) MIPAS-E climatology, averaged for monsoon season and 60°E-120°E, (**b**) PAN from ECHAM5-HAMMOZ CTRL simulations, averaged for 60°E-120°E, (**c**) same as (**a**) but averaged over 70°W-120°W, (**d**) same as (**b**) but averaged over 70°W-120°W (**e**) same as (**a**) but averaged over 0-45°E, (**f**) same as (**b**) but averaged for 0-45°E. The vertical velocity field has been scaled by 300.*

Sub-Project

Paleoclimate

Basic Research

Isotopic analysis of rainwater at the Andaman Islands

Isotopic analysis of precipitation over the Andaman Islands in the Bay of Bengal was carried out for the year 2012 and 2013 in order to study the atmospheric controls on rainwater isotopic variations. **Fig. 14** shows the oxygen isotopic records ($\delta^{18}O$) of Port Blair rain water for the years 2012 and 2013. The oxygen and hydrogen isotopic compositions are typical of the tropical marine sites but show significant variations depending on the ocean-atmosphere conditions; maximum depletion was observed during the tropical cyclones. The isotopic composition of rainwater seems to be controlled by the dynamical nature of moisture rather than the individual rain events. Precipitation isotopes undergo systematic depletions in response to the organised convection occurring over a large area and are modulated by the integrated effect of convective activities. Precipitation isotopes appear to be linked to the 10-20 day mode of monsoon intraseasonal variability in addition to synoptic scale fluctuations. During the early to mid monsoon, the amount effect arose primarily due to rain re-evaporation but in the later phase, it was driven by moisture convergence rather than evaporation. Amount effect had distinct characteristics in these two years, which appears to be modulated by the intraseasonal variability of monsoon. It is shown that the variable nature of amount effect limits the ability to reconstruct the past-monsoon rainfall variability on annual to sub-annual time scale. [***Chakraborty S., Sinha N., Chattopadhyay R., Sengupta S.,*** *Mohan P.M.,* ***Datye A.****, Atmospheric controls on the precipitation isotopes over the Andaman Islands, Bay of Bengal,* ***Scientific Reports****, 6:19555, January 2016, DOI:10.1038/srep19555*]

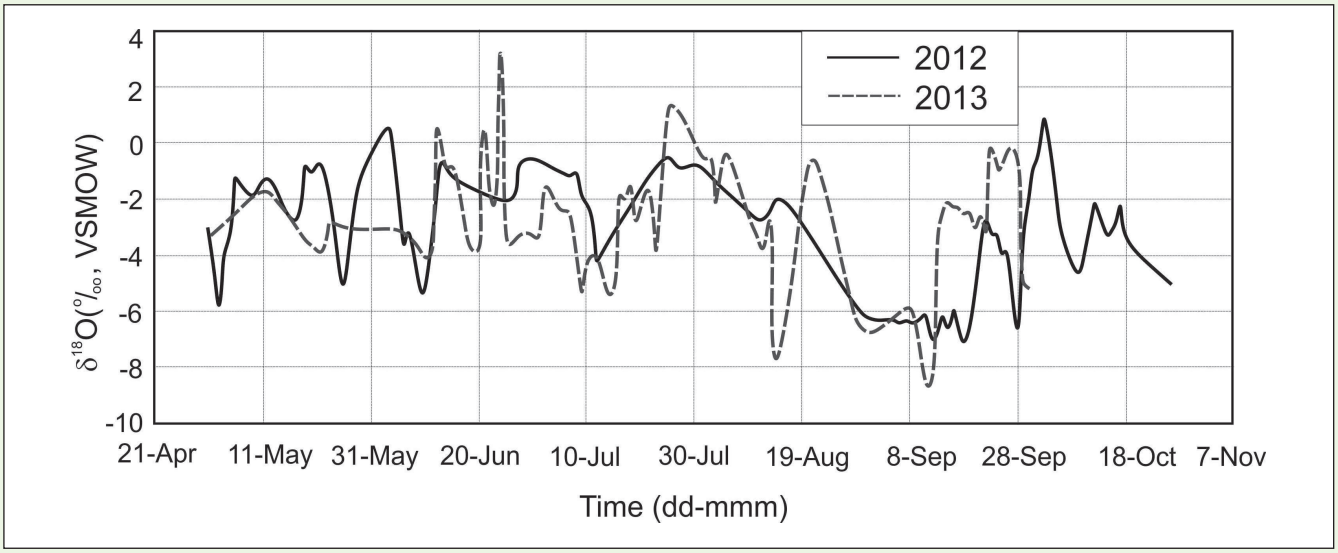


Fig. 14: *Intra-seasonal variations of the oxygen isotopic composition of rain water over the Andaman Island for the year 2012 and 2013.*

GHG, Fluxnet Program and Modeling

Basic Research

Variability in AIRS CO_2 during active and break phases of Indian summer monsoon

Indian summer monsoon (ISM) has a dominant westerly component from ocean to land with a strong tendency to ascend and hence, it may have role in CO_2 distribution in the atmosphere. A substantial component of ISM variability arises from the fluctuations on the intra-seasonal scale between active and break phases which correspond to strong and weak monsoon circulation. The changes in circulation pattern during active and break phases of Indian summer monsoon may have impact on distribution of CO_2 in the atmosphere. In view of this, an attempt is made to examine the link between circulation patterns during active and break phases of Indian summer monsoon and mid-tropospheric CO_2 retrieved from AIRS/AQUA satellite. Correlation analysis indicates the increase in AIRS CO_2 linked with strong monsoon circulation. Study also reveals that anomalous circulation pattern during active and break phases shows resemblance with high and low values of AIRS CO_2. Homogeneous monsoon regions of India show substantial increase in CO_2 levels during active phase. Hilly regions of India show strong contrast in CO_2 and vertical velocity during active and break phases (**Fig. 14**). [***Revadekar J.V., Ravi Kumar K., Tiwari Y.K., Valsala V.***, *Variability in AIRS CO_2 during active and break phases of Indian summer monsoon,* ***Science of the Total Environment****, 541, January 2016, DOI:10.1016/j.scitotenv.2015.09.078, 1200-1207*]

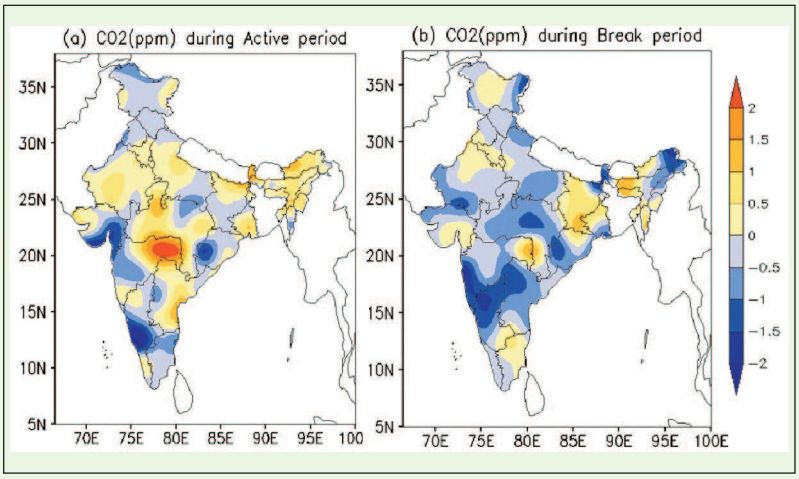


***Fig. 14**: Composite anomalies in AIRS CO_2 (ppm) during (**a**) active spell (left panel) and break spells (right panel) in Indian summer monsoon season for the period of 2003 to 2011.*

Atmospheric CO_2 source and sink patterns over the Indian region

An attempt is made to understand CO_2 sources and sinks patterns over the Indian region. CO_2 hot spot (source) and sink regions are identified from Carbon Tracker (CT-2010) model simulated fluxes for the latest 10 years (2000-2009) over the Indian land mass (8-40°N, 60-100°E). Long term trends are estimated over the hot spots and sink regions. Trends in fossil fuel emissions are compared with two bottom-up emission inventories: Regional Emission inventory in ASia (REASv1.11) for the period 2000-09 and Emission Database for Global Atmospheric Research (EDGARv4.2) for the period 2000-09. Estimated fossil fuel emissions over the hot spot region are ~500-950 gC/m^2/yr as obtained from the global model simulation, EDGARv4.2 and REASv1.11 emission inventory. Simulated total fluxes show increasing trends [1.39±1.01 /yr (19.8±1.9 TgC/yr) - 6.7±0.54 /year (97±12 TgC/yr)] over the hot spot regions and decreasing trends [-0.95±1.51 /yr (-1±2 TgC/yr) to -5.7±2.89 /yr (-2.3±2 TgC/yr)] over the sinks regions. Model simulated terrestrial ecosystem fluxes show decreasing trends (increasing CO_2 uptake) over the sink regions. Decreasing trends in terrestrial ecosystem fluxes imply that forest cover is increasing, which is consistent with India state of forest report (2009). Fossil fuel emissions show statistically significant increasing trends in all the data sets considered in this study. Estimated trend in simulated total fluxes over the Indian region is ~4.72±2.25 /yr (25.6 TgC/yr)

which is slightly higher than global growth rate ~3.1□ /yr during 2000-10 (**Fig. 15**). [***Fadnavis S.***, *Ravi Kumar K.*, ***Tiwari Y.K.***, *Pozzoli L., Atmospheric CO_2 source and sink patterns over the Indian region,* ***Annales Geophysicae****, 34, February 2016, DOI:10.5194/angeo-34-279-2016, 279-291*]

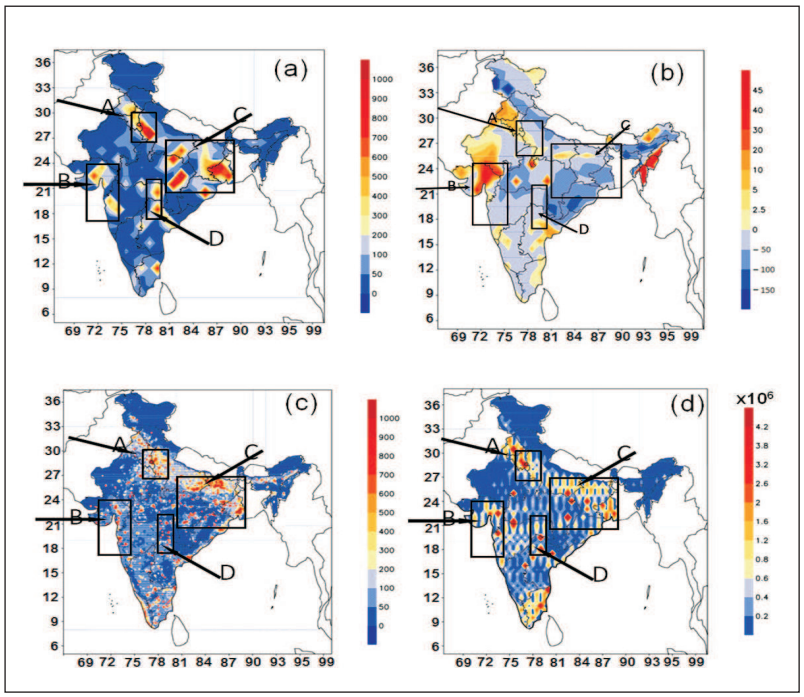


Fig. 15*: Regional distributions of (**a**) CT-2010 CO_2 fossil fuel fluxes (gC/m^2/yr) (2000-09), (**b**) difference between total and fossil fuel fluxes (gC/m^2/yr) as obtained from CT-2010 data averaged for the period 2000-09 over the Indian land mass, (**c**) Regional distributions of EDGARv4.2 CO_2 fossil fuel emission (gC/m^2/yr) (2000-05), (**d**) Regional distributions of REASv1.11 CO_2 fossil fuel emissions (gC/m^2/yr) (2000-09).*

Developmental Activities

Determination of CO_2 flux at terrestrial ecosystem of the north east India

Diurnal CO_2 flux has been estimated in a semi-evergreen, moist deciduous forest of the Kaziranga National Park (KNP) in Assam. **Fig.16** shows seasonality in diurnal variation of CO_2 exchange at KNP. The canopy acts as a sink during day-time due to enhanced photosynthetic activities. However, due to shading of leaves during winter, this process is slowed down resulting in weakening of atmosphere to biosphere CO_2 sink. This is the very first observation of its kind where flux data from northeast India has been reported. Seasonal as well as diurnal variations of carbon source and sink from this region is of high interest because of existence of some of India's dense forests which are predicted to play important role as global hotspot for flux exchange activities. In collaboration with IITM, the site is managed by Tezpur Central University, Tezpur, Assam.

A 15 m tower has been erected at an estuarine mangrove ecosystem at Pichavaram in Tamil Nadu. Various water parameters have been reported from this site. Installation of EC System along with a methane sensor was completed in January 2016 followed by soil sensor installation for better understanding of energy budget and biosphere-atmosphere flux estimation. In collaboration with IITM, the site is managed by M.S. Swaminathan Research Foundation, Annamalai Nagar, Tamil Nadu.

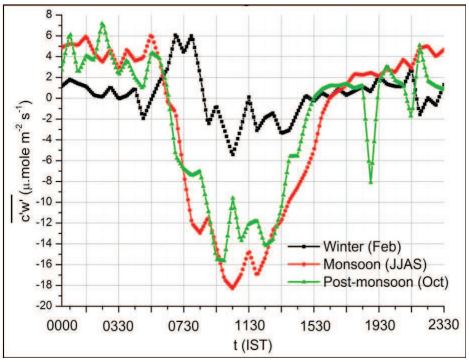


Fig. 16: *Diurnal variations (monthly mean) of CO_2 flux observed at the Kaziranga National Park during JJASO.*

Project

Short Term Climate Variability and Prediction

Project Director: Dr. Ashwini A. Kulkarni

Objectives

- To carry out basic research on variability and predictability of the tropical climate system required for improving forecast of monsoon.
- To study monsoon teleconnections.

Developmental Activities

Development of web portal RAINFO and TEMPINFO: 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 as to be used by the general public as well as farmers. These products would be very useful as inputs to impact assessment groups.

Basic Research

Prediction of summer monsoon rainfall over India and its homogeneous regions

The coherent regions for various meteorological parameters (sea level pressure, temperature, geopotential height and zonal wind anomalies) at the surface, 850, 500 and 200 hPa levels in pre-monsoon months and seasons have been identified by applying the shared nearest neighbour (SNN) algorithm. The time series were constructed by averaging the parameters over the respective clusters. The relationship between these time series and the summer monsoon rainfall over India and over well-defined homogeneous regions over India, (northwest India, central northeast India, northeast India, west central India and peninsular India) was examined during the positive and negative phases of effective strength index (ESI) tendency using multiple regression. Along with the linear relationship, the non-linear relationships between the cluster parameters and the seasonal rainfall were also considered. The prediction of monsoon rainfall over India may improve if the cluster parameters of various meteorological fields are obtained at different levels depending on the phase of ESI-tendency. Use of cross-validation procedure in selecting independent cluster parameters also helps to improve the prediction. During positive and negative phases of ESI-tendency, separate sets of independent cluster parameters were selected by cross-validation procedure. **Fig. 1(a)** depicts the observed and estimated summer monsoon rainfall over India for 1951-2012. Root mean square error (RMSE) on the domain 1951-2012 is 4.25, whereas CC between the observed and estimated rainfall departure is 0.90. **Fig. 1** (remaining graphs) shows the observed and estimated rainfall departures ( ) over five homogeneous regions of India for 1951-2012. The CCs between the actual and estimated rainfall departures are 0.90, 0.91, 0.88, 0.87 and 0.82 for NWI, WCI, CNEI, NEI and PI respectively. All estimated rainfall departure values in deficit/excess years are shown in **Fig. 2** and it is observed that extreme rainfall departures are qualitatively well predicted. The unprecedented droughts in 2002 and 2009, where all models failed to predict, are quantitatively well captured by this strategy. [***Kakade S., Kulkarni Ashwini,*** *Prediction of summer monsoon rainfall over India and its homogeneous regions,* ***Meteorological Applications,*** *23, January 2016, DOI:10.1002/ met.1524*]

Changes in climate extremes over major river basins of India

High-resolution gridded daily rainfall data (1951-2014) and gridded daily temperature data (1951-2013) are used to examine the temporal changes in the extreme rainfall and temperatures on daily time scales in major river basins of India. Trend analysis is carried out to examine the temporal changes in the frequency, area covered by extreme events and their intensities. Rainfall of 10 cm during summer monsoon (JJAS), maximum

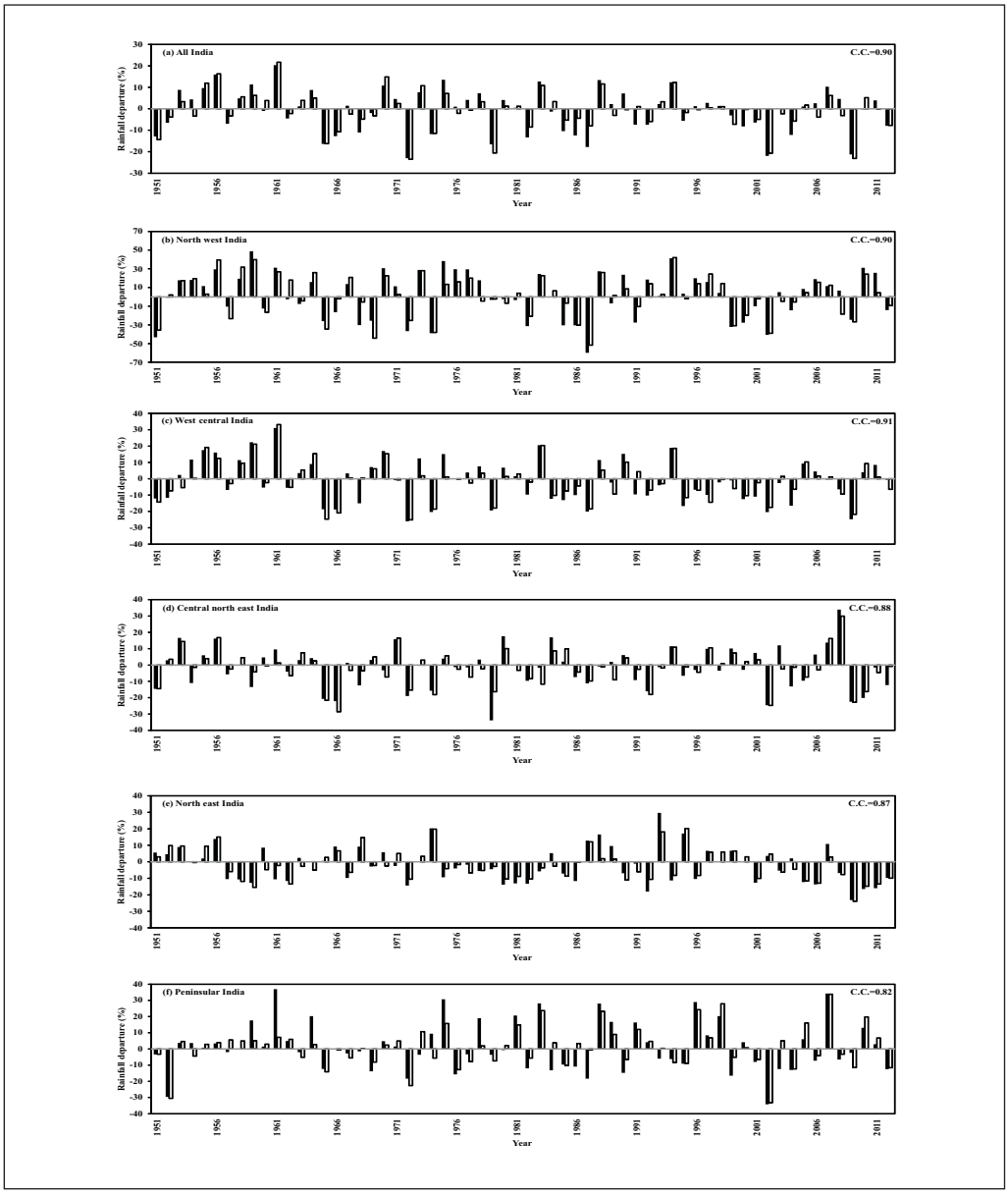


Fig. 1: *Estimated (white column) and observed (black column) summer monsoon rainfall percentage departures over All India (top panel) and subsequently followed over North west India, West central India, Central north east India, North east India and Peninsular India respectively; using separate equations depending upon positive or negative phase of ESI-tendency for 1951-2012.*

temperature of 40°C during summer season (MAM) and minimum temperature of 10°C during the winter season (DJF) were used as the thresholds to define the extreme weather events of rainfall and temperatures. Analysis indicates that during monsoon season, zero rainfall days are increasing in all the river basins except some parts of the Peninsular river basins. River basins located in the central parts of India show significant increase in the area covered by the heavy rainfall episodes and their intensity. Substantial rise in the monthly maximum temperatures is seen in the Krishna, Peninsular and West Coast river basins (**Fig. 3**). Frequency, area coverage and intensity of hot days during summer season are increasing significantly in the Peninsular river basins, while no substantial change was observed for cold days during winter season in any river basins of the study. [***Deshpande N.R., Kothawale D.R., Kulkarni Ashwini****, Changes in climate extremes over major river basins of India,* ***International Journal of Climatology****, online, February 2016, DOI: 10.1002/joc.4651*]

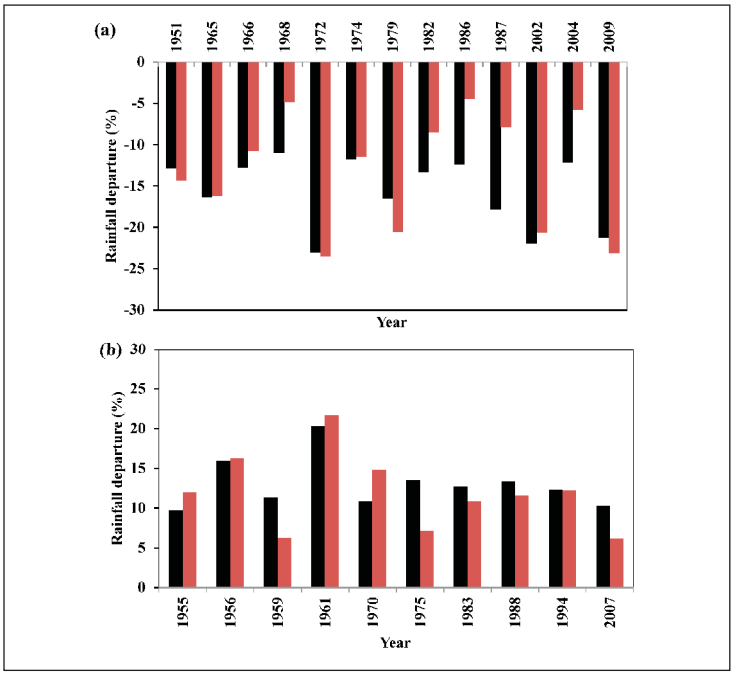


Fig. 2: *Observed (black) and estimated (red) all-India summer monsoon rainfall departures (%) during (**a**) deficient and (**b**) excess monsoon years during 1951-2012.*

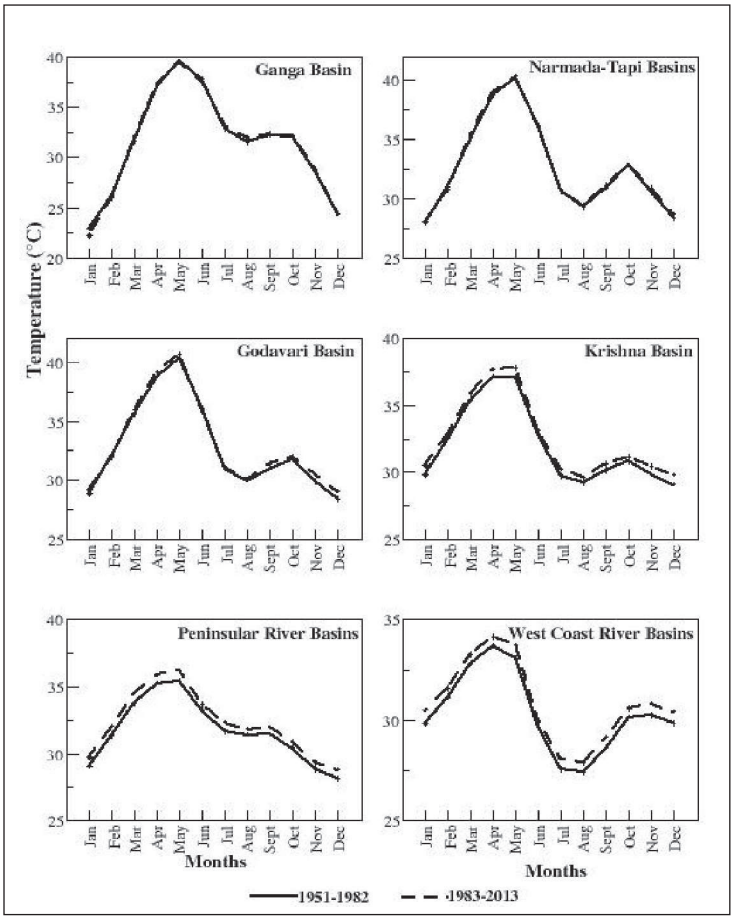


Fig. 3: *Annual cycle of monthly maximum temperatures.*

Project

Monsoon Mission

Project Directors: Dr. A.K. Sahai and Dr. A. Suryachandra Rao
Deputy Project Directors: Dr. C. Gnanaseelan and 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 frame work for improving prediction skill of 'Seasonal and Extended range predictions' and 'Short and Medium range (up to two weeks) predictions'.

At IITM, the principle focus of the Monsoon Mission is to develop 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 four sub-projects for better execution.

Sub-Projects

- Seasonal Prediction
- Extended Range Prediction
- Ocean Modelling and Data Assimilation
- 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). Retrospective forecast (hindcast) experiments have been carried out using the coupled model CFSv2 with this higher spectral resolution of T382 for 30 years, using various initial conditions (of different months) with 6 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 2015 South West monsoon season rainfall using high resolution CFSv2 model at IITM: Dynamical seasonal prediction for 2015 Summer Monsoon rainfall was prepared using the latest high resolution (T382 spectral resolution) research version of CFSv2 and was provided to IMD.

- Based on high resolution dynamical coupled model CFSv2 and using the February Initial condition, the experimental seasonal forecast suggested that rainfall during 2015 SW monsoon season (June to September) averaged over the country as a whole is likely to be 91% ± 5% of long period model average (LPMA).
- Based on high resolution dynamical coupled model CFSv2 and using the April Initial condition, the experimental seasonal forecast suggested that rainfall during 2015 SW monsoon season (June to September) averaged over the country as a whole is likely to be 88% ± 5% of long period model average (LPMA).

These predictions were very close to the actually realised rainfall, *i.e.*, 86% of long period average (LPA) over the country during the summer monsoon season (June-September) of 2015.

Forecast Verification: The output of CFSv2 model forecast (using atmospheric initial conditions from NCMRWF and ocean initial conditions from INCOIS) is being verified against IMD observed data.

Basic Research

Influence of extra-tropical sea surface temperature on the Indian summer monsoon: An unexplored source of seasonal predictability

Based on extensive analysis of observations and a series of climate model experiments, it has been established that slow variations of northern hemispheric extra-tropical sea surface temperature (SST) anomalies can augment seasonal predictability of the south Asian monsoon. The SST conditions and performance of the south Asian monsoon during 2013 boreal summer months (June-September) led to the hypothesis that the strong extra-tropical SST anomalies in the north Pacific and north Atlantic in conjunction with weak tropical SST anomalies (weak La-Nina) were responsible for the above normal rainfall over India during 2013. It is also argued that the 2013 SST pattern and above normal monsoon condition are not unique but has occurred in the past as well. Further, it was shown that there is a complementary pattern of strong extra-tropical SST and weak tropical SST that is associated with below normal south Asian monsoon rainfall. It is also shown that the extra-tropical SST pattern in the northern hemisphere is associated with a low frequency inter-decadal mode of variability indicating potential predictability associated with such extra-tropical SST forcing. Extensive experiments with an atmospheric general circulation model (AGCM) forced by such SST conditions elucidate the mechanism through which the extra-tropical SSTs influence the Indian monsoon. The SST anomalies affect the north-south temperature gradient and lead to a local displacement of the jet stream, setting up a quasi-stationary wave. Such a stationary wave, in turn, affects the tropospheric temperature (TT) over the southern Eurasia and influences the north-south TT gradient in

the region and thereby, influences the Indian monsoon. The discovery of this additional source of potential predictability together with the fact that the new generation coupled ocean-atmosphere models (*e.g.*, NCEP CFSv2) are capable in predicting the extra-tropical SST anomalies brightening the prospect of south Asian monsoon prediction.

The improved prediction skill of SST using NCEP CFSv2 gives some indication that the North Pacific and Atlantic (*i.e.*, patterns outside equatorial or ENSO regions) SST may be important and has the potential to impact the prediction skill of the Indian summer monsoon rainfall (ISMR). The real-time predictions of selected variables relevant for this study for the year 2013 using CFSv2 made from February 2013 initial conditions are shown in **Fig. 1**. The forecasts shown here are the mean of 27 ensemble predictions. **Fig. 1(b)** shows the evolution of the seasonal cycle of rainfall averaged over the Indian land mass for the year 2013 (black curve) in comparison with the climatological seasonal cycle (blue curve) indicating that the excess rainfall during the 2013 monsoon season mainly comes from June and July and it is consistent with observations. Similarly, **Fig. 1(c)** shows the spatial distribution of forecasted rainfall anomaly over the Indian land mass for the JJAS season. It may be seen that both plots indicate a good prediction of wet anomalies over the Indian region. The troposphere in CFSv2 has a known cold bias. In spite of this cold bias, relative warming is seen over the subtropical jet region as compared to the hindcast climatology (**Fig. 1(d)**). The dTT index shows persistent larger values above climatology indicating a stronger annual cycle in forecast mode (**Fig. 1(e)**). In short**, Fig. 1** indicates that the forecast of the large-scale features of inter-annual variability is consistent with observation. In order to support the claim that the extra-tropical SST anomalies were responsible for the above-normal monsoon rainfall during 2013, one additional forecast experiment was carried out for the 2013 monsoon with the same CFS model (T382 atmosphere) and with the same (five) initial conditions for GFS runs where ocean-atmosphere coupling is allowed only in the Tropics between 15°S and 15°N and climatological SST is prescribed elsewhere (coupled-Tropics run). The difference of ensemble mean forecasted seasonal anomaly of rainfall of this coupled-Tropics run from the global T382 coupled run (*i.e.*, actual real-time forecast run) is shown in **Fig. 1(f)**. The below-normal rainfall anomaly is clearly visible from the T382 'coupled-Tropics' forecast experiment over the Indian land mass (**Fig. 1(f)**). Also, the ensemble average of rainfall annual cycle and the dTT index for the coupled-Tropics run are plotted in **Fig. 1(b, e)** for comparison with the actual forecast run of 2013. The annual cycle of rainfall as well as the dTT index show that these are weaker than the actual forecast (*i.e.*, globally coupled forecast). These plots suggest that without the correctly forecasted positive SST anomalies in the North Pacific and North Atlantic, monsoon rainfall forecast for 2013 would have been that for a drought. This experiment clearly indicates that the monsoon of 2013 was indeed driven by extra-tropical SST. Thus, based on the GFS experiments, together with the success of CFSv2 real-time prediction for the year 2013, it is inferred that the SST mode involving strong SST anomalies in the extra-tropical Pacific and Atlantic and weak ENSO in the Tropics and related air-sea interactions have the ability to generate a stationary-wave response and modulate the northern hemispheric tropospheric temperature gradient and thereby the ISMR. [***Chattopadhyay R., Phani R., Sabeerali C.T., Dhakate A.R., Salunke K.D., Mahapatra S., Suryachandra A. Rao,*** *Goswami B.N., Influence of extratropical sea-surface temperature on the Indian summer monsoon: an unexplored source of seasonal predictability,* ***Quarterly Journal of Royal Meteorological Society****, 141, October 2015, DOI:10.1002/qj.2562, 2760-2775*]

What needs to be done to further improve the ISMR prediction skill in CFS V2?

Recently, by using carefully designed coupled model experiments, the authors demonstrated that the prediction skill of the all India summer monsoon rainfall (AISMR) in Climate Forecast System version 2 (CFSv2) model basically comes from the El-Niño Southern Oscillation-Monsoon teleconnection. On the other hand, contrary to observations, the Indian Ocean coupled dynamics do not have a crucial role in controlling the prediction skill of the AISMR in CFSv2; however, these are important for the proper simulation of the inter-annual variance of AISMR. It is shown that inadequate representation of the Indian Ocean coupled dynamics in CFSv2 is responsible for this dichotomy. Hence, improvement in the Indian Ocean coupled dynamics is essential for further improvement of the AISMR prediction skill in CFSv2. It is also shown that the

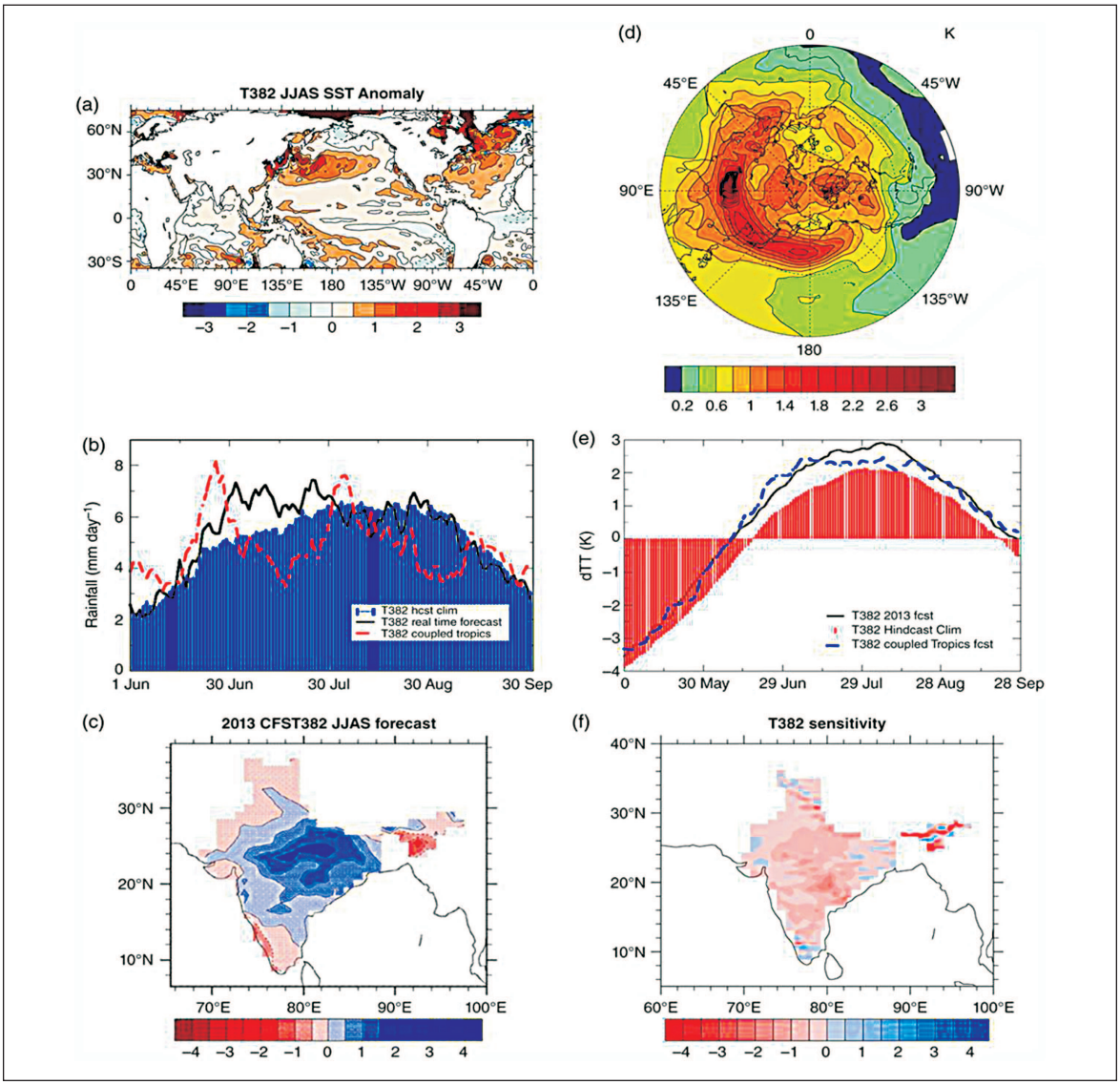


Fig 1: *The CFS T382 2013 forecast experiments:* ***(a)*** *real-time forecast of SST anomaly (in °C);* ***(b)*** *annual cycle of rainfall averaged over the Indian land mass for the actual forecast (black curve) and coupled-Tropics forecast run (red dashed curve) along with the evolution of model simulated climatological annual cycle (blue bars);* ***(c)*** *real-time forecast of JJAS rainfall anomaly (mm day^{-1}, shaded);* ***(d)*** *real-time JJAS tropospheric temperature anomaly (°C) forecast;* ***(e)*** *evolution of tropospheric temperature gradient (dTT index, black curve) for real-time forecast and coupled-Tropics forecast (dashed blue curve) and its hindcast climatology (bars);* ***(f)*** *the spatial pattern of JJAS rainfall obtained from coupled-Tropics CFS T382 run (see text) minus CFS T382 real-time forecast (mm day^{-1}). The anomalies in panels (**a**), (**c**) and (**d**) are calculated from a 28-year CFS T382 hindcast climatology.*

dry bias over the Indian landmass is primarily due to cold SST simulated in the tropical Indian Ocean. When SST bias is reduced in the Indian Slab run, the mean ISMR improved significantly over the Indian land mass (**Fig. 2**). [***George G., Rao Nagarjuna D., Sabeerali C.T., Srivastava Ankur, Suryachandra A. Rao****, Indian summer monsoon prediction and simulation in CFSv2 coupled model,* ***Atmospheric Science Letters****, 17, January 2016, DOI:10.1002/asl.599, 57-64*]

Large-scale teleconnection patterns of Indian summer monsoon as revealed by CFSv2 retrospective seasonal forecast runs

The seasonal prediction skill of Indian summer monsoon rainfall (ISMR) in the global ocean-atmospheric coupled model such as CFSv2 largely depends on the teleconnection of the model at advanced lead times. The current study analyses teleconnection relationships of large scale boundary forcing having predictive skill

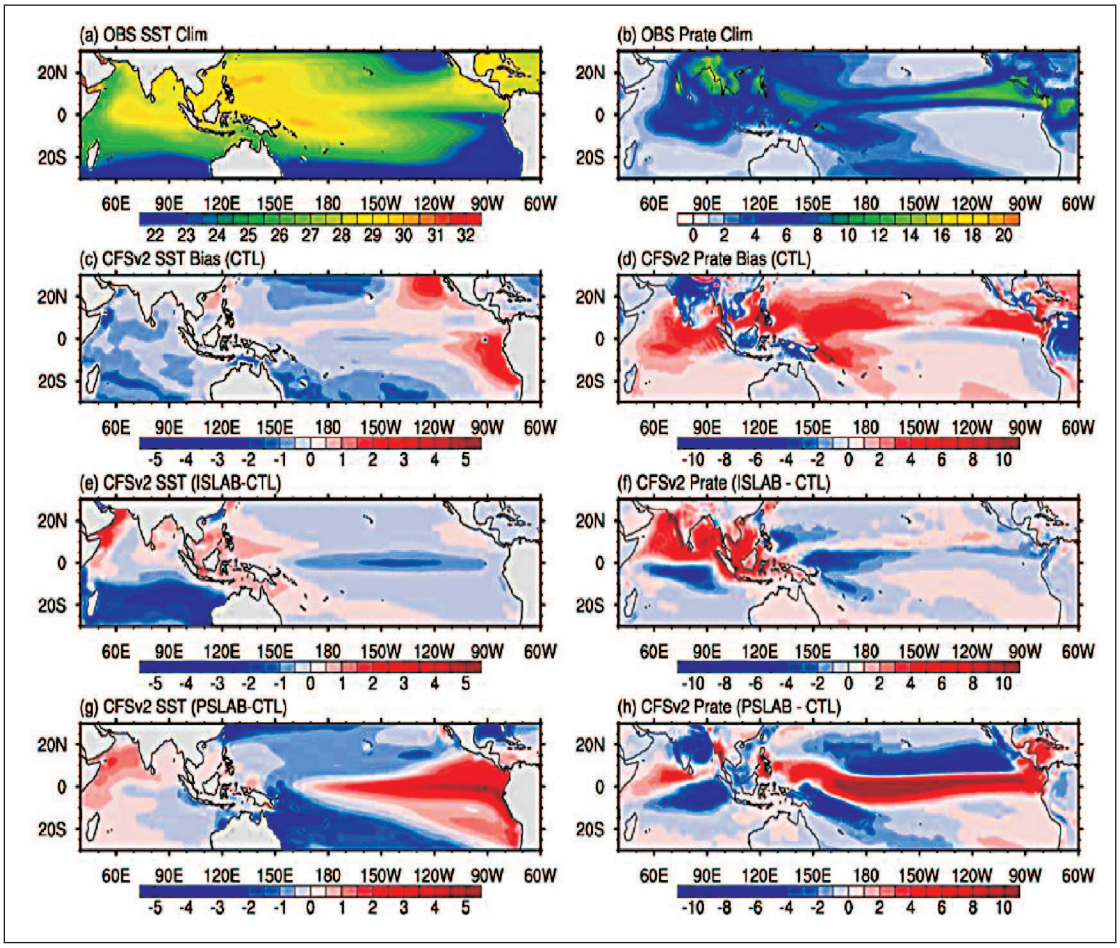


Fig. 2: ***(a)*** *Observed seasonal (JJAS) climatological SST,* ***(b)*** *observed seasonal (JJAS) climatological precipitation,* ***(c)*** *seasonal SST bias of CFSv2 control (CTL) run,* ***(d)*** *seasonal precipitation bias of CFSv2 control (CTL) run,* ***(e)*** *seasonal SST difference between ISLAB and CTL runs (ISLAB-CTL run),* ***(f)*** *seasonal precipitation difference between ISLAB and CTL runs (ISLAB-CTL run),* ***(g)*** *seasonal SST difference between PSLAB and CTL runs (PSLAB-CTL run),* ***(h)*** *seasonal precipitation difference between PSLAB and CTL runs (PSLAB-CTL run).*

with advanced lead time *e.g.*, El-Nino southern oscillation (ENSO)-monsoon teleconnection and Indian Ocean Monsoon teleconnections. Prediction skills in terms of correlations and teleconnection patterns are analysed based on hindcast runs with models initialised from February, March, April and May initial conditions. The model exhibits reasonable skill at a longer lead time (*e.g.*, forecasts initialised with February initial conditions, February IC run, *cc*>*0.5*) that is reasonably better when compared with that with forecast initialised at shorter lead time [April/May IC runs, *cc*<*0.5*].

The model shows unrealistic teleconnection of ISMR with Indian Ocean Dipole (IOD) and is unable to represent the large scale rainfall pattern over the Indian land region. The Equatorial Indian Ocean Oscillation (EQUINOO) shows unrealistic teleconnection with ISMR as well as equatorial Pacific from all the initial condition runs. Unrealistic EQUINOO and the IOD teleconnection suggest that the air-sea interaction in the Indian Ocean requires to be improved in the model. The relationship between El Nino-Southern Oscillation (ENSO) and monsoon in CFSv2 is realistic in terms of spatial pattern though it is somewhat stronger than that in observations. The ENSO-monsoon teleconnection spatial pattern shifts westward with decreasing lead time, resulting in unrealistic patterns as compared with observations, and causing a loss of prediction skill at shorter lead times. (**Fig. 3**) [***Chattopadhyay R., Suryachandra A. Rao, Sabeerali C.T., George G., Rao Nagarjuna D., Dhakate A., Salunke K.***, *Large-scale teleconnection patterns of Indian summer monsoon as revealed by CFSv2 retrospective seasonal forecast runs,*

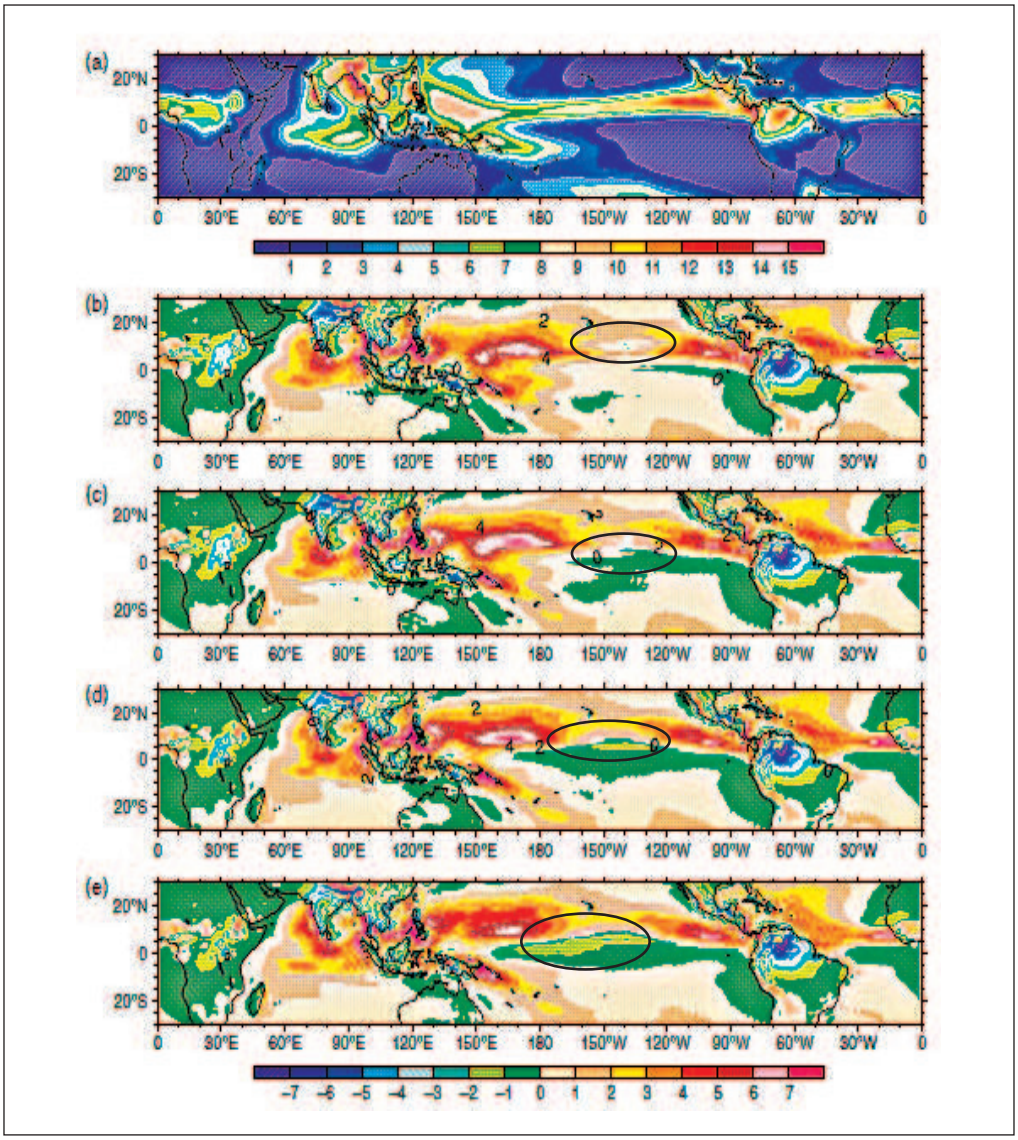


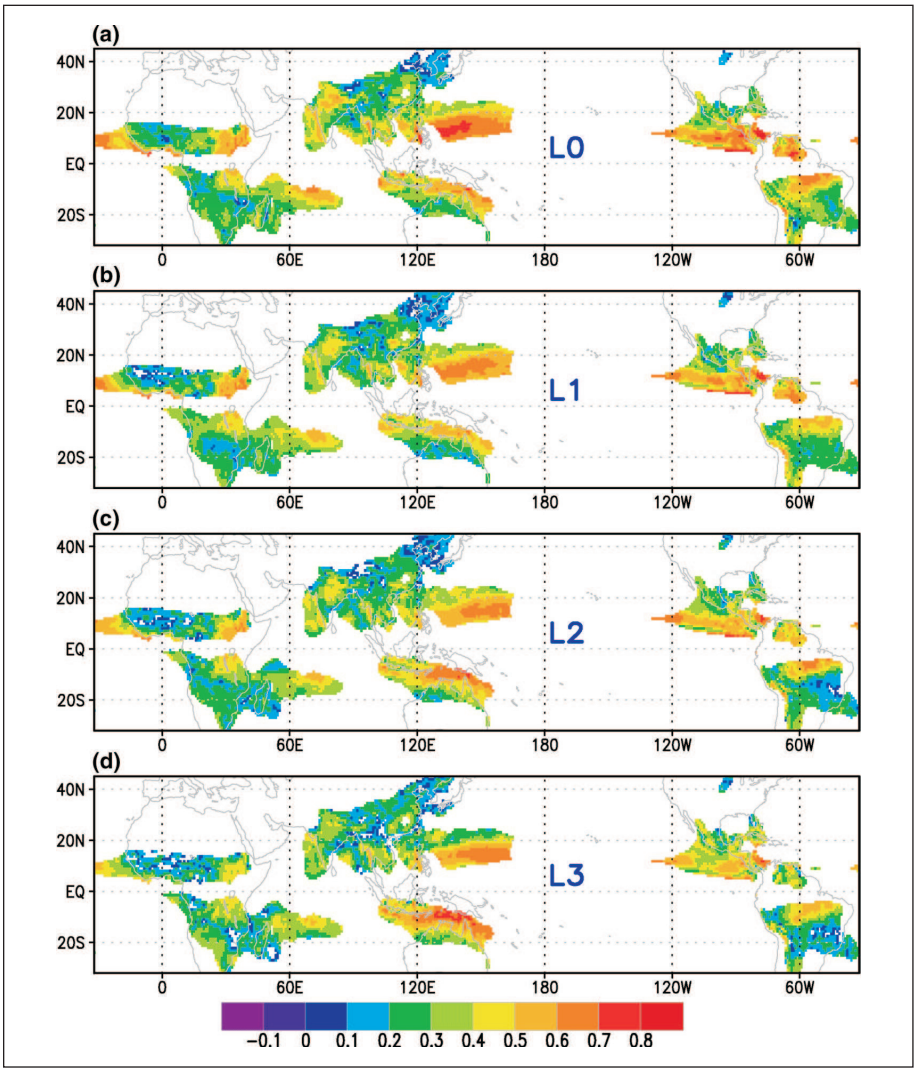
Fig.3. ***(a)*** *Climatological JJAS mean rainfall.* ***(b)-(e)*** *bias in mean rainfall from February, March, April and May initial conditions respectively. (Units mm/day). The black circles represent the shift in rainfall bias as lead time is reduced.*

International Journal of Climatology*, online, December 2015, DOI:10.1002/joc.4556*]

Predictability of global monsoon rainfall in NCEP CFSv2

This study evaluates the actual and potential prediction skill of the global monsoon rainfall using hindcast simulations by NCEP CFSv2 at zero to three lead forecast months (L0-L3). It is shown that the model has moderate skill in global monsoon rainfall (GMR) prediction, where the boreal summer monsoon rainfall forecast is more skillful than that of the austral summer. In general, the prediction skill of the GMR (actual and potential) increases with the decrease in lead forecast time, which is true for all the major regional monsoons, except the Australian monsoon **(Fig. 4)**. Over the Australian monsoon region, both actual and potential prediction skills in rainfall increase with increase in lead forecast. The forecast skill of tropical SST during austral summer is a maximum at 3-month lead forecast (*i.e.*, July initial conditions) and that is associated with spring predictability barrier. Using partial least square (PLS) regression method, it is shown that the major predictor (first latent vector) of the boreal and austral summer monsoon rainfall variability is ENSO, and the influence of ENSO on rainfall variability is much stronger in the model as compared to the observation. The second PLS

regression mode is associated with the non-ENSO variability like tropical Atlantic, Indian, subtropical northwest Pacific Ocean variability, mid-latitude interactions, etc. However, the model has very poor skill in reproducing the second mode, particularly during the boreal summer monsoon season. It is also shown that a significant part of the Indian summer monsoon rainfall variability is controlled by other than ENSO variability and the model has limited success in capturing that. [***Saha Subodh K., Sujith K., Pokhrel S., Chaudhari H. S., Hazra A.***, *Predictability of Global Monsoon Rainfall in NCEP CFSv2,* ***Climate Dynamics,*** *online, December 2015, DOI:10.1007/s00382-015-2928-z*]



Sub-Project

Extended Range Prediction

Developmental Activities

Real-time prediction of 2015 monsoon season

Real time prediction of 2015 monsoon season has been given by the newly developed CFS based Grand Ensemble Prediction System (CGEPS). The CGEPS could predict the large scale enhanced and suppressed phases of convection associated with monsoon intraseasonal oscillations reasonably well. The CGEPS could provide a general outlook on the following features at least 10-15 days in advance: the formation of the low pressure system (Ashoba), its movement towards Oman coast and the associated weakening of monsoon current in the first half of June, the large scale reduction in rainfall in the first half of July, mid August and first week of September; revival of monsoon by the end of July and mid September. The predictability skill was limited to mostly 10 days over almost all homogeneous regions, except southern peninsula (**Fig. 5**), which may be attributed to the dominance of synoptic scale variance during 2015 monsoon season compared to intraseasonal variance.

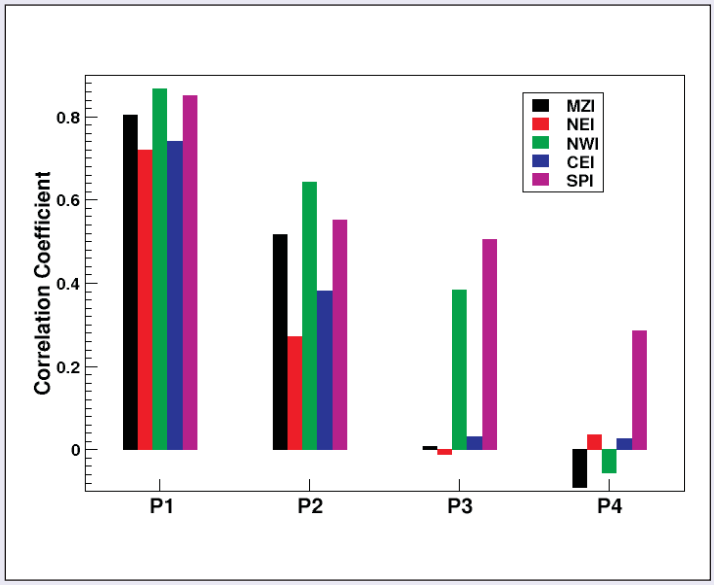


Fig. 5: *Correlation coefficient between the predicted and observed rainfall anomaly over homogeneous regions of India, where MZI, NEI, NWI, CEI and SPI represents monsoon zone, northeast India, northwest India, central India and south peninsular India respectively.*

Development and evaluation of an objective criterion for the real-time prediction of Indian summer monsoon onset in a coupled model framework

This study reports an objective criterion for the real-time extended range prediction of Monsoon Onset over Kerala (MOK), using circulation as well as rainfall information from the 16 May initial conditions of the Grand Ensemble Prediction System based on the coupled model – CFSv2. Three indices are defined – one from rainfall measured over Kerala, and others based on the strength and depth of low level westerly jet over the Arabian Sea. While formulating the criterion, the persistence of both rainfall and low level wind post MOK date has been considered to avoid the occurrence of "bogus onsets" that are unrelated to the large scale monsoon system. It is found that the predicted MOK date matches well with the MOK date declared by the India Meteorological Department, the authorised principal weather forecasting agency under Govt. of India, for the period 2001-2014 **(Fig. 6)**. The proposed criterion successfully avoids predicting "bogus" onsets, which is a major challenge in the prediction of MOK. Furthermore, the evolution of various model-predicted large scale and local meteorological parameters corresponding to the predicted MOK date are in good agreement with that of the observation, advocating the robustness of the devised criterion and the suitability of CFSv2 model for MOK prediction. However, it is to be noted that the criterion proposed here can be used only in the dynamical prediction framework, as it necessitates input data on the future evolution of rainfall and low level wind. [***Joseph S., Sahai A.K., Abhilash S., Chattopadhyay R., Borah N.****, Mapes B.E.,* ***Rajeevan M.****, Kumar A., Development and evaluation of an objective criterion for the real-*

time prediction of Indian Summer Monsoon onset in a coupled model framework, ***Journal of Climate****, 28, August 2015, DOI:10.1175/JCLI-D-14-00842.1, 6234-6248*]

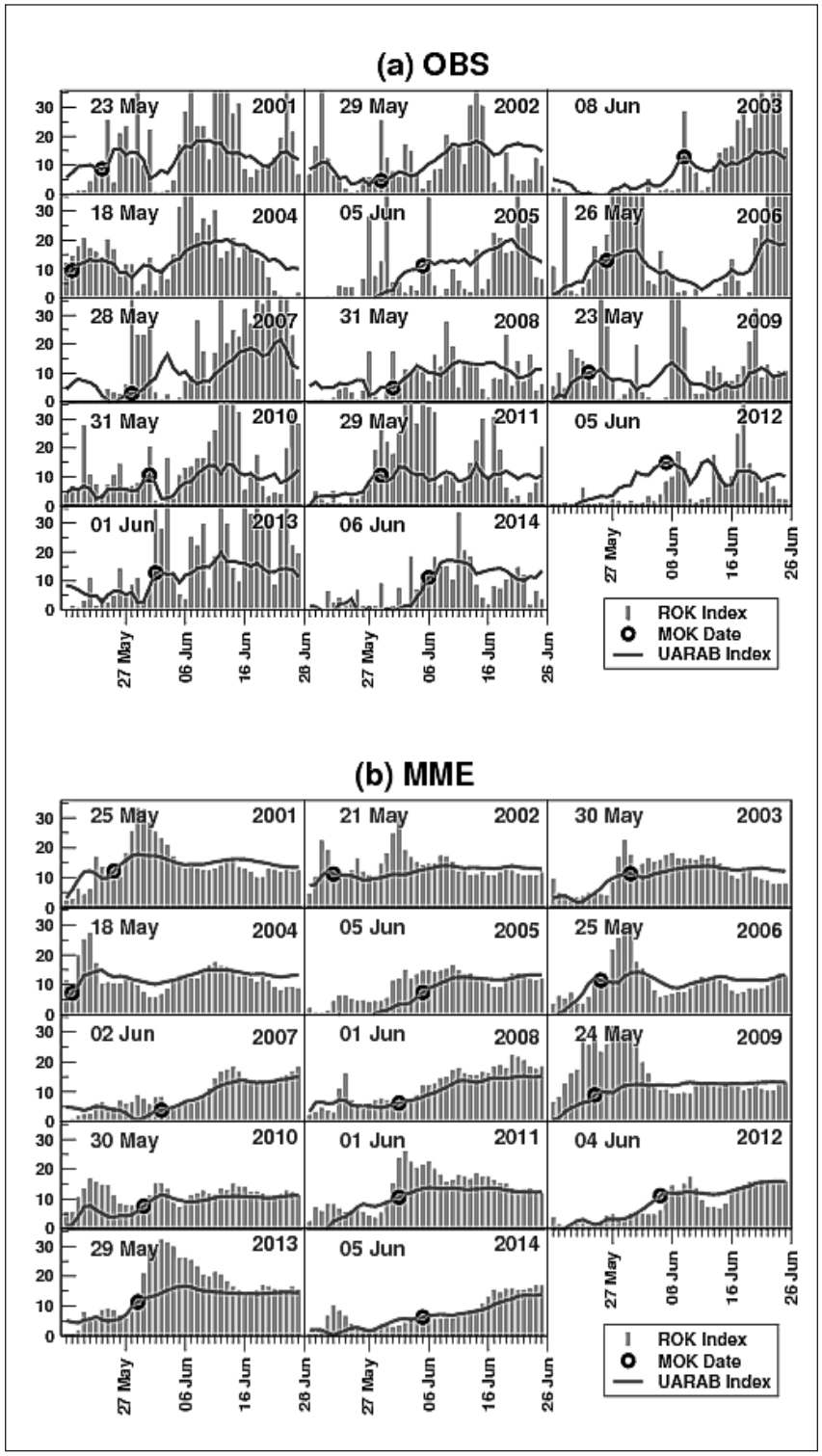


Fig. 6: *Evolution of rainfall (ROK index) and low level zonal wind (UARAB index) used for formulating the criteria in (**a**) OBS and (**b**) MME. For each year, the ROK index is shown as solid bars, UARAB index as thick solid line, and the MOK date is shown as open circle.*

Improved spread-error relationship and probabilistic prediction from CFS based Grand Ensemble Prediction System

Using single model ensembles (SMEs) based on a suite of different variants of CFSv2 model to increase the spread without relying on very different codes or potentially inferior models, a multi-model ensemble prediction system is described. The SMEs are generated not only by perturbing the initial condition, but also using different resolutions, parameters, and coupling configurations of the same model (CFS and its atmosphere component, GFS). Each of these configurations was created to address the role of different physical mechanisms known to influence error growth on the 10-20 day time-scale. Finally, the multi-model consensus forecast, including ensemble-based uncertainty estimates, is developed. Statistical skill of this CFS-based Grand Ensemble Prediction System (CGEPS) is better than the best participating single model ensemble (SME) configuration, because increased ensemble spread reduces over-confidence errors **(Fig. 7)**. [***Abhilash S., Sahai A.K., Borah N., Joseph S., Chattopadhyay R., Sharmila S., Rajeevan M.****, Mapes B.E., Kumar A., Improved Spread-Error Relationship and Probabilistic Prediction from the CFS-Based Grand Ensemble Prediction System,* ***Journal of Applied Meteorology and Climatology****, 54, July 2015, DOI:10.1175/JAMC-D-14-0200.1, 1569-1578*]

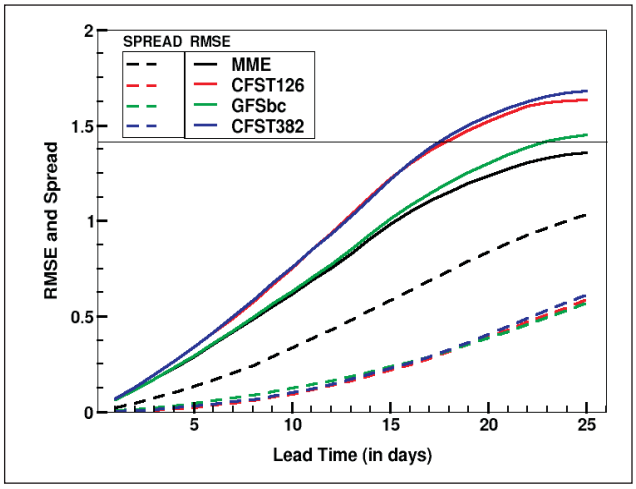


Fig. 7: Bivariate RMSE and spread of MISO indices from CFST126, CFST382, GFSbc and MME.

Basic Research

Extremes in June rainfall during the Indian summer monsoons of 2013 and 2014: Observational analysis and extended-range prediction

The onset/progression phase of the Indian summer monsoon (ISM) is very crucial for the agricultural sector of the country as it has strong bearing on the sowing of kharif crops, which in turn, affects overall food grain production and hence, food security. The recent ISMs of 2013 and 2014 exhibited quite distinct progression phases. While 2013 had one of the fastest advancement in the last 70 years, 2014 witnessed a comparatively lethargic progression phase. The major difference was felt in the early monsoon month of June, with 2013 (2014) monthly rainfall being +34% (−43%) of its long period average. Observational investigations reveal that, during June 2013, the monsoon trough was very active in its normal position favouring low-level positive vorticity generation and moisture convergence, whereas the absence of monsoon trough during June 2014 facilitated the prevalence of a strong low-level anticyclonic circulation over central India hampering the northward progression of the ISM **(Fig. 8)**. It is found that June 2013 (2014) was associated with (i) stronger (weaker) north-south tropospheric temperature (TT) gradient with positive (negative) TT anomalies over Eurasia and north of 60°N; (ii) negative (positive) SST anomalies over the equatorial Indian Ocean, northwestern Arabian Sea and equatorial eastern Pacific; (iii) stronger (weaker) monsoonal Hadley circulation; and (iv) stronger (weaker) Walker circulation in response to the negative (positive) SST anomalies over the equatorial Pacific. The study also examines the skill of an Ensemble Prediction System (EPS) in predicting the observed contrasting behaviour during June 2013/2014 on extended range (~15-20 days in advance) in real time. The EPS not only forecasted the observed discrepancy, but also predicted the influential role of the large-scale meteorological conditions prevalent during June 2013 (2014), thus demonstrating the remarkable skill of the EPS in predicting June extremes. [***Joseph S., Sahai A. K., Chattopadhyay R., Sharmila S., Abhilash S., Rajeevan M., Mandal R., Dey A., Borah N., Phani R.**, Extremes in June rainfall during Indian summer monsoons of 2013 and 2014: Observational Analysis and Extended range prediction, **Quarterly Journal of Royal Meteorological Society**, online, February 2016, DOI:10.1002/qj.2730*]

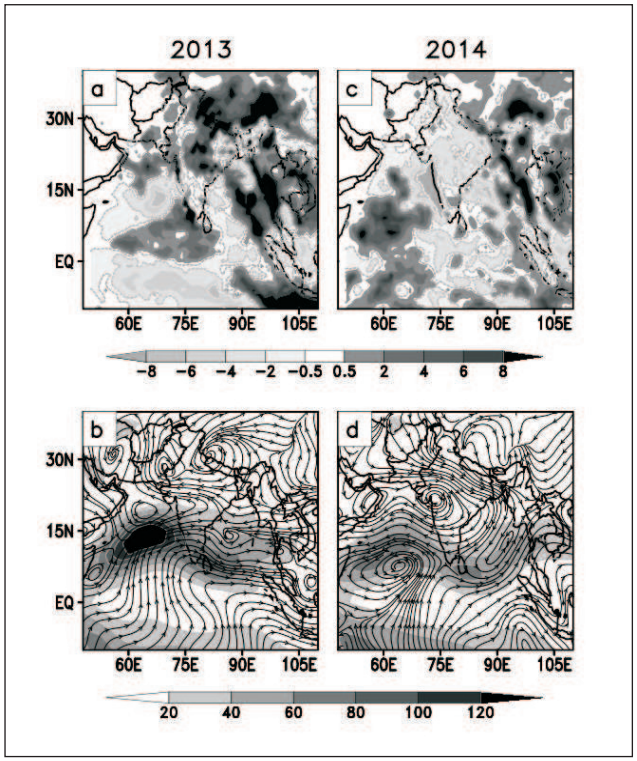


*Fig. 8: (**a**) Rainfall anomaly (shading, mm day^{-1}) and (**b**) 850 hPa anomalous wind (streamlines) and the KE (shading, m2 s^{-2}) of its rotational component, during June 2013. (**c**) and (**d**) are same as (**a**) and (**b**), but for June 2014.*

Ocean Modeling and Data Assimilation

Development Activities

Evolution of 2015-16 El Niño as seen in IITM GODAS

The evolution of 2015-16 El Niño in the data assimilation system IITM GODAS is demonstrated. **Fig. 9** shows the vertical structure of anomalous temperature in the equatorial Pacific during February 2015 to January 2016 from IITM GODAS and Hadley Centre EN4.1.1 (Had-EN4). It is important to note that SST and upper ocean temperature anomalies are well captured by IITM-GODAS and are consistent with Had-EN4. The eastward propagation of subsurface temperature and the associated surface warming in the east and central Pacific are evident in both IITM-GODAS and Had-EN4. The propagation of cold subsurface temperature anomalies in the west is limited to 170°W due to strong westerly wind bursts and the associated generation of downwelling Kelvin waves. The intraseasonal variations in the subsurface temperature are also evident.

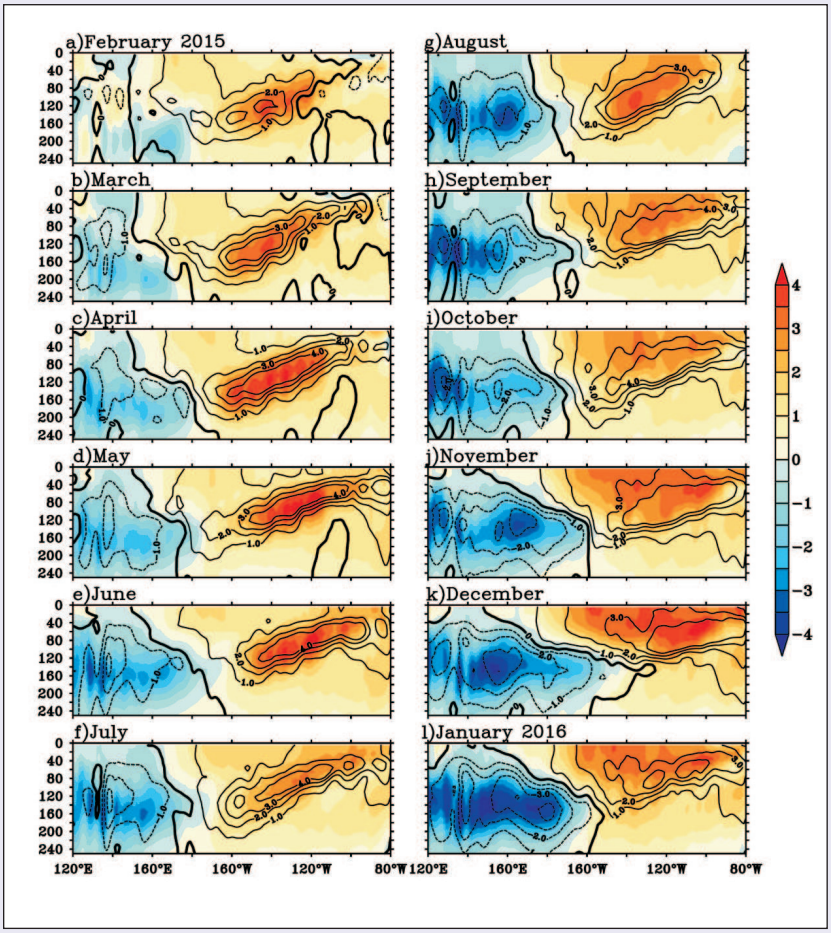


*Fig. 9: Longitude-depth section of temperature anomalies (°C) averaged over 5°S to 5°N during (**a**) June 2015 to (**h**) January 2016 from IITM-GODAS (shaded) and Had-EN4 (contours) over Pacific Ocean.*

Satellite sea surface salinity assimilation in IITM-GODAS

AQUARIUS observed sea surface salinity has been assimilated in IITM-GODAS to examine the evolution of several oceanic parameters such as SST, SSS, MLD and BLT. Several sensitivity experiments are conducted by assimilating *in-situ* only, AQUARIUS SSS only and *in-situ* + AQUARIUS SSS. It is found that both *in-situ* + AQUARIUS and AQUARIUS showed much reduction in the MLD bias **(Fig. 10).**

Assimilating synthetic profiles versus ARGO observations

Synthetic temperature and salinity profiles of the upper ocean have been derived from satellite altimeter for assimilation. The sensitivity of coupled model forecasts to the synthetic profiles versus ARGO observations based ocean initial conditions is carried out. It is clear from **Fig. 11** that the synthetic profiles assimilation is at par with ARGO profiles assimilation. It provides an alternative to ARGO in generating the ocean initial conditions. Considering the large volume and frequency of altimeter observations, this study highlights the potential use of satellite altimeter based assimilation.

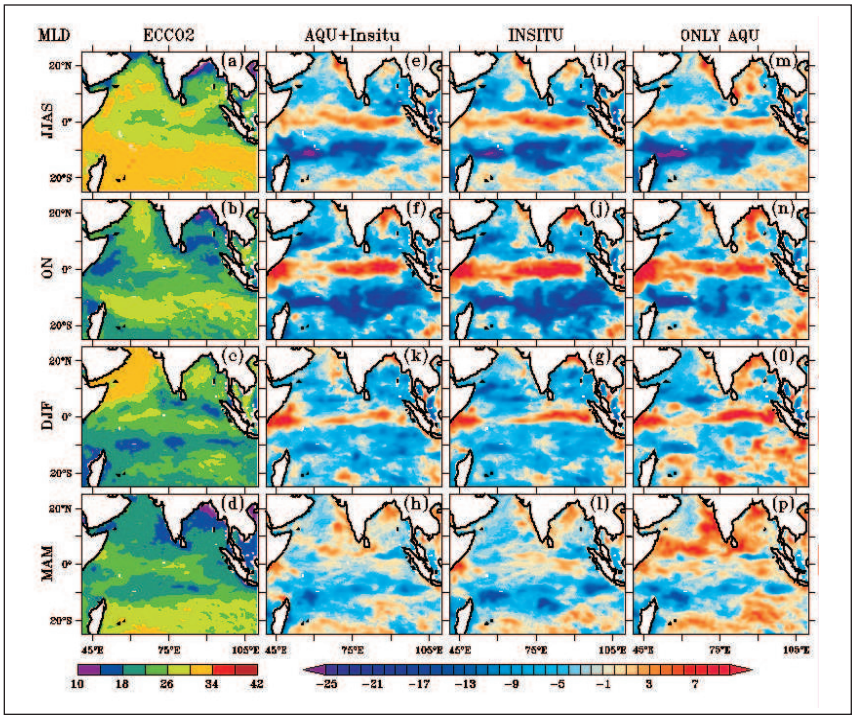


Fig. 10: ***Mean MLD*** *(shaded, m) from ECCO2 analysis for (**a**) JJAS (**b**) ON, (**c**) DJF and (**d**) MAM; bias (shaded, m) with respect to ECCO2 for AQU + In-situ experiment (i.e., AQU + In-situ experiment minus ECCO2) for (**e**) JJAS (**f**) ON (**g**) DJG, (**h**) MAM; (**i**) to (**l**) are similar to (**e**) to (**h**) but biases for In-situ experiment; (**m**) to (**p**) are similar to (**e**) to (**h**) but the biases for only-AQU experiment.*

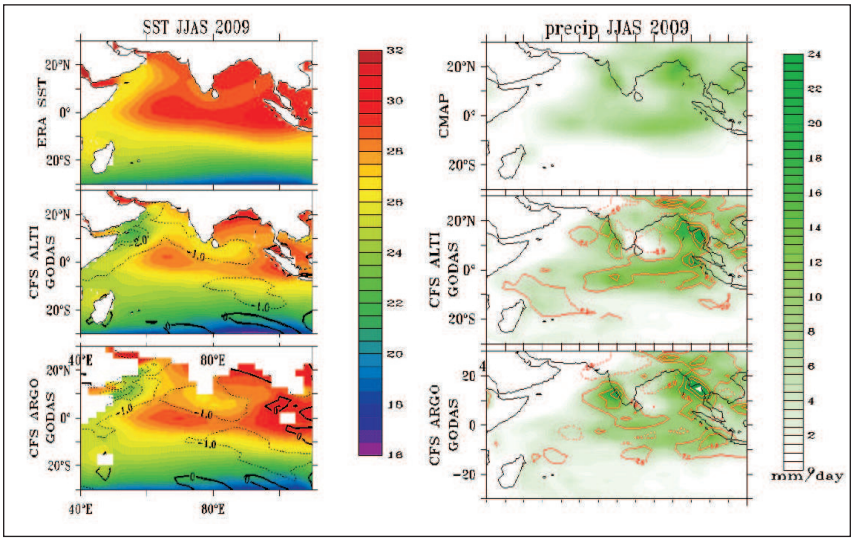


Fig. 11: *Coupled model simulation of SST (**left panel**) and precipitation (**right panel**) based on ocean initial conditions using synthetic profiles and ARGO profiles.*

Basic Research

Tropical Indian Ocean surface salinity bias in Climate Forecasting System coupled models and the role of upper ocean processes

Sea surface salinity (SSS) biases and its seasonal tendency over the Tropical Indian Ocean (TIO) in the coupled models [Climate Forecasting System version 1 (CFSv1) and version 2 (CFSv2)] are examined. Both CFSv1 and CFSv2 overestimate SSS over the TIO throughout the year. CFSv1 displays improper SSS seasonal cycle over the Bay of Bengal (BoB), which is due to weaker model precipitation and improper river runoff, especially during summer and fall. Over the southeastern Arabian Sea (AS), weak horizontal advection associated with East Indian coastal current during winter limits the formation of spring fresh water pool. On the other hand, weaker Somali jet during summer results in reduced positive salt tendency in the central and eastern AS. Strong positive precipitation bias in CFSv1 over the region off Somalia during winter, weaker vertical mixing and absence of horizontal salt advection lead to unrealistic barrier layer during winter and spring. The weaker stratification and improper spatial distribution of barrier layer thickness (BLT) in CFSv1 indicate that not only horizontal flux distribution but also vertical salt distribution displays large discrepancies. Absence of fall Wyrtki jet and winter equatorial currents in this model limit the advection of horizontal salt flux to the eastern equatorial Indian Ocean. The associated weaker stratification in eastern equatorial Indian Ocean can lead to deeper mixed layer and negative Sea Surface Temperature (SST) bias, which in turn, favour positive Indian Ocean Dipole bias in CFSv1. It is important to note that improper spatial distribution of barrier layer and stratification can alter the air-sea interaction and precipitation in the models. On the other hand, CFSv2 could produce the seasonal evolution and spatial distribution of SSS, BLT and stratification better than CFSv1. However, CFSv2 displays positive

bias in evaporation over the whole domain and negative bias in precipitation over the BoB and equatorial Indian Ocean, resulting net reduction in the fresh water availability. This net reduction in fresh water forcing and the associated weaker stratification lead to deeper (than observed) mixed layer depth and is primarily responsible for the cold SST bias in CFSv2. However, the overall improvement of mean salinity distribution in CFSv2 is about 30% and the mean error has reduced by more than 1 psu over the BoB (**Fig. 12**). This improvement is mainly due to better fresh water forcing and model physics. Realistic run off information, better ocean model and high resolution in CFSv2 contributed for the improvement. Further improvement can be achieved by reducing biases in the moisture flux and precipitation. [***Parekh A., Chowdary J.S., Ojha S., Fousiya T.S., Gnanaseelan C.****, Tropical Indian Ocean surface salinity bias in Climate Forecasting System coupled models and the role of upper ocean processes,* ***Climate Dynamics****, Online, June 2015, DOI:10.1007/s00382-015-2709-8*]

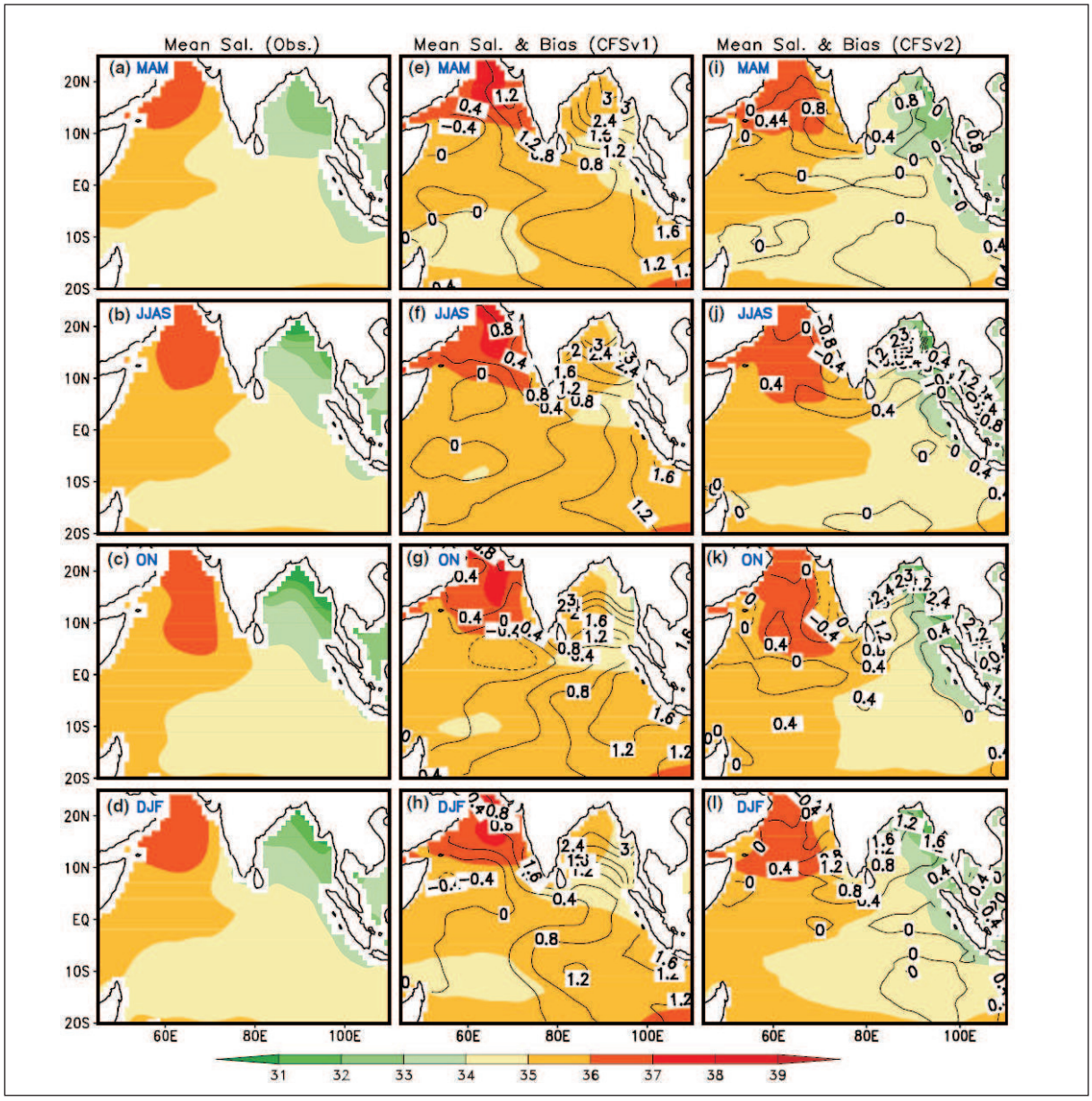


Fig. 12: *Surface Salinity (PSU) climatology from observations (**a**) MAM, (**b**) JJAS, (**c**) ON and (**d**) DJF. (**e**)-(**h**) is similar to (**a**)-(**d**) but for CFSv1 and (**i**)-(**l**) is similar to (**a**)-(**b**) but for CFSv2. Contours represent model salinity bias (model minus observed) for (**e**)-(**h**) CFSv1 and (**i**)-(**l**) CFSv2.*

Role of large scale surface circulation changes and Indonesian Through Flow in modulating the sea surface warming pattern in the Tropical Indian Ocean

The increased rate of Tropical Indian Ocean (TIO) surface warming has gained a lot of attention in the recent years mainly due to its regional climatic impacts. The processes associated with this increased surface warming is highly complex and none of the mechanisms in the past studies could comprehend the important features associated with this warming such as the negative trends in surface net heat fluxes and the decreasing temperature trends at thermocline level. In this work, a previously unexplored aspect *i.e.*, the changes in large scale surface circulation pattern modulating the surface warming pattern over TIO is studied. Ocean reanalysis datasets and a suit of Ocean General Circulation Model (OGCM) experiments are used to address this problem. Both reanalysis and OGCM reveal strengthening large scale surface circulation pattern in the recent years. The most striking feature is the intensification of cyclonic gyre circulation around the thermocline ridge in the southwestern TIO. The strengthening means westerlies over the equatorial region are conducive to convergence in the central and divergence in the western equatorial Indian Ocean (IO) resulting central warming and western cooling. The resulting east west SST gradient further enhances the equatorial westerlies. This positive feedback mechanism supports strengthening of the observed SST trends in the equatorial Indian Ocean. The cooling induced by the enhanced upwelling in the west is compensated to a large extent by warming due to reduction in mixed layer depth, thereby keeping the surface temperature trends in the west to weak positive values. The OGCM experiments showed that the wind induced circulation changes redistribute the excess heat received in the western TIO to central and east thereby enhancing warming in the central equatorial IO. The increased surface warming in the central TIO increases the latent heat loss, and keeps the net heat flux trends negative. Model sensitivity experiments reveal that the subsurface cooling at thermocline level in TIO is contributed by variability in Pacific via Indonesian Through Flow whereas the surface warming trend is mainly induced by the changes in the local forcing (**Fig. 13**). The long term changes in IO Rossby waves are forced by the Pacific. The thermocline shoaling in the west is therefore amplified by the remote influence of the Pacific via wave transmission through Indonesian archipelago. [***Rahul S., Gnanaseelan C.**, Can large scale surface circulation changes modulate the sea surface warming pattern in the Tropical Indian Ocean? **Climate Dynamics**, online, August 2015, DOI:10.1007/s00382-015-2790-z*]

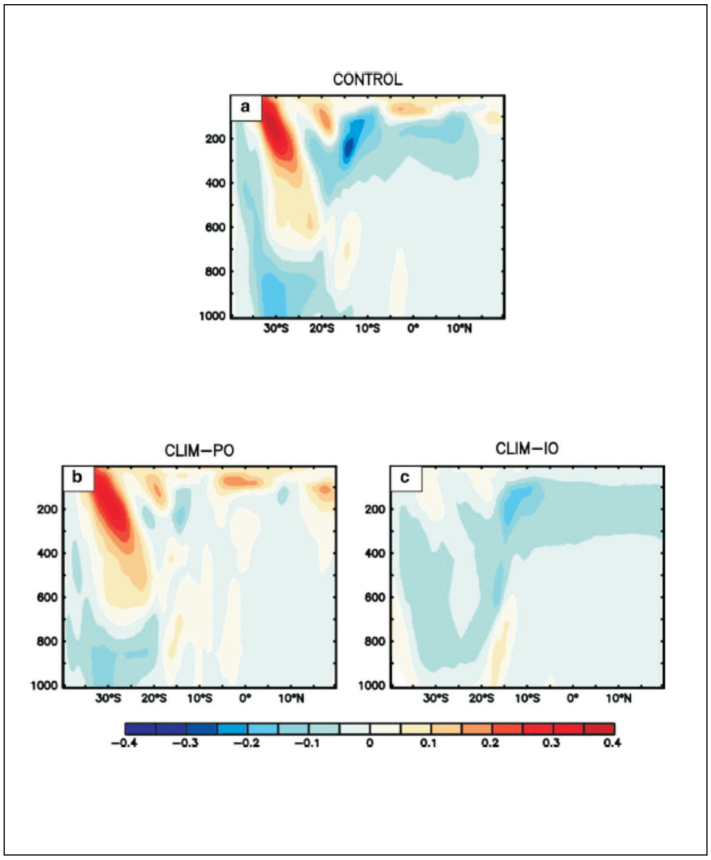


Fig. 13: *Subsurface temperature trends (°C/decade, averaged from 50°E to 100°E) in (**a**) CONTROL, (**b**) CLIM-PO and (**c**) CLIM-IO experiments. In CONTROL experiment model is forced with CORE Inter Annual Forcing (IAF) from 1958 to 2008. In CLIM-PO experiment, the Pacific Ocean is forced with climatological forcing, while IO is forced with interannual forcing. In CLIM-IO experiment, IO is forced with climatological forcing and Pacific is forced by interannual forcing.*

Tropical Indian Ocean response to the decay phase of El Niño in CFSv2 free run and associated changes in Indian summer monsoon

The response of tropical Indian Ocean (TIO) sea surface temperature (SST) to El Niño decay phase and its impacts on South Asian summer monsoon in the National Centers for Environmental Prediction (*NCEP*) Climate Forecast System version2 (CFSv2) free run is investigated. The TIO basin-wide warming induced by El Niño at its peak phase (winter; DJF) and next spring (MAM+1) is reasonably well captured by the model but with weak magnitude. However, TIO SST anomalies are very weak in the model during the El Niño decaying summers. Though El Niño decay is delayed by two months in the model, decay of TIO SST warming is faster than the observations (**Fig. 14**). Anomalous latent heat loss from ocean and a feeble southern TIO Rossby waves associated with weak wind response to El Niño are mainly accountable for rapid decay of TIO SST warming by mid-summer in the model. This suggests that JJA+1 TIO SST response to El Niño decay phase in the model is poorly represented. The model is able to capture the SST anomalies associated with the northwest Pacific anticyclone at the peak phase of El Niño but fail to maintain that during the decay phase in MAM+1 and JJA+1. It is found that precipitation and circulation anomalies associated with TIO SST warming over the South and East Asian regions are disorganised in the model during the decay phase of El Niño. Rainfall anomalies over the southwest TIO, west coast of India, northern flank of northwest Pacific anticyclone and over Japan in JJA+1 are poorly represented by the model. Analysis of lower troposphere stream function and rotational wind component reveals that northwest Pacific anticyclone shifted far eastward to the date line in the model during JJA+1 unlike in the observations. Anomalous divergence observed over the western TIO and convergence in the northwest Pacific are absent in the model during JJA+1. Extension of anomalous tropospheric warming from TIO region to equatorial western Pacific is also very weak in the model due to poor representation of TIO SSTs and the subsequent absence of any Kelvin wave response. Anomalous Walker circulation persisted from DJF to JJA+1 due to El Niño late decay in the model unlike in the observations. This is also found to be responsible for the redundant changes in SST, rainfall and circulation over the Indo-western Pacific in the model. This study demonstrates that it is essential to represent the decay phase of El Niño and the associated TIO response accurately to have realistic simulations of summer monsoon in the decaying year. [***Chowdary J.S., Parekh A., Kakatkar R., Gnanaseelan C., Srinivas G., Singh Prem, Roxy M.***, *Tropical Indian Ocean response to the decay phase of El Niño in a coupled model and associated changes in south and east-Asian summer monsoon circulation and rainfall,* ***Climate Dynamics****, online, October 2015, DOI:10.1007/s00382-015-2874-9*]

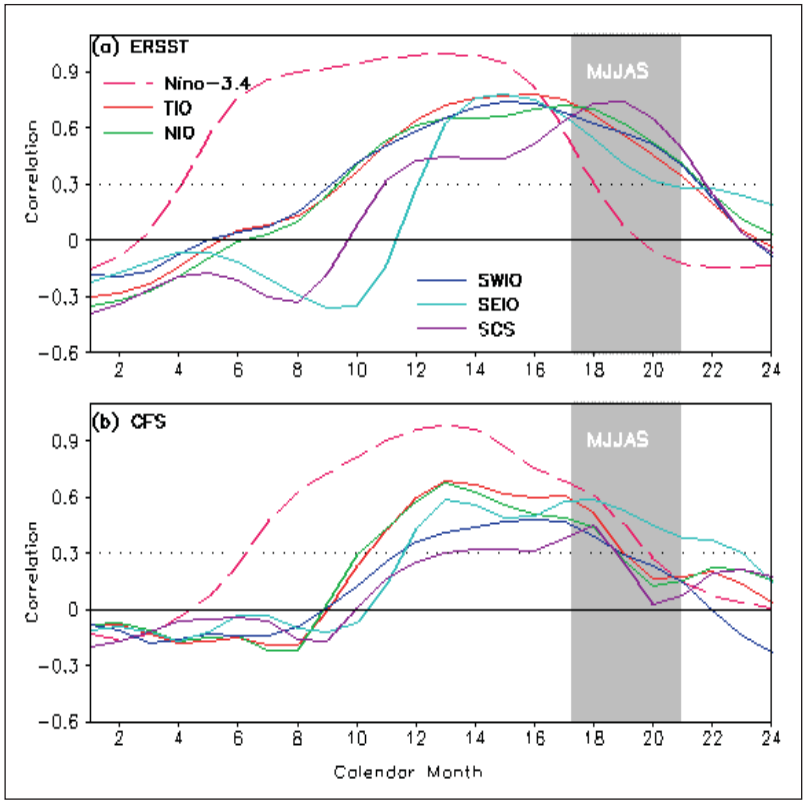


Fig. 14: *DJF Niño-3.4 SST index correlation with the TIO (20°S to 20°N and 40°E to 100°E) NIO (Equator to 20°N and 50°E to 100°E), SWIO (15°S to 5°S and 50°E to 70°E), SEIO (10°S to Equator and 90°E to 110°E) and SCS (4°N to 20°N and 105°E to 120°E) SST anomalies during the El Niño developing and decay year (**a**) ERSST and (**b**) CFSv2-free run.*

Sub-Project

Parameterization of Physical Processes and Analysis

Development Activities

The CFS model shows significant bias in representing the seasonal and intraseasonal variability of Indian summer monsoon. To improve the biases, super-parameterization (SP) has been implemented which shows substantial improvement over the default CFSv2 version. However, as the SP framework is relatively costly, the following improvement is made which is cost effective:

- As the default CFSv2 has simpler cloud microphysics (Zhao and Carr, 1997) which only diagnoses the total cloud condensate, a prognostic cloud scheme which will compute the tendencies of cloud hydrometeors namely water vapour, cloud ice, cloud water, snow, graupel and rain have been used in the revised CFSv2 version (CFSCR) **(Fig. 15)**. A similar approach has been followed by other centres such ECMWF, GFDL, etc. Six classes of hydrometeors improve the grid scale clouds and the stratiform rainfall as seen from the fifteen years free run of the model. The above modification is based on the papers of Abhik *et al.* 2013 and Jiang *et al.* 2011 establishing the mechanism of cloud hydrometeors and monsoon intraseasonal oscillation.

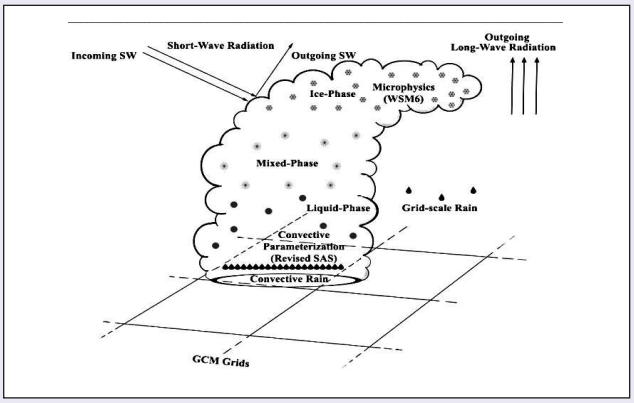


Fig. 15: *A schematic for the interaction among the convection-cloud-radiation through revised SAS convective parameterization, gridscale cloud microphysics WSM6 & RRTM radiation in the CFSCR.*

In a holistic approach, convection-cloud processes-radiation has been modified/revised and a new version of CFSv2 has been developed. This development is similar to what has been done in ECMWF IFS by Forbes *et al.* (2011).

As mentioned by Arakawa and Wu (2014), there is a need to modify the convective parameterization using stochastic framework. Keeping this in view, a stochastic multicloud model parameterization has been developed in collaboration with the University of Victoria under the monsoon mission and has been successfully tested in CFSv2. Detailed testing and configuration are presently under way.

Basic Research

Simulation of the Indian summer monsoon in the Superparameterized Climate Forecast System Version 2: Preliminary results

An analysis of a 5-year (from 1 January 2009 to 31 December 2013) free run of the superparameterized (SP) Climate Forecast System (CFS) version 2 (CFSv2) (SP-CFS), implemented for the first time at a spectral triangular truncation at wavenumber 62 (T62) atmospheric horizontal resolution is presented. The SP-CFS simulations are evaluated against observations and traditional convection parameterized CFSv2 simulations at T62 resolution as well as at some higher resolutions. The metrics for evaluating the model performance are chosen in order to mainly address the improvement in systematic biases observed in the CFSv2 documented in earlier studies. While the primary focus of this work is on evaluating the improvement of the simulation of the Indian summer monsoon (ISM) by the SP-CFS model, some results are also presented within the context of the global climate. The SP-CFS significantly reduces the dry bias of precipitation over the Indian subcontinent

(Fig. 16) and better captures the monsoon intraseasonal oscillation (MISO) modes. SP-CFS also improves the northward and eastward propagation of high- and low-frequency modes of ISM. Compared to CFSv2, the SPCFS model simulates improved convectively coupled equatorial waves; better temperature structures both spatially and vertically, leading to a significantly improved relative distribution of variance for the synoptic disturbances and low-frequency tropical intraseasonal oscillations (ISOs) **(Fig. 17)**. This analysis of the development of SP-CFS is particularly important as it shows promise for improving the cloud process representation through an SP framework and is able to improve the mean as well as intraseasonal characteristics of CFSv2 within the context of the ISM. [*Goswami B.B., **Krishna R.P.M., Mukhopadhyay P.**, Khairoutdinov M., Goswami B.N., Simulation of the Indian summer monsoon in the Superparameterized Climate Forecast System Version 2: Preliminary results, **Journal of Climate**, 28, November 2015, DOI:10.1175/JCLI-D-14-00607.1, 8988-9012*]

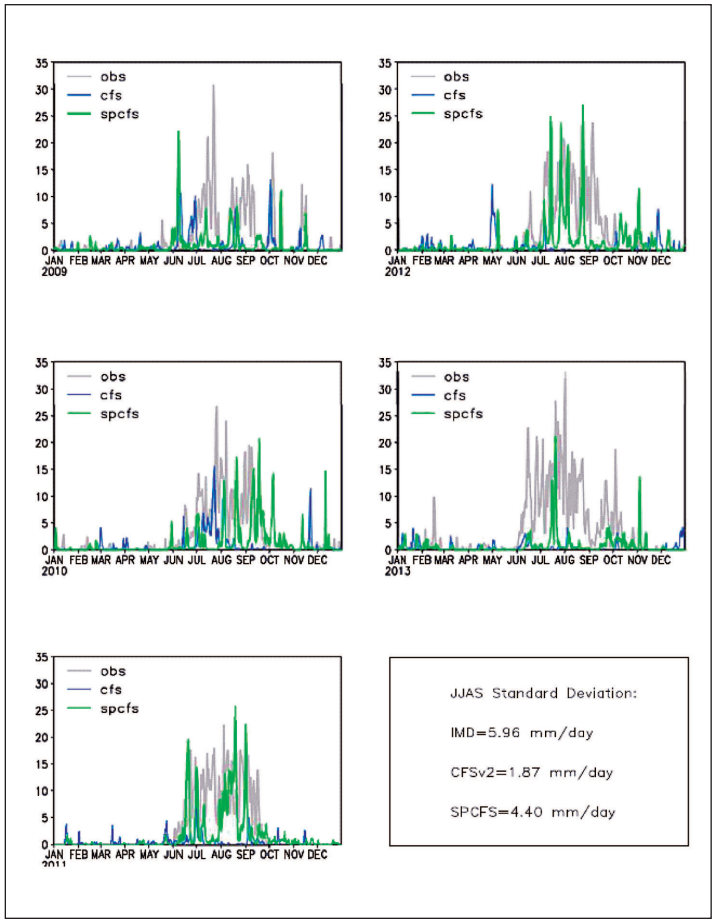


Fig.16: *Evolution of rainfall over central India (18°-28°N, 73°-82°E) for observations (IMD; gray line), CFSv2 (blue line), and SP-CFS (green line), for all 5-year (2009-13) of the simulated climate.*

Diagnosis of boreal summer intraseasonal oscillation in high resolution (T382) NCEP climate forecast system

The ability of high resolution (T382) National Centers for Environmental Prediction coupled atmosphere-ocean climate forecast system version2 (CFS T382) in simulating the salient spatio-temporal characteristics of the boreal summer time mean climate and the intraseasonal variability is examined. The shortcomings of the model are identified based on the observation and compared with earlier reported biases of the coarser resolution of CFS (CFS T126). It is found that the CFS T382 reasonably mimics the observed features of basic state climate during boreal summer. But some prominent biases are noted in simulating the precipitation, tropospheric temperature (TT) and sea surface temperature (SST) over the global tropics (**Fig. 18).** It is interesting to note that while CFS T126 shows colder SST and tropospheric temperature bias, CFS T382 shows a warmer SST and tropospheric temperature bias. However, the nature of rainfall bias remains similar with dry bias over Indian land mass and wet bias over Indian Ocean and tropical pacific region **(Fig. 19).** Although CFS T382 primarily reproduces the observed distribution of the intraseasonal variability over the Indian summer monsoon region, some difficulty remains in simulating the boreal summer intraseasonal oscillation (BSISO) characteristics. The simulated eastward propagation of BSISO decays rapidly across the Maritime Continent, while the northward propagation appears to be slightly slower than observation. However, the northward propagating BSISO convection propagates smoothly from the equatorial region to the northern latitudes with observed magnitude. Moreover, the observed northwest-southeast tilted rain band is not well reproduced in CFS T382. The warm mean SST bias and inadequate simulation of high frequency modes appear to be responsible for the weak simulation of eastward propagating BSISO. Further analysis of the convectively coupled equatorial waves (CCEWs) indicates that model overestimates the gravest

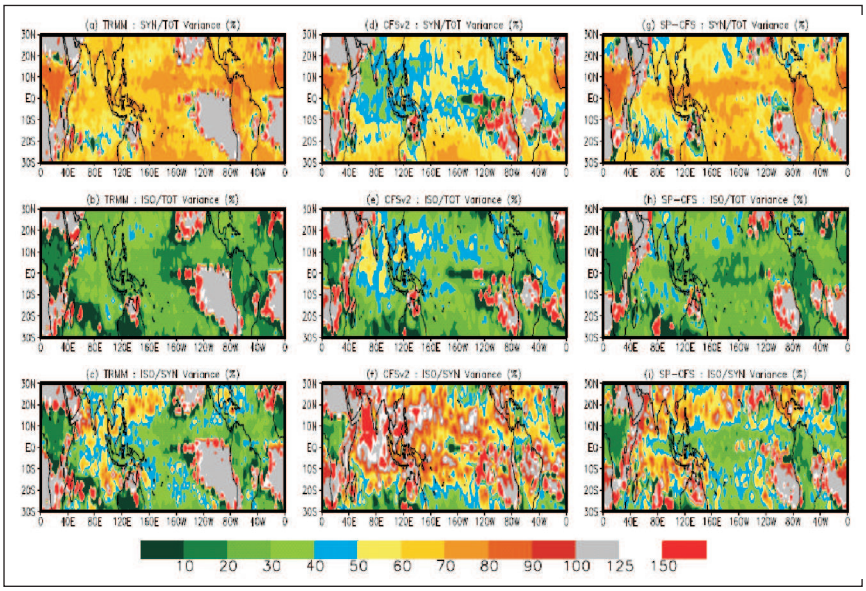


Fig. 17: *Ratios of synoptic-scale (2-10-day band passed) variance to total variance for* ***(a)*** *TRMM,* ***(d)*** *CFSv2, and* ***(g)*** *SP-CFS; ratio of ISO scale (10-90 day band passed) variance to total variance for* ***(b)*** *TRMM,* ***(e)*** *CFSv2, and* ***(h)*** *SP-CFS; and ratio of ISO-scale variance to synoptic scale variance for* ***(c)*** *TRMM,* ***(f)*** *CFSv2, and* ***(i)*** *SP-CFS. All of the variances are computed for JJAS daily rainfall anomalies (mmday^{-1}).*

equatorial Rossby waves and underestimates the Kelvin and mixed Rossby-gravity waves. Based on analysis of CCEWs, the study further explains the possible reasons behind the realistic simulation of northward propagating BSISO in CFS T382, even though the model shows substantial biases in simulating mean state and other BSISO modes. [***Abhik S., Mukhopadhyay P., Krishna R.P.M., Salunke K.D., Dhakate A.R., Suryachandra A. Rao****, Diagnosis of boreal summer intraseasonal oscillation in high resolution NCEP climate forecast system,* ***Climate Dynamics****, 46, May 2016, DOI:10.1007/s00382-015-2769-9, 3287-3303*]

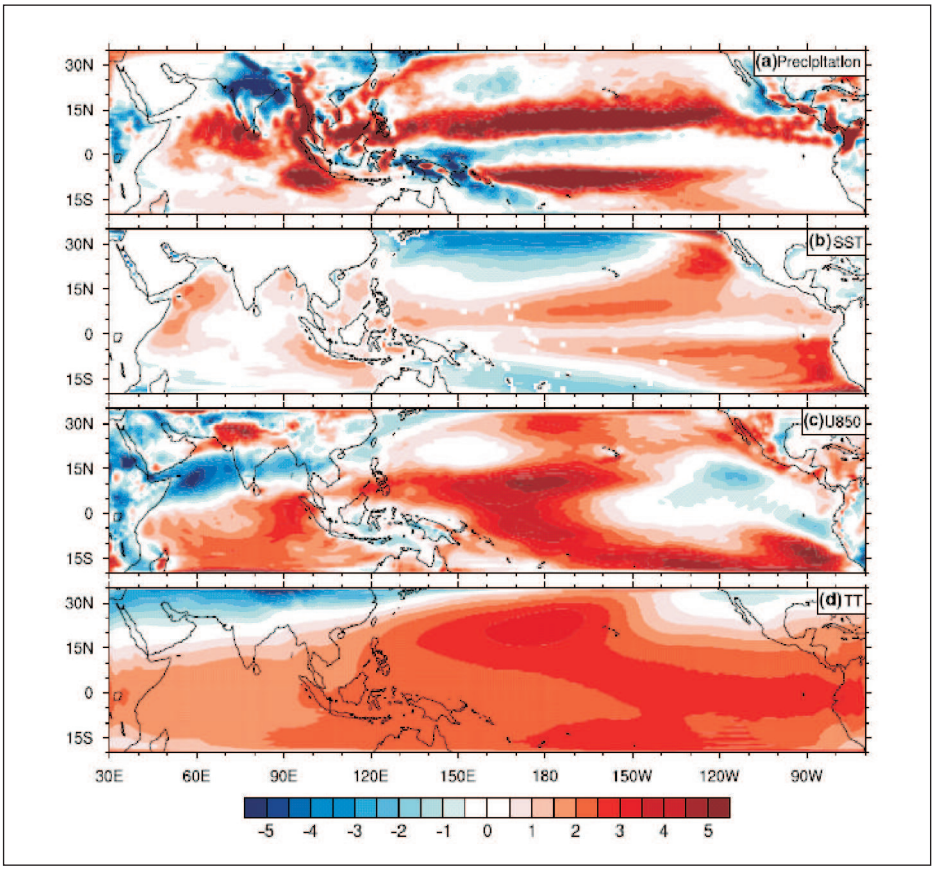


Fig. 18: *Seasonal mean bias in* ***(a)*** *precipitation (mm day^{-1}),* ***(b)*** *SST (°C),* ***(c)*** *zonal wind at 850 hPa (m s^{-1}) and* ***(d)*** *tropospheric temperature (TT, K) relative to TRMM, TMI and CFSR.*

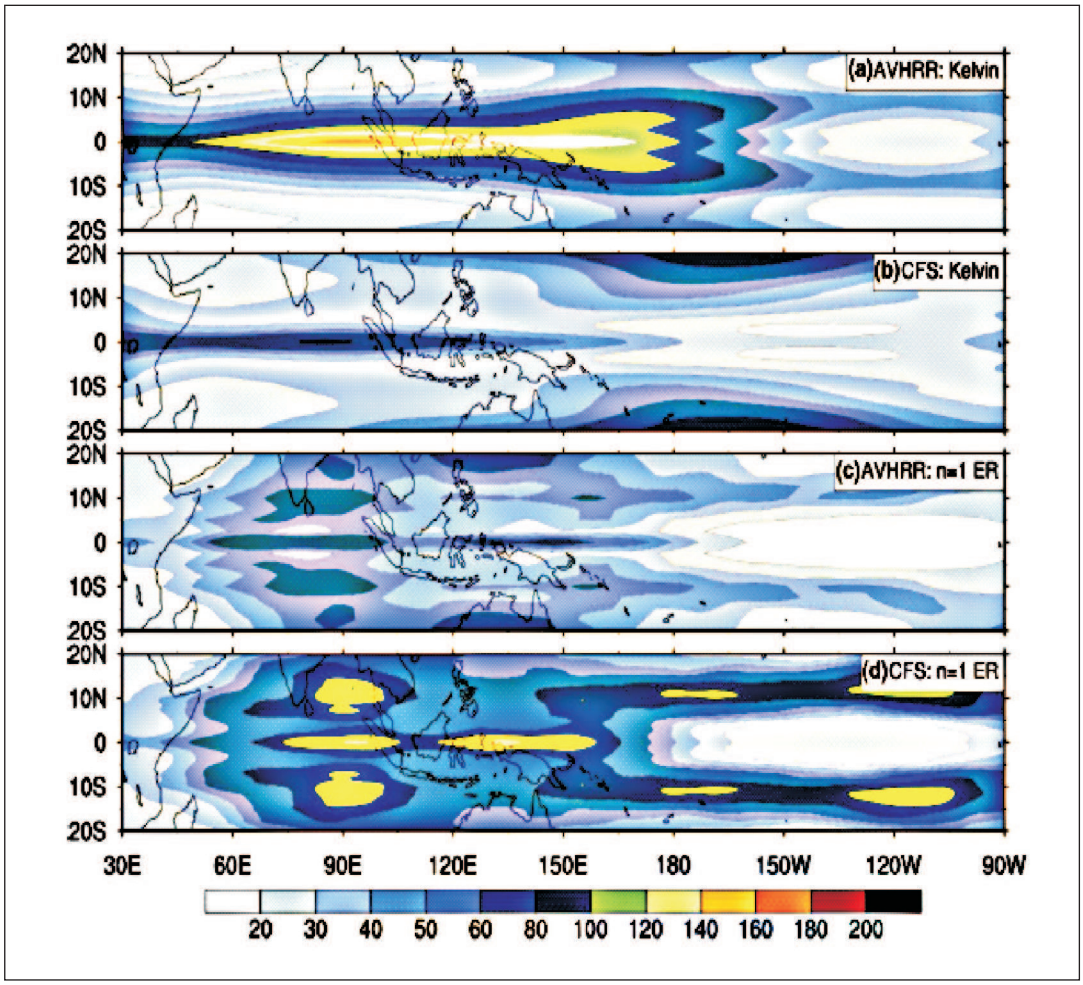


***Fig. 19**: Distribution of boreal summer time OLR variance (W^2m^{-4}) of (**a**), (**b**) Kelvin and (**c**), (**d**) n = 1 ER for AVHRR and CFS T382 respectively.*

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)

Basic Research

Particle size distribution properties in mixed-phase monsoon clouds from *in situ* measurements during CAIPEEX

A comprehensive analysis of cloud and ice particle size distributions, ice water content, ice number concentration, parameterization for these parameters derived from *in situ* airborne observations during the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) is presented. *In situ* airborne observations in the developing stage of continental convective clouds during premonsoon (PRE), transition, and monsoon (MON) period at temperatures from 25°C to −22°C are used in the study. The PRE clouds have narrow drop size and particle size distributions compared to monsoon clouds and showed less development of size spectra with decrease in temperature. Overall, the PRE cases had much lower values of particle number concentrations and ice water content compared to MON cases, indicating large differences in the ice initiation and growth processes between these cloud regimes. This study provided compelling evidence that in addition to dynamics, aerosol and moisture are important for modulating ice microphysical processes in PRE and MON clouds through impacts on cloud drop size distribution. Significant differences are observed in the relationship of the slope and intercept parameters of the fitted particle size distributions (PSDs) with temperature in PRE and MON clouds (**Fig. 1**). The intercept values are higher in MON clouds than PRE for exponential distribution which can be attributed to higher cloud particle number concentrations and ice water content in MON clouds. The PRE clouds tend to have larger values of dispersion of gamma size distributions than MON clouds, signifying narrower spectra. The relationships between PSDs parameters are presented and compared with previous observations (**Fig. 2**), which could be used in numerical models and for deriving parameters such as ice water content from radar observations. [***Patade S., Prabha T.V.,*** *Axisa D.,* ***Gayatri K.,*** *Heymsfield A., Particle size distribution properties in mixed-phase monsoon clouds from in situ measurements during CAIPEEX,* ***Journal of Geophysical Research****, 120, October 2015, DOI:10.1002/2015JD023375, 1-23*]

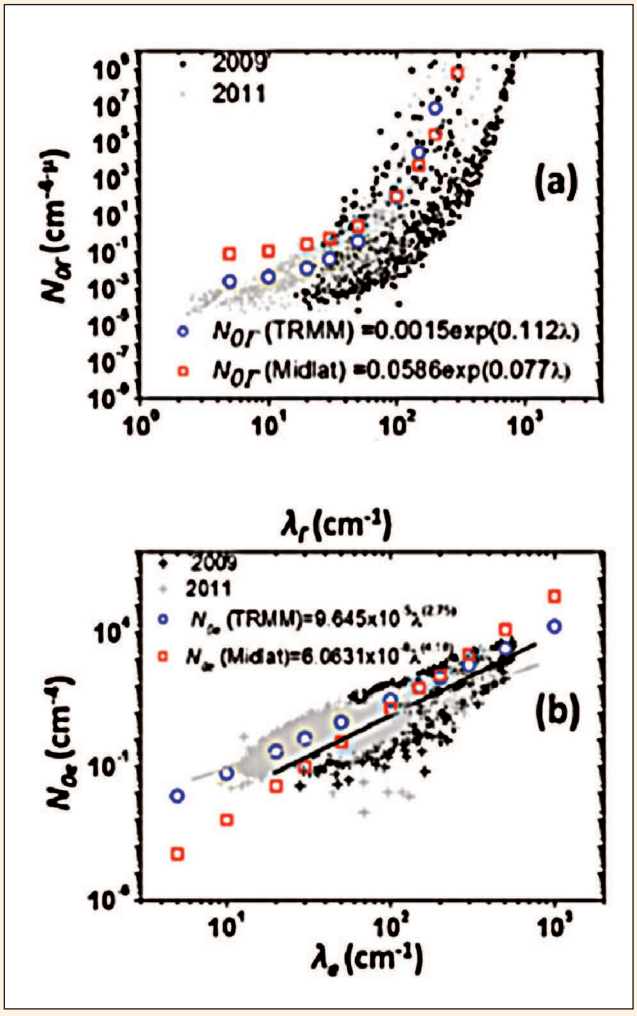


Fig. 1*: Relationship between the intercept and slope parameters of particle size distributions observed from CAIPEEX and comparison with satellite and mid-latitude parameterizations.*

Serial No.	Relationship Between	Previous Studies	CAIPEEX-II
1	λ_Γ and λ_e	1. $\lambda_\Gamma = 0.24\ \lambda_e^{1.34}$ [*Heymsfield et al.*, 2002]; deep subtropical and tropical precipitating clouds with cloud top temperature as low as −50°C 2. $\lambda_e = 2.74\ \lambda_\Gamma^{0.75}$ [*Heymsfield*, 2003]; synoptically generated midlatitude and convectively generated tropical ice clouds with cloud top temperatures as low as −50°C	$\lambda_e = e^{(1.84\ +\ 0.59 \ln \lambda_\Gamma)}$ $r = 0.92$
2	μ and λ_Γ	1. $\mu = 0.14\ \lambda_\Gamma^{0.64} - 2$ [*Heymsfield et al.*, 2002] 2. $\mu = 0.076\ \lambda_\Gamma^{0.80} - 2$ [*Heymsfield*, 2003] 3. $\mu = 0.6\ \lambda_\Gamma^{0.382} - 3$ [*Heymsfield et al.*, 2013]; for convective region, convective and stratiform clouds using data from 10 field programs spanning the temperature range of −86 to 0°C	$\mu = -1.03 + 0.006\ (\lambda_\Gamma)$ $(r = 0.52)$
3	μ and $N_{o\Gamma}$	1. $\mu = 0.21 \ln (0.12\ N_{0\Gamma})$ [*Heymsfield et al.*, 2002]	$\mu = -0.45 + 0.17 \ln (N_{0\Gamma})$ $(r = 0.9)$
4	D_{max} and λ_e	1. $D_{max} = 9.46\ \lambda_e^{-0.91}$ [*Heymsfield et al.*, 2002]	$D_{max} = e^{(12.14 - 1.13 \ln \lambda_e)}$ $(r = -0.93)$
5	D_{max} and λ_Γ	1. $D_{max} = 3.23\ \lambda_\Gamma^{-0.61}$ [*Heymsfield et al.*, 2002] 2. $D_{max} = 5.21\ \lambda_\Gamma^{-0.81}$ [*Heymsfield*, 2003] 3. $D_{max} = 4.36\ \lambda_\Gamma^{-0.77}$ [*Heymsfield et al.*, 2013]; $T > 60$°C	$D_{max} = e^{(10.39 - 0.76 \ln \lambda_\Gamma)}$ $(r = -0.95)$
6	$N_{0\Gamma}$ and λ_Γ	1. $N_{0\Gamma}$ (TRMM) $= 0.0015 \exp(0.112\ \lambda_\Gamma)$ 2. $N_{0\Gamma}$ (Midlat) $= 0.0586 \exp(0.077\ \lambda_\Gamma)$ [*Heymsfield*, 2003]	
7	N_{0e} and λ_e	1. N_{0e} (TRMM) $= 9.645 \times 10^{-5}\ \lambda_e^{2.75}$ 2. N_{0e} (Midlat) $= 6.631 \times 10^{-8}\ \lambda_e^{4.18}$ [*Heymsfield*, 2003]	$N_{0e} = e^{(-7.1 + 2.03\ \ln \lambda_e)}$ $(r = 0.77)$
8	$N_{0\Gamma}$ and T	1. N_{0e} (for snow) $= -0.02\ T + 7.53$ [*Woods et al.*, 2008]; for frontal precipitation systems	$N_{0\Gamma} = e^{(1.15 + 0.01\ T)}$ $(r = -0.04)$
9	IWC and λ_Γ		IWC $= e^{(3.08 - 0.47 \ln \lambda_\Gamma)}$ $(r = -0.55)$
10	IWC and λ_e	$\lambda_e = 1380\ \text{IWC}^{-0.147}$ [*Morrison et al.*, 2011]; shallow mixed-phase and deep arctic cloud systems with minimum cloud top temperature −30°C	IWC $= e^{(3.51 - 0.33 \ln \lambda_e)}$ $(r = -0.53)$
11	IWC and D_{max}		IWC $= e^{(-8.14 + 0.83\ \ln\ Dmax)}$ $(r = 0.6)$
12	N_i versus IWC	$N_i = 5.33\ \text{IWC}^{0.627}$ [*Morrison et al.*, 2011]	$N_i = e^{(6.44 + 0.82\ \ln(\text{IWC}))}$ $(r = 0.8)$
13	IWC and T		IWC $= e^{(-3.15 - 0.115 * T)}$ $(r = -0.33)$

***Fig. 2**: Parameterization for ice water content, ice number concentration and other particle size distribution related parameters proposed from CAIPEEX, compared with published literature.*

Airborne and ground based CCN spectral characteristics: An inference from CAIPEEX- 2011

A first time comprehensive study of Cloud Condensation Nuclei (CCN) and associated spectra from both airborne and ground campaigns of Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) conducted over the rain shadow region of the Western Ghats for September-October 2011 is illustrated. The ground based CCN number concentration and activation diameter showed bimodality in the diurnal variations (**Fig. 3**). Observations of CCN spectra during clean, polluted and highly polluted conditions indicated significant differences between the airborne and ground observations. Cloud base CCN number concentrations are three times more diluted than thaose of the surface measurements at different super-saturations. Vertical variation of CCN concentration is illustrated from airborne observations in the clean, polluted and highly polluted conditions with different air mass characteristics. The atmospheric mixing in the wet conditions is mainly through the mechanical mixing and the dry conditions were favored by convective mixing, and were dominated by more CCN than the wet conditions. The new particle formation and growth events have been observed and were found more often during the conditions with convective mixing. The average critical activation diameter (at 0.6 SS) observed at the ground is ≈ 60 nm and availability of large number of particles below this limit was due to the new particle formation. Observations give convincing evidence that the precipitable water and liquid water path is inversely proportional to the CCN number concentration, and this relationship is largely dictated by the meteorological conditions. [***Varghese M., Prabha Thara V.,** Malap N., **Resmi E.A., Murugavel P., Safai P.D.,** Axisa D., **Pandithurai G., Dani K.**, Airborne and ground based CCN spectral characteristics: Inferences from CAIPEEX-2011, **Atmospheric Environment**, 125, January 2016, DOI:10.1016/j.atmosenv.2015.06.041, 324-336*]

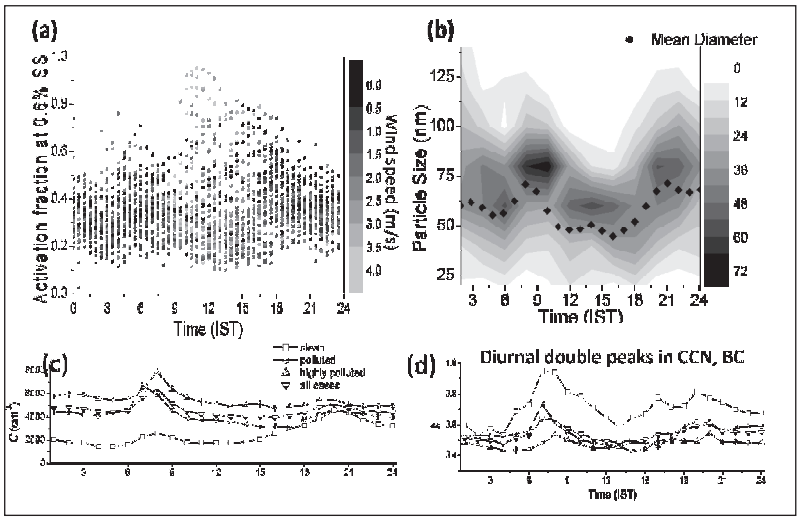


***Fig. 3**: Diurnal variation of activation fraction at 0.6%SS (**a**) and particle size distribution (**b**) of submicron particles, CCN spectra coefficient (**c**) and (**d**).*

Atmospheric abundances of black carbon aerosols and their radiative impact over an urban and a rural site in SW India

Observations on black carbon (BC) aerosols over an urban site (Pune) and a rural, high altitude site (Sinhagad) during summer and winter seasons over the period of 2009-2013 are reported. Apart from the temporal variation of BC over both the sites, its mass fraction to total suspended particulates (TSP) is studied. Finally, using the chemical composition of TSP and BC in the OPAC model, season-wise optical properties of aerosols are obtained which are further used in the SBDART model to derive the aerosol radiative forcing (ARF) at surface and top of the atmosphere and thereby the atmospheric forcing and heating rates in each season over both the sites. BC mass concentration and its mass fraction to TSP (Mf BC) were higher at Pune than at Sinhagad, indicating impact of more anthropogenic sources. At both the sites, winter season witnessed higher BC concentrations than summer as well as higher Mf BC which is due to the prevailing favorable meteorological conditions in winter. Diurnal variation of BC showed different patterns at Pune and Sinhagad in terms of strength and occurrence of high and low values that could be attributed to varying local boundary layer conditions and source activities at both the sites. Negative ARF indicated cooling at top of the atmosphere and at surface leading to warming of the atmosphere at both the sites. However, surface cooling and atmospheric warming was more dominant at Pune leading to higher atmospheric heating rates, underlining the impact of absorbing BC aerosols which were about three times more at Pune than Sinhagad. [***Raju M.P., Safai P.D., Vijaykumar K.**, Devara P.C.S., Naidu C.V., **Rao P.S.P., Pandithurai G.**, Atmospheric abundances of black carbon aerosols and their radiative impact over an urban and a rural site in SW India, **Atmospheric Environment**, 125, January 2016, DOI:10.1016/j.atmosenv.2015.09.023, 429-436*]

Variability in optical properties of atmospheric aerosols and their frequency distribution over a mega city New Delhi, India

The role of atmospheric aerosols in climate and climate change is one of the largest uncertainties in understanding the present climate and in capability to predict future climate change. Due to this, the study of optical properties of atmospheric aerosols over a mega city New Delhi which is highly polluted and populated was conducted for two years to see the aerosol loading and its seasonal variability using sun/sky radiometer data. Relatively higher mean aerosol optical depth (AOD) (0.90 ± 0.38) at 500 nm and associated Angstrom exponent (AE) (0.82 ± 0.35) for a pair of wavelength 400-870 nm were observed during the study period indicating highly turbid atmosphere throughout the year. Maximum AOD value is observed in the months of June and November while minimum is in transition months March and September. Apart from this, highest value of AOD (AE) is observed in the post-monsoon [1.00 ± 0.42 (1.02 ± 0.16)] season followed by the winter [0.95 ± 0.36 (1.02 ± 0.20)] attributed to significance contribution of urban as well as biomass/crop residue burning aerosol which is further confirmed by aerosol type discrimination based on AOD vs AE. During the pre-monsoon season, mostly dust and mixed types aerosols are dominated. AODs value at shorter wavelength observed maximum in June and November while at longer wavelength, maximum AOD is observed in June only. For the better understanding of seasonal aerosol modification process, the aerosol curvature effect is studied which shows a strong seasonal dependency under a high turbid atmosphere, which is mainly associated with various emission sources. Five days air mass back trajectories were

computed. These suggest different patterns of particle transport during the different seasons. Results suggest that mixtures of aerosols are present in the urban environment, which affect the regional air quality as well as climate. The present study will be very much useful to the modeler for validation of satellite data with observed data during estimation of radiative effect. [*Tiwari S.,* ***Tiwari Suresh****, Hopke P.K., Attri S.D., Soni V.K., Singh A.K., Variability in optical properties of atmospheric aerosols and their frequency distribution over a mega city "New Delhi," India,* ***Environmental Science and Pollution Research****, online, January 2016, DOI:10.1007/s11356-016-6060-3*]

Observational and simulated cloud microphysical features of rain formation in the mixed phase clouds observed during CAIPEEX

CAIPEEX Aircraft observations noticed higher ice particle concentrations in Hallet-Mossop zone (−3 to − 8 °C) with existence of smaller and larger cloud droplets, rimed needles columns, and graupel particles. Observations strongly suggested the active presence of Hallet-Mossop (1974) process in this cloud. The higher correlations found between slope and intercept parameters of exponential size distributions indicated efficient secondary ice production as well as to the aggregation growth of ice particles. First time Large Eddy Simulation (LES) in combination with observations unraveled the important role of Hallet-Mossop (HM) process and its link with warm rain and graupel formation and showed that raindrop freezing plays a crucial role in graupel formation in the early stage of ice development (**Fig. 4**). The observed mean values of microphysical parameters including liquid water content, ice water content, ice number concentrations, and reflectivity showed good agreement with model simulations. Primary ice nuclei have only a minor role in the total ice mass in these clouds. [***Patade S., Shete S., Malap N., Kulkarni G., Prabha T.V.,*** *Observational and simulated cloud microphysical features of rain formation in the mixed phase clouds observed during CAIPEEX,* ***Atmospheric Research****, 169, March 2016, DOI:10.1016/j.atmosres. 2015.09.018, 32-45*]

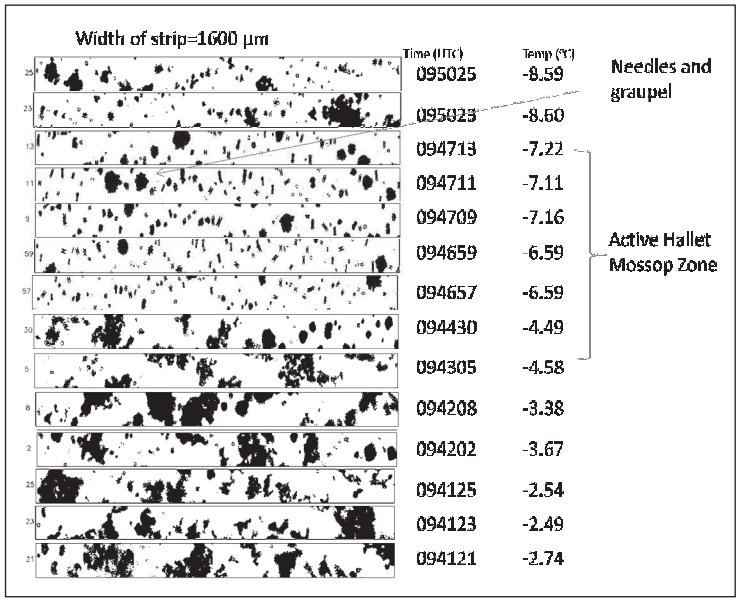


Fig. 4: Ice particle mages from CAIPEEX observations show for the first time that Hallet-Mossop ice multiplication is active in the monsoon clouds. This was also simulated in the study.

Developmental Activities

- **BHU Varanasi Site:** The extensive CAIPEEX ground campaign in Varanasi with host of several instrumentations is completed successfully. This has resulted in a yearlong observations at this site. Varanasi micro-meterorological flux tower observations are ongoing, which has completed two years of observations.
- CAIPEEX 2015 airborne experiment was conducted for 75 hours in the triangular area between Kolhapur, Mahabaleshwar and Solapur. As part of the experiment, aerosol, cloud microphysics, aerosol and gaseous chemistry have been carried out. Vertical profiling of clouds in the rain shadow area, aerosol and cloud observations over Mahabaleshwar, and over the Arabian Sea was carried out. GHG and aerosol chemistry observations over these locations were done for the first time. With the completion of Phase-III 2015, CAIPEEX project has resulted in 820 hours of airborne observations over Indian region and is a major achievement.
- **Fluid Dynamics Laboratory (FDL)** is under progressive development and instruments are being procured.
- **Wind profiler**: Lower tropospheric wind profiler (Astra Inc.) was installed in Pune for wind profile measurements in colocation with microwave radiometer for evaluation and testing during monsoon season.

Sub-Project

High-Altitude Cloud Physics Laboratory (HACPL)

Developmental Activities

- Time-of-flight (TOF) Aerosol chemical speciation monitor is installed, tested and put in operation at HACPL for aerosol chemical speciation measurements. This will help in characterizing the dominant chemical species in aerosol. Initial results show the dominance of organic compounds which can be source for secondary organic aerosols over this region.



Fig. 5: *Time-of-Flight Aerosol Chemical Speciation Monitor.*

- Two Radiosonde soundings (3 GMT, 12 GMT) at HACPL and 1 sounding at IITM, Pune (8 GMT) were conducted during July 2015 during the CAIPEEX aircraft campaign.
- For Volatile Organic Compounds (VOC) measurements, a PTRMS (Proton Transfer Reaction Mass Spectrometer) was deployed at HACPL on campaign mode (on loan from SAFAR-Pune) during June-July 2015 and data has been collected and being analysed.

Basic Research

Seasonal variability of aerosol and CCN over HACPL

Aerosol-CCN variability and their relationship were studied for the first time at Mahabaleshwar, a high altitude (1348 m AMSL) site in the Western Ghats by using observations of one year (June 2012 to May 2013). The study was done in two sections in which first temporal variability (diurnal and seasonal) of aerosol and CCN was analysed. Later, CCN to aerosol ratio and other microphysical properties were investigated along with detailed discussion on possible sources of aerosol. Diurnal variation in aerosol and CCN concentration has shown relatively higher values during early morning hours in monsoon season, whereas in winter and pre-monsoon, it was higher in the evening hours (**Fig. 6**). Seasonal mean variation in aerosol and CCN (SS above 0.6□) has shown higher (less) in monsoon (winter) season. Temporal variation reveals dominance of fine-mode aerosol during monsoon season over the study region. The temporal variation of activation ratio, *k*-value (exponent of CCN Super-saturation spectra) and geometric mean aerosol diameter were also analysed. Variation of activation ratio was higher in monsoon, especially for SS 0.6-1□. The analysis also showed high *k*-value during monsoon season as compared to other seasons (Pre-monsoon and winter) which may be due to dominance of hygroscopic aerosols in the maritime air masses from the Arabian Sea and biogenic aerosol emissions from the wet forest. Analysed mean aerosol diameter is much smaller during monsoon season with less variability compared to other seasons. Overall analysis showed that aerosol and CCN concentration was higher over this high altitude site despite of dominant sink processes such as cloud scavenging and washout mechanisms indicating local emissions and biogenic Volatile Organic Compounds (BVOC) emissions from wet forest as major sources. [***Leena P. P., Pandithurai G., Anilkumar V., Murugavel P., Sonbawne S.M., Dani K.K.****, Seasonal variability in aerosol, CCN and their relationship observed at a high altitude site in*

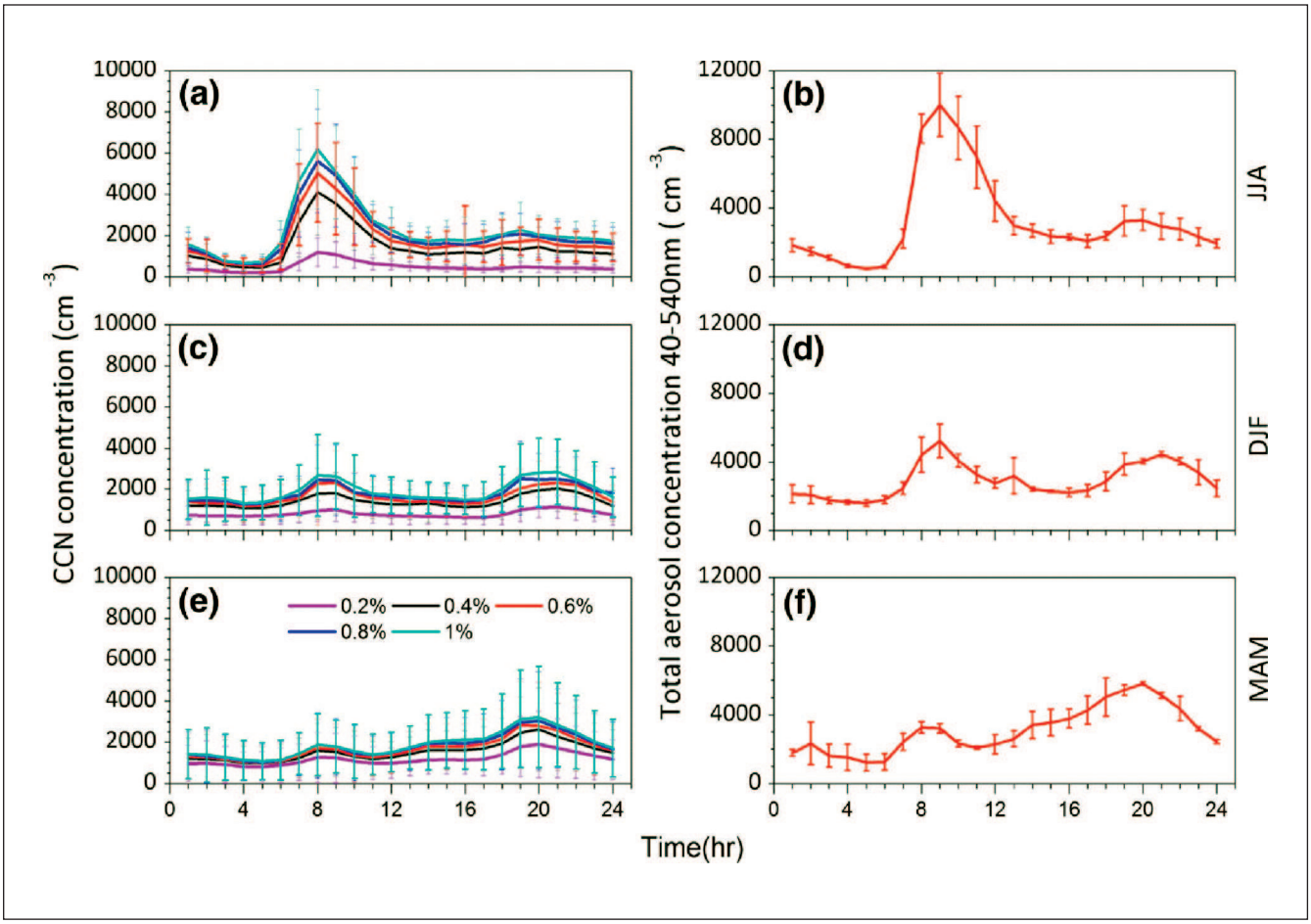


Fig. 6: *Diurnal variation in CCN concentration (**a, c, e**) for different super saturations and total aerosol concentration 40-540 nm (**b, d, f**) for the period June 2012 to May 2013.*

*Western Ghats, **Meteorology and Atmospheric Physics**, Online, September 2015, DOI:10.1007/s00703-015-0406-0*]

Aerosol Indirect Effects from ground-based retrievals

Aerosol induced changes in cloud microphysical and radiative properties were studied for the first time using ground-based and airborne observations over a semi-arid rain shadow region. The study was conducted for non-precipitating, ice free clouds during monsoon (July to September) and post-monsoon (October) months, when cloud condensation nuclei (CCN) concentrations over the region of interest increased monotonically and exhibited characteristics of continental origin. A Multi Filter Rotating Shadowband Radiometer (MFRSR) and Microwave Radiometric profiler (MWRP) were used to retrieve the cloud optical depth (COD) and liquid water path (LWP) respectively from which cloud effective radius (CER) was obtained. The study highlights the following points: a) Aerosol Indirect Effect (AIE) at different super saturations (SS) showed maximum value, significant at 95 , at 0.4 SS at higher LWP bin (250-300 g/m^2). Also, significant AIE values are found at 0.6 and 0.8 SS but at lower LWP bin (200-250 g/m^2) and at 1 SS at 150-200 g/m^2. The relationship between CCN and CER showed high correlation at 0.4 SS at higher LWP, while at higher SSs, good correlations are observed at lower LWPs; b) High AIE observed can also be one of the causative factors for rainfall deficiency over the rain shadow region; c) At lower LWP (100-150 g/m^2) and lower super saturations, AIE is predominantly negative which indicates the existence of Anti-Twomey effect, though higher super saturations show a slight establishment of positive AIE; d) For non-precipitating monsoon clouds, the switch-over from Anti-Twomey to Twomey effect takes place above 100 g/m^2 and at higher SSs over a rain shadow region; e) From the combined ground-based and aircraft observations, a boomerang

shaped curve between CF and sub-cloud aerosol concentrations indicated the dominance of microphysical effect at aerosol concentrations below 1500 cm^{-3} and radiative effect at concentrations above 1500 cm^{-3}; and f) The post-monsoon period is more favorable for microphysical-radiative effects due to increase in aerosol absorbing nature along with concentrations. (**Fig. 7**) [***Harikishan, G., Padmakumari B., Maheskumar R.S., Pandithurai G.**, Min Q.L., Aerosol indirect effects from ground-based retrievals over the rain shadow region in Indian subcontinent, **Journal of Geophysical Research**, 121, February 2016, DOI:10.1002/2015JD024577*]

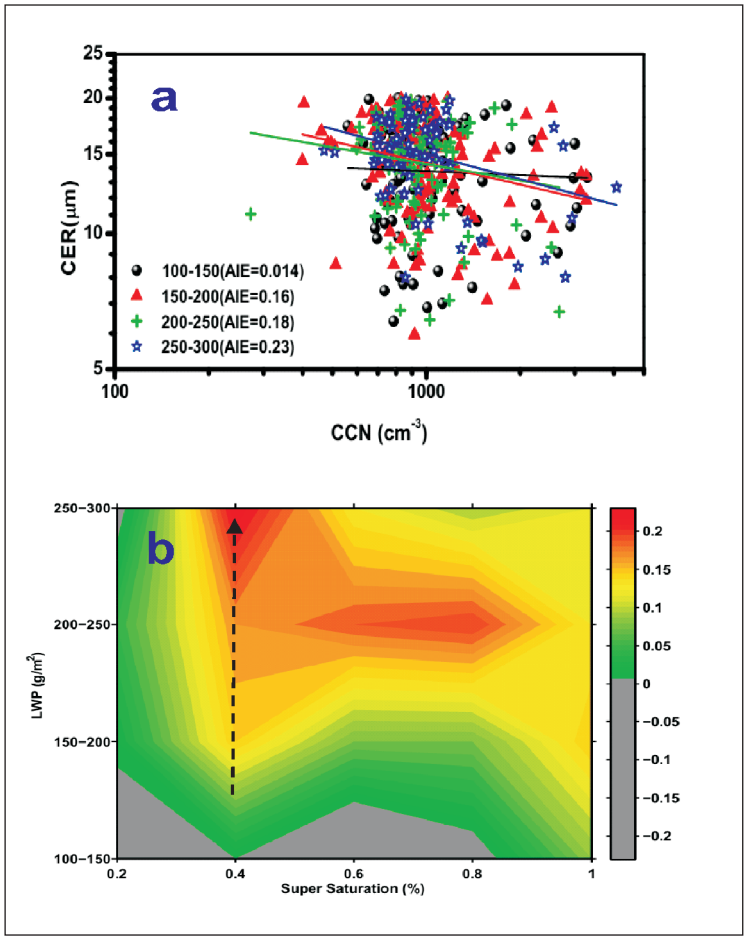


Fig. 7: *(**a**) Relationship between CCN (cm^{-3}) and effective radius for different LWP bins. Each line represents the power law fit. (**b**) AIE calculated at different super saturations and for different LWP Bins.*

Analysis of sunlight absorption spectra related to atmospheric trace gases in the tropics

The vertical column densities (VCDs) of NO_2 and O_3 derived from ground-based UV-visible spectrometer and satellite-based OMI instrument during the period 01 March - 31 December 2010 are shown in **Fig. 8**. The OMI is on board the Earth Observing System (EOS)-Aura Ozone Monitoring Instrument-Differential Optical Absorption Spectroscopy (OMI-DOAS). The OMI is a nadir viewing imaging UV-visible spectrometer that provides daily global O_3 and NO_2 with $0.25^{\circ}\times0.25^{\circ}$ resolutions of level 2 datasets. The VCDs of NO_2 and O_3 are derived at SZAs of 90° at sunset. The seasonal mean values (averaged VCDs) have been calculated, that is for the summer (March, April, May), rainy (June, July, August, September) and winter (October, November, December) seasons. The mean VCDs of O_3 derived using ground-based measurement in the summer, rainy and winter seasons are 7.16×10^{18}, 7.35×10^{18} and 7.06×10^{18} molecules/cm^2 respectively, whereas in satellite measurement, these are 7.06×10^{18}, 7.15×10^{18} and 6.84×10^{18} molecules/cm^2 in summer, rainy and winter seasons respectively. The O_3 mean values in the rainy season are found to be higher than those in summer and winter seasons from both ground and satellite based measurements. The mean VCDs of NO_2 derived using ground-based measurement in the summer, rainy and winter seasons are 3.09×10^{15}, 3.40×10^{15} and 3.54×10^{15} molecules/cm^2 respectively, whereas in satellite measurement, these are 2.62×10^{15}, 2.77×10^{15} and 3.21×10^{15} molecules/cm^2 respectively. The NO_2 mean values in winter season are found to be higher than those in summer and rainy seasons from both ground and satellite based measurements. In the winter season, NO_2 is observed to be high whereas O_3 is low. During day time, photochemical reaction takes place in the presence of sunlight. The NO_2 is produced from industry, traffic and biomass burning leads to high in VCDs of NO_2 in winter season. At a certain concentration, NO_2 starts to deplete O_3 by reaction. Hence, The VCDs of O_3 are observed to be lowest in winter season due to the loss of ozone within NO_2 and O_3 reaction during the winter season. [***Meena G.S., Lal D.M.**, Analysis of sunlight absorption*

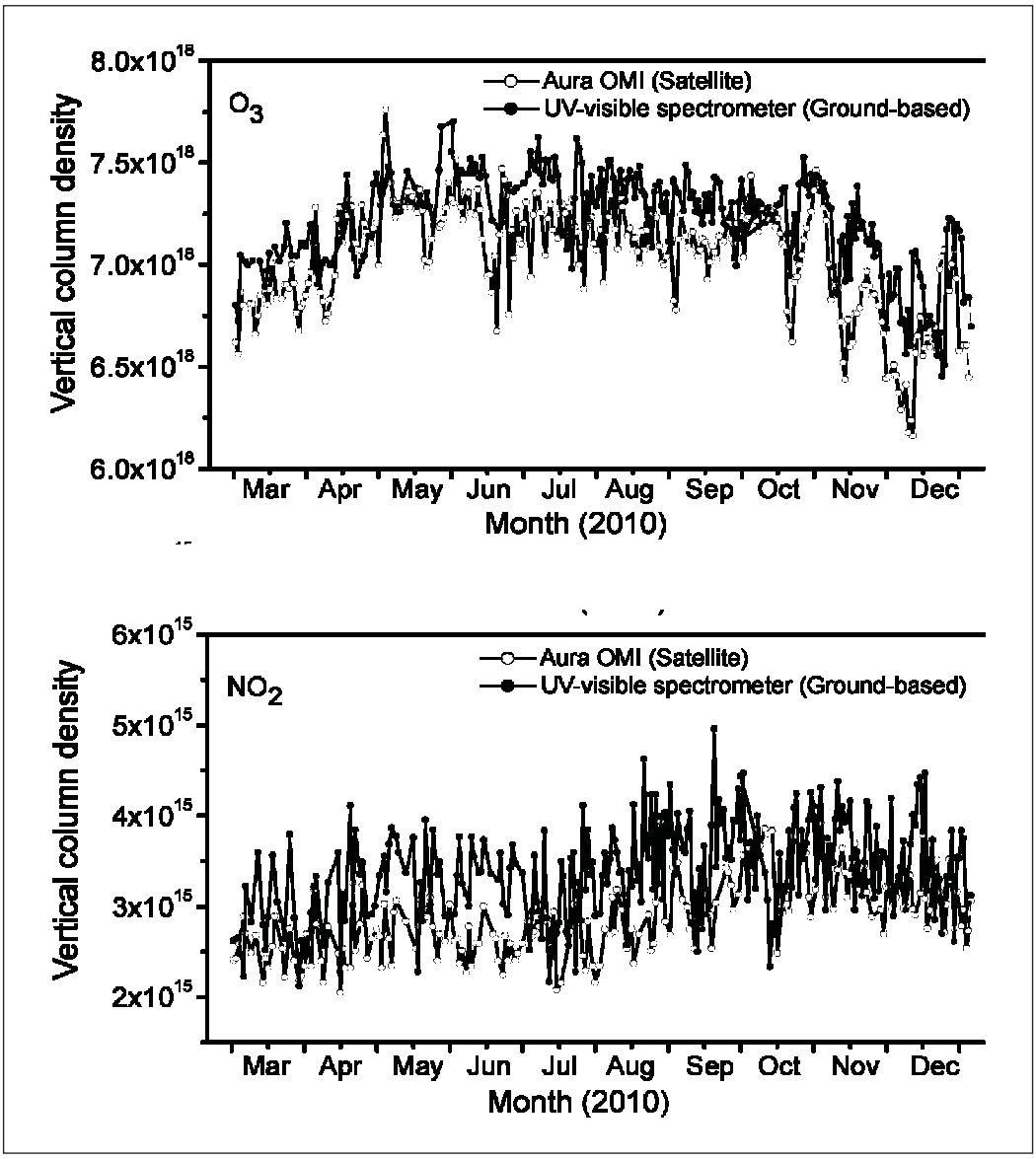


Fig. 8: *Vertical column densities (VCDs) of NO_2 and O_3 measured from ground-based UV-visible spectrometer and the Aura OMI satellite during the period 01 March - 31 December 2010.*

spectra related to atmospheric trace gases in the tropics, ***International Journal of Remote Sensing****, 37, March 2016, DOI:10.1080/ 01431161.2016. 1151569, 1362-1375*]

Black carbon in cloud-water and rain water during monsoon season at Sinhagad

The results of measurements of black carbon (BC) from ground-based wet-only rainwater (RW) and cloud-water (CW) sampling at a mountain field station at Sinhagad situated in south western India during the period from June 2008 to October 2010 are presented. The amount of BC in the sample was determined by photometry at a wavelength of 528 nm after a procedure including the filtration through a 0.4 mm polycarbonate membrane filter. Water soluble concentrations of major anions in RW and CW were also determined. The average concentration of BC in RW (16 µmol dm^3) is higher by at least a factor 2 than that found in similar studies reported from other parts of the world. On the other hand, the average concentration of BC in CW (47 µmol dm^3) is lower by about a factor of 2 than that found at

other sites. The ratio between the average concentrations in CW and RW varies from 2 (K) to 7 (SO_4). The ratio for BC was about 3. No significant difference was observed for pH. A feature observed is that the concentrations of all the chemical components including BC were higher in CW than in RW. A comparison between the clean cases (**Fig. 9A**) and the polluted cases (**Fig. 9B**) shows no substantial differences except for pH which is significantly lower (*i.e.*, higher concentration of hydrogen ion) in CW than in RW. Analysis of air mass back trajectories and of correlations between the various components indicates that long range transport of pollutants and dust from East Africa and Southern part of the Arabian Peninsula might contribute to the high concentrations of BC and some of the ionic constituents at Sinhagad during the monsoon season. As a final comment, it is suggested that these data on BC in cloud water and in rainwater could be useful for testing and validating climate/chemistry models that include explicit consideration of BC. [***Budhavant K.B., Rao P.S.P., Safai P.D.***, *Leck C., Rodhw H., Black carbon in cloud-water and rain water during monsoon season at a high altitude station in India,* ***Atmospheric Environment****, 129, March 2016, DOI:10.1016/j.atmosenv.2016.01.028, 256-264*]

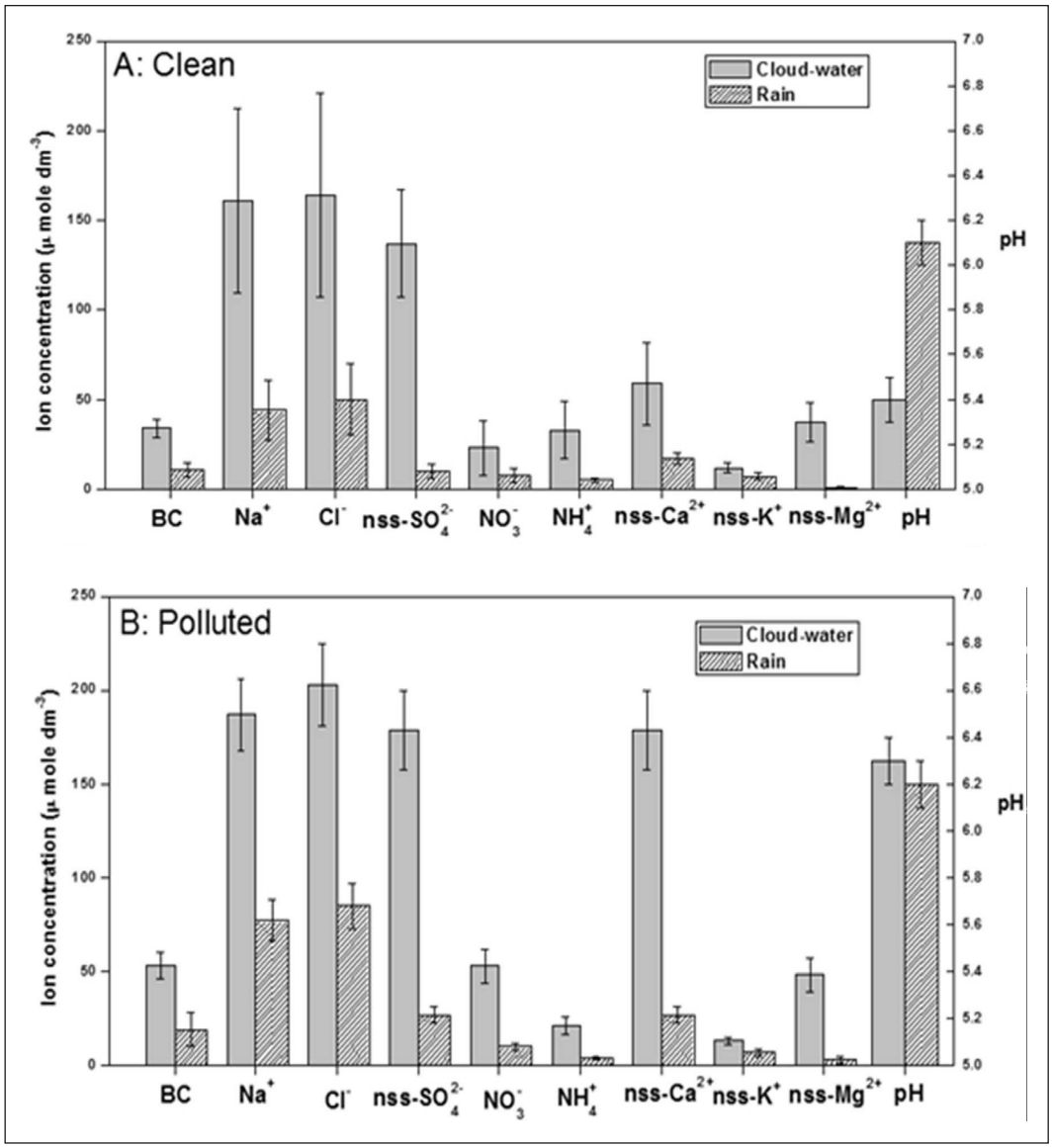


Fig. 9: *Comparison of BC and ionic concentrations in CW (light gray) and RW (lines):* ***A****. Clean environment and* ***B****. Polluted environment. Vertical lines represent the confidence intervals (90%).*

Sub-Project

Radar and Satellite Meteorology

Developmental Activities

- Radar observations were conducted in coordination with CAIPEEX aircraft observations from the Kolhapur base during June-July 2015.
- Necessary guidelines on technical specifications, data requirement, scanning strategies, and product retrieval for the Ka-band radar development project are being provided to SAMEER, Mumbai.

Basic Research

Mesoscale kinematics derived from X-band Doppler radar observations of convective versus stratiform precipitation and comparison with GPS radiosonde profiles

Single Doppler analysis techniques known as Velocity Azimuth Display (VAD) and Volume Velocity Processing (VVP) are used to analyse kinematics of mesoscale flow such as horizontal wind and divergence using X-band Doppler weather radar observations, for selected cases of convective, stratiform and shallow cloud systems near tropical Indian sites: Pune (18.58°N, 73.92°E, 560 m asl) and Mandhardev (18.51°N, 73.85°E, 1297 m asl). The vertical profiles of horizontal wind estimated from radar VVP/VAD methods agree well with GPS radiosonde profiles, with the Low Level Jet (LLJ) at about 1.5 km during monsoon season well depicted in both. The vertical structure and temporal variability of divergence and reflectivity profiles are indicative of the dynamical and microphysical characteristics of shallow convective, deep convective and stratiform cloud systems (**Fig. 10**). In shallow convective systems, vertical development of reflectivity profiles is limited below 5 km. In deep convective systems, reflectivity values as large as 55 dBZ were observed above freezing level. The stratiform system shows the presence of a reflectivity bright band (~35 dBZ) near the melting level. The diagnosed vertical profiles of divergence in convective and stratiform systems are distinct. In shallow convective conditions, convergence was seen below 4 km with divergence above. Low-level convergence and upper level-divergence is observed in deep convective profiles, while stratiform precipitation has mid-level convergence present between lower-level and upper-level divergence. The divergence profiles in stratiform precipitation exhibit intense shallow layers of 'melting convergence' at 0°C level, near 4.5 km altitude, with a steep gradient on both the sides of the peak. The level of non-divergence (LND) in stratiform situations is lower than that in convective situations. These observed vertical structures of divergence are largely indicative of latent heating profiles in the atmosphere, an important ingredient of monsoon dynamics. [***Deshpande S.M., Dhangar N., Das Subroto Kumar, Kalapureddy M.C.R., Chakravarty K., Sonbawne S., Konwar M.****, Mesoscale kinematics derived from X-band Doppler radar observations of convective versus stratiform precipitation and comparison with GPS radiosonde profiles,* ***Journal of Geophysical Research****, 120, November 2015, DOI:10.1002/2014JD022595, 11536-11551*]

Temporal and structural evolution of a tropical monsoon cloud system using X-band radar

This is a case study focusing on the horizontal and vertical structure of monsoon precipitating clouds and its temporal evolution as observed by the X-band radar. The radar reflectivity factor is used as a proxy for measure of intensity of cloud system. Result shows that the radar reflectivity has a strong temporal variation in the vertical, with a local peak occurring in the afternoon hours. Relatively shallow structure during the late night and early morning hours is noticed. The observed cloud tops reached up to 8 km heights with reflectivity maxima of about 35 dBZ at ~5 km. The spatial and vertical evolution of radar reflectivity is consistent with the large-scale monsoon circulation. The variations in the outgoing longwave radiation (OLR) from the Kalpana-1 satellite and vertical velocity and cloud-mixing ratio from the MERRA reanalysis data were also analysed. [***Das S.K., Deshpande S.M., Das S.S., Konwar M.,***

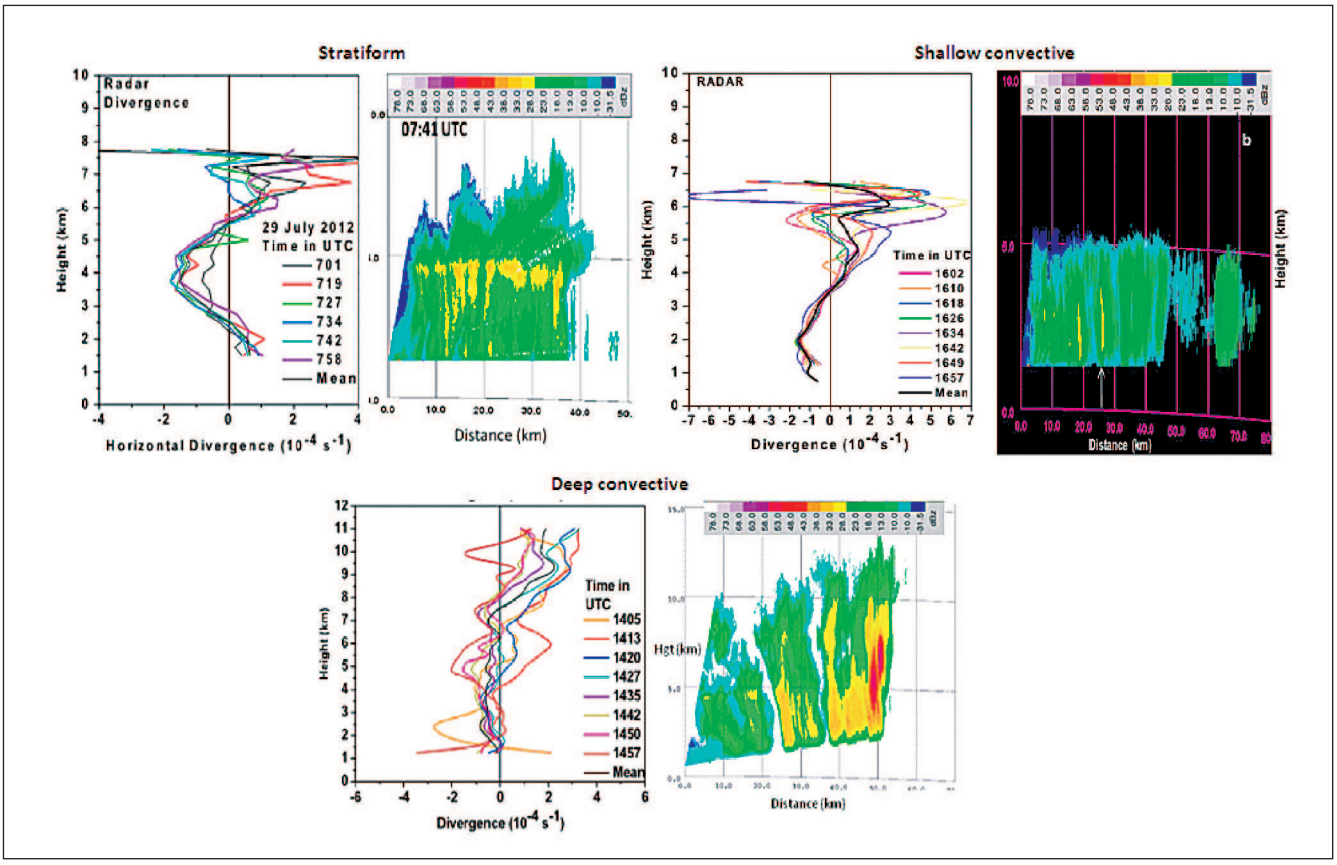


Fig. 10: *X-band radar observations of divergence (10^{-4} s^{-1}) and reflectivity (dBZ) profiles in different cloud types such as stratiform, shallow and deep convective clouds of 29 July 2012, 27 September 2012 and 11 October 2011 respectively.*

***Chakravarty K., Kalapureddy M.C.R.**, Temporal and structural evolution of a tropical monsoon cloud system: A case study using X-band radar observations, **Journal of Atmospheric and Solar Terrestrial Physics**, 133, October 2015, DOI:10.1016/j.jastp.2015.08.009, 157-168*]

Unprecedented hailstorms over north peninsular India during 2014

Unprecedented, widespread and devastating hailstorms occurred during February and March 2014 over north peninsular India (study area). A diagnostic study has been carried out to understand the causes for the same. Over the study area, the atmosphere was convectively unstable due to the incursion of warm and moist air from the Bay of Bengal and the Arabian Sea which was overlaid by cold and dry mid-latitude westerlies caused due to the unusual upper oceanic heat content of the Pacific Ocean. At the surface and lower levels, anticyclonic flow over the central India produced easterly winds and cyclonic circulation over the Arabian Sea at 850 hPa level produced westerly winds over the peninsular India. Meeting of these winds caused convergence of moist air in the lower levels. The troughs in the upper level westerlies provided the divergence in the upper levels. As a consequence of this convergence/divergence structure, synoptic scale slow rising motion occurred over the study region (**Fig. 11**). This released the convective instability to cause deep and wide convection with cloud bases at ~1500 m above mean sea level and the tops well above the freezing level. Release of latent heat of deposition of water vapour provided extra buoyancy and produced strong updrafts causing explosive growth of the clouds reaching to very high levels and formation of large hails in the clouds. This atmospheric set up was result of combined effect of planetary and synoptic forcings which persisted for ~3 weeks. [***Kulkarni J.R., Morwal S.B., Narkhedkar S.G., Maheskumar R.S., Padmakumari B., Sunitha Devi S., Rajeevan M.**, Unprecedented hailstorms over north peninsular India during February-March 2014, **Journal of Geophysical Research**, 120, April 2015, DOI:10.1002/2015JD023093*]

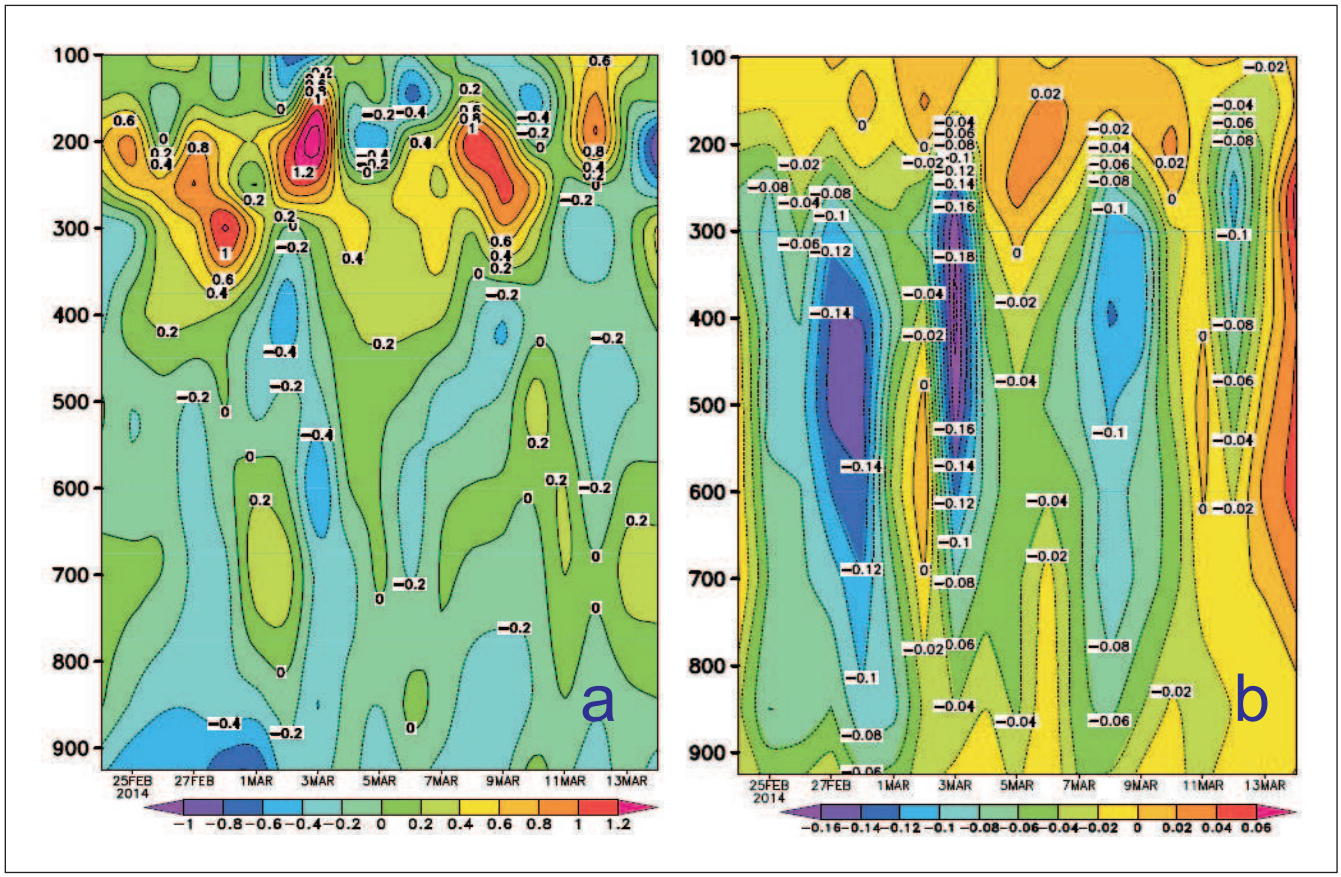


Fig. 11: Vertical distribution of (**a**) divergence (10^{-5} s^{-1}) and (**b**) omega values (Pa s^{-1}) over the study area (15-23°N, 75-80°E) during 24 February to 14 March 2014.

Cloud characteristics over the rain-shadow region during monsoon withdrawal and post-withdrawal periods

Cloud characteristics over the rain-shadow region of the north central peninsular India has been studied using C-band radar data for the period 21 September – 30 October 2011. The period covers withdrawal and post-withdrawal periods of monsoon 2011. Though the study has been carried out for one season, it has been shown that it is representative of climatic feature over the region. The cloud characteristics have been discussed in the context of large scale dynamical and thermodynamical conditions over the region using NCEP wind data and radiosonde data respectively. The large scale dynamic and thermodynamical conditions were found favourable for occurrence of widespread and deep convection. The cloud top heights show tri-modal distribution with peaks at 2-3, 4-6 and 8-12 km which are associated with cumulus, congestus and cumulonimbus clouds respectively. The tops of these three types of clouds are found to be associated with the stable layers in the atmosphere. The frequency of congestus clouds was the highest. The cloud characteristics over the region differ from other tropical land and oceanic regions in respect of maximum height, mean duration and cumulative frequency distribution. Distribution of cloud top height and duration show deviation from lognormality in the lower ends. It indicates that the cloud growth mechanism is different than that observed over other tropical land and oceanic regions and also due to the large wind shear prevailed over the region. During the period, a large number of suitable clouds were found available for hygroscopic and glaciogenic cloud seeding **(Fig. 12)**. [***Morwal S.B., Narkhedkar S.G., Padmakumari B., Maheskumar R.S., Kothawale D.R., Dani K.K.****, Burger R., Bruintjes R.T.,* ***Kulkarni J.R.****, Cloud characteristics over the rain-shadow region of North Central peninsular India during monsoon withdrawal and post-withdrawal periods,* ***Climate Dynamics****, 46, January 2016, DOI:10.1007/s00382-015-2595-0, 495-514*]

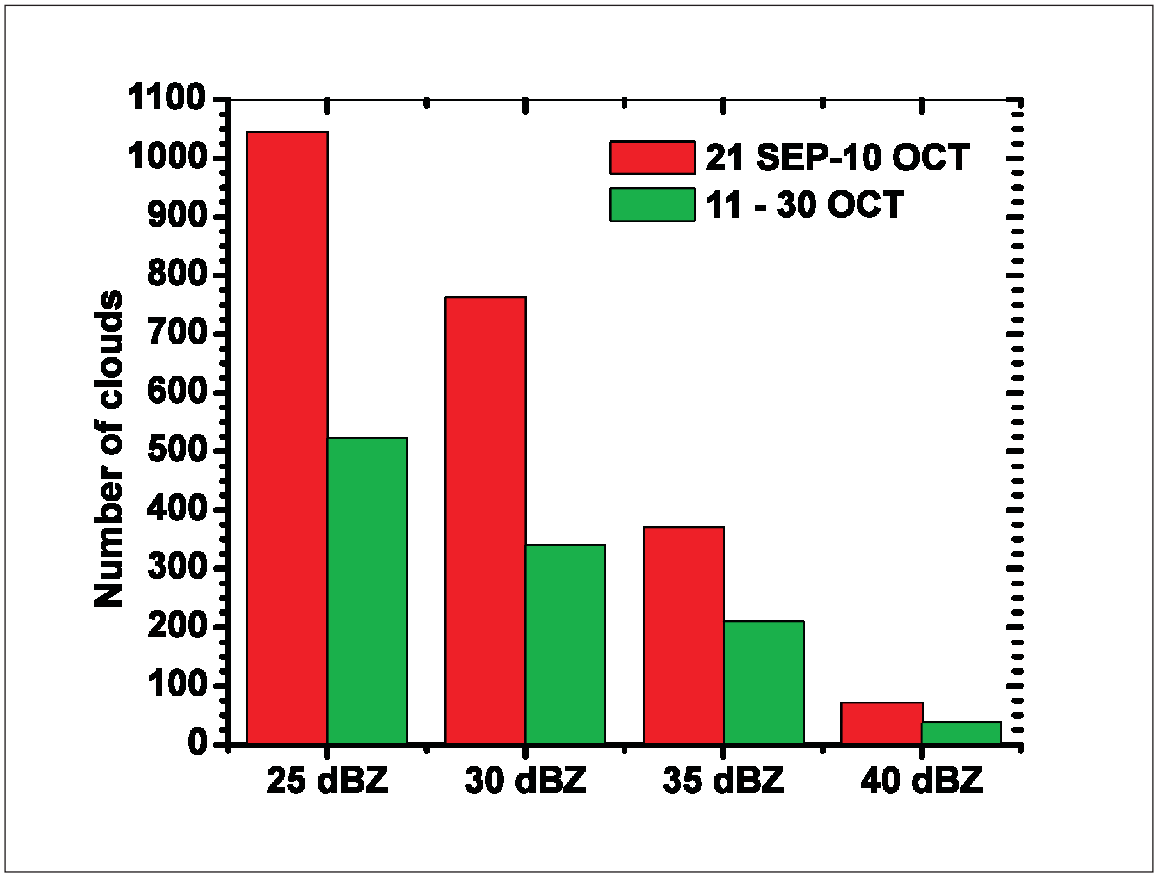


Fig.12: *Distribution of clouds of reflectivity 25 dBZ, 30 dBZ, 35 dBZ and 40 dBZ during the withdrawal (red) and post-withdrawal (green) periods of 2011.*

Potential role of the February-March southern annular mode on the Indian summer monsoon rainfall: A new perspective

Relationship between the Southern Annular Mode (SAM) and the India Summer Monsoon Rainfall (ISMR) has been examined based on the data period 1983-2013. Results reveal that the February-March SAM is significantly related with the subsequent ISMR. A positive (negative) SAM during February-March is favourable (unfavourable) for the summer monsoon rainfall over the Indian sub-continent. The delayed response is relayed through the central Pacific Ocean. The SAM during February-March has two distinct modes of variability, wherein, a positive (negative) SAM shows a high (low) pressure anomaly at the mid-latitude region of 40°S and a low (high) pressure anomaly over the sub-polar region of 70°S. A hypothesis is proposed that when a negative (positive) phase of February-March SAM occurs, it gives rise to an anomalous meridional circulation in a longitudinally locked air-sea coupled system over the central Pacific that persists up to the subsequent boreal summer and propagates from the sub-polar latitudes to the equatorial latitudes inducing a warming (cooling) effect over the central equatorial Pacific region. In turn, this effect concomitantly weakens (strengthens) the monsoon rainfall over the Indian sub-continent. Thus, the February-March SAM could possibly serve as a new precursor to foreshadow the subsequent behaviour of the Indian summer monsoon. [***Prabhu A., Kripalani R.H., Preethi B., Pandithurai G.***, *Potential role of the February-March southern annular mode on the Indian summer monsoon rainfall: A new perspective,* ***Climate Dynamics****, online, November 2015, DOI:10.1007/s00382-015-2894-5*]

Sub-Project

Thunderstorm Dynamics

Developmental Activities

Lightning Location Network: Lightning Location Network installed over Maharashtra to understand the characteristics of lightning occurring over this region has been strengthened with installation of three more sensors at Mahabaleshwar, Nanded and Phalghar. The performance of this network in detecting lightning is being assessed and is found to be performing well. The recent occurrence of large scale thunderstorms with hails in October 2015 has been captured with great accuracy by this network. A protocol is being discussed with India Meteorological Department, Mumbai to give the information about impending lightning strikes to the Government of Maharashtra. The precautions needed to minimise the loss of life due to lightning are communicated to the Department of Disaster Management, Govt. of Maharashtra.

Micrometeorological Tower: A 6 m micro-meteorological tower with sensors for wind speed and direction, air temperature, relative humidity, atmospheric pressure and rainfall at 1 m and 5 m is installed at IITM campus. Shortwave incoming and outgoing and net radiation sensors were installed at 1.6 m. These measurements will be useful for the study of surface boundary layer characteristics during winter season. The data are being collected continuously from all these sensors and stored in the data logger.

Basic Research

Role of orography in inducing high lightning flash rate at the foothills of the Himalayas

Many studies in the recent past have shown that the local orography can generate intense vertical velocity and effect a change in lightning flash rate by interacting with prevailing wind and/or large scale processes. Bourscheidt *et al*. [2009] in their study over South Brazil have shown that the terrain slope has more influence than altitude on thunderstorm occurrence and lightning activity. Role of orography in inducing high lightning flash rate at the foothills of the Himalayas is examined using the surface electric measurements obtained beneath three thunderstorms with almost similar characteristics at Guwahati located close to the Himalayan foothills in northeastern India. All these thunderstorms occurred after midnight and lasted for a short duration of less than an hour, and active stage of these thunderstorms lasted for 10 to 25 minutes. These thunderstorms exhibited very high peak flash rates ranging from 40 to 80 flashes per minute during the active stage, however, no severe weather phenomenon such as heavy precipitation and high winds were observed at the ground during these thunderstorms. The observations suggest that many severe thunderstorms occur over this region during late evening/night hours. Moisture conversion at foothills due to radiative cooling at mountain tops during nighttime may be responsible for triggering such deep convections over Guwahati during the pre-monsoon season. [***Pawar S.D., Gopalakrishnan V., Murugavel P.**, Role of orography in inducing high lightning flash rate at the foothills of Himalaya, **Earth, Planets and Space**, 67:51, April 2015, DOI:10.1186/s40623-015-0221-3, 1-7*]

Role of solar activity on convection process

Role of solar activity, convective available potential energy, surface temperature and difference of land-ocean surfaces on convection processes is studied. Different processes for initiation of discharge are discussed. It is observed that events like sprites and halos are caused by the upward quasi-electrostatic fields associated with intense cloud-to-ground discharges while blue starter, blue jet and gigantic jet are caused by charge imbalance in thunderstorm during lightning discharges. Elves are generated by the electromagnetic pulse radiated during lightning discharges. Relationship between lightning activity/global electric circuit and climate is discussed. [***Siingh D.**, Singh R.P., Sarvan Kumar, **Dharmaraj T.**, Singh A.K., Singh Ashok K., **Patil M.N.**, Singh S., Lightning and middle atmospheric discharges in the atmosphere, **Journal of Atmospheric and Solar***

Terrestrial Physics, 134, November 2015, DOI:/10.1016/j.jastp.2015.10.001, 78-101]

Production mechanism and characteristics of new particle formation

Observations of mobility distribution of ions are being made continuously at IITM using a Neutral Air Ion Spectrometer (NAIS) to study formation of new particles and their characteristics. Observations made during rain events show that charged nanoparticles are produced by splashing of raindrops. Observations show that mechanism responsible for the generation of intermediate ions is more efficient than that for the generation of heavy large ions during periods of high rain intensity. Relative roles of Lenard and Blanchard effects are suggested in generating excess of negative intermediate ions in the initial stages and excess of positive cluster ions in the later stages of a rain shower respectively. Further, it is observed that splashing generates excess of negative ions in each ion category. Concentrations of rain-generated ions increase/decrease with rain. **(Fig. 13)** [***Kamra A.K., Gautam A.S., Siingh D.**, Charged nanoparticles produced by splashing of raindrops, **Journal of Geophysical Research**, 120, July 2015, DOI:10.1002/2015JD023320, 6669-6681*]

Atmospheric ions and new particle formation events at a tropical location

Characteristics of small, intermediate and large ions and nanometre particles, and the influences of environmental conditions and local topography on them are studied during new particle formation (NPF) events. Total ion concentrations in this size range were approximately double on event days than on non-event days. The NPF events were generally preceded by 2-3 hours period of enhanced concentration of ions and aerosols (PECIA) which are associated with katabatic winds from the surrounding hill-slopes at the study site. During PECIA, ions ≤ 8 nm diameter grew faster and attained mode diameters greater than those of neutral particles. PECIA provided the ions of less than 8 nm diameter and reduced the condensation sinks and thus, contributed to the development of conditions conducive for NPF. [***Kamra A.K., Siingh D., Gautam A.S.**, Kanawade V.P., Tripathi S.N., Srivastava A.K., Atmospheric ions and new particle formation events at a tropical location, Pune, India, **Quarterly Journal of Royal Meteorological Society**, 141, October 2015, DOI:10.1002/qj.2598, 3140-3156*]

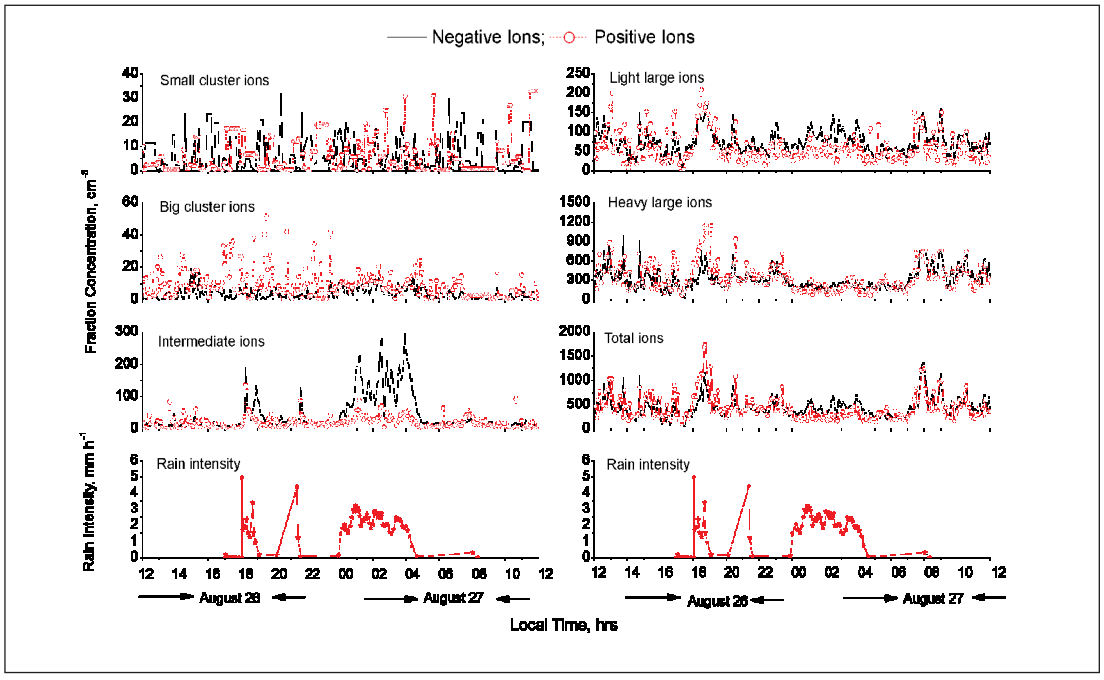


***Fig. 13**: Variations of the fraction concentrations of different categories of ions and rain intensity with local time on 26-27 August 2010.*

Simulation Studies

Raindrop charges and electric fields produce an electrostatic force which opposes the surface tension force and affects the balance of other forces acting on raindrop and thus, affect its shape (Pruppacher and Klett, 2010). The electrical force in the vertical electric field acts along its minor axis and counteracts the aerodynamic forces making them first spherical and then, prolate in shape with the increase in electric field. However, in the case of horizontal electric field, both aerodynamic and electrical forces act together and tend to stretch the drop along its major axis. Thus, these contribute to destabilise the drop.

The time-averaged axis ratios, frequency and amplitude of oscillations of water drops of 2.67-6.60 mm diameter were determined by suspending them in a vertical wind tunnel in presence of 0, 100, 300, and 500 kV m^{-1} horizontal electric fields using a high speed camera at 1000 frames per second (**Fig. 14**). A systematic decrease in the drop's axis-ratio is observed with increase in its diameter and/or horizontal electric field. The results obtained with high speed camera are in good agreement with earlier results. The drop distortion due to horizontal electric field is more pronounced for drops in the size-range of 3.36-6.00 mm diameter showing that the electrical forces progressively enhance the horizontal elongation of the drop resulting in its instability at 6.60 mm.

The drop oscillation frequency computed from temporal variation of axis ratio decreases with increase in drop size but shows no significant change in oscillation frequency in the horizontal electric field of ≤500 kV m^{-1}. However, the oscillation amplitude increases with increase in drop size up to a threshold value and then, flattens-off in the electric field of ≤ 300 kV m^{-1} demonstrating the nonlinear effect of net forces acting on such large drops. In higher electric field of 500 kV m^{-1}, gradual increase in the amplitude of oscillation with an increase in drop diameter has been observed. Moreover, for a particular drop size, the amplitude of oscillation decreases with increase in the electric field up to 500 kV m^{-1}. [***Bhalwankar R., Deshpande C.G., Kamra A.K.***, *Shape and oscillations of the water drops freely suspended in horizontal electric field: A wind tunnel study,* ***Journal of Atmospheric and Solar Terrestrial Physics****, 133, October 2015, DOI:10.1016/ j.jastp.2015.09.004, 169-177*]

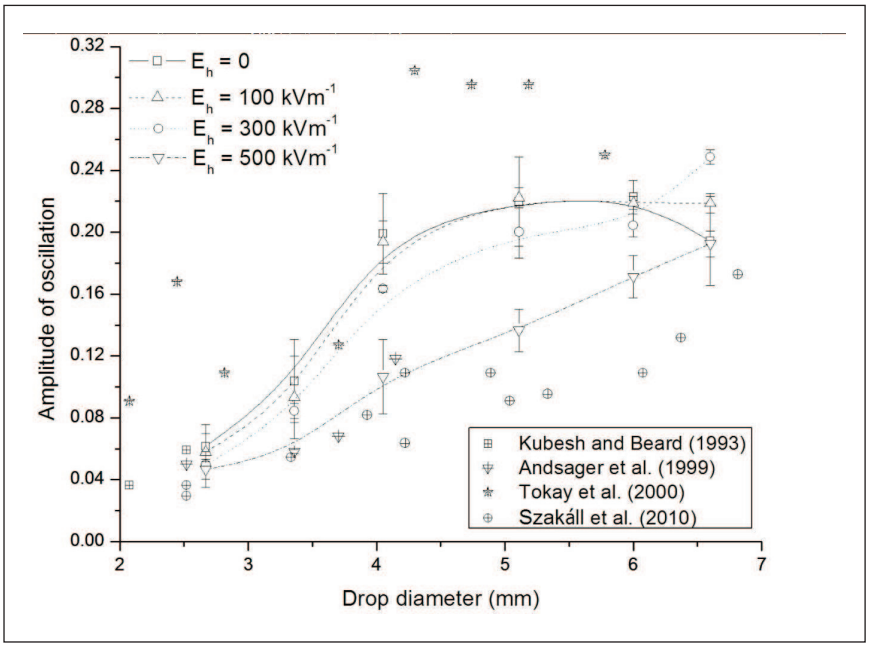


Fig. 14: *Variations in amplitude of oscillations with drop diameters in absence and presence of horizontal electric fields with error bars. Symbols represent mean values of the amplitude. Earlier experimental results of Kubesh and Beard (1993), Andsager et al. (1999), Tokay et al. (2000) and Szakáll et al. (2010) are also plotted.*

Project

National Facility for Airborne Research (NFAR)

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 in the process of procuring a research aircraft as the National Facility for Airborne Research (NFAR) in the 12th five year plan (2012-17) and it will be managed by IITM, Pune. This aircraft will be used for all airborne atmospheric research in the country and is planned to be positioned at Aurangabad. Depending on the research objectives, the aircraft operations will be conducted from different bases in the country. The research aircraft will carry several state-of-the-art sophisticated scientific instruments. At Aurangabad airport, facilities for maintenance and repair of aircraft, development, installation, calibration and modifications of scientific instruments onboard will be made available in the hangar.

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 modelling
- Cloud microphysics and precipitation process studies

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

To understand the atmospheric processes in the lower atmosphere, utilization of Unmanned Aerial Vehicle (UAV) is also explored. A single UAV instrumented with aerosol, radiation and meteorological parameters is in the process of procurement. In the later stages, 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 Forecasting 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, namely "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.).

Developmental Activities

Implementation of SAFAR-Mumbai: The project SAFAR-Mumbai was inaugurated by Dr. Harsh Vardhan, Hon'ble Union Minister for Science - Technology and Earth Sciences (Govt. of India) and Mr. Devendra Fadnavis, Hon'ble Chief Minister of Maharashtra on 23 June 2015. Under the project, 10 Air Quality Monitoring Stations have been established across Mumbai and surrounding region to monitor air quality and weather parameters. Air Quality and weather data monitored under the project and its 3 day advance forecast with associated health advisories is being disseminated through Digital Display boards installed across Mumbai region, unified SAFAR web portal (safar.tropmet.res.in), IVRS No-1800 180 1717, Mobile App-SAFAR-Air.

SAFAR-Mumbai system is commissioned by IITM in association with IMD's Regional Meteorological Centre, Mumbai and Municipal Corporation of Greater Mumbai (MCGM). This has marked a beginning of the services of "SAFAR", developed for the Mumbai region. Highlights of "SAFAR-Mumbai" launch:

- Release of Mumbaichi-Hawa (Marathi) and Mumbai-Air (English): A booklet for common citizens to know about SAFAR services.
- Launch of Mobile App for Mumbai: Detailed SAFAR data in terms of Air Quality Index and health advisories. SAFAR-Air mobile app was developed for android phones earlier. During this year, new version of Android SAFAR-Air Mobile App has been developed. In addition, a new mobile app for iPhone OS (iOS) is developed and released along with SAFAR-Mumbai launch. It is available at the App Store.
- Launch of Online Unified SAFAR Web Portal for Mumbai, Delhi and Pune: Detailed SAFAR data in terms of Air Quality Index and advisories.

SAFAR Mumbai dedicated to nation by remotely switching ON all LED digital display boards erected in Mumbai on 14 locations. The SAFAR-Mumbai delivers the following services to the citizens of Mumbai:

1. **Air Quality**: Colour-coded index based current and 3-day forecast with health advisories.
2. **Harmful Radiation**: Severity of UV radiation (UVI) with associated skin advisories.
3. **Weather**: Current and 1-day advance forecast.
4. **Extreme Events**: Alert for extreme pollution and weather events.
5. **Emission Scenario**: Accounting location-wise sources of air pollution.

SAFAR acts as an early warning system for air quality and weather. Data generated through the system is useful for various departments of Municipal Corporation of Greater Mumbai (MCGM) and Navi Mumbai Municipal Corporation (NMMC) including disaster management unit, environment department, health division, aviation sector, city development planning, etc. who are using

the SAFAR products in their respective environmental status report (ESR).

Initialization of SAFAR-Ahmedabad: The initial planning and discussion related with implementation of SAFAR project for Ahmedabad and Ganghinagar twin cities has been initiated. Preliminary survey has been conducted in Ahmedabad for identification of suitable location for installation of Air Quality Monitoring Station (AQMS) and Automatic Weather Station (AWS).

An MoU has been signed with the Space Application Centre (SAC), Indian Space Research Organisation, Dept of Space (Govt. of India), Ahmedabad for scientific cooperation in the project SAFAR-Ahmedabad.

The Municipal Commissioner of Ahmedabad has approved the installation of rest of the AQMS, AWS and Digital Display Systems across Ahmedabad city. Site identification survey will be initiated jointly with the nodal person of Ahmedabad Municipal Corporation (AMC).

Basic Research

Air quality simulation over South Asia using Hemispheric Transport of Air Pollution version-2 (HTAP-v2) emission inventory and Model for Ozone and Related chemical Tracers 3 (MOZART-4)

Distribution of tropospheric ozone (O_3) and its precursors are presented for the South Asia using the Model for Ozone and Related chemical Tracers (MOZART-4) and Hemispheric Transport of Air Pollution version-2 (HTAP-v2) emission inventory. The model present-day simulated O_3, carbon monoxide (CO) and nitrogen dioxide (NO_2) are evaluated against surface-based, balloon-borne and satellite-based (MOPITT and OMI) observations. The model systematically overestimates surface O_3 mixing ratios (range of mean bias about: 1-30 ppbv) at different ground-based measurement sites in India (**Fig. 1**). Comparison

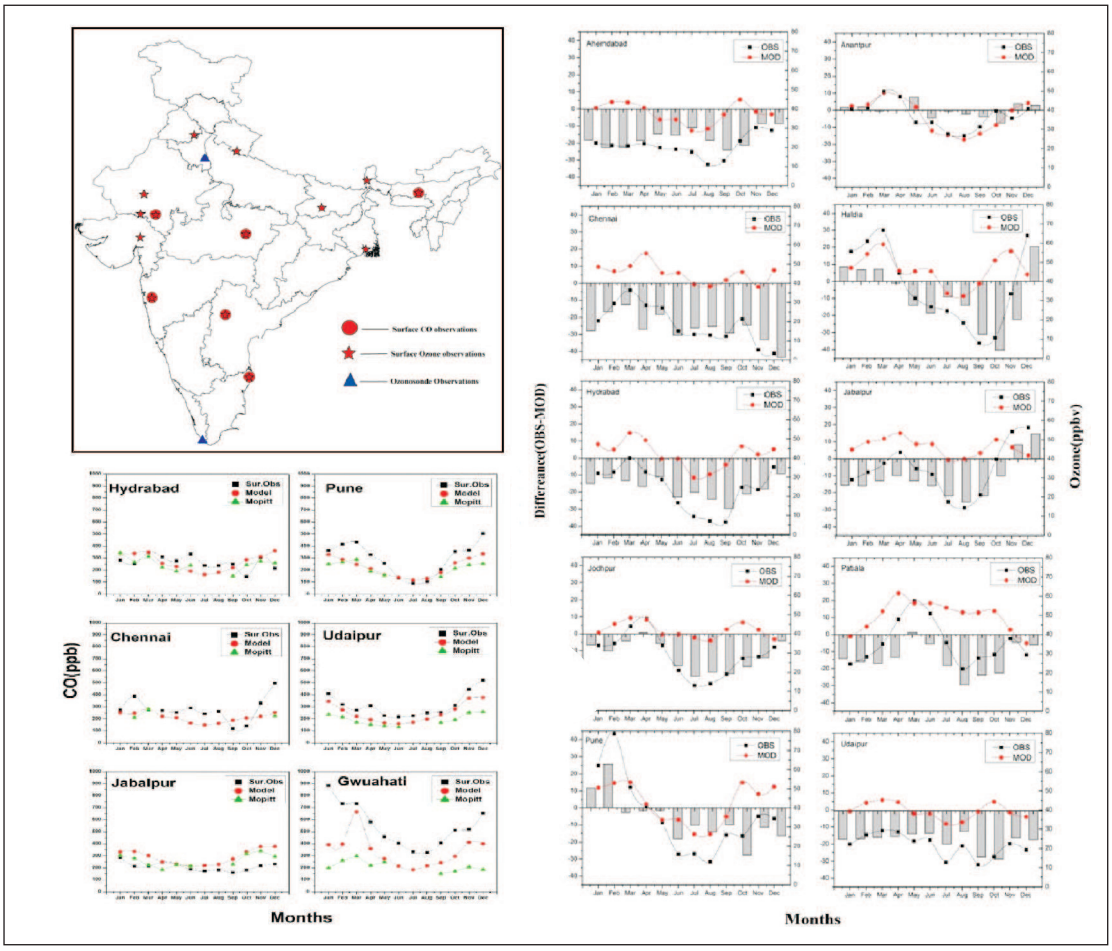


Fig.1: *Comparison between modeled (MOZART) and observed surface ozone and CO.*

between simulated and observed vertical profiles of ozone shows a positive bias from the surface up to 600 hPa and a negative bias above 600 hPa. The simulated seasonal variation in surface CO mixing ratio is consistent with the surface observations, but has a negative bias of about 50-200 ppb which can be attributed to a large part to the coarse model resolution. In contrast to the surface evaluation, the model shows a high bias of about 15-20 × 10^{17} molecules/cm^2 over South Asia when compared to satellite derived CO columns from the MOPITT instrument. The model also overestimates OMI retrieved tropospheric column NO_2 abundance by about 100-250 × 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. [***Surendran D.E., Ghude S.D., Beig G.****, Emmons L.K.,* ***Jena C.****, Rajesh Kumar, Pfister G.G.,* ***Chate D.M.****, Air quality simulation over South Asia using Hemispheric Transport of Air Pollution version-2 (HTAP-v2) emission inventory and Model for Ozone and Related chemical Tracers (MOZART-4),* ***Atmospheric Environment****, 122, December 2015, DOI:10.1016/j.atmosenv.2015.08.023, 357-372*]

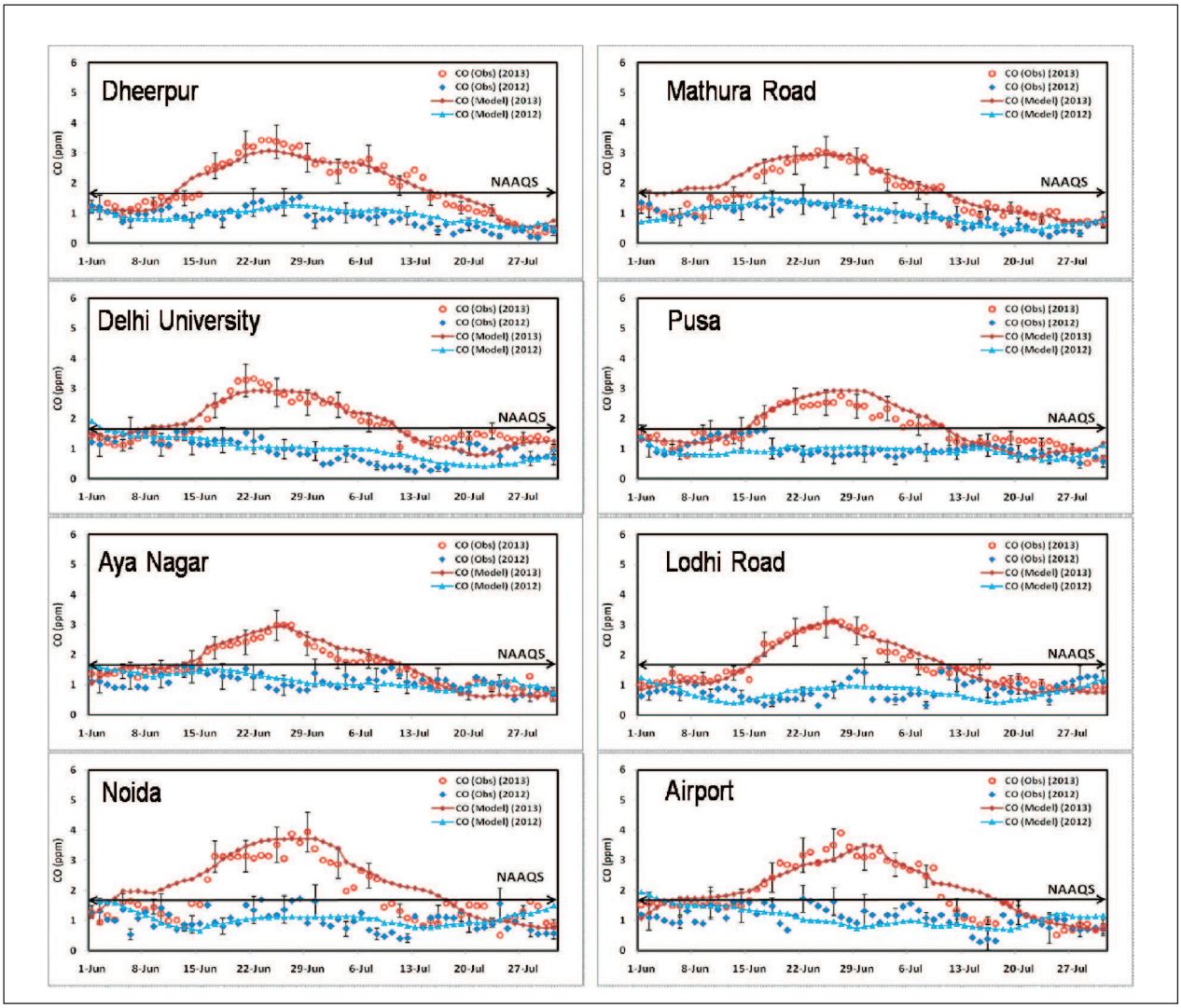


Fig. 2*: Distribution of CO volume mixing ratio (8h average) as observed during the onset of monsoon period in 2012 and 2013 at various locations in Delhi. The model simulated results for background runs are also shown.*

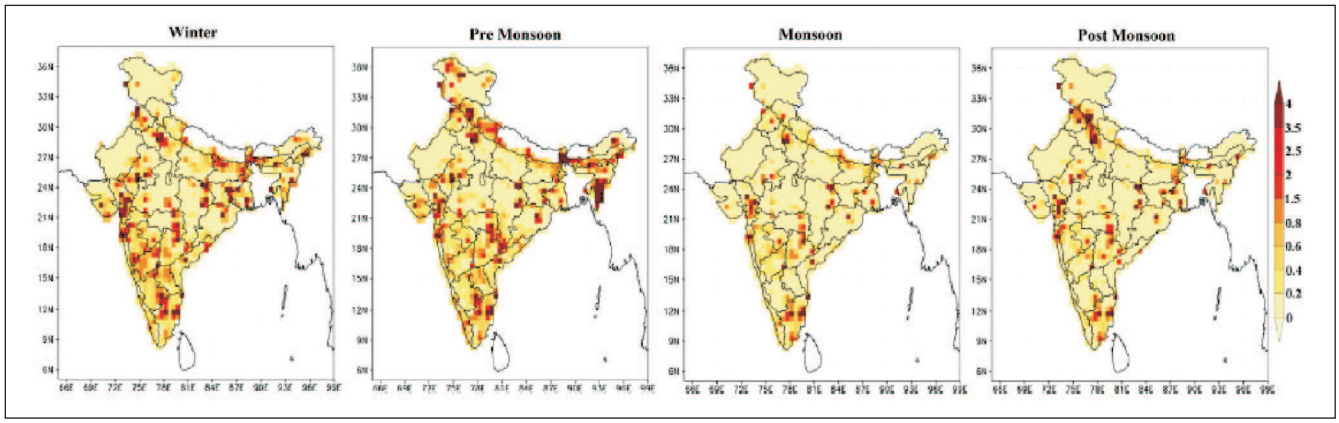


Fig. 3: Spatial distribution NO_x emissions from optimised Top-Down inventory (emission unit is 10^{11} NO molecules/cm^2/s) for winter, pre-monsoon, monsoon and post-monsoon seasons. Seasons are mentioned on top of the each panel.

Role of transport in elevated CO levels over Delhi during onset phase of monsoon

Carbon monoxide is one of the most toxic pollutants. While local anthropogenic emission sources contribute significantly to pollutant levels in a megacity Delhi, meteorology can significantly modulate carbon monoxide (CO) levels. It is demonstrated that the concentration of CO 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 generally drops down significantly. Level of CO in 2013 is compared with normal monsoon year 2012. The research provides a hypothesis to interpret this long lasting high concentration CO episode and validate using interactive high resolution WRF-Chem model (**Fig. 2**). The model indicates 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. [***Srinivas R., Panicker A.S., Parkhi N.S.**, Peshin S.K., **Beig G.**, Sensitivity of online coupled model to extreme pollution event over a mega city Delhi, **Atmospheric Pollution Research**, 7, January 2016, DOI:10.1016/j.apr.2015.07.001, 25-30*]

Inter-comparison of different NOx emission inventories and associated variation in simulated surface ozone in Indian region

The study addresses different anthropogenic NO_x emission inventories and examines the associated variation in simulated surface ozone (O_3) in India. Six anthropogenic NO_x emission inventories, namely Emission Database for Global Atmospheric Research (EDGAR), Intercontinental Chemical Transport Experiment-Phase B (INTEX-B), Regional Emission Inventory in Asia (REAS), MACCity, Indian National Emission Inventory (India_NOx), and Top-Down NO_x emission inventory for India (Top-Down) are included in the comparison. These emission inventories were included in regional chemical transport model WRF-Chem to simulate tropospheric column NO_2 and surface O_3 mixing ratios for the month of summer (15 March to 15 April) and winter (December) in 2005. Predicted tropospheric column NO_2 using different NO_x emission inventory is evaluated with the OMI satellite observations. Spatial distribution NO_x emissions from optimised Top-Down inventory for winter, pre-monsoon, monsoon and post-monsoon seasons are shown in **Fig. 3**. Seasons are done. All emission inventories show similar spatial features, however uncertainty in NO_x emissions distribution is about 20-50□ over rural regions and about 60-160□ over the major point sources. Compared to OMI, the largest bias in simulated tropospheric NO_2 columns is seen in the REAS emission inventory, followed by EDGAR inventories during winter. Simulations using different NO_x emission inventories produce maximum deviation in daytime 8-h averaged O_3 of the order of 9-17 ppb (15-40□) in summer and 3-12 ppb (5-25□) in winter over most of the land area. The simulation suggests that choice of NO_x emission inventories have significant effect on surface O_3 concentration for air quality studies over India. [***Jena C., Ghude S.D., Beig G., Chate D.M.**, Kumar Rajesh, Pfister G.G., **Lal D.M., Surendran D.E., Fadnavis S.**, Van der A R.J., Inter-comparison of different NOx emission inventories and associated variation in simulated surface ozone in Indian region, **Atmospheric Environment**, 117,*

September 2015, DOI:10.1016/j.atmosenv.2015.06.057, 61-73]

Characterization of Particulate matter and carbonaceous aerosol over two urban Environments in Northern India

Monitoring and simultaneous sampling of Particulate matter (PM_{10} and $PM_{2.5}$) was carried out for the first time over two urban sites in Northern India (Jabalpur and Udaipur) during December 2010 to November 2012 (up to August 2012 over Udaipur). The samples of $PM_{2.5}$ were analyzed for elemental carbon (EC) and organic carbon (OC) using advanced DRI Thermal optical carbon Analyzer. The monthly mean PM_{10} values were as high as 149±44 μgm^{-3} over Jabalpur (JBL) and 171±42.2 μgm^{-3} over Udaipur (UDPR). $PM_{2.5}$ mass over JBL varied between 25-79 μgm^{-3} and over UDPR between 24-82 μgm^{-3}. The monthly mean OC concentration varied from 16.8±8.1μgm^{-3} to 35.3±12.1 μgm^{-3} over JBL and from 9.1±3.2 to 42.6± 13.1μgm^{-3} over UDPR (**Fig. 4**). The variation of monthly mean EC concentration was from 3.9 to 10.3 μgm^{-3} over JBL and from 3 to 10.9 μgm^{-3} over UDPR. The contribution of the Total Carbon (TC) to PM_{10} was found to be between 18-41% over JBL and 16-38% over UDPR. The contribution of TC to $PM_{2.5}$ was in the range of 41-92% over JBL and 32-87% over UDPR. The EC showed higher concentration in winter and minimal values in monsoon. The OC/EC ratio showed low variation over JBL compared to that over UDPR suggesting spectrum of sources responsible for EC and OC components over UDPR. Formation of secondary organic carbon (SOC) was also recognized as a potential component altering OC/EC ratio. Up on extracting the sub fractions, it is found that OC3 is the major component over both the sites contributing up to 45% to the total OC. EC1 (derived at 580°C) was found to be the major EC component contributing up to 74% over the sites. [***Panicker A.S., Ali K., Beig G., Yadav S.,*** *Characterization of particulate matter and carbonaceous aerosol over two urban environments in Northern India,* ***Aerosol and Air Quality Research****, 15, December 2015, DOI:10.4209/aaqr.2015.04.0253, 2584-2595*]

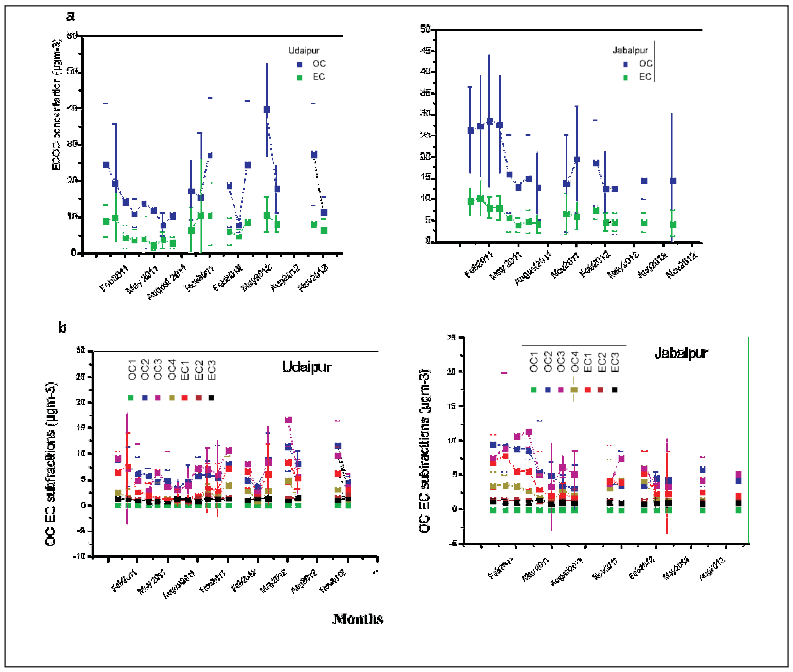


Fig 4: *Monthly variation of (**a**) OC and EC over Udaipur and Jabalpur; (**b**) Variation of subfractions of OC and EC over Udaipur and Jabalpur.*

Winter Fog Campaign 2015-16

The Ministry of Earth Sciences (MoES), Government of India has taken up an initiative to conduct an observational campaign to understand different physical features of fog and factors responsible for its genesis, intensity and duration, and for improving nowcasting and forecast of winter fog. This project is planned because of increasing winter fog occurrence, and failure of the Numerical Weather Forecast (NWPs)/climate models for prediction of fog microphysics, and lack of instruments to be used for forecasting applications. This requires developing integration techniques of observations and numerical predictions. The pilot campaign conducted at Indira Gandhi International Airport (IGIA) and ICAR-Indian Agricultural Research Institute (IARI) in New Delhi during the winter season (December 2015 to February 2016) was inaugurated by Dr. M. Rajeevan, Secretary, MoES on 17 December 2015. The campaign will be repeated during next 2-3 winter seasons.

The main objective of the proposed field campaign is to study the characteristics and variability of fog events over Delhi and the associated dynamics and thermodynamics and cloud microphysics. These observations will ultimately improve our understanding of fog events and our capability in its prediction. The observational campaign included simultaneous measurements of surface micro-meteorological conditions, radiation balance, turbulence, thermo-dynamical structure of the surface layer, optical, micro-physical and chemical properties of fog and aerosol to describe the complete environment in which fog develops. These measurements are aimed to form the basis for understanding some of the key questions on fog formation and dispersion. These measurements will be used for modeling efforts with the ultimate aim to improve the prediction skill. In addition, Indian National Centre for Medium Range Weather Forecasting Unified Model (NCUM) and National Center for Atmospheric Research (NCAR) Weather Forecasting Model (WRF) coupled with Chemistry are planned for fog prediction over the Indo-Gangetic region at a spatial resolution of 17 and 2 km respectively.

At IGI Airport, New Delhi, the campaign was conducted with cooperation and support from Airport Authority of India and GMR group. ICAR-IARI and Indian Institute of Science Education and Research (IISER), Mohali also participated in the observational campaign. For modeling efforts, IITM, Pune and NCMRWF, Noida are involved.

The campaign was conducted under the leadership of IITM in collaboration with India Meteorological Department (IMD), New Delhi. The campaign was 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 and ICAR-IARI in New Delhi for the fog 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. Tethersonde measurements of aerosol, BC, temperature and RH were carried out in the fog layer in collaboration with Tata Institute of Fundamental Research (TIFR) Balloon facility.



Fig.: *Radiometer and wind profiler installed at IGI for Fog campaign.*





Fig.: *Tower instrumentation setup for Fog campaign.*

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 ICMPO is 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 responsibilities of the ICMPO also include support to CLIVAR/GEWEX Monsoon Panel, CLIVAR/IOC-GOOS Indian Ocean Regional 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 activities of ICMPO also include production of CLIVAR Exchanges, development of Monsoon 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. 66 (Special issue on Monsoons: Advancing understanding of monsoon variability and improving prediction).
- CLIVAR Exchanges No. 67 (Special issue on Sustained Ocean Observing and Information in Support of Ocean and Climate Research)
- CLIVAR Exchanges No. 68 (Special issue on Celebrating 50 years of Indian Ocean Research).

CLIVAR Brochure 2016: ICMPO contributed in the preparation and designing of the CLIVAR Brochure 2016.

Development of CLIVAR Monsoon Web Pages: ICMPO has developed web pages for Monsoon Panel Regions: Asian-Australian Monsoon, American Monsoon, African Monsoon and Indian Ocean/Monsoons Cross Panel Activities. Information about Events, News, Conferences, Symposia, Training Programs and Meeting Minutes are being uploaded periodically on www.clivar.org.

Support to CLIVAR/GEWEX Monsoon Panel: ICMPO conducted four Doodle Polls and organised four online meetings using GoToMeeting software for: American Monsoon, Asian-Australian Monsoon, Indian Ocean/Monsoons Cross Panel Activities and African Monsoon.

Project

Centre for Advanced Training

Project Director: Dr. Vinu Valsala

Objectives

- To establish a state-of-the-art advanced training centre in earth system sciences and climate.
- To create a large pool of trained and dedicated multi-disciplinary climate and earth system scientists.

Overview

The Centre was established by Ministry of Earth Sciences (MoES) at IITM to cater 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 to work in the MoES institutions. The meet main objectives, the Centre runs a job linked induction training programme where the trainees are provided with in-depth hands on expertise on individual physical processes of the land, ocean, atmosphere, biosphere and cryosphere with special emphasis on climate modeling.

The Centre has successfully run three batches of the training programme since its inception in 2010. In response to the notifications, 5000+ applications each for the Batch-I and Batch-II and 7000+ applications for the Batch-III were received. After the completion of the induction training, the trainees were placed in the constituent institutes of the MoES (*see* **Table 1)**.

Placement of Batch-III trainees

Out of the 23 Batch-III candidates who successfully completed the training by December 2014, one has resigned. Due to some administrative reasons, the remaining 22 candidates were initially appointed as Project Scientist-B in the various MoES organisations w.e.f. from June 2015: five at IITM, two at INCOIS, five at IMD, three at NCAOR, three at NCMRWF, three at NCESS, and one at INCOIS. Subsequently, as per the orders of MoES, the Batch-III trainees were regularised at MoES institutions in a phased manner as per the seniority list prepared by the MoES. In the first phase, 11 trainees were posted as Scientist-B w.e.f. from August 2015 at different MoES institutions: five at IITM, three at INCOIS and three at NIOT. In the second phase, the remaining 11 trainees were posted as Scientist-B w.e.f. from November 2015 at different MoES institutions: two at IITM, three at NCAOR and six at NCESS.

Batch	IITM	INCOIS	NIOT	NCMRWF	NCAOR	NCESS	IMD	Total
Batch-I	10	2	2	2	1	0	0	17
Batch-II	16	0	0	0	1	0	0	17
Batch-III	7	3	3	0	3	6	0	22
Total	33	5	5	2	5	6	0	56

Table 1: *Placements of CAT-ESSC Trainee Scientists at the different MoES institutions.*

Pre-PhD course work for IITM JRFs

CAT is conducting the two-semester course work designed as the Pre-PhD programme for a batch of the following 14 IITM Junior Research Fellows (JRFs):

S. No.	Name of Candidate	Qualification
1	Abhishek Gupta	M.Sc. (Physics)
2	Manpreet Kaur	M.Sc. (Physics)
3	Deepak Suryavanshi	Integrated BS-MS (major Maths, minor Physics)
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)

Revision of Pre-PhD Syllabus for IITM JRFs

The syllabus for the two-semester Pre-PhD coursework for IITM JRFs has been revised by examining the syllabuses of training courses of IMD, IISc and IITM. As per the new syllabus, the first semester offers exclusive training (without research work) and the second semester offers partial training and partial research. The revision was carried out by a committee (Dr. V. Valsala, Dr. P. Mukhopadhyay and Dr. H.P. Borgaonkar as members) appointed by the Director, IITM. The revised syllabus has the following six core courses for the Semester-1 and eight courses for the Semester-2:

Semester-1 courses

C1- Dynamics of Atmosphere and Ocean-I

C2- Physical Meteorology and atmospheric thermodynamics

C3- Tropical Weather and Climate

C4- Climatology and General Circulation

C5- Mathematical Methods, Statistics and Computer Application

C6- Meteorological and Oceanographic Observations

Semester-2 courses

C1- Dynamics of Atmosphere and Oceans (Geophysical Fluid Dynamics)-II

C2- Large scale air-sea interaction

E1- Physical Meteorology-II (Cloud physics, aerosol physics, air pollution, atmospheric chemistry, upper atmosphere)

E2- Modelling of atmosphere and oceans (numerical methods, physical parameterizations, data assimilation methods)

E3- Climate Science, General Circulation, Monsoon Dynamics

E4- Advanced Statistics, mathematics and computer programming

E5- Satellite and Radar Meteorology

E6- High Performance Computing

Faculty

The committee has identified the following experts as faculty members for teaching the above mentioned courses.

From IITM

Dr. P. Mukhopadyay

Dr. Suryachandra Rao

Dr. Vinu Valsala

Dr. Ramesh Vellore

Dr. Shivsai Dixit

Dr. Anupam Hazra

Dr. Abhilash S.

Dr. G. Pandithurai

Dr. Thara Prbhakaran

Dr. Rajib Chattopadhyay

Dr. C. Gnanaseelan

Dr. R.H. Kriplani

Dr. Ashwini Kulkarni

Dr. Anant Parekh

From outside IITM

Ms. Sunitha Menon, IMD, Pune

Ms. Sathi Devi, MTI, IMD, Pune

Mr. Mohapatra, IMD, Delhi

Mr. M. Tandon, Pune

Dr. U.S. De, IITM (Retrd.)

Prof. Raghu Murtugudde, University of Maryland

The classes of IITM JRFs were started from August 2015. The mid-term exams were conducted during October-November 2015. Final term exams for Semester-I were conducted in February 2016.

Basic Research

Mesoscale and intraseasonal air-sea CO_2 exchanges in the western Arabian Sea during boreal summer

The western Arabian Sea is one of the intense upwelling regions of the global oceans and a venue for systematic seasonal cycle of intense biological production and carbon sources. The summer monsoon upwelling brings the nutrient and carbon rich sub-surface water to the surface all along the Somali-Arabian coasts in the western Arabian Sea. The oceanic pCO_2 ramps up during the summer monsoon in the western Arabian Sea as evidenced by the ship-based measurements. However, apart from the seasonal variability in oceanic pCO_2 in this region, the 'with-in-the season' variability, here termed as intra-seasonal variability which is confined to the band of 20-90 day periodicity was not widely studied. With the help of a simple biogeochemical model and high-resolution offline transport model, the pCO_2 and air-sea CO_2 flux variability of the western Arabian Sea was investigated. The focus was on the boreal summer season to find that there is a strong air-sea interaction of carbon cycle over the Somali region of the western Arabian Sea where the intraseasonal variability during this season is clearly evident in the intense variability in winds, the strength of the upwelling, the evolution of meso-scale eddies, oceanic pCO_2 and air-sea CO_2 fluxes. The oceanic pCO_2 variability in this intraseasonal band over the Somali region is also remarkably consistent with the other variables and is found to be driven by sea surface temperatures (SST) albeit with a counteracting but relatively minor influence from the dynamics of dissolved inorganic carbon (DIC). Intraseasonal cooling of SST by corresponding variability in the upwelling causes net reduction in pCO2 here at intraseasonal band which offsets the increase in pCO2 caused by the biogenic new-production of dissolved inorganic carbon. This interaction is mainly along the northern periphery of the Great Whirl. The variability in pCO_2 here is intimately linked to the SST variability. The 20-90 day band in pCO_2 accounts for about 40□ of the monthly mean variability of the sea-to-air CO_2 fluxes of this region in boreal summer. [***Valsala V., Murtugudde R.**, Mesoscale and intraseasonal air-sea CO_2 exchanges in the western Arabian Sea during boreal summer, **Deep-Sea Research I**, 103, September 2015, DOI:10.1016/j.dsr.2015.06.001, 101-113*]

PhD and M.Tech. Programme

Project Director: Dr. H.P. Borgaonkar

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. And the ten students of the second year of the 27th batch are doing their project work at IITM. Courses on Mathematical and Statistical Methods, Physical and Dynamic Oceanography, Data Assimilation and Parameterisation, and Radar Meteorology for M.Tech. were conducted at IITM.

M.Sc. (Atmospheric Science) Programme

Under the IITM and the Department of Atmospheric and Space Science (DASS) of S.P. Pune University collaborative M.Sc. (Atmospheric Science) Programme, 09 students were admitted in this programme for the academic session 2015-17. The M.Sc. second year students (08) of the batch 2014-16 are doing their project work at IITM. Following courses for this programme were conducted at IITM: Physical Meteorology, Numerical Methods, Mathematical Methods, Statistical Methods, Fundamentals of Ocean Science, Dynamic Meteorology, Satellite and Radar Meteorology, Climate Science, Data Assimilation and Parameterisation, Atmospheric Chemistry and Air Pollution, Instrumental and Observation Techniques.

Faculty for M.Tech. and M.Sc. Programmes

Following scientists of IITM worked were awarded Adjunct Professorship by Savitribai Phule Pune University for the academic year 2015-16. They worked as faculty for the mentioned M.Tech. and M.Sc. courses.

Name, Designation	Professorship Awarded
Dr. C. Gnanaseelan, Scientist-F	Adjunct Professor
Dr. H.P. Borgaonkar, Scientist-E	Adjunct Professor
Dr. (Mrs.) Ashwini Kulkarni, Scientist-E	Adjunct Professor
Dr. S. Chakraborty, Scientist-E	Adjunct Professor
Dr. M.S. Mujumdar, Scientist-D	Adjunct Professor
Dr. P. Mukhopadhyay, Scientist-E	Adjunct Associate Professor
Dr. Ramesh Vellore, Scientist-E	Adjunct Associate Professor
Dr. Madhuchandra Reddy, Scientist-D	Adjunct Associate Professor
Dr. Roxy Mathew, Scientist-D	Adjunct Associate Professor
Dr. J.S. Chowdary, Scientist-D	Adjunct Associate Professor
Dr. S.A. Dixit, Scientist-D	Adjunct Assistant Professor
Mr. M. Mahakur Scientist-C	Adjunct Assistant Professor
Dr. Anant Parekh, Scientist-C	Adjunct Assistant Professor
Dr. Manish Joshi, Scientist-C	Adjunct Assistant Professor
Mrs. Rashmi Khandekar, Scientist-B	Adjunct Assistant Professor
Ms. J.S. Deepa, Scientist-B	Adjunct Assistant Professor

Award of PhD by Savitribai Phule Pune University, Pune

Student	Thesis Title	Guide (s)
Mr. R. Srinivas	High resolution on-line chemistry transport modeling for atmospheric chemical constituents in developing forecasting system for Delhi	Dr. G. Beig
Ms. Sharmila Sur	Studies on the characteristics of intraseasonal oscillations during extreme monsoon years: Observations and model simulations	Dr. A.K. Sahai Prof. B.N. Goswami
Ms. Nabanita Borah	Extended range prediction of Indian summer monsoon: Development of a non-linear technique and bias correction of dynamical model forecast	Dr. A.K. Sahai Prof. B.N. Goswami
Mr. S. Rahul	A model study of India-Ocean warming and associated processes	Dr. C. Gnanaseelan
Ms. Soumi Chakravorty	Understanding the basin scale interannual warming of the Indian Ocean and its regional impacts	Dr. C. Gnanaseelan
Ms. Trina Bose	Long term reconstruction of climatic parameters using proxies from dated tree ring samples from Western Himalayas	Dr. S. Chakraborty Dr. H.P. Borgaonkar
Mr. Abhik Santra	Impact of cloud processes on tropical intraseasonal oscillation: Numerical modeling studies	Dr. P. Mukhopadhyay Prof. B.N. Goswami
Mr. C.K. Jena	High resolution NOx emission estimates for India based on satellite measurements and regional chemistry transport model	Dr. Sachin D. Ghude Dr. G. Beig
Mr. Ruchit R.D.	Characteristics of tropospheric winds over the tropical Indian region from Radar and Lidar measurement	Dr. P. E. Raj Dr. K.M.C. Reddy
Ms. Radhika D. Kanase	Numerical study of Indian ocean cyclones using regional mesoscale model	Dr. (Mrs.) P.S. Salvekar
Mr. T. Dharmaraj	Studies on the atmospheric boundary layer in different environments over the Indian region	Dr. P.E. Raj
Mrs. Sayanthini Ojha	Study of variability in the vertical structure of Tropical Indian Ocean and its impact on air-sea interaction	Dr. C. Gnanaseelan
Ms. Aaditi H. Deshpande	Study of variability in the Equatorial Indian Ocean currents and their regional impact	Dr. C. Gnanaseelan
Mr. S.B. Kakade	Prediction of Indian monsoon rainfall on smaller space-time scales	Dr. (Mrs.) A.A. Kulkarni
Mr. Vijay Kumar Soni	Multi-decadal solar radiation trends and tropospheric aerosol forcing over India	Dr. G. Pandithurai Dr. D.S. Pai, (IMD)
Mr. Chilukoti Nagaraju	Decadal changes in the relationship between Indian and Australian summer monsoons	Dr. K. Ashok

PhD Awarded by Banaras Hindu Univesity, Varanasi

Mr. Deen Mani Lal	The role of aerosol on changing climate over Indo-Gangetic plain	Dr. M.K. Srivastava Dr. Suresh Tiwari Dr. S.D. Ghude

PhD Awarded by University of Barcelona, Spain

Mr. Mahesh Shinde	Implementation of a high resolution regional ocean model for investigating air-sea interaction in the Mediterranean area	Dr. Jordi Isern-Fontanet Prof. Dr. Ileana Blade Mendoza

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

Student	Title	Guide(s)
Mr. M.D. Chipade	Energetics of zonal waves and variability of Indian summer monsoon	Dr. S.M. Bawiskar
Mrs. Tanusri Chakraborty	Intercontinental transport and distribution of air pollutants over south Asia	Dr. G. Beig
Mr. Gibies George	Role of ocean-atmosphere coupling in the seasonal prediction of south Asia monsoon	Dr. A. Suryachandra Rao

Thesis submitted to Andhra University for the Award of PhD

Mr. S.D. Sanap	Study on aerosol-monsoon interactions over Indian subcontinent using satellite data and CMIP5 simulations	Dr. G. Pandithurai Prof. K. Niranjan

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 2015-16, about 80 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.

Important Events and Activities

Important Events

- **Teacher's Training Workshop on 'Introduction to Indian Climate and Climate Change'** was organised by the Indian Meteorological Society, Pune Chapter (IMSP) in collaboration with IITM, IMD and S.P. Pune University at IITM, Pune during 04-08 May 2015. The event was sponsored by the Ministry of Earth Sciences (MoES), Govt. of India and IMSP. Experts from the organising institutions deliberated on various issues related to the Indian climate and climate change. Participants were also taken on a study tour of IITM's High-Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar where they had a hands-on experience about the laboratory's work.

- **International Day of YOGA:** IITM in collaboration with Vijnana Bharati organised an event to celebrate the first International Day of Yoga at IITM on 21 June 2015. The United Nations General Assembly (UNGA) recently recognised 21 June as the International Day of Yoga to be observed annually. The event also highlighted the importance of Yoga in living a healthy life. Demonstrations about different *Yoga Asanas* were arranged. Prof. Bhushan Patwardhan, Director Interdisciplinary School of Health Sciences, S.P. Pune University delivered a special talk on 'Scientific aspects of Yoga'. On this occasion, a Marathi book entitled '*Bharatiya Stree ani Yog*' by Mrs. Shymal Railkar was also released. Mrs. Railkar gave talk on '*Asan Se Aseem Tak*'. Dr. M. Rajeevan, Director, IITM and Mr. Jayantrao Sahasrabudhe, National Organising Secretary of Vijnana Bharati also spoke on the occasion.

- **Inauguration of SAFAR-Mumbai:** The System of Air Quality and Weather Forecasting and Research (SAFAR) for Mumbai was inaugurated by Dr. Harsh Vardhan, Hon'ble Union Minister of Science and Technology and Earth Sciences, Govt. of India, and Shri Devendra Fadnavis, Chief Minister of Maharashtra at a function held at the Y.B. Chavan Auditorium, Nariman Point, Mumbai on 23 June 2015. SAFAR-Mumbai is commissioned by IITM in association with the IMD's Regional Meteorological Centre, Mumbai and the Municipal Corporation of Greater Mumbai (MCGM).

- **MoES eResources Consortium Workshop** was organised by the Ministry of Earth Science (MoES) at IITM during 16-17 July 2015. It was a user awareness programme on various eResources and scientific databases such as Web of Science, Scopus and Sciencedirect made available through the MoES Consortium. The workshop was attended by many scientists, research fellows and students of IITM and 20 trainees of the IMD's Meteorologist Grade-II Training Course (Batch 21).

- **Aaditya HPC Training Workshop** with hands-on experience was conducted at IITM during 22-23 July 2015, which was attended by many scientists.

- **Cabinet Approval for ICMPO at IITM**: The Union Cabinet has formally approved the establishment of International Climate Variability and Predictability (CLIVAR) Monsoon Project Office (ICMPO) at IITM on 12 August 2015.

- **Seventh National Workshop on Climate Change** was jointly organised by the Centre for Climate Change Research (CCCR), IITM and the Ministry of Earth Sciences (MoES) at National Centre for Earth Science Studies (NCESS), Thiruvananthapuram during 19-20 August 2015.

- **A Workshop Oriented Towards Scientific Reporting**: In an effort to familiarise journalists reporting on weather and climate sciences about the advances in the field, Indian Meteorological Society, Pune Chapter (IMSP) in association with IITM organised a 2-day workshop at IITM during 08-09 October 2015.

- **First WMO Workshop on Operational Climate Prediction** was organised by the World Meteorological Organization (WMO), Geneva at IITM during 09-11 November 2015. Prof. Sulochana

Gadgil, an eminent scientist and ex-professor from IISc, Bengaluru was the Chief Guest on the occasion. Dr. Rupa Kumar Kolli, Chief, World Climate Applications and Services Division at WMO and Dr. B. Mukhopadhyay, DDGM-Climatology at IMD, Pune were also present. About 42 participants from Japan, UK, Russia, Korea, USA, Argentina, Philippines, South Africa, Spain, Singapore, Chad, Costa Rica, Serbia, Jamaica, Canada, Niger, Barbados, Myanmar, Switzerland and India etc. attended the workshop. During the workshop, scientists discussed the background and current operational practices in climate prediction on global, regional and national scales for developing a consensus about the ways for improving operational climate prediction around the world.

- **Foundation Day Celebrations:** IITM celebrated its 54th Foundation Day on 17 November 2015 at its premises. On this occasion Dr. A.S. Kiran Kumar, Chairman ISRO and Secretary, Department of Space was the Chief Guest. Prof. Rajat Moona, Director General, CDAC was the Guest of Honour. Prof. Vinod K. Gaur, Chairman, Governing Council, IITM chaired the function. In addition to the main function, the celebration included the presentation of various awards viz. 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 (introduced from this year onwards) were presented. On this occasion, a scientific report entitled 'IITM Research Report on Monsoon 2015' was released by the hands of Dr. Kiran Kumar. 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. The celebrations concluded in the evening with a cultural programme. Several ex-employees and special invitees, in addition to the existing employees and their families, attended the function.

  - Presentation of the 27th annual IITM Silver Jubilee Award for the year 2014 to a paper entitled 'Role of interaction between dynamics, thermodynamics and cloud microphysics on summer monsoon precipitating clouds over the Myanmar Coast and the Western Ghats' by Siddharth Kumar, A. Hazra and B.N. Goswami published in the international journal Climate Dynamics, 43, August 2014, 911-924.
  - Presentation of the Annual Excellent Performance Award for the year 2014 to Mr. Kiran Salunke, Mr. S.G. Purandare, Mr. R.N. Kulkarni and Mr. E.M. Botla for the Scientific Support, Technical, Administrative and Multi-Tasking Staff category respectively.
  - Presentation of the Best Student Paper Award for the year 2014 to the following two papers:
    - Role of thermocline-SST coupling in the evolution of IOD events and their regional impacts' by A. Deshpande, J.S. Chowdary and C. Gnanaseelan published in the international journal Climate Dynamics, 43, July 2014, 163-174.
    - Time evolution of monsoon low-level jet observed over an Indian tropical station during the peak monsoon period from high-resolution Doppler wind lidar measurements' by R.D. Ruchith, P.E. Raj, M.C.R. Kalapureddy, S.M. Deshpande, and K.K. Dani published in the international journal Journal of Geophysical Research, 119, February 2014, 1786-1795.
  - Prof. Ananthakrishnan Best Thesis Award for the year 2014 was presented to Dr. C.T. Sabeerali for his PhD thesis entitled 'Modulation of Monsoon Intra-seasonal Oscillations by Global Warming'.
  - A special Foundation Day Lecture on the topic 'High Performance Computing in India' by Prof Rajat Moona, Director General, CDAC, Pune.
- **AsiaFlux Workshop 2015:** A joint conference comprising the AsiaFlux Workshop 2015 and the meeting of the International Society for Photogrammetry and Remote Sensing (ISPRS) TC WG VIII/3: Weather, Atmosphere and Climate Studies, titled “Challenges and Significance of Ecosystem Research in Asia to Better Understand

Climate Change" was arranged at IITM during 22-29 November 2015. The event was organised by IITM in association with the National Remote Sensing Centre (ISRO), Hyderabad, and was jointly supported by Asia-Pacific Network for Global Change Research (APN), LI-COR Biosciences, USA, National Institute for Agro-Environmental Science (NIAES), Japan, National Institute for Environmental Studies (NIES), Japan. The event started with a 3-day training course on 'Ecosystem carbon flux monitoring using eddy covariance theory' during 22-24 November 2015, followed by the Workshop and plenary sessions in AsiaFlux 2015. The workshop was inaugurated by the Chief Guest Dr. V.K. Dadhwal, Director, National Remote Sensing Centre (ISRO), Hyderabad, Dr. Akira Miyata, Chair of AsiaFlux, and Director of the Agro-Meteorology Division of NIAES, Japan and Dr. M. Rajeevan, Director, IITM. The workshop brought together scientists, researchers, academicians and entrepreneurs from all over the world to discuss the various challenges in eco-system research and to understand the possible effects of climate change on ecosystem in Asia. Around 100 participants made oral and poster presentations. Several manufacturers of atmospheric and meteorological sensors also participated in the event. About 60 early career scientists deliberated on various aspects of ecosystem research, collaborative potentials among themselves and future career path in the 'Young Scientist Meeting', arranged during the event.

- **Annual Monsoon Workshop-2015** and **National Symposium on Understanding & Forecasting the Monsoon Extremes** were held at IITM during 23-24 February 2016. The event was jointly organised by Indian Meteorological Society (IMS) Pune Chapter, IITM, India Meteorological Department (IMD), Ministry of Earth Sciences (MoES), Ocean Society of India (OSI) and Center for Development of Advanced Computing (CDAC).

- **Prof. P.R. Pisharoty Distinguished Lecture:** IITM and the Indian Meteorological Society, Pune Chapter jointly organised the Eighth Prof. P.R. Pisharoty Distinguished Lecture by Dr. Mitchell W. Moncrieff, NCAR, USA on 23 February 2016 at the Institute. The theme of the lecture was 'Organised convection in a New Era for Global Models'.

- **CCCR Climate Data Portal** has been identified as a nodal server for the Earth System Grid Federation (ESGF) for dissemination of climate change information for the South Asian region available from CORDEX. This data portal will also be used for disseminating the CMIP6 projections generated by IITM ESM in the near future. The ESGF is an international collaboration with a current focus on serving the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP) and supporting climate and environmental science in general.

Important Meetings

- **CAIPEEX 2015 Plan**: A meeting of experts was held on 11 May 2015 at IITM for discussion on CAIPEEX 2015 Plan. Dr. K. Krishnamoorty, ISRO, Prof. D.R. Sikka, Former Director of IITM, Prof. G.S. Bhat, IISc, Bengaluru, Prof. Pradeep Kumar, SP Pune University and Dr. J.R. Kulkarni (Retd. from IITM), were invited to attend this meeting.

- **CAIPEEX-2015 Campaign Plan Meeting**: A meeting of the National Steering Committee was organized at IITM on 15 June 2015 for discussion on CAIPEEX 2015 Plan. Prof. D.R. Sikka, Prof. G.S. Bhat, Dr. Vidhyadhar Mudkavi, Dr. R.R. Kelkar, Prof. Pradeep Kumar and Dr. J.R. Kulkarni attended the meeting.

  Fifth Scientific Steering Committee (SSC) Meeting of the Monsoon Mission was organised on 12 August 2015 at IITM. The Chairman Dr. Shailesh Nayak, Secretary, MoES attended the meeting through Video Conferencing. The Meeting was Co-chaired by Prof. J. Srinivasan.

- **Brainstorming Meeting:** *A* one day brainstorming meeting on 'Observational campaign for understanding and predication of winter FOG' was organised at IITM on 13 August 2015. Scientists from IMD-Delhi, IIT-Delhi, IIT-Bombay, IIT-Madras, NCMRFW-Delhi, IISER-Mohali, IITM-Pune and ICIMOD, Nepal discussed the operational, climatology, experimental and modeling aspects of fog.

- **PhD Programme and Research Collaboration**: To initiate the joint PhD Programme and research collaboration as per the MoU signed earlier, a meeting of IITM and IIT-Bombay faculties was organised on 22 August 2015 at IIT-Bombay. Director, IITM chaired the meeting. The meeting mainly intended to decide the modalities for registration of PhD scholars from IITM at IIT-Bombay. The meeting also discussed the possible areas where the two premier Institutes could collaborate for mutual benefit of research on weather and climate sciences.
- **ESM Training School**: A teleconference of experts from CCCR, IITM, GFDL, NOAA and ICTP was organised on 26 August 2015 for preparing the science plan for ESM training school (a joint activity of MoES and ICTP) to be held at IITM during 18-29 July 2016. Drs. R. Kishnan, J. Sanjay, V. Ramesh and P. Swapna from IITM participated in the teleconference.
- **Meeting of ISRO-ADCOS** meteorological satellites study team was organised at the Institute on 19 September 2015 to identify outstanding science questions in meteorology which need data from space-based experiments.
- **A Brainstorming Meeting on Radar Meteorology** was organised at IISc, Bengaluru jointly with Divecha Centre for Climate Change during 25-26 September 2015, keeping the future perspective of radar meteorology network in India. About 40 participants attended the meeting from various operational agencies, industries, academia and research organisations (such as IITM, IISc, NARL, SPL, SAC, SAMEER, CUSAT, MoES, DST, IAF, BEL, ECIL, Wavelet Technologies - Data Patterns). Dr. M. Rajeevan, Director, IITM suggested that recommendations on human resource development can be implemented at IITM. In addition to this, IITM can also support to arrange an annual workshop on radar meteorology. Dr. Shailesh Nayak, Former Secretary, MoES suggested that MOES should take up the development programme on Radar Meteorology in order to improvise the utilisation of radar techniques and data usage for useful applications and to involve R- D institutions in developing products. He also suggested inducting quality resource persons through a job-guaranteed training programme.
- **Lightning Location Network Meeting**: A meeting of IITM and District Disaster Management Authority (DDMA) was held on 12 October 2015 at Parbhani (Maharashtra) to discuss the capabilities of IITM's lightening data which are generated by installation of Lightning Location Network throughout Maharashtra and providing the same to DDMA on regular basis. The precautions that need to be taken to minimise loss of life due to lightening were also discussed.
- **Brainstorming Meeting on Monsoon Modelling:** The meeting was organised at IITM on 12 February 2016, where Prof. Jagdish Shukla from George Mason University (GMU) Center for Ocean-Land-Atmosphere Studies (COLA) was the Chief Guest. Mr. V.R. Durai, IMD, Delhi; Dr. D.S. Pai, IMD, Pune and Dr. Gopal Iyengar were the other invitees for the meeting.

Collaborative Programmes

- **MoU with Helmholtz Association, Germany** was signed in April 2015 for cooperation in the field of Earth System Sciences, with the purpose to facilitate understanding and cooperation for activities and programmes in the field of Earth System Sciences. The broad objective of this cooperation is to allow exchange of scientific resources and technical knowledge to support development of programmes in Earth System Sciences. Specific activities include utilising satellite and airborne data for atmospheric research, studies on South Asian monsoon, ship expeditions, oceanographic, meteorological and climate research.

Observational Programmes/Field Campaigns

- **Stalactite sampling**: Stalactite samples were collected from different reserved forest areas of Andaman and Nicobar Islands during 24-31 May 2015. Three stalactite samples were collected from Baratang caves.
- **Observational campaign at Port Blair:** To understand the dynamic behaviour of moisture, IITM completed its observational campaign for

Monsoon 2015. Atmospheric data and vapour samples for isotopic analysis were collected for the period of June - September 2015 at Port Blair, Andaman and Nicobar Islands. In another observational campaign, ground level vapours were collected at the National Institute of Ocean Technology Campus at Port Blair during 25 May to 05 October 2015. Rainwater at various sampling frequencies was also collected.

- **Tree-ring Sampling:** Field expeditions by IITM scientists to the forests of north and northwest Kashmir valley for collecting tree-ring samples were conducted in collaboration with Department of Earth Sciences, University of Kashmir, Srinagar during 24 August to 02 September 2015. More than 100 tree core samples of conifers such as *Pinus, Abies, Cedrus* were collected from high altitude sites (2500 m amsl and above). These collections would be useful addition in the existed tree-ring network from the Himalayas and the central - peninsular India for dendroclimatic studies. Many samples and related data were collected under such difficult situations when trees are located in deep forest and at stiff slopes of the mountain.

- **Observations at Antarctica:** IITM scientists participated in a field campaign for conducting continuous ground-based of trace gases (halogen oxides, oxidised volatile organic compounds and nitrogen dioxide) using a Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) at the Bharati Antarctic Station during 03 November 2015 to 04 March 2016. The MAX-DOAS observations enable constructing a vertical profile of these gases in the lower troposphere, which aid satellite validation. These measurements will be used to understand the reactive atmospheric chemistry processes in Antarctica and help shed light on the emission sources and impacts of climatically important trace gases such as halogen oxides, which result in fast depletion of ozone in the Antarctic troposphere. The campaign was part of 35th Indian Scientific Expedition to Antarctica (35-ISEA) organised by National Centre for Antarctic and Ocean Research (NCAOR), Goa.

- Field work in Ahmednagar district to survey the sites for speleothem samples was conducted on 29 March 2016.

- **Lightning Strikes**: A team of Thunderstorm Dynamics group at IITM visited Nanded district of Maharashtra during 12-14 August 2015 to study the frequent incidences of lightning strikes reported by people of some villages in the district. The spots where lightning struck were inspected and information was collected from the local people who had witnessed such events. The District Collector was advised about the measures needed to be taken to reduce losses due to lightning.

Computer and IT Services

- Beta version of four modules of the Integrated Office Automation Systems (IOAS) is ready for implementation. The remaining modules are under testing.

- The SSL VPN facility for accessing the resources such as ftp-server, network, printers and HPC from outside has been enhanced to the latest system.

Infrastructure Development

Work completed

- Repairs of Director Bungalow; Staircase wall floors, plinth protection and entrance approach at CGMD side of Phase-II Building; and external and internal road work for office campus.

- Interior work of New Delhi Branch Office.

- Chain link fencing work at IITM.

- Renovation of one block of Type-II Quarters, IITM Colony.

- Replacement of paver blocks in front of Phase-II building.

- Development of landscape work of CCCR office building.

- Construction of the Student's hostel Building at IMD, Pune premises *(civil and internal electrical work, interior and furnishing work, procurement of kitchen equipment are in progress)*

Work in progress

- Renovation of one block of Type-II Quarters, IITM Colony.

- Site development work for installation of de-ionisation plant and foundation of water tunnel in Fluid dynamic laboratory.

Science Popularisation Programmes

- **National Science Day:** The Institute celebrated the National Science Day on 27 February 2016 (as 28 February 2016 was a closed holiday) 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. 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 28-29 February 2016. 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. Dr. G. Beig, Dr. R.K. Yadav, Mrs. S. Das, Mr. V.H. Sasane, Ms. Neha Parkhi, Mr. Nikhil Korhale from IITM participated in the exhibition. 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:** The Institute celebrated the World Meteorological Day on 23 March 2015 at its premises in a befitting manner. This year, the theme of the day was 'Hotter, Drier, Wetter: Face the Future'. As a part of the celebration, a public lecture on the topic 'Hotter, Drier and Wetter Earth' by Mr. B. Mukhopadhyay, ADGM(R), IMD, Pune was arranged. On this occasion, competitions on Drawing, Essay Writing, Poster Presentation, Model Presentation and Elocution were arranged where around 60 candidates from different schools and colleges participated. Prizes were distributed to the Winners of the different competitions. The event was organised in association with the Pune Chapter of Indian Meteorological Society, ENVIS Centre at IITM and IMD, Pune.

- **National Pollution Control Day**: The day was celebrated at IITM on 02 December 2015 by organising an awareness event on the theme 'Celebrate with us to protect our planet: a step forward to make our globe clean - green'. As part of the programme, different activities were organised where about 110 students from sixteen different schools in Pune city participated. The event was coordinated by the ENVIS Centre on Acid Rain - Atmospheric Pollution at IITM.

- **India International Trade Fair (IITF)-2015:** The MoES organized an exhibition at IITF-2015 at Pragati Maidan, New Delhi during 14-27 November 2015. Mr. Abhay SD Rajput represented IITM in the MoES exhibition during 23-27 November 2015.

- **Indian International Science Festival (IISF-2015):** IITM participated in the MoES exhibition at the Indian International Science Festival (IISF-2015) held at Indian Institute of Technology (IIT), New Delhi during 04-08 December 2015. Mr. T. Dharmaraj, Dr. A.K. Srivastava, Ms. Chaitri Roy, Mr. Malay Ganai and Dr. D.S. Bisht represented 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 thoughout the year. Such visits were coordinated by Mr. M.D. Chipade, 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 going 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.

Special Days/Weeks Observed

- **Anti-Terrorism Day** was observed on 21 May 2015. On this day, a pledge was administered to the Institute's employees.
- **Sadbhavana Diwas** was observed on 20 August 2015. The theme of Sadbhavana is to promote national integration and communal harmony among people of all religions, languages and regions. The idea behind observance of 'Sadbhavava Diwas' is to eschew violence and to promote goodwill among people.

  Swachh Bharat Abhiyaan: As per the guidelines received by the Ministry of Earth Sciences (MoES) regarding Hon'ble Prime Minister's wish about continuing 'Cleanliness Drive' up to 15 August 2015, the Institute carried out the Swachh Bharat Abhiyann – Cleanliness Drive at its premises during 04-14 August 2015.
- **Vigilance Awareness Week** was observed during 26-31 October 2015 as per the guidelines of Central Vigililance Commission (CVC), Government of India. A pledge on anti-corruption was administrated to the employees of the Institute on 26 October 2015. A slogan completion was arranged on the theme 'Preventive vigilance as a tool of good governance'. The concluding function of the week was organised on 29 October 2015 where Mr. C.G. Kumbhar, IPS (Former DIG) was the Chief Guest. Mr. Kumbhar delivered a lecture on this occasion. Prizes were presented to the winners of the slogan competition.
- **Communal Harmony Campaign Week (Quami Ekta Week)** was observed during 19-25 November 2015. IITM employees took the pledge on Communal Harmony on 23 November 2015.

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 73 journals (64 foreign and 09 Indian) with online access to 64 foreign and 3 Indian journals for the year 2015 (costing approx. Rs. 62.58 lakhs). Subscription 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) 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 Five (35) books covering majority of the Institute's research areas (costing approx. Rs. 1.88 lakhs) were purchased. Payments for paper publications charges/page charges/article processing charges/excess length fee for thirteen papers of the Institute scientists were approx. Rs. 7.44 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 2014-15, 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 11th and 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. Institute participated in National Science Day Celebration of the GMRT at Narayangaon.

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 2015-16, the Governing Council had its 91st and 92nd meetings on 12 August 2015 and 29 January 2016 respectively.

The Institute has been maintaining 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 Organization (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 tenth meeting of the Research Advisory Committee was held during 12-13 January 2016 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 2016

Category	No. of Posts
Research	149
Scientific Support Staff	19
Technical Support Staff	05
Isolated Staff	02
Admin. Support Staff	40
MTS	22
Total	237

Staff Changes

Appointments: Research Staff

- Ms. Aditi Modi, Scientist-B, 20 October 2015.
- Mr. Manmeet Singh, Scientist-B, 20 October 2015.
- Ms. Smruti Gupta, Scientist-B, 20 October 2015.
- Mr. Subrata Mukherjee, Scientist-B, 03 November 2015.
- Mr. Pramit Kumar Deb Burman, Scientist-B, 04 November 2015.
- Mr. Sujit Mali, Scientist-B, 01 January 2016.
- Mr. Ambuj Jha, Scientist-B, 07 January 2016.

Appointments: Administrative Staff

- Mr. V.R. Patil, Senior Manager, 02 February 2016.

Retirement on Superannuation

- Mr. G.M. Jambhale, Senior Executive, 31 May 2015.
- Mr. M.T. Badhe, MTS, 31 May 2015.
- Mr. C.C. Rathod, MTS, 31 May 2015.
- Mrs. Y.K. Bhonde, Assistant Manager, 30 June 2015.
- Mr. S.B. Ghanwat, MTS, 30 September 2015.
- Dr. (Mrs.) Indira Joshi, Scientist-D, 30 September 2015.
- Mr. B.C. Morwal, Technician Grade-F, 30 September 2015.
- Mr. S.S. Mulye, Scientist-C, 31 December 2015.
- Mrs. M.K. Kulkarni, Scientist-D, 31 March 2016.

Resignation

- Mr. Nadiminti P. Kumar, Scientist-B, 07 August 2015.
- Mr. Ketan Kulkarni, Scientist-C, 28 October 2015.
- Dr. M. Rajeevan, Director, 05 December 2015.

Transfer

- Dr. (Mrs.) Resmi E.A., Scientist-C to NCESS, Thiruvanthapuram, 04 January 2016.

Status of SC/ST/OBC/ Reservation as on 31 March 2016:

Category	SC	ST	OBC	Total
Research	13	06	23	42
Scientific Support Staff	05	05	01	11
Technical Support Staff	03	00	00	03
Isolated Staff	00	00	00	00
Administrative Support Staff	04	05	05	14
MTS	07	03	02	12
Total	**32**	**19**	**31**	**82**

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, 9.09% and 4.54% 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 29th and 30th meetings at IITM, Pune on 11 August 2015 and 29 January 2016 respectively. The present Finance Committee is chaired by Prof. V.K. Gaur.

Budget

The grant received and the actual expenditure incurred for the period 2015-16 are as follows (In Crores):

Schemes	Opening Balance	Funds Received	Other Receipts	Total Funds	Total Expenditure	Balance
Total-A						
Advanced Training in Earth System Science - Climate	13.07	8.00	1.29	22.36	14.11	8.25
Centre for Climate Change Research	-1.77	3.73	0.27	2.23	1.80	0.43
High Performance Computer System	63.85	0.00	4.52	68.37	29.44	38.93
IITM Operations - Maintenance	5.88	17.35	0.13	23.36	22.23	1.13
Metropolitan Air Quality - Weather Services	-5.88	16.00	0.63	10.75	10.23	0.52
Monsoon Mission	0.88	27.60	0.06	28.54	22.36	6.18
Physics and Dynamics of Tropical Clould	-1.41	18.00	0.19	16.78	20.52	-3.74
Short Term Climate Prediction - Variability	2.62	5.10	0.04	7.76	4.17	3.59
National Facility for Airborne Research (NFAR)	7.87	0.00	0.38	8.25	0.39	7.86
Total -A	**85.11**	**95.78**	**7.51**	**188.40**	**125.25**	**63.15**
B- Non-Plan	**5.01**	**27.82**	**0.71**	**33.54**	**30.98**	**2.56**
C - Sponsored Projects	**0.41**	**0.66**	**0.00**	**1.07**	**0.74**	**0.33**
Total (A+B+C)	**90.53**	**124.26**	**8.22**	**223.01**	**156.97**	**66.04**

The Auditors appointed by the Governing Council M/s C.R. SAGDEO - Co., Pune conducted the audit for the year 2015-16. 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	62,550,701.75	311,137.05	62,861,838.80
Consumable	7,257,740.00	44,267.00	7,302,007.00
Dead Stock	3,604,044.00	--	3,604,044.00
Total	**73,412,485.75**	**355,404.05**	**73,767,889.80**

Official Language Implementation

- Continuous efforts are being made for compliance of Official Language Policy of the Union.
- Town Official Language Implementation Committee (TOLIC), Pune inspected the Institute on 18 June 2015 to review the use of official language at the Institute.
- Official Language Implementation Committee Meetings was held on 01 May, 14 August, 12 November 2015 and 30 March 2016.
- Hindi Advisory Committee Meeting was held on 11 August 2015.
- Quarterly Progress Reports for the progressive use of Hindi in the Institute the quarters ending on 30 June 2015, 30 September 2015 and 31 December 2015 were prepared and submitted to the Ministry of Home Affairs, Department of Official Language, Navi Mumbai; the Ministry of Earth Sciences; and town Official Language Implementation Committee, Pune.
- A One Day Hindi workshop was organised on 25 June 2015 at the Institute. Dr. Rajbahadur, Senior Hindi Officer, HEMRL, Pune and Dr. Nityanand Singh, Retired scientist 'F', IITM delivered lectures on 'Rajbhasha Niti' and *'Mausam aur Bhartiya Adhyatma'* respectively.
- Another One Day Hindi Workshop was organised on 19 November 2015 at the Institute. A lecture on *'Rajbhasha Hindi ki Disha, Dasha avm Sambhavanayen'* was delivered by Mr. Sunil Keshav Deodhar, Programme Officer, Akashwani, Pune.
- Another One Day Hindi Workshop on the subject *'Paribhashik Shabdavali'* was organised on 25 February 2016 at the Institute. A lecture was delivered by Dr. Rajbahadur, Senior Hindi Officer, HEMRL, Pune.
- **Hindi Week Celebration**: IITM celebrated Hindi Week from 07-14 September 2015. The quiz, essay writing, poem recitation, antakshari, noting and drafting, solo song etc. competitions were organised during the Week. A large number of employees participated in these competitions. An *Akhil Bhartiya Kavi Sammelan* was organised on 11 September 2015 as a part of the celebrations. Renowned poets of national level participated in programme. Hindi Week concluding function and Prize Distribution Programme was organised on 14 September 2015. Dr. Rajkishor Pandey, Scientist 'G' and Associate Director, HEMRL, Pune was the Chief Guest on the occasion.
- In-house Hindi Magazine *'Indradhanush'* special issue on 'National Hindi Scientific Seminar' was released at the hands of Dr. M. Rajeevan, Director, IITM in the Official Language Implementation Committee meeting held on 01 May 2015. *'Indradhanush'* was awarded with a Rajbhasha shield for the 'Excellent Hindi Magazine' at the Hindi Conference and Workshop organised by *Rajbhasha Avam Prabandhan Vikas Sanstha* at Kodaikanal, Tamilnadu during 14-16 May 2015.
- The Institute has been awarded with a Certificate of Appreciation for the Best Performance in Official Language Implementation by Town Official Language Implementation Committee, Pune.
- Department of Official Language, Ministry of Home Affairs, Govt. of India had assigned the responsibility of Town Official Language Implementation Committee-2, Pune to IITM. The Director, IITM and Hindi Officer are the Chairman and Member-Secretary of TOLIC-2 Pune respectively. Central Government offices located in Pune are the Members of this Committee. Institute is responsible to carry out the review of the work related to the Official Language and to conduct two meetings in a year. First half yearly meeting was conducted at the Institute on 08 December 2015.
- Classes for *Pragya* and *Praveen* were conducted by the Hindi Teaching Scheme, Department of Official Langauge, Govt. of India from 06 July 2015 at the Institute. About 40 employees were trained and 29 of them passed the examination successfully.

Awards and Honours

Dr. M. Rajeevan

- Chairman, Satellite Study Team for Meteorology, ISRO.

Dr. R. Krishnan

- Member, Indian Delegation led by Honourable Minister of Earth Sciences, 17th World Meteorological Congress, Geneva, Switzerland, 01-04 June 2015.

Dr. G. Beig

- Member, WCRP Core-Project for Stratosphere-Troposphere Processes and their Role in Climate for an initial term of three years (January 2016 onwards).

Dr. S. Chakraborty

- Resource person in the International Earth Science Olympiad, Department of Geology, Anna University, Chennai, 13-31 May 2015.
- Organising Secretary, International Conference 'Asiaflux-2015' on Challenges and Significance of Ecosystem Research in Asia to Better Understand Climate Change, IITM, Pune, 22-29 November 2015.
- Chair, Inaugural Session, International Conference 'Asiaflux-2015' on Challenges and Significance of Ecosystem Research in Asia to Better Understand Climate Change, IITM, Pune, 22-29 November 2015.

Dr. Thara Prabhakaran

- Chaired a session on 'Observational aspects of ecosystem response to rainfall variability in monsoon regime', Challenges and Significance of Ecosystem Research in Asia to Better Understand Climate Change – a joint conference of the AsiaFlux Workshop 2015 and ISPRS TC WG VIII/3: Weather, Atmosphere and Climate StudiesWeather, Atmosphere and Climate Studies, IITM, Pune, India, 22-29 November 2015.
- Member, WMO Expert Team on Weather Modification since January 2016.

Dr. G. Pandithurai

- Member, Satellite Study Team for Meteorology, ISRO.
- Chaired a session 'SKYNET Applications for air pollution studies', IV International SKYNET workshop, Rome, Italy, 02-04 March 2016.

Dr. (Mrs.) S.S. Fadnavis

- Member, Scientific Steering Group (SSG) for 'Stratospheric Sulfur and its role in Climate' programme of 'Stratosphere-troposphere Processes And their Role in Climate (SPARC)'.
- Chaired a session 'Convection - Upper troposphere and Lower stratosphere (UT/LS)', Atmospheric Composition And The Asian Summer Monsoon (ACAM) Workshop, 06-10 June 2015, Bangkok, Thailand.

Dr. P. Mukhopadhyay

- Received the Ministry of Earth Sciences (MoES) Certificate of Merit for the year 2015 for his outstanding contribution in the field of Atmospheric Science and Technology.

Dr. (Mrs.) B. Padmakumari

- Member, Satellite Study Team for Atmospheric Sciences, ISRO.

Dr. Milind Mujumdar

- Chief Guest for the Science, Art and Craft Exhibition at Acharya Shree Vijay Vallabh School, Pune on 26 February 2016.

Dr. Vinu Valsala

- Elected as Indian National Young Academy of Science Fellow (INYAS) for the period of 2016 to 2020 by the Indian National Science Academy (INSA).

Dr. Anoop Mahajan

- Kavli Foundation Fellow of the National Academy of Sciences (NAS), U.S.

Dr. Roxy Mathew Koll

- Kavli Foundation Fellow of the National Academy of Sciences (NAS), U.S.

- Outstanding Reviewer Award by Elsevier in recognition of contributions as a reviewer for the journal Deep-Sea Research, May 2015.
- Co-convener of Ocean Science Session 'Understanding Climate Change and Variability Using State of the Art Climate Models', Asia Oceania Geosciences Society (AOGS) 2015 Conference, Singapore, 02-07 August 2015.
- Member, CLIVAR Indian Ocean Region Panel for the period 2016-2018.

Dr. A.K. Srivastava

- Alexander von Humboldt Foundation Fellowship of Germany (CONNECT Follow-up) for working visit at the Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany.
- Member, Organising Committee, 5th International Conference on Earth Science - Climate Change (Earth Science-2016), Bangkok, Thailand, 25-27 July 2016.

Dr. (Mrs.) A.A. Prabhu

- Postdoctoral Fellow, Climate System Research Group at Pukyong National University, Busan, South Korea, 01 January 2016 to 31 December 2016.

Dr. Kaustav Chakravarty

- Co-Convenor, Annual Monsoon Workshop-2015 and National Symposium on Understanding and Forecasting the Monsoon Extremes, 23-24 February 2016.

Dr. Abhilash Panicker

- Young Associate Award by International Center for Theoretical Physics (ICTP), Italy for the period 2016-2021 for research in the field of aerosols.

Ms. Chaitri Roy

- Best Poster Award at the 'National Climate Science Conference', Divecha Centre for Climate Change Indian Institute of Science, Bengaluru, 02-03 July 2015.

Ms. Shikha Singh

- Best Poster Award at the 'National Climate Science Conference', Divecha Centre for Climate Change Indian Institute of Science, Bengaluru, 02-03 July 2015.

Dr. Deewan Singh Bisht, Dr. Omkar Nath Shukla, Mr. Dilip E. Shinde and Mr G.E. Dhongade

- MoES Annual Award for Best Employees for the year 2015 under the category 'Group B', 'Group B', 'Group C' and 'Multi Tasking Staff' respectively.

Dr. Rokkam R. Rao

- Member, Project Advisory Board of Ocean Acoustics programme of NIOT, Chennai.
- Member, Board of Studies, Department of Meteorology and Oceanography, Andhra University, Vishakhapatnam.
- Member, Governing Council of INCOIS, Hyderabad.
- Member, Ocean Observing System Project Review Board of NIOT, Chennai.

Dr. R.H. Kripalani

- Main convener, Atmospheric Science Session 'Monsoon Climates over South, East and Southeast Asia' at the Asia-Oceania Geosciences Society 2015, Singapore, 02-07 August 2015.

Ms. Aditi Deshpande, SRF

- Best Student (oral) Presentation Award for the paper entitled 'Equatorial Indian Ocean subsurface current variability and its role on strengthening Indian Summer Monsoon' with C. Gnanaseelan at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Mr. Raju Attada, IITM RA

- Best Poster Award at Glace India 'Workshop on Identifying Climate Change Information Needs and Training on Climate modeling and Climate Change Research, Innovation and Service', Jawaharlal Nehru University, New Delhi, 09-10 April 2015.

Mr. Mahesh Kalshetti, M.Tech. Student

- Best Poster Award for his paper 'Characteristics of clouds and precipitation in and around Mahabaleshwar during the active and break phase of Indian Summer Monsoon by using cloud radar' with G. Pandithurai and K. Chakravarty at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Mr. G. Srinivas, IITM RF

- Best Student Poster Award for his paper 'Surface and Subsurface temperature biases Over the Indo-

Pacific Ocean in CFSv2 during summer monsoon' with J.S. Chowdary, C. Gnanaseelan and Anant Parekh at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Ms. Saranya Ganesh S., IITM RF

- First Prize for the oral presentation of her paper entitled 'Cyclogenesis prediction over North Indian Ocean using an Ensemble Prediction system' with S. Abhilash, A.K. Sahai, S. Joseph, and R. Chattopadhyay at IMSP Annual Workshop: Monsoon-2015, IITM Pune, 23-24 February 2016.

Mr. Vimal Koul, M.Tech. Student

- Best Student (Oral) Presentation Award for his paper 'Seasonal Prediction of Indian Summer Monsoon in the NCEP CFSv2: Role of Ocean Initial Conditions' with Anant Parekh, G. Srinivas, Rashmi Khandekar, J.S. Chowdary and C. Gnanaseelan at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Ms. C. Roja, M.Tech. Project Intern

- Best Student Presentation Award for her paper 'The dynamical linkage between the south Asian monsoon extremes and large scale circulation over the Indo-Pacific region' with M. Majumdar, K.P. Sooraj and P. Bhaskar at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Mr. Vivek Shilimkar, M.Sc. Student

- Awarded prestigious Japanese Government Monbukagakusho MEXT Scholarship (2015-2018), September 2015.

Ms. Aditi Rathod, M.Sc. Student

- Best Student (Poster) Presentation Award for her paper 'Radiative forcing of carbonaceous aerosols over two urban environments in Northern India' with Abhilash. Panicker, Kaushar Ali and Gufran Beig at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Mr. Soumojit Bose, M.E. Project Intern

- Best Poster Award for his paper 'Application of Radar Derived kinematics for Monsoon Intra-Seasonal Variability' with M.C.R. Kalapureddy at IMSP Annual Workshop: Monsoon 2015, IITM Pune, 23-24 February 2016.

Visitors

International

- **Dr. David Delene**, Research Assoc. Professor, Atmospheric Sciences Department, University of North Dakota/Kyathi Climate Modification Consultants (KCMC), **USA**, 09-17 June 2015 and 28-30 March 2016.
- **Dr. Hamada Jun-Ichi** and **Dr. Jun Matsumoto**, Tokyo Metropolitan University, **Japan**, 30 July 2015.
- **Dr. Taiichi Hayashi**, Kyoto University, **Japan**, 30 July 2015.
- **Dr. Toru Terao**, Kagawa University, **Japan**, 30 July 2015.
- **Prof. V. Chandrasekar**, Distinguished Professor, Colorado State University, **USA**, 21-22 August 2015.
- **Dr. Chulkyu Lee**, Climate Change Monitoring Division, Korea Meteorological Administration (KMA), Seoul, **South Korea**, 22 September 2015.
- **Prof. Hugh Coe**, University of Manchester, **UK**, 22 September 2015.
- **Dr. J. Vivekanandan**, Senior Scientist, NCAR, **USA**, 27-29 September 2015.
- **Dr. John McGregor**, Retirement Fellow, CSIRO Oceans and Atmosphere, **Australia**, 29 October – 03 November 2015.
- **Dr. Duncan Axisa**, Research Application Laboratory (RAL), NCAR, **USA**, 01-07 November 2015.
- **Dr. Andrei Sinkevich**, Main Scientist, Department of Cloud Physics and Atmospheric Electricity, A.I. Voeikov Main Geophysical Observatory, St Petersburg, **Russia**, 01-04 November 2015.
- **Dr. Martin Schultz**, Head of Group Global Atmospheric Modeling, Institute of Energy and Climate Research, Research Center Jülich, **Germany**, 04-09 November 2015.
- **Prof. Olivier Pauluis**, New York University, **Abu Dhabi**, 06-14 November 2015.
- **Dr. Yushi Morioka**, Japan Agency for Marine-Earth Science Technology, **Japan**, 22-29 November 2015.
- **Dr. Holger Mahlke**, Karlsruhe Institute of Technology (KIT), **Germany**, 01 December 2015.
- **Prof. Wojciech W. Grabowski**, Senior Scientist, NCAR, **USA**, 17-30 January 2016.
- **Dr. Mona Behl**, Associate Director, The Georgia Sea Grant College Program, University of Georgia, **USA**, 20 January 2016.
- **Mr. Phil Croateau**, Aerodyne, Massachusetts, **USA**, 19-22 January 2016.
- **Prof. Mike Wallace**, University of Washington, **USA**, 21-22 January 2016.
- **Prof. Jagadish Shukla**, University Professor, George Mason University (GMU) - Center for Ocean-Land-Atmosphere Studies (COLA), **USA**, 11-13 February 2016.
- **Dr. Mitchell W. Moncrieff**, Senior Scientist from National Centre for Atmospheric Research (NCAR), **USA**, 22-26 February 2016. He also visited HACPL on 26 February 2016.
- **Prof. Jun Matsumoto**, Dr. Tomoshige Inoue and Prof. Hamada Jun-Ichi, Tokyo Metropolitan University, **Japan**, 14-19 March 2016.
- **Prof. Atul K. Jain**, Department of Atmospheric Sciences University of Illinois, Urbana, **USA**, 21-22 March 2016.

National

- **Prof. B.V. Rathish Kumar**, Professor, Indian Institute of Technology Kanpur, 11 May 2015.
- **Dr. Swaroop Sahoo**, Asst. Professor, Kalinga Institute of Industrial Technology, Odisha, 21-26 May 2015.
- **Dr. G.D. Bairagi**, Principal Scientist and Head, Agriculture and Soils Division, Remote Sensing Applications Centre, M.P. Council of Science - Technology, Bhopal, 28 May 2015.

- **Dr. Jagvir Singh**, Scientist-D, Ministry of Earth Science (MoES), 30 May 2015.
- **Prof. R.K. Mall**, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, 14 May and 02-04 June 2015.
- **Prof. T.S. Pranesha**, Prof. and Head, Department of Physics, BMS College of Engineering, Bengaluru, 16 June 2015.
- **Dr. G. Mrudula**, NAL, Bengaluru, 21-26 July 2015.
- **Prof. U.R. Rao**, Ex-Chairman, Indian Space Research Organisation (ISRO) and Ex-Chairman, IITM Governing Council, 24-26 July 2015.
- **Dr. Chandra Bhushan**, Deputy Director General, Centre for Science and Environment, New Delhi, 29 July 2015.
- **Mr. Srikanth** and **Mr. Dharmadas**, National Centre for Earth Science Studies (NCESS), Trivandrum, 29 September - 14 October 2015.
- **Dr. S. Raghavan**, Deputy Director-General of Meteorology (Retired), India Meteorological Department (IMD), 28 October 2015.
- **Mr. Krishna Chand**, Astra Microwave Ltd., Hyderabad, 19-20 October 2015.
- **Dr. Srikanth Nadadur**, Embassy Science Fellow, National Institute of Environmental Health Sciences (NIEHS), US Embassy, New Delhi, 16 November 2015.
- **Dr. Amir Bazaz**, IIHS, Bengluru, 26 November 2015.
- **Dr. S.B. Thampi**, Scientist-F, Regional Meteorological Centre, Chennai, 9-10 September 2015.
- **Dr. Sandip Pattanaik**, Asst. Prof., Department of Earth Science, Indian Institute of Technology (IIT) Bhubaneshwar along with his 14 students, 09 December 2015.
- **Dr. Anil Kumar**, Group Director, Southern Ocean Group, NCAOR, Goa, 25-26 January 2016.
- **Dr. Harsh Vardhan**, Union Minister for Ministry of Science - Technology and Ministry of Earth Sciences (MoES), **Dr. M. Rajeevan**, Secretary, MoES, **Dr. Shailesh Nayak**, Former Secretary, MoES and **Dr R.R. Kelkar**, Former Director General, IMD, 01 February 2016.
- **Dr Sami Ullah Bhat, Assistant Professor, 2 faculty members and a student group**, Department of Environmental Science, University of Kashmir, Srinagar, 18 February 2016.
- **Prof. V. Venugopal**, Associate Professor, Centre for Atmospheric and Oceanic Sciences (CAOS), Indian Institute of Science (IISc), Bengaluru, 22-26 February 2016.
- **Dr. Srinivasa Ramanujam**, Assistant Professor, School of Mechanical Sciences, Indian Institute of Technology (IIT) Bhubaneswar, 23-27 February 2016.
- **Mr. Aninda Bose**, Senior Editor - Hard Sciences, Springer (India) Private Ltd., New Delhi, 09 March 2016.
- **Dr. Joy Merwin Monteiro**, Indian Institute of Science (IISc), Bengaluru, 21 March 2016.

Visitors to HACPL, Mahabaleshwar/RADAR Site, Mandhardev

- **Dr. Shailesh Nayak**, Secretary, MoES, New Delhi, 17 April 2015.
- **Prof. D.R. Sikka**, Former Director, IITM, 13 May 2015.
- **Journalists**, Press Association, Pune, 20 May 2015.
- **Dr. Jagvir Singh**, Scientist-D, MoES, 30 May 2015.
- **Mr. Abhishek, Mr. Vishnu Patil** and **Mr. Budhisagar Kharat** (engineers), SAMEER, Mumbai, 10 June 2015.
- **Prof. V.K. Gaur**, Chairman, Governing Council - Finance Committee, IITM and, Honorary Emeritus Scientist, CSIR, Fourth Paradigm Institute, Bengaluru, 13-14 August 2015.
- **Participants**, AsiaFlux-2015 Workshop, 28 November 2015.

Seminars

By Visitors

Prof. B.V. Rathish Kumar, Professor, Indian Institute of Technology Kanpur

- An overview of WEBS-FEM in modelling and simulation, 11 May 2015.

Prof. T.S. Pranesha, Prof. and Head, Department of Physics, BMS College of Engineering, Bengaluru

- Quantum computation – An introduction, 16 June 2015.

Dr. Chulkyu Lee, Climate Change Monitoring Division, Korea Meteorological Administration (KMA), Seoul, South Korea

- Global atmospheric watch activities in Korea, 22 September 2015.

Prof. Hugh Coe, University of Manchester, UK

- Ground and aircraft observations of aerosols and aerosol-cloud interactions, 22 September 2015.

Dr. S. Raghavan, Deputy Director-General of Meteorology (Retired), India Meteorological Department (IMD)

- Physics, Meteorology and the Social Sciences, 28 October 2015.

Dr. John McGregor, Retirement Fellow, CSIRO Oceans and Atmosphere, Australia

- Development and application of cubed-sphere models at CSIRO, 30 October 2015.

Dr. A.A. Sinkevich, Main Scientist, Main Geophysical Observatory, St. Petersburg, Russia

- Assessment of cloud seeding results, 02 November 2015.
- Atmospheric Electricity Measurements in Russia, 04 November 2015.

Dr. Martin Schultz, Head of Group Global Atmospheric Modeling, Insittute of Energy and Climate Research, Jülich, Germany

- Global surface ozone observations and analyses: Insights from the WMO Global Atmosphere Watch Programme and the Tropospheric Ozone Assessment Report, 06 November 2015.

Prof. Olivier Pauluis, Professor, Courant Institute of Mathematical Sciences and co-PI at the Center for Prototype Climate Modeling at New York University, Abu Dhabi

- The atmospheric heat engine – for general audience, 12 November 2015.
- Isentropic analysis of convective motions, 13 November 2015.

Dr. Yushi Morioka, Japan Agency for Marine-Earth Science Technology (JAMEST)

- Interannual-decadal climate variability in the southern Indian Ocean, 26 November 2015.

Dr. Holger Mahlke, Karlsruhe Institute of Technology (KIT), Germany

- Influence of orography on deep convection initiation in Central Europe, 01 December 2015.

Dr. Harry Hendon, Senior Scientist, BMRC, CAWCR, Melbourne, Australia (*IITM RAC Member*)

- Impact of QBO on the predictability of MJO, 11 January 2016.

Prof. Wojciech W. Grabowski, Senior Scientist, NCAR, **USA**

- Untangling microphysical impacts on deep convection applying piggybacking methodology, 28 January 2016.

Dr. Srinivasa Ramanujam, Assistant Professor, Indian Institute of Technology (IIT), Bhubaneswar

- A methodology to combine numerical model simulation with 'active-passive combine' observations for geophysical parameter retrievals, 26 February 2016.

Mr. Aninda Bose, Senior Editor - Hard Sciences, Springer (India) Private Ltd., New Delhi

- The Elements of Scientific Publishing, 09 March 2016.

Prof. Jun Matsumoto, Tokyo Metropolitan University, Japan

- MAHASRI 10-year activity and beyond, 16 March 2016.

Dr. Tomoshige Inoue Tokyo Metropolitan University, Japan

- Characteristics of summer monsoon rainfall associated with the 2011 Chao Phraya River flood in Thailand, 16 March 2016.

Prof. Atul K. Jain, Department of Atmospheric Sciences University of Illinois, Urbana, USA

- Integrated assessment modeling of bio-geochemical cycles, climate change and impacts, 22 March 2016.

Internal Discussions Seminars

Dr. C. Gnanaseelan

- Oceanic Features during the 2015 monsoon onset phase, 1st IITM Monsoon Discussion Forum, 20 May 2015.

Dr. Hamza Varikoden

- Large scale features of monsoon 2015, 1st IITM Monsoon Discussion Forum, 20 May 2015.

Dr. S. Joseph

- Extended Range Prediction of the Onset and Initial progression phase of 2015 monsoon, 1st IITM Monsoon Discussion Forum, 20 May 2015.

Mr. S.P. Ghanekar

- Synoptic Scale Features associated with the Onset Phase of Monsoon 2015, 1st IITM Monsoon Discussion Forum, 20 May 2015.

Ms. Resmi E.A.

- Observational features prior to the onset of summer monsoon, 1st IITM Monsoon Discussion Forum, 20 May 2015.

Mr. Ankur Srivastava

- CFSv2 T382 Seasonal Forecast, 1st IITM Monsoon Discussion Forum, 20 May 2015.
- CFSv2 T382 Seasonal Forecast, 4th IITM Monsoon Discussion Forum, 10 September 2015.

Dr. (Mrs.) Thara Prabhakaran

- Challenges in linking cloud microphysics observations with numerical models and recent developments with CAIPEEX, 12 June 2015.
- Progress and future evolution, 3rd IITM Monsoon discussion, 04 August 2015.

Mr. Bhupendra Bahadur Singh

- Large scale features: Progress of the Monsoon, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Dr. (Mrs.) Medha Deshpande

- Synoptic Scale Features associated with the ONSET and advance of Monsoon 2015, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Mr. Subharthi Chowdhuri

- Observational features as obtained from the High Altitude Cloud Physics Laboratory, Mahabaleshwar, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Dr. (Mrs.) Savita B. Morwal

- Extremely Heavy Rainfall over Mumbai on 19 June 2015 and associated convection as seen through Radar, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Dr. (Mrs.) Swapna Panickal

- Second IITM Monsoon Discussion Progress and future evolution Oceanic features, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Mr. Avijet Dey

- Extended Range Prediction, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Mr. Maheswar Pradhan

- CFSv2 T382 Seasonal Forecast, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

D. S. Pai, IMD, Pune

- Status of 2015 SW Monsoon Rainfall, 2nd IITM Monsoon Discussion Forum, 25 June 2015.

Mr. Malay Ganai

- Synoptic Scale Features associated with the advance of Monsoon 2015, 3rd IITM Monsoon Discussion Forum, 04 August 2015.

Dr. Sooraj K.P.

- Current progress and evolution: Large Scale features, 3rd IITM Monsoon Discussion Forum, 04 August 2015.

Dr. Sreenivas Pentakota

- Progress and future evolution: Oceanic features, 3rd IITM Monsoon Discussion Forum, 04 August 2015.

Mr. Raju Mandal

- Extended Range Prediction and verification of progression of the Indian Summer Monsoon 2015, 3rd IITM Monsoon Discussion Forum, 04 August 2015.

Dr. Rajib Chattopadhyay

- Perspective from Seasonal Forecasting Group, 3rd IITM Monsoon Discussion Forum, 04 August 2015.

Ms. Snehlata Tirkey

- Synoptic Scale Features Associated with the Advance of Monsoon 2015, 4th IITM Monsoon Discussion Forum, 10 September 2015.

Dr. Manish K. Joshi

- Large Scale features: Current Progress and Evolution, 4th IITM Monsoon Discussion Forum, 10 September 2015.

Mrs. Rashmi A. Khandekar

- Performance and Progress: Oceanic features, 4th IITM Monsoon Discussion: Performance and Progress, 10 September 2015.

Mr. Balaji B.

- Observational features of monsoon, 4th IITM Monsoon Discussion Forum, 10 September 2015.

Ms. Shilpa Malviya

- Extreme rainfall event over south-west M.P., 4th IITM Monsoon Discussion Forum, 10 September 2015.

Dr. Abhilash S.

- Extended Range prediction of Monsoon 2015: Performance and Outlook, 4th IITM Monsoon Discussion Forum, 10 September 2015.

Dr. P. Mukhopadhyay

- Synoptic Features, 5th IITM Monsoon Discussion Forum, 12 October 2015

Dr. M. Rajeevan

- Large Scale Features of the 2015 Monsoon, 5th IITM Monsoon Discussion Forum, 12 October 2015.

Dr. Anant Parekh

- Withdrawal and seasonal performance: Oceanic Features, 5th IITM Monsoon Discussion Forum, 12 October 2015.

Mrs. Mercy Varghese

- Observational features of monsoon 2015 during withdrawal, 5th IITM Monsoon Discussion Forum, 12 October 2015.

Dr. A.K. Sahai

- Performance and Skill of the Extended Range prediction During Monsoon 2015, 5th IITM Monsoon Discussion Forum, 12 October 2015.

Dr. Suryachandra A. Rao

- CFSv2 T382 Seasonal Forecast and its Verification, 5th IITM Monsoon Discussion Forum, 12 October 2015.

IITM Colloquium

Dr. Roxy Mathew Koll

- Indian Ocean warming – its extent, and impact on the Monsoon and Marine Productivity, 29 April 2015.

Ms. Sharmila Sur

- Future Extreme Monsoon Variability under climate change, 29 April 2015.

Dr. (Mrs.) Sushmitha Joseph

- Development and evaluation of an objective criterion for the real-time prediction of Indian summer monsoon onset in a coupled model framework, 15 May 2015.

Ms. Soumi Chakravorty

- Understanding the basin scale interannual warming of the Indian Ocean and its regional impacts, 29 May 2015.

Dr. (Mrs.) Thara Prabhakaran

- Challenges in linking cloud microphysics observations with numerical models and recent developments with CAIPEEX, 12 June 2015.

Dr. J. Sanjay

- Regional Climate Downscaling over South Asia-CORDEX Initiative, 14 July 2015.

Dr. Toru Terao, Kagawa University

- Heating mechanisms of sea surface temperatures over tropical oceans after El Nino, 30 July 2015

Dr. Hamada Jun-Ichi, Tokyo Metropolitan University

- Interannual rainfall variability over northwestern Jawa, Indonesia and its relation to ENSO and Asian winter monsoon, 30 July 2015.

Dr. Taiichi Hayashi, Kyoto University

- Comparison of rain gauges in heavy rainfall condition, 30 July 2015.

Dr. Jun Matsumoto, Tokyo Metropolitan University

- Rainfall, flood and rice production in the Ganges-Brahmaputra River Basins, 30 July 2015.

Prof. R. Murtugudde, Professor and CBFS Executive Director, CMNS-Atmospheric - Oceanic Science University of Maryland, USA (also, Visiting Faculty at IISER, Pune)

- ENSO Diversity, Asymmetry and Extremes: A Unifying High-Frequency Driver, 20 October 2015.
- A Multi-Scale Interaction in the Indian Ocean at Sub-seasonal to Multi-Decadal Timescales. 27 October 2015.

Prof. Sulochana Gadgil

- El Nino and the Indian rainfall in June, 16 December 2015.

Dr. P. Mukhopadhyay

- An attempt to correct the archive of History of Cyclone regarding Bombay Cyclone of 6 June 1882, 16 December 2015.

Dr. Suhas E., JPL, Pasadena, USA

- Convective parameterisation: Current status and future scope, 18 December 2015.

Mr. Amey Pathak, Research Fellow, Department of Civil Engineering, Indian Institute of Technology Bombay

- Understanding the impact of atmospheric moisture transport on Indian summer monsoon rainfall, 23 December 2015.

Mr. Suyash Bire, Research Fellow, SOMAS, Stony Brook University, New York, USA

- Complexities of Eastern Boundary Current Systems, 23 December 2015.

Prof. Wojciech W. Grabowski, Senior Scientist, NCAR, USA

- Towards global large eddy simulation: super-parameterization revisited, 25 January 2016.

Prof. Mike Wallace, University of Washington

- The MJO, the MISO and the Pacific-Japan pattern, 21 January 2016.
- The MJO: Phase velocity, group velocity and teleconnections, 21 January 2016.

Dr. Mitchell Moncrieff, Distinguished Scientist, Climate and Global Dynamics Laboratory, Atmospheric Modeling and Predictability group, NCAR, UCAR

- Organised Tropical Convection in a Near-Saturated Environment, 25 February 2016.
- Organised Convection, Tropical Wave, and MJO Interaction, 26 February 2016.

Prof. Joy M. Monteiro, IISc, Bengaluru

- Upper level structure of the MJO, 21 March 2016.

Seminar on PhD Synopsis

Mr. M.V.S. Ramarao

- Land surface hydrological response over the Indian monsoon region under changing climate, 24 September 2015.

Ms. Madhura Ranade

- High resolution modeling of winter-time weather and climate processes over western Himalayas under a changing climate, 30 November 2015.

Mr. Harikishan Gandham

- Study of cloud macro and micro physical properties and their response to aerosol from insitu and remote sensing techniques, 30 November 2015.

Mrs. Priya P.

- Modelling studies on hydro-meteorological response of Indus river basin to heavy monsoon rain events under changing climate, 25 January 2016.

Mrs. Preeti Bhaskar

- Variability and teleconnections of South and East Asian summer monsoons in a warming environment, 25 February 2016.

Mrs. Shamal Manas Marathe

- Linear and non-linear evolution and interannual variability of sea surface temperature in the tropical Pacific, 31 March 2016.

Lectures Delivered Outside

Dr. R. Krishnan

- High resolution simulations of the South Asian monsoon under changing climate, Physical Research Laboratory, Ahmedabad, 11 June 2015.
- Deciphering the desiccation trend of the South Asian monsoon in a warming climate, Department of Meteorology, University of Reading, UK, 06-10 November 2015.
- IITM Earth System Modeling, Advanced Refresher Course, Meteorological Training Institute, IMD, Pune, 24 August 2015.
- IITM Earth System Model for investigating Long Term Climate Variability and change, Sardar Patel University, Gujarat, 04 March 2016.

Dr A.K. Sahai

- The challenge of summer monsoon prediction in the Extended Range: Where do we stand? Climate Seminar Series, IIT-Bombay, Mumbai, 25 March 2015.

Dr. A. Suryachandra Rao

- Ocean Dynamics, University Center for Earth and Space Sciences (UCESS), University of Hyderabad, Hyderabad, 01-04 April 2015. (*series of lectures*)
- Ocean Atmosphere Interactions, University Center for Earth and Space Sciences (UCESS), University of Hyderabad, Hyderabad, 29 July - 01 August 2015 and 27-31 October 2015. (*series of lectures*)
- Seasonal prediction of Indian summer monsoon, Centre for Atmospheric and Oceanic Sciences (CAOS), Indian Institute of Sciences, Bengaluru, 8-10 June 2015.

Dr. C. Gnanaseelan

- Modelling the ocean processes, SERB School, Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, 27-28 May 2015.
- Changing patterns of ocean dynamics and their impact on Indian Ocean warming, Indian Institute of Space Science and Technology, Trivandrum, 18 August 2015.
- Physical Oceanography, Forecasters Training Course, IMD Pune, May to September 2015 *(series of lectures)*.

Dr. (Ms.) Thara Prabhakaran

- Aerosol cloud interaction in Indian context, TIFR Centre for Interdisciplinary Sciences, Hyderabad, 05 May 2015.
- CAIPEEX, Advanced Meteorological Training Course (Batch No. 175), Meteorological Training Institute, IMD, Pune, 05 August 2015.

Dr. H.P. Borgaonkar

- Palaeoclimatology, Forecasters Training Course, Meteorological Training Institute, IMD, Pune, 12 October 2015.
- Climate from Tree-ring: Indian Perspective, Department of Earth Sciences, Kashmir University, Srinagar, 25 August 2015.

Dr. S.D. Pawar

- Atmospheric Electricity, IMD's Trainees Met-II Course, Batch-21, February 2016 (*05 lectures*).

Dr. S. Chakraborty

- Palaeo-Climatology, Forecasters Training Course of Batch No. 183 of Gr. B Departmental Officers of IMD, Meteorological Training Institute, Pune, 17 February 2016.
- Earth System Science – Atmosphere, International Earth Science Olympiad, Department of Geology, Anna University, Chennai, 16-17 May 2015 (***05** lectures*).

Dr. (Mrs.) Ashwini Kulkarni

- Statistical techniques in Atmospheric and Ocean Sciences, Qatar Meteorological Department, Doha, Qatar, 25 October - 05 November 2015 (*20 lectures and 20 Hands-on sessions*).

Dr. Suresh Tiwari

- Assessment of carbonaceous aerosols over northern part of India: Mass level and its impact on regional climate, Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden, 13 October 2015.

Dr (Mrs.) S.K. Patwardhan

- Basic ideas on Bioclimatology and Applied Climatology, Forecasters Training Course, Meteorological Training Institute, IMD, Pune, 14 October 2015.

Dr. D.M. Chate

- A series of 12 lectures on *v*arious Atmospheric compositions and Chemistry topics, Centre for Earth and Space Sciences, University of Hyderabad, 03-08 September 2015.
- Environmental impact assessments for health effect and crop damage by air pollution, Department of Environment Sciences, Refresher Course of Assistant Professors, S.P. Pune University, 09 October 2015 (*two lectures*).

Dr. P. Mukhopadhyay

- Challenges of representing realistic cloud and convection in a climate forecast model for improved simulation of tropical intraseasonal oscillation, Department of Mathematics and Statistics, University of Victoria, Victoria, Canada, 21 April 2015.

Dr. Vinu Valsala

- Computer programming and applications, Advanced Meteorological Training Course, India Meteorology Department, Pune, 25-29 May 2015.
- Elective course in Earth System Sciences and Biogeochemistry, University Centre for Earth and Space Sciences, University of Hyderabad, Hyderabad, 11-13 February 2016 *(series of 8 lectures)*.

Dr. Shivsai Dixit

- Thermodynamics, MKSSS's Cummins College of Engineering for Women, Pune, 02 September 2015.

Dr. Roxy Mathew Koll

- Role of ocean on climate, Met.Gr. II Training Course, Meteorological Training Institute, IMD, Pune, 10 July 2015.
- Ocean warming and its impact on the marine productivity in the Arabian Sea, New York University, Abu Dhabi, UAE, 15 November 2015.
- Interplay between the Indian Ocean, ENSO and the Monsoon in a warming environment, International Centre for Theoretical Physics (ICTP), Trieste, Italy, 19 November 2015.
- Rapid warming in the Indian Ocean and its impact on the monsoon and the marine productivity, Euro-Mediterranean Centre on Climate Change (CMCC), Bologna, Italy, 20 November 2015.
- Indian Ocean warming - the cause and effect, Indian Institute of Technology-Bombay, Mumbai, 09 September 2015.

Dr. Y.K. Tiwari

- Greenhouse gases monitoring and modeling, what we do, why we do, Uka Tarsadia University, Surat, 27 December 2015.

Dr. Swapna P.

- The IITM Earth System Model, Brazilian Earth System Model (BESM) Summer School, INPE-CPTEC, Cachoeira Paulista, Brazil, 27-28 August 2015.

Dr. A.K. Srivastava

- Atmospheric aerosol measurements and its impact assessment - IITM perspective, Leibniz Institute for

Tropospheric Research (TROPOS), Leipzig, Germany, 11 June 2015.

- Heterogeneity in aerosol characteristics over the Indo-Gangetic Basin: implications to optical and associated radiative forcing", Institute of Environment and Sustainable Development (IESD), Banaras Hindu University, Varanasi, 14 August 2015.
- Pollution Monitoring Instrumentations for Ozone and Other Pollutants, CPCB training programme, TERI University, 04 January 2016.

Dr. R.K. Yadav

- A lecture in the Refresher course in Climate Change, UGC-Human Resource Development Centre, University of Allahabad, 26 February - 17 March 2016.

Dr. N. Gandhi

- Palaeo-Climatology, Forecasters Training Course of Batch No. 183 of Gr. B Departmental Officers of IMD, Meteorological Training Institute, Pune, 18 February 2016.

Dr. J.S. Chowdary

- Physical Oceanography and air-sea interactions, Forecasters Training Course, IMD, New Delhi 13-14 January 2016 and 27 January – 02 February 2016 *(series of lectures)*.
- Physical Oceanography, Met. Gr. II Course Batch No. 21 (Semester II), IMD, Pune, 10 November – 16 December 2015 *(series of lectures)*.
- Physical Oceanography and air-sea interactions, Forecasters Training Course, Batch No. 182, IMD, Pune, 11 January – 01 April 2016 *(series of lectures)*.

Dr. R.H. Kripalani

- South Asian Summer Monsoon and Relation between South and East Asian Monsoon, Nanjing University of Information Science and Technology (NUIST), Nanjing, China, 12-18 October 2015 (*03 lectures*).
- Statistical Applications in oceanic and atmospheric sciences, Meteorologist Grade-II Trainees Batch 21 and 22, India Meteorological Department, May-June 2015 and October 2015-January 2016.

Deputation Abroad

Dr. M. Rajeevan

- Workshop on 'Intraseasonal to Seasonal climate Variations and Predictions', JAMSTEC, **Japan**, 01-05 September 2015.

Dr. R. Krishnan

- INDNOR collaborative Workshop on the project 'Climate Change and its Impacts on the selected Indian Hydrological System using Earth System and High Resolution Modeling, Bergen, **Norway**, 02-07 May 2015.
- Member, Delegation led by the Hon'ble Minister of Earth Sciences, Govt. of India to 17th World Meteorological Congress, Geneva, **Switzerland**, 30 May - 06 June 2015
- Workshop on 'Intraseasonal to Seasonal climate Variations and Predictions', JAMSTEC, **Japan**, 01-05 September 2015.
- Workshop on 'Sub-Seasonal Predictability', European Centre for Medium Range Weather Forecasting (ECMWF), Reading University, Reading, **UK**, 02-05 November 2015.
- Collaborative research work on investigation and to understand the basic dynamics and predictability of heavy rain events over the Himalayan region that often occur during the summer monsoon season, Department of Meteorology, Reading University, Reading, **U.K**., 06-10 November 2015.

Dr. G. Beig

- Seventh International Workshop on 'Air Quality forecasting Research (IWAQFR)' and GURME SAG Meeting, Maryland, **USA**, 01-04 September 2015.
- WHO Expert Meeting on Consultation on available evidence for the future update of the WHO Global Air Quality Guidelines, Bonn, **Germany**, 29 September – 01 October 2015.
- International Workshop of WMO GAW Research Meteorology and Environment Scientific Advisory Group (SAG) and Weather Information Service Engine (WISE) Project, Seoul, **Korea**, 09-12 November 2015.

Dr. A. Suryachandra Rao

- Sixth Session of the South Asian Climate Outlook Forum (SASCOF-6), 19-22 April 2015 and Water users forum on the topic Flood Forecasting in South Asian region, Dhaka, **Bangladesh**, 22-23 April 2015.
- SAARC Monsoon Initiative Programme: Two-day Meeting of SAARC Working Group on Monsoon (SWGM), 31 August - 01 September, 2015 and Two Day Seminar on Monsoon initiative, 02-03 September 2015, Colombo, **Sri Lanka**.
- First Joint SOA-MoES Workshop, Guangzhou, China and China-South Asian Countries Marine Cooperation Workshop, **China,** 15-20 December 2015.

Dr. Supriyo Chakraborty

- Second Research Coordination Meeting on Stable Isotopes in Precipitation and Palaeoclimatic Archives in Tropical Areas to Improve Regional Hydrological and Climate Impact Models, IAEA, Vienna, **Austria**, 15-19 June 2015.

Dr. G. Pandithurai

- IV International SKYNET workshop, Rome, **Italy**, 02-04 March 2016.

Dr. (Mrs.) Ashwini Kulkarni

- Training on 'Statistical Techniques in Atmospheric and Ocean Sciences', Qatar Meteorological Department, **Doha**, 25 October - 05 November 2015.
- Workshop on Climate and environment change impacts on Indus basin waters, ICIMOD, Kathmandu, **Nepal**, 17-18 February 2016.

Dr. D.M. Chate

- International conference on “Our Common Future Under Climate Change (CFCC)”, UNESCO, Paris, **France**, 05-12 July 2015.

Dr. J. Sanjay

- Asia Oceania Geosciences Society (AOGS) 2015 Conference, **Singapore**, 01-05 August 2015.

Panel Discussion on Technology aspects of climate change science, India Pavilion of COP21, Paris, **France**, 09-12 December 2015.

Dr. Suresh Tiwari

- Rossby Visiting Fellowship, International Meteorological Institute, Stockholm University, **Sweden,** 01 September 2015 - 28 February 2016.

Dr. (Mrs.) S.S. Fadnavis

- Second International Workshop on Atmospheric Composition and the Asian Summer Mosoon (ACAM), Bangkok, **Thailand**, 06-11 June 2015.
- Fourth Chemistry-Climate Model Initiative SPARC CCMI Workshop' and participation in CCMI related activities, ISAC-CNR, Frascati, **Italy**, 04-09 October 2015.
- Meeting on Dynamics, Transport and Chemistry of the UTLS Asian Monsoon, NCAR, Boulder, CO, **USA**, 07-11 March 2016.

Dr. P. Mukhopadhyay

- Workshop on Stochasticity and Organization of Tropical Convection, Banff International research Station, Alberta, Canada and to deliver lectures at University of Victoria, **Canada**, 20 April – 01 May 2015.
- ECMWF, Annual Seminar 2015 on Physical Processes in Present and Future Large-Scale Models, ECMWF, Reading, **UK**, 01-04 September 2015.
- International Science conference on MAHASRI and Extended International Science Committee meeting of MAHASRI, TOKYO Metropolitan University**, Japan**, 02-05 March 2016.

Dr. Vinu Valsala

- Asia Oceania Geosciences Society Meeting 2015 (AOGS-2015), **Singapore**, 01-08 August 2015.
- National Institute of Environmental Studies (NIES), Tsukuba, **Japan**, 16-23 January 2016.
- New York University, **Abu Dhabi**, 21-25 March 2016.

Dr. Milind Mujumdar

- INDNOR International Collaborative Workshop on the project 'Climate Change and its Impacts on the selected Indian Hydrological System using Earth System and High Resolution Modeling, Bergen, **Norway**, 02-07 May 2015.
- High Resolution Climate Projections in Adaptation at Scale in Semi-Arid Regions (ASSAR) Climate Training Course 'Understanding Climate Information and Adaptation in the Context of Semi-arid Regions', University of Cape Town (UCT), **South Africa**, 24 August - 06 September 2015.

Dr. A. Hazra

- Visited Department of Atmospheric Sciences, National Taiwan University (NTU), Taipei, Taiwan and attended the Workshop on 'NTU cloud and aerosol microphysical parameterization', National Taiwan University, **Taiwan**, 28 March – 13 April 2016.

Dr. Ramesh Vellore

- HIMAP Coordinating Lead Author's Workshop, ICIMOD Headquarters, Kathmandu, **Nepal**, 26-28 January 2016.

Dr. Anoop Mahajan

- Lectures on Halogen Chemistry in the Marine Boundary Layer at King Abdullah University of Science and Technology, **Saudi Arabia**, 17-21 May 2015.
- Collaborative Program on halogen chemistry modeling, University of McGill, **Canada**, 22-31 July 2015.
- Indo-US Frontiers of Science Meeting, University of California, Irvine, **USA**, 09-12 August 2015.

Dr. S. Abhilash

- Advance School and workshop on Subseasonal to Seasonal (S2S) Prediction and Application to Drought Prediction, Abdus Salam International centre for Theoretical Physics (ICTP), **Italy**, 23 November – 04 December 2015.

Dr. S.D. Ghude

- Workshop on the Task Force on Hemispheric Transport of Air pollutants (HTAP), 11-15 May 2015 and scientific discussion on Modelling Aspect of Wintertime Fog Scientist, National Centre for Atmospheric research (NCAR), Boulder, Colorado, **USA**, 07-08 June 2015.

Second International Workshop on Atmospheric Composition and the Asian Summer Mosoon (ACAM) and ACAM Training School, Bangkok, **Thailand**, 08-13 June 2015.

Dr. (Mrs.) Swapna P.

- Workshop on the India-Brazil-South Africa-IBSA-Ocean Earth Sytem Modeling (ESM), Itamonte, **Brazil**, 27-29 July 2015.

Dr. Roxy Mathew Koll

- European Geoscience Union (EGU) General Assembly 2015, Vienna, **Austria**, 12-17 April 2015.
- Asia Oceania Geosciences Society (AOGS) 2015 Conference, **Singapore**, 01-07 August 2015.
- Sixth Indo-American Frontiers of Science Symposium, U.S. National Academy of Sciences, Irvine, **USA**, 09-20 August 2015.
- Discussions and Invited Talk on 'Ocean Warming and its Impact on Marine Productivity over the Arabian Sea', New York University, **Abu Dhabi**, 14-15 November 2015.
- CLIVAR-ICTP Workshop on 'Past and Future Climate Shifts: Decadal Climate Variability and Predictability, Abdus Salam International centre for Theoretical Physics (ICTP), **Italy**, 16-24 November 2015**.**

Dr. Bipin Kumar

- PALM-2015 Seminar, Chinese University of Hong Kong, **Hong Kong**, 21-25 September 2015.
- Scientific meeting of Project Team for Climate Change Adaptation Technology, JAMSTECH, Tokyao, **Japan**, 16-17 February 2016.

Dr. Yogesh Tiwari

- 28th Global Atmospheric Watch Training and Education Center (GAWTEC) Training Course, Environmental Research Station, Schreefernerhaus (UFS) Zugspitze, **Germany**, 10-23 May 2015.
- Discussion on Greenhouse gases monitoring Techniques, Laboratories Des Sciences Du Climate De L'envirinment (LSCE), Paris, **France**, 23-30 May 2015.
- Second WCC SF6 training and Seventh Asia pacific GAW Workshop on 'Greenhouse Gases', Anmyeondo Seoul, Jeju Island, **South Korea**, 19-24 October 2015.

Dr. S. Sengupta

- Onsite training for routine operation, maintenance and troubleshooting of laser water vapour and carbon dioxide isotope analyser, Los Gatos Research, Mountain View, CA **USA,** 28 November – 14 December 2015.

Mr. Sudhir S. Sabade and **Mr. Manmeet Singh**

- 2nd WCRP Pan-Asia ESGF Training Workshop for CORDEX, National Institute of Meteorological Sciences (NIMS), Jeju, **South Korea**, 23-25 February 2016.

Dr. (Mrs.) Medha Deshpande

- ECMWF, Annual Seminar 2015 on Physical Processes in Present and Future Large-Scale Models, ECMWF, Reading, **UK**, 01-04 September 2015.

Dr. Sreenivas Pentakota

- To work on the project 'Improving Monsoon Prediction with a Coupled Ensable Kalman Filter Data Assimilation System, University of Maryland, **USA**, 01 November 2015 – 30 April 2016.

Dr. A.K. Srivastava

- CONNECT follow-up Program of Humboldt Foundation, Leibniz, Institute for Tropospheric Research (TROPOS), Leipzig, **Germany**, 01-30 June 2015.

Dr. Phani Murli Krishna

- To work on the Monsoon Mission Project: An approach for multiscale and multicloud parametrization to improve the CFS model fidelity of monsoon weather and climate through better organized tropical convection, University of Victoria, **Canada**, 28 September – 31 December 2015.

Mr. Malay Ganai

- First WCRP Summer School on Climate Model Development 'Atmospheric Moist Processes', Max Plank Institute for Meteorology, Hamburg, **Germany**, 13-28 June 2015.

Mr. Pramit Kumar Deb Burman

- AsiaFlux Mini-Workshop on Remote Sensing and Ecological/Environmental Monitoring, National Taiwan University (NTU), Taipei, **Taiwan**, 02-04 March 2016.

Mr. Sandeep Narayansetti and **Ms. Jyoti Jadhav**

- Brazilian Earth System Model (BESM) Summer School, INPE-CPTEC, Cachoeira Paulista, **Brazil**, 27 July - 08 August 2015.

Mr. Mriganka Biswas

- 35th Indian Scientific Expedition to Antarctica, Maitri and Bharati stations, **Antarctica**, 03 November 2015 – 03 March 2016.

Ms. Chaitri Roy

- Second International Workshop on Atmospheric Composition and the Asian Summer Mosoon (ACAM), Bangkok, **Thailand**, 06-12 June 2015.

Ms. Smrti Gupta

- Training programme on the General of Regional Climate Data Derived from Statistical Downscaling Techniques, APCC, Bhusan, **South Korea**, 7-12 December 2015.

Mr. Sudarsan Bera

- Workshop on thermodynamic analysis of atmospheric and oceanic flows, New York University, **Abu Dhabi**, 11-13 December 2015.

Dr. Manish Kumar Joshi

- Research in Earth System Physics, International Center for Theoretical Physics (ICTP), Trieste, **Italy**, 01 April – 31 May 2015 *(under "Junior Associateship" award from ICTP)*.

Ms. Priya Pattancheri

- European Geosciences Union (EGU) General Assembly 2015, Vienna, **Austria**, 12-17 April 2015.

Dr. R.H. Kripalani

- Invited talks and Discussion with Research Team, Nanjing University of Information Science and Technology (NUIST), Nanjing, **China**, 12-18 October 2015**.**

Mr. Pithhani RDS Prakasarao

- 4th User Workshop of GlobEmission 2015, Doha, **Qatar**, 24-25 November 2015.

Regular Staff (as on 31 March 2016)

Research Staff
Director

Scientist-G
Dr. R. Krishnan
Dr. Gufran Beig
Dr. A.K. Sahai
Scientist –F
Dr. A. Suryachandra Rao
Dr. C. Gnanaseelan
Scientist –E
Dr. P.S.P. Rao
Dr. H.P. Borgaonkar
Dr. S.D. Pawar
Dr.(Mrs.) Thara Prabhakaran
Dr. S. Chakraborty
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Dr. G. Pandithurai
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Dr. P.D. Safai
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Dr. Suresh Tiwari
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Dr. P. Mukhopadhyay
Dr. Vinu Valsala
Mr. S. Mahapatra
Dr. Ramesh Vellore
Dr. H.S. Chaudhari
Dr. Devendraa Siingh

Dr. Subodh Kumar Saha
Scientist -D
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Dr. (Mrs.) N.R. Deshpande
Dr. T. Dharmaraj
Dr.(Mrs.) S.B. Morwal
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Dr. Shivsai Dixit
Mr. K.K. Dani
Dr. R.S. Maheskumar
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Dr. S.G. Narkhedkar
Dr. (Mrs.) Susmitha Joseph
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Dr. K.M.C. Reddy
Dr. Abhilash S.
Dr. (Mrs.) Swapna P.

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Dr. Subrata Kumar Das
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Mr. N.K. Agarwal
Mr. S.S. Sabade
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Mr. A.K. Saxena (Civil Engg.)
Scientist –C
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Mrs. Sompriti Deb Roy
Mr. Abhay S.D. Rajput
Mr. Mata Mahakur
Mrs. M.N. Kulkarni
Dr. (Mrs.) Amita Ajay Prabhu
Mrs. R.V. Bhalvankar
Dr. (Mrs.) M.S. Deshpande

Mr. Jnanesh S.P. (Electrical Engg.)
Dr. Sabin T.P.
Dr. A.K. Srivastava
Dr. M.I.R. Tinmaker
Mr. Mahesh Dharua (Mech. Engg.)
Dr. Phani Murali Krishna
Dr. K.P. Sooraj
Dr. H.N. Singh
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Mr. G.R. Chintalu
Mr. Somaru Ram
Mr. Bhupendra Bahadur Singh
Mr. Balaji B.
Mrs. Mercy Varghese
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Mr. M.D. Chipade
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Dr. (Mrs.) Leena P.P.
Mr. Appala Ramu Dandi
Mrs. Renu Subrata Das
Mr. Subharthi Chowdhuri
Mrs. U.S. Iyer
Scientist –B
Mrs. Sathy Nair
Mr. Tanmay Goswami
Mr. Malay Ganai
Mr. Sudarsan Bera
Mrs. Archana Rai
Mr. Prajeesh A. G.
Mr. Vivek Singh
Mr. Amit Kumar Verma

Mrs. Rashmi Anant Khandekar
Mr. Sandeep Narayanasetti
Mr. Maheswar Pradhan
Mr. Ankur Srivastava
Mr. Raju Mandal
Mr. Avijit Dey
Mr. Mriganka Sekhar Biswas
Ms. Chaitri Roy
Ms. Shikha Singh
Mr. Sahadat Sarkar
Ms. Shilpa Malviya
Ms. Deepa J.S.
Ms. Snehlata Tirkey
Ms. Aditi Modi
Mr. Manmeet Singh
Ms. Smrati Gupta
Mr. Subrata Mukherjee
Mr. Pramit Kumar Deb Burman
Mr. Sujit Maji
Mr. Ambuj Kumar Jha
Scientific Support Staff
Scientific Officer Grade-II
Mrs. S.U. Athale
Mrs. S.S. Naik
Mr. D.W. Ganer
Mr. V.R. Mali
Mrs. S.R. Inamdar
Mrs. A.R. Seshagiri
Mrs. V.V. Sapre
Mr. V.H. Sasane
Scientific Officer Grade-I
Mrs. S.B. Patankar
Scientific Assistant Grade-C
Mr. A.R. Dhakate
Scientific Assistant Grade-B
Mr. V. Vasudevan

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Mr. Deewan Singh Bisht
Mr. A.L. Sagar
Mr. R.T. Waghmare
Mr. K.D. Salunke
Scientific Assistant Grade-A
Mr. A.S. Gautam
Mrs. P.S. Buchunde
Technical Support Staff
Technician Grade-F
Mr. H.K. Trimbake
Technician Grade-E
Mr. S.M. Thorat
Mr. R.A. Paradkar
Mr. S.G. Purandare
Technician Grade-D

Technician Grade-C
Mr. S.P. Hasnale
Isolated Staff (Driver Isolated Staff)
Mr. P.S. Jagtap
Mr. S.A. Sayyed
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Senior Manager
Mr. V.R. Patil
Manager
Mr. S.M. Hendre
Joint Manager

Deputy Manager
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Mr. S.N. Prasad
Mrs. R.S. Salunke
Ms. M.M. Lakra
Mrs. R.S. Ovhal

Deputy Manager (Hindi)
Dr. Omkar Nath Shukla
Assistant Manager
Mr. Y.S. Belgude
Mrs. Sheetal Deshmukh
Assistant Manager (Hindi)

Senior Executive (Hindi Translator)

Senior Executive
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Mrs. A.A. Ursekar
Mr. Y.J. Pawar
Mr. G.M. Limaye
Executive
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Mr. V.R. Khare
Mrs. S.S. Devale
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Mr. S.B. Gaikwad
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Mr. G.R. Handrale
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Mr. K.D. Barne
Coordinator Grade-IV
Mrs. S.P. Iyer
Coordinator Grade-III
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Mr. R.K. Nandanwar
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Mr. C.R. Joshi
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Mr. V.V. Bamble
Mr. S.N. Dandekar
Mr. D.L. Rawade
Mr. S.V. Raut
Mr. P.P. Vyawahare
Mr. D.D. Takawale
Mr. G.E. Dhongade
Mr. Rakesh Bhandari
Mr. T.L. Mundhe
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Mr. K.M. Kamble
Mrs. D.J. Titkare
Mrs. K.Y. Chavan
Mr. E.M. Botla
Mr. M.S. Waghela
Mr. H.E.Nindhane
Mr. I.O. Dulguch
Mr. I.R. Mehetre

***This list is not as per the seniority.**

Other than Regular Staff (as on 31 March 2016)

INSA Honorary Scientist : Dr. A.K. Kamra

Under Short-Term Contract

Prof. B.N. Goswami, Pisharoty Professor	Mr. Rohit Dilip Patil, Associate Engineer (HACPL)
Mr. Anil Kumar V., Associate Scientist Grade-I (HACPL)	Mr. Mangesh Mohanrao Goswami, Associate Engineer (Electrical)
Dr. Manish Kumar Joshi, Project Scientist-C	Mr. Padmakar Devidasrao Domutwar, Assistant Engineer (Audio Video)
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Mr. Harikrishna Devisetty, Junior Engineer (Instrumentation/ Electronics)	Mr. Swapnil Shankar Nalawade, Junior Engineer (Instrumentation/Electronics)
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Mr. Prodip Acharja	Ms. Jyoti Jadhav	Mr. Srinivas G.
Mr. Pithani R.D.S. Prakasarao	Ms. Saranya Ganesh S	Ms. Ananya Karmakar
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Publications

Papers published in peer-reviewed national and international journals

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Publications

Papers Published in Journals	:	**149**
Cumulative Impact Factor	:	**468.451**
Average Impact Factor	:	**3.144**
Papers Published in Books, Reports, Proceedings, etc.	:	**10**

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, 2016, 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 2016 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, 2016 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/-
(AJAY S JOSHI)
(Partner)
(Membership No.110708)

Pune
August 03, 2016

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. Further the Fixed Asset Register was not updated as on 31st March 2016 and due to which the Physical Verification Process was not completed.	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. 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 Non-Plan 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.	IITM - NCL both the organizations 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 31-03-2016

1. CORPUS/ CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
CORPUS/ CAPITAL FUND	1	5513871135.25	5302592481.04
RESERVES AND SURPLUS	2	11349143.37	11072958.37
EARMARKED/ ENDOWMENT FUNDS	3	3284574.91	4078698.34
SECURED LOANS AND BORROWINGS			
UNSECURED LOANS AND BORROWINGS			
DEFERRED CREDIT LIABILITIES			
CURRENT LIABILITIES AND PROVISIONS	4	150019968.20	240046250.54
INTEREST TO BE ADJUSTED AGAINST FUTURE GRANTS (PLAN)	15	74987269.00	86935977.00
INTEREST TO BE ADJUSTED AGAINST FUTURE GRANTS (NON-PLAN)	15	4616637.00	15690258.60
2. TOTAL		**5758128727.73**	**5660416623.89**
1. ASSETS			
FIXED ASSETS	5	4452004985.84	4001661537.37
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUNDS			
INVESTMENTS - OTHERS			
CURRENT ASSETS LOANS ADVANCES ETC.	6	1306123741.89	1658755086.52
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)			
3. TOTAL		**5758128727.73**	**5660416623.89**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS		0.00	0.00

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD/YEAR ENDED 31-03-2016

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services Grants/Subsidiser Fees/Subscriptions Income from Investments (Income on Invest from earmarked/ endow. Funds transferred to Funds) Income from Royalty Publication etc. Interest Earned Other Income Increase/(decrease) in stock of Finished goods and works-in-progress	7 10	873630500.00 2446111.87	963322853.00 3528129.00
TOTAL (A)		**876076611.87**	**966850982.00**
EXPENDITURE			
Establishment Expenses Other Administrative Expenses etc. Expenditure on Schemes Interest Depreciation during the year	11 13 A 14	311528986.42 601610529.84 216684677.00	324655966.92 580148291.25 193922859.00
TOTAL (B)		**1129824193.26**	**1098727117.17**
TOTAL (C) - Prior Period Expenses (Exp. Incurred before 01.04.2014, but payment made in the F.Y. 2014-15	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		**-253747581.39**	**-131876135.17**
SIGNIFICANT ACCOUNTING POLICIES CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS			

RECEIPTS AND PAYMENTS
FOR THE PERIOD / YEAR ENDED 31-03-2016

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
I. Opening Balances			**I. Establishment expenses**		**309758469.42**
a) Cash in hand		**163815.00**	**II. Payment made against various project funds**		**7414223.41**
b) Bank Balances			**III. Advances to Others than project**		**424363.00**
i) In current accounts - SBI - Main A/c		**937572820.01**	**IV. Advance to staff**		**7865761.00**
ii) In current accounts - PNB Main A/c		**239140325.79**	**V. Deposits with**		**0.00**
iii) In current accounts - SBI - Project A/c		**9034787.78**	**VI. Overheads**		**87037.00**
iv) In deposit accounts		**12588929.00**	**VII. Funds Retained from suppliers**		**151331246.10**
			VIII. Statutory Liability		**288328725.35**
II. Grants Received		**1236030500.00**	**Short Term Climate Prediction**		**41656397.04**
1) Advanced Training in Earth System Science and Climate	80000000.00				
2) Centre for Climate Change Research (CCCR)	37330500.00		Recurring	45212858.51	
3) IITM - Operations - Maintenance	173500000.00		Non-Recurring	5811993.53	
4) Metropolitan Air Quality and Weather Services	160000000.00		Advance	3490105.00	
5) Monsoon Mission	276000000.00		Total	54514957.04	
6) Physics - Dynamics of Tropical Clouds	180000000.00		Less: Advance adjusted	12858560.00	
7) Short Term Climate Prediction and Variability	51000000.00				
8) Non-Plan	278200000.00				
			Centre for Climate Change Research		**18038621.80**
			Recurring	9561191.30	
III. Interest Received			Non-Recurring	6914773.00	
Non-Plan Interest (to be adjusted against future grants)		**4616637.00**	Advance	6336749.00	
1) On Bank deposits	4550142.00		Total	22812713.30	
2) Penal Interest	20397.00		Less: Advance adjusted	4774091.50	
3) Interest on Scooter Advance	18285.00				
4) Interest on Car Advance	15000.00				
5) Interest on Computer Advance	1094.00		**Advance Training in Earth System Science & Climate**		**141125325.00**
6) HBA Interest	11719.00		Recurring	11829508.00	
			Salary	1770517.00	
			Non-Recurring	135450223.00	
			Advance	1175603.00	
			Total	150225851.00	
			Less: Advance adjusted	9100526.00	

RECEIPTS AND PAYMENTS
FOR THE PERIOD / YEAR ENDED 31-03-2016

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
b) Plan Interest - On Schemes (to be adjusted against future grants)		**74987269.00**	**IITM Operations & Maintenance**		**222313771.15**
1) Advanced Training in	12868468.00		Recurring	207091678.27	
2) Centre for Climate Change Research	2680961.00		Non-Recurring	14232661.90	
3) Climate Variability - Dynamics	14865.00		Advance	3147160.00	
4) Metropolitan Air Quality - Weather System	6259166.00		Total	224471500.17	
5) Monsoon Mission	595502.00		Less: Advance adjusted	2157729.02	
6) NFAR	3783819.00				
7) Short Term Climate Prediction	406058.00				
8) PDTC	1924325.00		**Monsoon Mission**		**223615493.00**
9) HPC	45183882.00		Recurring	220821560.00	
10) IITM O- M	1270223.00		Non-Recurring	64275.00	
			Advance	306788157.00	
			Total	527673992.00	
IV. Other Income		**2446111.87**	Less: Advance adjusted	304058499.00	
1) Licence Fee	1188258.00				
2) Guest House	358525.00				
3) Fees from Student	218573.00		**Metropolitan Air Quality and Weather Services**		**102270106.44**
4) Misc.Receipts	276009.87		Recurring	4058601.90	
5) Cont. to Pensioners medical scheme	266400.00		Non-Recurring	77480790.54	
6) Water charges	56606.00		Advance	96813352.00	
7) Maint. Of Colony Welfare	57040.00		Total	178352744.44	
8) Maint. of Office Vehicle	24700.00		Less: Advance adjusted	76082638.00	
V. Any other receipts		**387742919.09**	**HPC - 2**		**294375512.68**
1) Receipts from various project	6620099.98		Recurring	22073143.86	
2) Funds Retained from suppliers	51949698.11		Non-Recurring	374471873.50	
3) Claims Receivable	7803117.00		Advance	535006873.68	
4) Statutory liabilities	285666513.00		Total	931551891.04	
5) Deposits with	0.00		Less: Advance adjusted	637176378.36	
6) Advance to others than project	354208.00				
7) Overheads	363222.00				
8) Deposits from creditors	26846223.00		**Physics & Dynamics of Tropical Clouds**		**205188153.00**
9) Adv. to staff	8139838.00		Recurring	80417374.00	
			Non-Recurring	51118062.00	

RECEIPTS AND PAYMENTS
FOR THE PERIOD / YEAR ENDED 31-03-2016

RECEIPTS	AMOUNT		PAYMENTS	AMOUNT	
VI. Accrued Interest		**426938.00**	Advance	132660307.61	
			Total	264195743.61	
			Less: Advance adjusted	59007590.61	
			National Facility for Airborne Research		**3858316.00**
			Recurring	544614.00	
			Non-Recurring	1483473.00	
			Advance	3772773.00	
			Total	5800860.00	
			Less: Advance adjusted	1942544.00	
			X. Claims Receivable		**919392.00**
			XI. Deposits From Creditors		**14828745.00**
			XII. Accrued Interest		**359933.00**
			XIII. Closing Balance		
			a) Cash in hand		**153815.00**
			b) Bank Balances		
			i) In current accounts - SBI - Main A/c		**574156804.67**
			ii) In current accounts - PNB Main A/c		**275551751.55**
			iii) In current accounts - SBI - Project A/c		**7402308.93**
			iv) In deposit accounts		**13726781.00**
TOTAL		**2904751052.54**	**TOTAL**		**2904751052.54**

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-

Sr. No.	Particulars	Rate 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. R. KRISHNAN)
DIRECTOR

Pune
August 3, 2016

AS PER OUR REPORT OF EVEN DATE,
FOR AND ON BEHALF OF
C. R. SAGDEO & CO.
CHARTERED ACCOUNTANTS,
(Firm's Registration No.108959W)

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

भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
INDIAN INSTITUTE OF TROPICAL METEOROLOGY



ईएसएसओ–भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
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