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भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
Indian Institute of Tropical Meteorology

Annual Report
2023-2024

RESEARCH ADVISORY COUNCIL MEETING

Meeting in progress

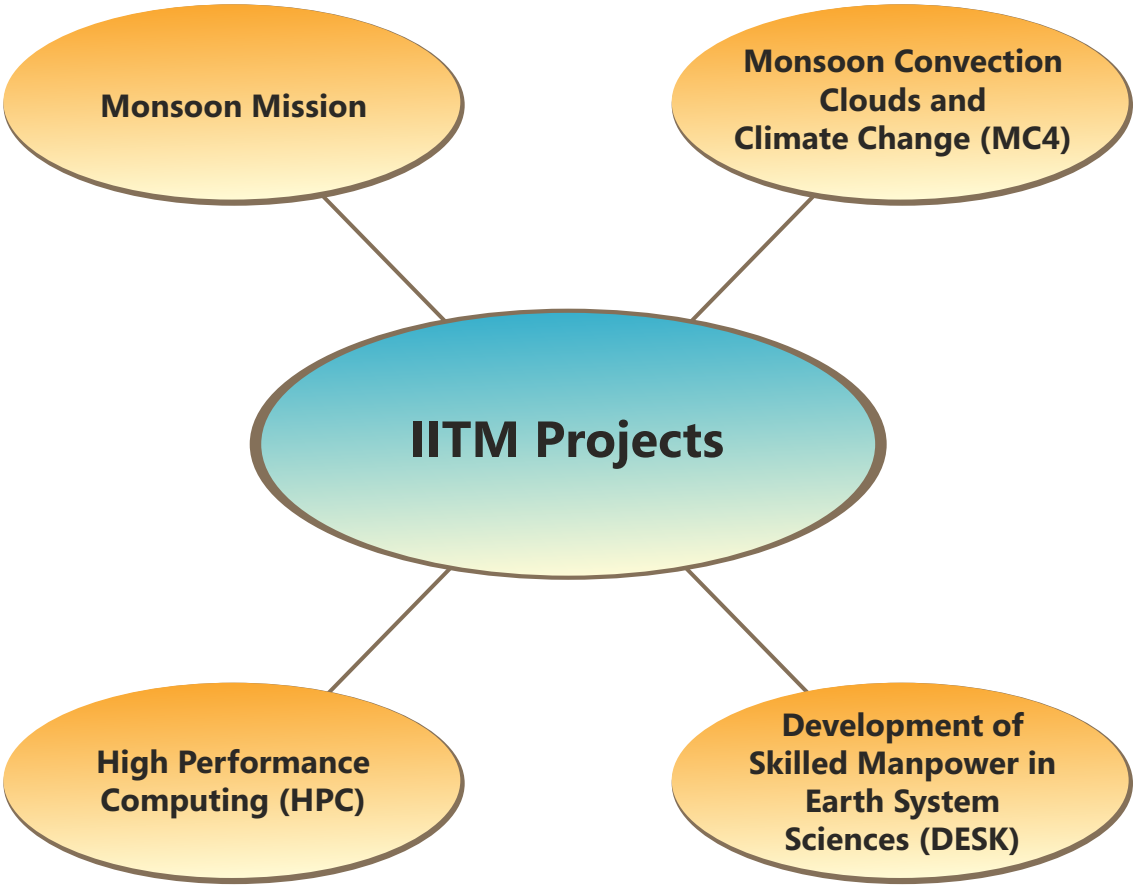
Poster Session

Annual Report
2023-24

Indian Institute of Tropical Meteorology

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

Dr. Homi Bhabha Road, Pashan, Pune - 411 008, Maharashtra, India
URL : http://www.tropmet.res.in Phone : 91-020-25904200
E-mail : lip@tropmet.res.in Fax : 91-020-25865142



Organisational Flow Chart of R&D Activities

IITM SOCIETY

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

IITM GOVERNING BODY

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

IITM FINANCE COMMITTEE

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

IITM RESEARCH ADVISORY COMMITTEE

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

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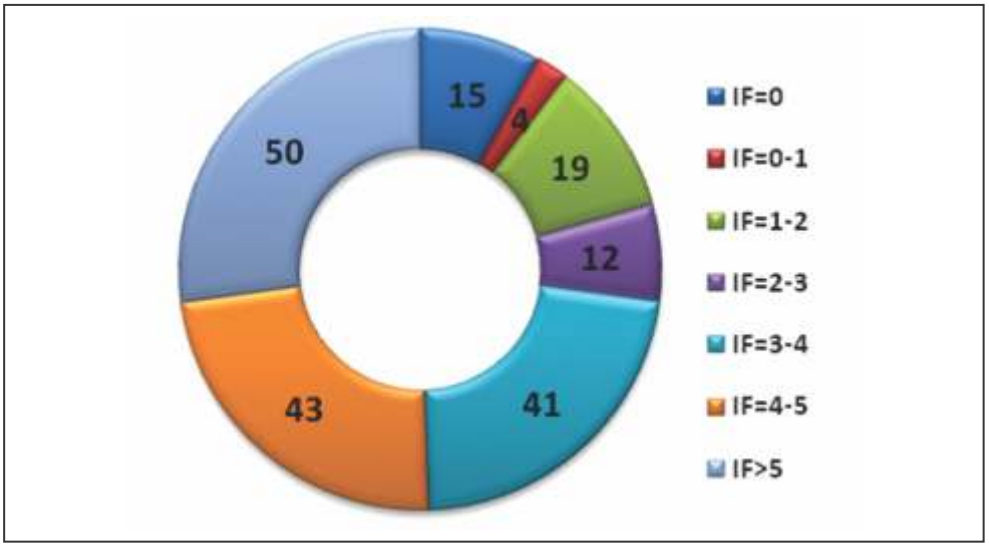
IITM Publications at a Glance

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



Impact Factor wise distribution of IITM publications during the year 2023-24.

Summary of Publications during the year 2023-24	
Total No. of papers published in Journals	184
Papers with Impact Factor	169
Papers without Impact Factor	15
Cumulative Impact Factor	908
Average Impact Factor	4.935
Other Publications	18

Foreword

I am pleased to present an overview of the new research and achievements conducted by the Indian Institute of Tropical Meteorology (IITM), Pune during the financial year 2023-24. With the vision to be a Global Centre of Excellence through basic research and development (R&D) on all aspects of the Tropical Atmosphere-Ocean System required to improve Weather and Climate Forecasts, IITM has risen to this cause by delving into a diverse range of topics, each contributing to our holistic comprehension of the Earth's climate system and cutting-edge scientific problems in tropical meteorology and atmospheric sciences. IITM's research bridges the gap between the past and present, increasing our understanding of weather and climate and the underlying processes required for making reliable weather predictions and climate projections.

The roadmap for achieving the vision of IITM has relied on continuously enhancing the following three key components of the Institute (a) scientific understanding (b) infrastructure improvement (c) human resource development. IITM's scientific contributions have significantly advanced our understanding of the land-ocean-atmosphere climate system and successfully translated this understanding to provide skilful forecasts of weather, climate, and air quality on different spatial and temporal scales. Today, IITM is one of the top world Centres of excellence in Weather and Climate Science for societal applications. Here, I am happy to record the excellent progress made by IITM during 2023-24. The Executive Summary in the Annual Report provides a quick overview of some noteworthy research and development contributions under different projects. Highlighted below are a few significant events and activities, scientific research outcomes and accomplishments over the last year.

- **IITM Foundation Day:** Last year, the Institute celebrated the 62nd Foundation Day on 17th November 2023. On this occasion, Dr. M. Ravichandran, Secretary, Ministry of Earth Sciences highlighted the importance of Weather and Climate Research for improved understanding, predictions and services to society. He also pointed out the need to develop capabilities in Weather Management by 2047 during the Amrit Kaal. This occasion was graced by the Chief Guest Shri Nilesh M. Desai, Director, Space Application Centre, Ahmedabad and Guests of Honour Prof. Janardhan Padmanabhan, INSA Senior Scientist, Physical Research Laboratory, Ahmedabad and Prof. Trenton Franz, University of Nebraska, USA, who delivered the following Foundation Day lectures.
- Shri Nilesh M. Desai "Indian Space Missions for Meteorology and Future Perspectives".
- Prof. Janardhan Padmanabhan "Explosive solar events – A looming threat to our modern way of life".
- Prof. Trenton Franz (online mode) – "Revolutionzing Land Surface Soil Moisture Monitoring – Pioneering a National Scale Operational Network with Cosmic-Ray Neutron Sensors across India".
- **Mini-workshop for preparing Vision Document for Amrit Kaal - Viksit Bharat @2047:** A mini-workshop was conducted at IITM during 12-14 February 2024 to deliberate and compile the MoES Vision Document for Viksit Bharat@2047 during the Amrit Kaal. The workshop aimed to identify key thrust areas for MoES with detailed

deliverables and pathways to achieve them. The participants in this mini-workshop included representatives nominated from MoES institutions and experts from other scientific institutions.

Dr. M. Ravichandran, Secretary, Ministry of Earth Sciences provided an introduction to the MoES vision document for Viksit Bharat @2047. The mini-workshop was chaired by Prof. J. Shukla, Distinguished University Professor at George Mason University, USA and was co-chaired and hosted by Director, IITM.

The discussions were conducted in two parts. First, the overall vision for MoES was deliberated in a plenary session with all the attendees. During this, four areas were identified for more detailed discussions. The group was then split into four breakout groups according to the attendees' expertise, and feedback from the individual breakout groups was discussed in a plenary and accordingly the recommendations were prepared for the MoES Vision 2030 and 2047.

- Following the recommendations of the IITM Research Advisory Committee (RAC), a brainstorming meeting was conducted to develop a Tropical Biometeorology Program of National importance. A concept report of the TBM program is being prepared.
- **Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Phase-IV:** The CAIPEEX Policy report was released by Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, during the MoES Foundation Day, 27 July 2023. A scientific article on CAIPEEX published was published in Bulletin of American Meteorological Society (BAMS) (Thara Prabhakaran et al. 2023).
- **Visit of Hon'ble Minister of Earth Sciences:** Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, visited IITM on 15th July 2023 and subsequently the High Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar on 05 October 2023. The HMoES was very appreciative of the scientific research carried out by the institute.
- **Atmospheric Research Testbed (ART) Central India facility:** The ART-CI facility has been formally inaugurated by Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences on March 12, 2024. The site was initialised in 2021 on ~100 acres of land at Silkheda village in the Sehore District of Madhya Pradesh to provide important observations for better understanding on processes related to convection, clouds and land-atmosphere interactions in the core monsoon zone region.
- IITM scientists published 184 papers in peer-reviewed journals with a Cumulative Impact Factor of 908 and an Average Impact Factor of 4.935.
- Twelve PhD students who graduated over the last year were guided by IITM scientists.
- Several IITM scientists have brought laurels and honours to our Institute for their outstanding performance and achievements. This includes Dr Roxy Mathew Koll, who has been awarded the prestigious Rashtriya Vigyan Puraskar: Vigyan Yuva Shanti Swarup Bhatnagar Award for the year 2024 in Earth Science.
- Several activities were undertaken for the promotion of Rajbhasha including the Vishwa Hindi Diwas 2024 competitions on 05 January and 10 January 2024 and the National Joint Rajbhasha Scientific Seminar - 2024, jointly organised by Agharkar Research Institute (ARI), CSIR- National Chemical Laboratory (NCL), National Centre for Cell Science (NCCS) and IITM.
- IITM organised several seminars/events, National and International workshops, and conferences during the last year, including the Prof. Anantha Krishnan Colloquium, IMSP Annual Monsoon Workshop (AMW) and National Symposium.
- **ICRC-CORDEX 2023 Conference:** The International Conference on Regional Climate -Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX-2023) was successfully organized jointly by CCCR-IITM, MoES, the

Abdus Salam International Centre for Theoretical Physics (ICTP, Italy), the Swedish Meteorological and Hydrological Institute (SMHI), and the World Climate Research Program (WCRP) with physical hubs in Pune, India and Trieste, Italy in hybrid mode during 25-29 September 2023. It was attended by 67 offline (in person) participants and 36 online participants.

- IITM participated in the mega science event 9th India International Science Festival 2023 and the science expo at the Giant Metrewave Radio Telescope (GMRT) observatory. Additional public lectures were conducted on important days such as National Science Day, World Meteorological Day and Earth Day, World Water Day, International Women's Day, International Day of Forests, World Migratory Bird Day, International Day of Biological Diversity, and World Environment Day.
- Various activities were conducted under the Mission LiFE, including the National Mega Event, sessions for Warkaries of the Pandharpur Yatra, sessions at the Guruvansh English Medium School and the Venutai Yashvantrao Chavan Primary School.
- For the 9th International Day of Yoga on 21 June 2023, the employees of the institute actively participated in the Yoga session organized in the Institute.
- Several important research and development studies were carried out during the last year. Below are some of the noteworthy scientific research outcomes and accomplishments:
- Under the Monsoon Mission, the genesis, track, intensity, and landfall of Severe Cyclonic Storm (SCS) "REMAL" over the Bay of Bengal was forecast with a long lead time of 5-6 days by the GEFST1534 ensemble forecast system, and the forecasts were shared with IMD.
- The Centre for Climate Change Research (CCCR) started preparations for CMIP7 (using the IITM-ESM3 (TCO126 atmospheric model ~ 67 km Gaussian grid) and high-resolution ocean model (0.25-degree near equator) and the IPCC AR7 process. The climate projections will be disseminated through the Earth System Grid Federation (ESGF) server that is being hosted at CCCR, IITM, Pune.
- The Climate Variability and Prediction (CVP) group has developed the first version of the IITM Decadal Climate Prediction System (IITM-DCPS). Decadal hindcasts/forecasts prepared from 1980 to 2023 are made available to the WMO Lead Centre for Global Annual to Decadal Climate.
- Observational studies were conducted at Kaziranga National Park (KNP, with Tezpur University), Pichavaram mangrove site (with NCCR, Chennai), ART-Central India, Silkheda, near Bhopal and ARIES, Nainital for measuring GHG fluxes, weather and land surface parameters.
- Fundamental atmospheric chemistry studies & observational campaigns were conducted to understand chemistry and climate interactions.
- Atmospheric Research Testbed (ART) – Central India: Conducted **Monsoon-2023 observational campaign** at ART-CI in coordination with IMD RS/RW sites (twice daily) in the Central Indian region. These datasets have been shared with NCMRWF, Noida for data assimilation & preparation of initial conditions in modelling study.
- Four X-band radars are being installed over the Mumbai Metropolitan region as part of the urban radar network. A MESO-scale rain gauge network (MESONET) comprising of 117 rain gauges distributed over the Mumbai region was established to have real-time rainfall information.
- Lower Atmospheric Research Using Unmanned Aerial System Facility (LARUS) UAV - field campaigns were conducted for profiling the atmospheric boundary layer at Osmanabad.

- The CAIPEEX ground facility observations at the Solapur and Tuljapur sites are ongoing. Solapur C-band radar maintenance work was carried out by CAIPEEX in-house team with the help of IMD Chennai. The system is now revived, and data is being shared with IMD in real time. The Solapur C-band radar data is being displayed on the MAUSAM website.
- **Thunderstorm Dynamics:** Six new lightning location sensors have been added to the Lightning Location Network for improving the accuracy of detection & location. The updated DAMINI- Mobile App provides lightning alerts in 15 languages. IITM also participated in India's maiden Arctic Winter Expedition, which was launched by HMoES. IITM successfully installed an Electric Field Mill & Maxwell current Antenna at the Himadri.
- Continuous observations, modelling and forecasting of air quality have continued. The air-quality forecasts are used to support the Decision Support System (DSS) in Delhi NCR.
- Winter Fog Campaign WiFEX (2023-24) was successfully conducted. A state-of-the-art aerosol lab was set up at IMD headquarters as a part of WiFEX-23-24. The WiFEX experiment was expanded to Jevar Airport. A 21-member ensemble fog forecasting has been set up to provide more reliable forecasts.
- With the current 4 Petaflops HPC Pratyush, a new HPC system capacity (12.9 Petaflop, including 1.16 Petaflop separate AI/ML system) is being installed at IITM.
- **Development of Skilled Manpower in Earth System Science and Climate (DESK):** DESK has successfully implemented the **MoES Research Fellowship Programme (MRFP**) and the **fourth batch** of 12 MRFP was recruited in 2023.
- During 2023-24 **DESK conducted various training programs** with the help of Library, Information and Publications Division, and Computer Division.

All these achievements were possible only with the collective efforts of all the scientific, technical, support & administrative staff of IITM. I extend my heartiest congratulations and sincerely thank the entire IITM family for their excellent contributions and dedicated efforts.

The strong support from the Ministry of Earth Sciences (MoES) has been the backbone for all the scientific research and development work at IITM. I am grateful to the support and guidance from the Society, Governing Body, Finance Committee, and Research Advisory Committee of the Institute, which have been crucial in enabling the above achievements.

IITM aims to continue the pursuit of excellence, forging a path toward a more informed and resilient future. I'm very optimistic that IITM will sustain the sincere efforts with energy and vigour and also enhance the scientific collaborations with our sister MoES Institutions plus various universities, academia, industry, and scientific institutions to reach greater heights and strengthen our country's weather and climate services for societal benefit, in the years to come.

R. Krishnan
Director

Executive Summary

During the financial year 2023-24, the Indian Institute of Tropical Meteorology (IITM) made considerable research contributions in different areas of atmospheric sciences, meteorology, monsoon - predictions and variability and climate change. Some of the important research contributions and achievements of the year 2023-24 are summarised below.

IITM celebrated its 62nd Foundation Day on 17 November 2023 in a befitting manner. Shri Nilesh M.Desai, Director, Space Application Centre (SAC), Ahmedabad, was the Chief Guest, and Prof. Janardhan Padmanabhan, INSA Senior Scientist at Physical Research Laboratory, Ahmedabad, and Prof. Trenton Franz, Associate Professor at the University of Nebraska, Lincoln, USA, were the Guests of Honor. Best Employees Awards 2023 were presented for 5 categories viz. Research category, Administrative staff category, Scientific support staff category, Project staff category and for Hindi outstanding contribution in year 2023. Complete program was live streamed and is available on IITM YouTube channel.

Visit of Hon'ble Minister of Earth Sciences: Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences visited IITM on 15th July 2023 and HACPL, Mahabaleshwar on 05 October 2023 respectively and appreciated the work carried out by the institute.

Publications: IITM scientists published 184 papers in peer-reviewed journals with a Cumulative Impact Factor of 908 and an Average Impact Factor of 4.935.

IITM's 'Web of Science' Citation Report (dated 31.03.2024) states: h-index: 114, Average citation per item: 25.47, Number of times cited: 84,139; Citing articles: 41,479; Total Publications: 3303.

Monsoon Convection, Clouds and Climate Change (MC4)

Centre for Climate Change Research (CCCR):

- **Climate Change Modelling & Projections:** The IITM-ESMv2 (Swapna et al. 2018) successfully contributed to the CMIP6 and IPCC AR6. A next generation version of the IITM Earth System Model (IITM-ESMv3) has been developed using the Triangular Cubic Octahedral grid (TCO126) global atmospheric model (~ 67 km gaussian grid x 64 levels) and global ocean model (360 Lon x 300 Lat x 50 levels), high resolution (0.25 deg) near equator (10S – 10N) and will contribute to the CMIP7 experiments of WCRP and IPCC Assessment Report AR7. IITM-ESMv3 shows improvements in capturing the Indian summer monsoon rainfall & circulation.
- Global high-resolution projections (T574, 27 km grid) were generated using the atmospheric version of IITM ESM with CMIP6 boundary conditions. The climate projections will be disseminated through the Earth System Grid Federation (ESGF) server that is being hosted at CCCR, IITM, Pune.
- Eddy Covariance Systems for Greenhouse Gas Monitoring: The implementation of eddy covariance systems equipped with CO_2, CH_4, and H_2O sensors across diverse ecosystems such as at Kaziranga National Park and Pichavan Mangrooves, etc. facilitates real-time monitoring and quantification of net ecosystem exchange (NEE) of greenhouse gases.
- Collaborative Research Initiated by signing Memoranda of Understanding (MoUs) in July 2023 with institutions such as Tezpur University and Aryabhatta Research Institute promote collaborative research on biosphere-atmosphere gas exchanges, enhancing data collection and analysis capabilities.
- Under the Atmospheric Chemistry Observations in Polar Regions, instrumentation deployed at the Indian Antarctic base, Bharati, has enabled the measurement of halogen compounds in the lower troposphere, contributing to the validation of halogen emission parameterizations within atmospheric chemistry models.
- High-Altitude Balloonsonde Campaign – a collaborative observational campaign was

conducted in August 2023 involved high-altitude balloonsonde measurements at Nainital, India, aimed at investigating water vapor transport into the lower stratosphere and its implications for ozone layer dynamics.

- Paleoclimatological Studies Using Dendrochronology: Research utilizing tree-ring chronologies from various sites in the Western Himalayas provides insights into historical climatic variations, highlighting the influence of hydrological factors on tree growth and regional climate responses over millennia.
- **ICRC-CORDEX 2023 Conference:** The International Conference on Regional Climate - Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX-2023) was successfully organized jointly by CCCR-IITM, MoES, the Abdus Salam International Centre for Theoretical Physics (ICTP, Italy), the Swedish Meteorological and Hydrological Institute (SMHI), and the World Climate Research Program (WCRP) with physical hubs in Pune, India and Trieste, Italy in hybrid mode during 25-29 September 2023. It was attended by 67 offline (in person) participants and 36 online participants.

Climate Variability and Prediction (CVP)

- Developed the **first version of IITM Decadal Climate Prediction System (IITM-DCPS).** Decadal hindcasts/forecasts prepared for the period of 1980-2023 and made available to the WMO Lead Centre for Global Annual to Decadal Climate Update https://hadleyserver.metoffice.gov.uk/wmolc/
- Variability of summer monsoon depressions over the Bay of Bengal with special emphasis on El Niño cycle has been studied. Improvement in the skill of CMIP6 decadal hindcasts for extreme rainfall events over the Indian land mass have been studied.For the first time, in the study, used the quantile mapping approach to downscale and bias correct the CMIP6 DCPP rainfall simulation/ hindcast for the better representation of EREs.

Atmospheric Research Testbeds (ART)

- IITM has established three ART sites across India viz., Orographic-ART at Mahabaleshwar (High Altitude Cloud Physics Laboratory - HACPL) and the Urban-ART focused on the Mumbai Metropolitan region and ART- Central India to provide important observations for better understanding on processes related to convection, clouds, and land-atmosphere interactions in the core monsoon zone region.
- The Atmospheric Research Testbest facility in Central India (ART-CI) has been inaugurated virtually by Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences on 12th March 2024. This ART-CI is established on ~100 acres of land in Silkheda, Sehore district, Madhya Pradesh. IITM has deployed first phase of atmospheric instrumentation and started observations using Dual Polarization C-band Doppler Weather Radar, Microwave radiometric profiler, Ceilometer, Micro rain radar, Disdrometer, Radiosonde, 72 m tall tower for GHG and flux measurements, CCN counter and Aethalometer. The physical infrastructure such as 33 KV electrical sub-station, internal roads connecting different observing facilities, boundary wall with main entrance gate, security cabins, solar streetlights, high mast lights for illuminating the campus etc. have been established in the campus.
- **Monsoon-2023 observational campaign has been conducted** at ART-CI using an established set of sophisticated instruments such as C-band Dual Polarization Doppler Weather Radar, etc to study convective and microphysical properties in the monsoon core zone. The campaign was in coordination with IMD RS/RW sites (twice daily) in the Central Indian region. The datasets generated have been shared with NCMRWF, Delhi for data assimilation & preparation of initial conditions in modelling study.
- Several observational studies and model sensitivity experiments of cloud and precipitation microphysical processes have been conducted at

the **High-Altitude Cloud Physics Laboratory at Mahabaleshwar (Orographic ART)**. The Potential Aerosol Mass (PAM) oxidation chamber to investigate the oxidation of precursor gases have been implemented which produce secondary organic aerosol (SOA) mass and in turn its role on CCN activation.

- As part of Mumbai MESONET, four short-range X-band dual-polarimetric radars in the form of a network is being set up over the Mumbai Metropolitan region to better capture the spatial and temporal variability of rainfall.
- A disdrometer network for rainfall microphysics in the ten cities (viz., New Delhi, Mumbai, Kolkata, Chennai, Pune, Mahabaleshwar, Kochi, Bhopal, Silkheda, Lakshadweep Island) has been established. These locations differ widely with respect to their geographical and climatic variations.
- Under the **Lower Atmospheric Research Using Unmanned Aerial System Facility (LARUS), Unmanned Aerial Vehicle (UAV) mission flight**s were conducted successfully with onboard instrumentation for boundary layer profiling of meteorological parameters and aerosol physical and chemical properties over Osmanabad.
- **Drone-based observational campaign was conducted at ART Bhopal** in collaboration with NIOT Chennai using in-house designed mini GHG gas sensor system around 72m tower for inter comparison of CO_2 and CO. A portable mini Radiosonde Ground Receiver (mRGR) System was developed at IITM for meteorological data telemetry from a UAV/Drone/Balloon, and published as IITM Technical Report.

Physics and Dynamics of Tropical Clouds (PDTC):

- **The Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)** Phase-IV Program aims to understand cloud and rainfall processes in tropical clouds and to formulate guidelines for rain enhancement through cloud seeding. IITM conducted an airborne observational campaign in 2018-19 included cloud seeding and detailed observations of clouds and their processes; with over 480 hours of observations. CAIPEEX Phase IV results have been published in BAMS. A Policy and guidance report on cloud seeding by MoES has been released during MoES Foundation Day -2023 which is available online.
- Under the CAIPEEX, comprehensive Ground Observations at Solapur and Tuljapur have been conducted. Continuous data collection on meteorological parameters, aerosol characteristics, cloud, and precipitation properties is ongoing, supported by advanced observational instruments like C-band radar, wind profilers, and automatic rain gauges. The network of 120 automatic rain gauges has been upgraded to ensure real-time monitoring.
- **IITM participated in the** EKAMSAT/ ASTRAL (Arabian Sea Transition Layer) cruise field campaign during 8-26 June 2023 over Arabian Sea. IITM focusses on the investigation of high concentration of black carbon aerosols during monsoon over the Arabian Sea. For this, various sophisticated instruments such as Aethalometer, Scanning Mobility Particle Sizer (SMPS), Cloud Condensation Nuclei (CCN) counter; Aerosol sampler, Dust collector Microtops sun photometer have been deployed on the Cruise.
- Approved by the Ministry of Earth Sciences (MoES), the Urban Meteorological Network in Delhi is being deployed. This initiative focuses on establishing a comprehensive observational system in New Delhi. The project includes advanced instrumentation such as wind profilers, lidars, microwave radiometers, and X-band radar to monitor aerosols, clouds, and meteorological variables for urban weather forecasting.
- Pre-Monsoon Lidar Campaign for Aerosol Profiling was conducted in collaboration with SRM University to profile vertical aerosol distributions during the pre-monsoon season at Solapur. This study is

critical for understanding aerosol-cloud interactions and their potential impacts on the monsoon transition period.

- Development of Wall-Turbulence Models and Monsoon Jet Simulations: The Fluid Dynamics Laboratory (FDL) developed a new theoretical framework for modeling friction in wall turbulence and established a wall-jet experimental setup to simulate the dynamics of the monsoon low-level jet. The lab also introduced an innovative technique for identifying turbulent-nonturbulent interfaces (TNTI) in wall jets.
- Under the North East India Observational Network (NEION) project, new observational sites equipped with micro-rain radars, automatic rain gauges, and disdrometers have been established across Assam and Arunachal Pradesh. These additions are essential for improving rainfall estimation and prediction capabilities in the complex terrains of North-East India.
- Under the project - **Thunderstorm Dynamics** research reveals that pre-monsoon thunderstorms show more intra-cloud lightning compared to monsoonal thunderstorms. The cold cloud depth is most prominently linked with the with the observed IC:CG ratio. The implication of these observed results has the importance of separating CG lightning flash from total and can be used in numerical models to give a proper prediction of CG lightning in hazard mitigation.
- The occurrence of lightning over India is being monitored by IITM's Lightning Location Network (LLN). The LLN data is being shared in real-time with IMD and NCMRWF for inclusion in their forecast models and shared with National Disaster Management Authority (NDMA) & disaster management authority of various States such as, Andhra Pradesh, Odhisa, Uttarakhand, Uttar Pradesh and Tamil Nadu for producing lightning alerts in respective State's weather alerts. The LLN has been augmented with addition of 9 sensors and upgradation of servers. The updated version of DAMINI- Mobile App provides Lightning alerts in 15 languages.
- IITM has participated in the **India's maiden Arctic Winter Expedition (18 December 2023 to 15 January 2024) - FIRST TIME by India –** which was launched by HMoES on December 18, 2023. IITM has successfully installed Electric Field Mill and Maxwell current Antenna at Himadri which are operational now and data is being generated. This activity has been taken up under the project entitled "Study of lightning and global Electric circuit over Artic in Climate change scenario" - approved for the Indian Arctic Expedition November 2023 –March 2024.
- IITM has established collaborations with universities and State Disaster Management Authorities for research on thunderstorms and lightning.
- **Air Quality Early Warning System (AQEWS) and Metropolitan Air Quality and Weather Services (MAQWS)**
- As recommended by Research Advisory Committee of IITM, all three programs **Air Quality Early Warning System (AQEWS), Metropolitan Air Quality and Weather Services &Winter-Fog EXperiment (WiFEX)** have been merged together since 2023.
- **For air quality forecasting, IITM has developed next generation Air Quality Early Warning (AQEWS) and Decision Support System (DSS) Framework. This** AQEWS includes assimilation of chemical data from all types of monitoring platforms to improve the chemical initial condition. Established atmospheric chemistry observatory at Delhi for real-time source apportionment of Gases and Aerosol, under RASAGAM project and initiated 21 members ensemble forecasting for north India.
- The Decision Support System (DSS) developed by IITM enhances air quality management by quantifying contributions from local emissions and

external sources, including biomass burning from neighboring states. It operates using a numerical model framework that assimilates data from ground-based and satellite sources, providing actionable insights for emission reduction strategies during critical pollution episodes.

- The Decision Support System version 1.0 has demonstrated its utility in quantifying the impact of emission reductions on PM2.5 levels in Delhi. For instance, a projected 20% reduction in emissions could lead to a significant 12% decrease in PM2.5 concentrations, highlighting the system's capability to inform effective air quality management strategies.
- IITM has extended the AQEWS and DSS framework for Jaipur under a MoU signed with Rajasthan State Pollution Control Board (RSPCB). "Early warning and decision support system for air quality management in Jaipur".
- IITM has coordinated the MAPAN, SAFAR and mobile van activities for long term air quality measurements by aligning AQEWS and MAQWS. Under the System of Air Quality and Weather Forecasting and Research (SAFAR) project, regular air quality observations are being provided for four cities viz., for Delhi, Mumbai, Pune and Ahmedabad. As part of **MAPAN network** over the Himalayan Region, **MoU** for real time monitoring of air pollutants have been signed with: i) Hemvati Nandan Bahuguna Garhwal University (HNBGU), Srinagar Garhwal, Uttarakhand, India; ii) Sikkim University, Gangtok, Sikkim.
- IITM has **developed Air quality Integrated system for Risk Warning and Safety Enhancement (AIRWISE) for Megacities**. Operational support has been provided in existing daily Air Quality Forecasting systems (AQEWS) for Delhi and QATAR.
- **Winter Fog Campaign WiFEX (2023-24) was** successfully conducted during Nov 2023 to Feb 2024. State-of-the-art aerosol lab was set up at IMD headquarters as a part of WiFEX 23-24. The Cloud Condensation Nuclei Counter and Humidified Tandem Differential Mobility Analyzer were deployed at the IMD Aerosol Lab. Two sites viz., New Delhi Airport and upcoming NOIDA International Airport, Jewar were made operational during the campaign by adding sensors to measure atmospheric, radiation and soil parameters. Remote sensing instruments (ceilometer and microwave radiometer) were placed at the New Delhi airport supersite to probe boundary layer dynamics during fog episodes. A mobile fog observatory was set up with basic weather sensors and fog monitoring device (FM-120) to investigate the microphysical structure of fog in the IndoGangetic Plain. As a part of WiFEX 23-24, observations were carried out in different environments such as urban, semi-urban, rural and valley regions.

National Monsoon mission

The Monsoon Mission aims to improve the prediction of the Indian monsoon across all time scales, specifically by developing partnerships between national and international academic institutions, R&D organizations, and the Ministry of Earth Sciences (MoES). Significant improvements in the skill of seasonal, sub-seasonal and short and medium range forecasts of the Indian monsoon have resulted from the National Monsoon Mission (NMM). Following the successful outcomes from the first and second phases of the NMM, the third phase NMM-III was approved by the MoES, Govt. of India.

Short and Medium Range

- The IITM High-Resolution Global Forecast Model (HGFM), launched under the "Make in India" initiative in November 2023, has been run daily on an experimental basis since June 2022. A thorough evaluation is underway, and it is set to be handed over to the India Meteorological Department. The experimental forecast is accessible online.

- IITM has developed the Extreme Forecast Index (EFI) based on 10 years of Global Ensemble Forecast System (GEFS) climatology. The EFI provides a 5-day lead time for extreme weather events, capturing potential extremes well in advance, and has been handed over to IMD for daily operational forecasts.
- The GEFS T1534 ensemble forecasts accurately predicted the tracks, intensity, and landfall of tropical cyclones in 2023, including "MOCHA," "BIPARJOY," "TEJ," "HAMOON," "MIDHILI," and "MICHAUNG." These forecasts were used by IMD to generate final operational predictions.
- IITM's 6.5 km HGFM (Tco1534) model also accurately predicted the track, intensity, and landfall of cyclonic systems. Both GEFS and HGFM forecasts were shared with IMD, and ensemble tracks are available on IITM's website for public access.
- A bias-corrected GFS quantitative precipitation forecast has been developed for efficient flood forecasting in river basins across India. Wind and solar forecasts are also provided to public and private stakeholders.
- IITM signed an MoU with the Defence Research Development Organization's Armament Research and Development Establishment (ARDE) in October 2023. Under this collaboration, IITM provides GFS model forecast data for strategic defense locations based on ARDE's requirements.
- Revised cloud processes in the CFSv2 model at T126 (~100 km) resolution have improved the simulation and prediction of Indian summer monsoon rainfall, with better representation of cloud hydrometeors. This has led to improvements in rainfall variability and the northward propagation of rainfall bands.
- The Global Ensemble Forecast System (GEFS T1534) showed reasonable skill in predicting cyclonic disturbances over the North Indian Ocean during 2020-2021. The model accurately forecasted the genesis, track, intensity, and landfall of cyclonic disturbances with reduced track and landfall errors, providing critical insights for operational use.

Sub-seasonal Scale

- Accurate convection parameterization is crucial for minimizing model biases in simulating extreme events. New-Tiedtke scheme excels in predicting extreme precipitation events due to better representation of convection and low clouds.
- Cold wave (CW) events in India occur from November to February, with a new criterion and multi-model ensemble system used for monitoring and prediction. The multi-model ensemble system predicts CW events effectively up to 2-3 weeks in advance despite decreasing confidence for longer leads.
- Soil moisture plays a significant pre-conditioning role during active monsoon phases, influencing rainfall and boundary layer MSE. CFS model fails to capture realistic soil moisture feedback, contributing to rainfall dry bias.
- Analysis of large-scale convection and circulation changes during ISM 2022 reveals distinct patterns in precipitation and circulation between active and break phases.

Seasonal Scale

- Under Monsoon Mission-III, notable R&D advancements include the operationalization of the COARE 3.0 bulk flux algorithm with diurnal ocean skin temperature parameterization in CFSv2 to enhance model accuracy.
- The MMCFSv2 (Monsoon Mission Coupled Forecast System version 2.0) has significantly upgraded key components such as the atmospheric model (switching from Eulerian to Semi-Lagrangian dynamical core) and the ocean model (from MOM4 to MOM6), improving resolution and parameterization of physical processes.
- A new lightning parameterization scheme was developed for the Global Climate Model (GCM),

improving the prediction of extreme weather events related to lightning by incorporating aerosol-cloud interactions and advanced physical processes.

- International collaborations with organizations such as JAMSTEC, NTU Taiwan, and the UK Met Office (under the WCSSP program) have enhanced research on intra-seasonal variability and the simulation of Monsoon Intraseasonal Oscillations (MISOs), with a focus on correcting biases in monsoon rainfall predictions.
- Research under the Monsoon Mission has demonstrated that including river-routing models in CFSv2 improved sub-seasonal variability, particularly enhancing the representation of low-pressure systems (LPS) and MISO northward propagation by accurately simulating oceanic processes and air-sea interactions, which are vital for better monsoon predictions.

Unified model framework for Monsoon Variability and Predictability (UMVP)

- The Monsoon Mission-UMVP project has made notable advancements in improving the land model component of the CFS climate model. By increasing soil depth to 10 layers (totalling 10 meters), the project enhances the model's ability to simulate soil temperature and moisture, leading to a more accurate representation of land-atmosphere interactions. Additionally, the introduction of the Ball-Berry transpiration scheme improves the portrayal of plant physiology and evapotranspiration, resulting in more realistic rainfall predictions for the monsoon season.
- IITM's research has uncovered a significant link between spring land surface temperatures in the Western Third Pole region and June rainfall across the Asian monsoon zone. This relationship underscores the role of land surface processes in shaping monsoon variability. However, current climate models, including the IITM CFS, need to improve their ability to capture this teleconnection, particularly the impact of spring temperatures on subsequent monsoon rainfall, as highlighted by the LS4P project.

International Monsoons Project Office (IMPO)

- The IMPO was established in February 2022 at IITM through an agreement between IITM & WMO, with support from MoES, to support monsoon research activities of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP).

High Performance Computing (HPC) System

- **Pratyush HPC:** A 4 Petaflop HPC system is the only HPC system (has worldwide rank 201 on top500.org) available for R&D purpose for IITM and other MoES institutes. (The uptime Percentage: **99.5;** System issues resolved: **651;** User application issues handled: **521).** With the current 4 Petaflops HPC Pratyush, a new HPC system capacity (12.9 Petaflop, including 1.16 Petaflop separate AI/ML system) is under process of installation at IITM.
- **Atmospheric Research Data Center (ARDC):** Large data about **1.2 Petabytes** of data has been uploaded on the ARDC server and **238** users have registered to download the required data.
- **MoES AI/ML Virtual Center:** Under this, following developmental activities took place:

  Climate Downscaling and Prediction: Key advancements in applying deep learning for climate downscaling and weather prediction, including high-resolution urban precipitation models and global precipitation forecasting.

  Deep Learning for Weather Prediction in global scale: Novel methods are introduced for global precipitation prediction. This modified approach enhances the forecasting process, showing significant potential for creating efficient digital twins for real-time weather simulations.

Capacity Building and Human Resource Development

- 12 students graduated with a PhD, while 07 have submitted their doctoral thesis during the year 2023-24. The M.Sc. and MTech. Programmes in Atmospheric and Space Sciences are continued in collaboration with S.P. Pune University, Pune. More than 57 students of different UG/PG courses in science and engineering from various colleges, universities and institutions across the country were provided research guidance and facilities for their short-term project/internship under the guidance of IITM scientists.
- To facilitate Ph.D. admissions through AcSIR at IITM, an agreement (MoU) with the Academy of Scientific and Innovative Research (AcSIR) for Ph.D. program was signed on 25 January 2023. Under this MoU, IITM has become an Associate Academic Centre of AcSIR and has admitted 03 Ph.D. students through AcSIR channel to work for Ph.D. degree of AcSIR during academic year 2023-24. Apart from this, 08 IITM-JRFs also joined during 2023-24.
- IITM collaborates with universities to offer academic courses like M.Sc., M.Tech., and PhD, enhancing expertise in weather and climate sciences.
- DESK, under the REACHOUT programme, provides specialized training through JRF/SRF programmes and organizes workshops on targeted atmospheric science topics.
- The MoES Research Fellowship Programme (MRFP) successfully trained and recruited 12 JRFs in 2023 through an online selection process, preparing them for research in various institutes. Annual Progress Review were conducted for 32 MRFP Fellows from Batches I-III, providing feedback to students and their supervisors. MRFP students have published 59 research papers since 2019, with contributions to high-impact journals and collaborative research. Apart from this, the MRFP candidates actively engaged in academic conferences and workshops.
- DESK organized several national training workshops and webinars in 2023-24 with help of Library, Information and Publication Division and Computer Data Division of IITM, with topics ranging from climate impacts of carbonaceous aerosols to Weather Research and Forecasting (WRF) and Prof. Ananthakrishnan Colloquium, etc.

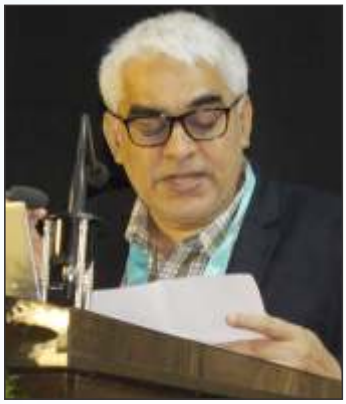
Library, Information and Publication Division:

- The LIP division managed the library resources, subscriptions, and digital content, including videos, reports, publications, institutional website and social media sites. It played a significant role in highlighting IITM achievements and actiticotes (including Rajabhasha activities, etc). In 2024, IITM has added Instagram and Linked-in accounts also. LIP played a role in popularizing meteorology and atmospheric sciences through various outreach activities.
- IITM organised several national and international virtual workshops, seminars, conferences, meetings, and short-term training programmes on different aspects of weather and climate sciences during the year.
- IITM has actively worked towards the **Rajbhasha official language implementation.** IITM staff participated in many events conducted and won awards. Under Sports activities**,** IITM has achieved numerous trophies and delivered outstanding performances at the MoES sports meet organized at INCOIS.

ICRC-CORDEX 2023

Dignitaries on dias (L-R) Dr. R. Krishnan, Dr. Kamaljit Ray and Dr. J. Sanjay

Lamp Lighting



Welcome address by
Dr. R. Krishnan

Inaugural address by
Dr. Kamaljit Ray

Keynote talk by
Prof. Koji Dairaku

Sessions in progress

Poster Session

Press Conference

Participants

Visit of Shri Kiren Rijiju
Honourable Cabinet Minister of Earth Sciences, Govt. of India,

Visit of Shri Kiren Rijiju, Honourable Cabinet Minister of Earth Sciences, Govt. of India to IITM Pune

Visit of Shri Kiren Rijiju, Honourable Cabinet Minister of Earth Sciences, Govt. of India to the High Altitude Cloud Physics Laboratory (HACPL) at Mahabaleshwar

62nd IITM FOUNDATION DAY CELEBRATIONS

Dignitaries on dias (L-R): Dr. R. Krishnan, Shri Nilesh Desai, Prof. Janardhan Padmanabhan and Dr. S.S. Fadnavis

Welcome Address by Dr. R. Krishnan

Lamp Lighting

Opening Address (online) by Dr. M. Ravichandran

Inaugural Address by Shri Nilesh Desai

Foundation Day Lecture by Prof. Janardhan Padmanabhan

Foundation Day Lecture (online) by Prof. Trenton Franz

(L-R) Mr. Ajit Prasad, Mr. Saffi Saiyad, Mrs. Manini Das and Mr. P.P. Vyawahare receiving 'IITM Best Employee Award 2023' for Administrative Staff Category.

(L-R) Dr. B.S. Murthy, Mr. V. Gopalakrishnan, Dr. Padma Kumari, Dr. H.S.Chaudhari, Mr. P. Murguvel, Dr. M.N. Patil, Dr. Prashant Pillai, Dr. Sabin T.P. and Dr. Rashmi A. Kakatkar receiving 'IITM Best Employee Award 2023' for Research Staff Category.

(R-L) Dr. Thara Prabhakaran, Dr. P Mukhopadhyay, Dr. Vinu Valsala, Dr. Medha Deshpande, Dr. Rahul Reddy, Mr. Yogesh Pawar and Mrs. Ashwini Pendharkar receiving Award for 'Outstanding Contribution in Implementation of Official Language'

Glimpse of the cultural activities on the occasion of the Foundation Day Celebrations

MINI-WORKSHOP ON

MoES VISION DOCUMENT FOR AMRIT KAAL (2047)

Meeting in progress

Participants

AIR FORCE OFFICER TRAINING PROGRAM

Air Force Officer Training Program: Session in progress, Lab visit and Participants

VISITORS

Dr. Evgueni Poliakov
USA

Mr. Siddhant Kerhalkar
USA

Prof. Mark Baskaran
USA

Prof. Ralf Toumi
UK

Dr. Jothiram Vivekanandan
USA

Dr. Sharmila Sur
Australia

Ms. Anja Katzenberger
Germany

Dr. Nitin Chowdhary
Sweden

Mr. Gautam Martanda
Germany

Dr. Grisa Mocnik
Slovenia

Dr. Ankur Srivastava
Australia

Dr. Tani Satyanarayana
Austria

Dr. Elizabeth A. DiGangi
USA

Prof. Pinaki Chakraborty
Japan

Dr. Vivek Mugundhan
Saudi Arabia

Dr. Steven Dobbie
UK

NATIONAL RAJBHASHA SEMINAR

HINDI PAKHWADA CELEBRATIONS

Welcome Address by Mr. Hans Pratap Singh

Dignitaries on dias

Inaugural Address and Release of 'Indradhanush' Hindi in-house magazine by Dr. R. Krishnan

Prize Distribution at 'Hindi Pakhwada Celebrations' Concluding Function

SWACHHATA ABHIYAN

Pledge administrated on the occasion of 'Swachhata Abhiyan'

Swachhata Abhiyan at PMC Hospital, Pashan

HEALTH CHECK-UP and BLOOD DONATION CAMPAIGN

Health Check-up and Blood Donation Campaign at IITM Pune

PLEDGE ADMINISTRATED ON VARIOUS OCCASIONS

'Unity Day'

'Constitution Day'

'Voters' Day'

'Vigilance Awareness Week'

SCIENCE POPULARIZATION

Visitors on Open Day, National Science Day Celebrations at IITM, Pune

Institute's Participation at National Science Day Celebrations, GMRT Narayangaon

WMO Day Lecture by Dr. Rupa Kumar Kolli

INDIA INTERNATIONAL SCIENCE FESTIVAL

Institute's Participation at India International Science Festival, Gurgaon

INTERNATIONAL DAY OF YOGA CELEBRATIONS

1. R&D Activities

Most of the R&D activities of IITM come under two major schemes of MoES: a) Monsoon Convection, Clouds and Climate Change (MC4), and b) Monsoon Mission. This chapter covers some important R&D work done and achievements during the year. For convenience, the major R&D activities executed at IITM are grouped into subheads and accordingly, this chapter is divided into sub-chapters as shown below:

1.1. Monsoon Convection, Clouds and Climate Change (MC4)

1.1.1. Centre for Climate Change Research (CCCR)

1.1.2. Physics and Dynamics of Tropical Clouds (PDTC)

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

1.1.2.2. Thunderstorm Dynamics

1.1.3. Atmospheric Research Testbeds (ARTs)

1.1.3.1. Central India ART, Silkheda (Bhopal)

1.1.3.2. Orographic ART (HACPL)

1.1.3.3. Urban ART (Radar and Satellite Meteorology)

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

1.1.4. Air Quality Early Warning System (AQEWS) and, Metropolitan Air Quality and Weather Services (MAQWS)

1.1.5. Climate Variability and Prediction (CVP)

1.2. Monsoon Mission

1.2.1. Short and Medium Range

1.2.2. Sub-seasonal Range / Extended Range Prediction

1.2.3. Seasonal Scale

1.2.4. Unified model framework for Monsoon Variability and Predictability (Monsoon Mission-UMVP)

1.2.5. International Monsoons Project Office (IMPO)

1.1.1. Centre for Climate Change Research (CCCR)

Project Director: Dr. J. Sanjay

Objectives

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

R&D Activities:

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

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

Highlights of Major Achievements

- Enhancement of Climate Understanding: The CCCR is dedicated to advancing the fundamental understanding of the Earth's climate system, focusing on identifying novel research areas pertinent to regional climate dynamics over the Indian subcontinent.
- Investigation of Biogeochemical Interactions: Research initiatives aim to elucidate biogeochemical interactions and their responses to environmental changes, particularly in relation to global warming phenomena such as monsoons and El Niño events.
- Development of IITM Earth System Model (IITM-ESMv3): The ongoing development of the IITM-ESMv3 incorporates high-resolution modeling techniques, including a triangular cubic octahedral grid, to enhance simulations of regional climate dynamics and improve precipitation bias over South Asia.
- Eddy Covariance Systems for Greenhouse Gas Monitoring: The implementation of eddy covariance systems equipped with CO_2, CH_4, and H_2O sensors across diverse ecosystems facilitates real-time monitoring and quantification of net ecosystem exchange (NEE) of greenhouse gases.
- Collaborative Research Initiatives: Strategic Memoranda of Understanding (MoUs) with institutions such as Tezpur University and Aryabhatta Research Institute promote collaborative research on biosphere-atmosphere gas exchanges, enhancing data collection and analysis capabilities.
- Atmospheric Chemistry Observations in Polar Regions: Instrumentation deployed at the Indian Antarctic base, Bharati, has enabled the measurement of halogen compounds in the lower troposphere, contributing to the validation of halogen emission parameterizations within atmospheric chemistry models.
- High-Altitude Balloonsonde Campaign: A collaborative observational campaign conducted in August 2023 involved high-altitude balloonsonde measurements at Nainital, India, aimed at investigating water vapor transport into the lower stratosphere and its implications for ozone layer dynamics.
- Paleoclimatological Studies Using Dendrochronology: Research utilizing tree-ring chronologies from various sites in the Western Himalayas provides insights into historical climatic variations, highlighting the influence of hydrological factors on tree growth and regional climate responses over millennia.

DEVELOPMENTAL ACTIVITIES

Development of next-generation IITM Earth System Model (IITM-ESMv3):

Significant progress has been made in the development of the next generation IITM Earth System Model (IITM-ESMv3), which will contribute to the CMIP7 experiments of WCRP and IPCC Assessment Report.

High resolution global Earth System model, IITM Earth System Model version-3 (IITM-ESMv3) with horizontal resolution of 67Km has been developed at CCCR, IITM. Successfully implemented triangular cubic octahedral grid (TCO grid) in IITM-ESM and is tested for TCO126 with 67 Km horizontal resolution. A 150-year long control simulation has been performed with IITM-ESMv3 and analysis shows improvement in the dry bias in precipitation over South Asian region and improvement in large-scale circulation features as compared to previous version. New vegetation scheme based on NRSC LULC data and new ocean grid with increased resolution near tropical regions are being tested in the IITM-ESMv3 **(Fig. 1)**. The IITM-ESMv3 version will be frozen and a pre-industrial control simulation as part of CMIP7 will be initiated using IITM-ESMv3 by December 2024. The CMIP7 forcings from WCRP is expected by the mid of 2025 and the other simulations as part of CMIP7 with IITM-ESMv3 will be initiated in 2025. The high-resolution climate projections will provide important information about the regional climate change in the Indian region.

High resolution (25Km) atmospheric-only version of IITM-ESM simulation for the historical and near future period is about to complete and the datasets will be disseminated publicly through the ESGF server at CCCR.

Greenhouse gases:CCCR is observing continuous in-situ atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), water vapor (H_2O), and its isotopes ($\delta^{13}C$, ^{17}O, ^{18}O) at Sinhagad, IITM Pune, and ART Silkheda Bhopal. Here are the details of these observations:

Fig.2: *GHG monitoring at Sinhagad, IITM Pune, and ART Silkheda Bhopal.*

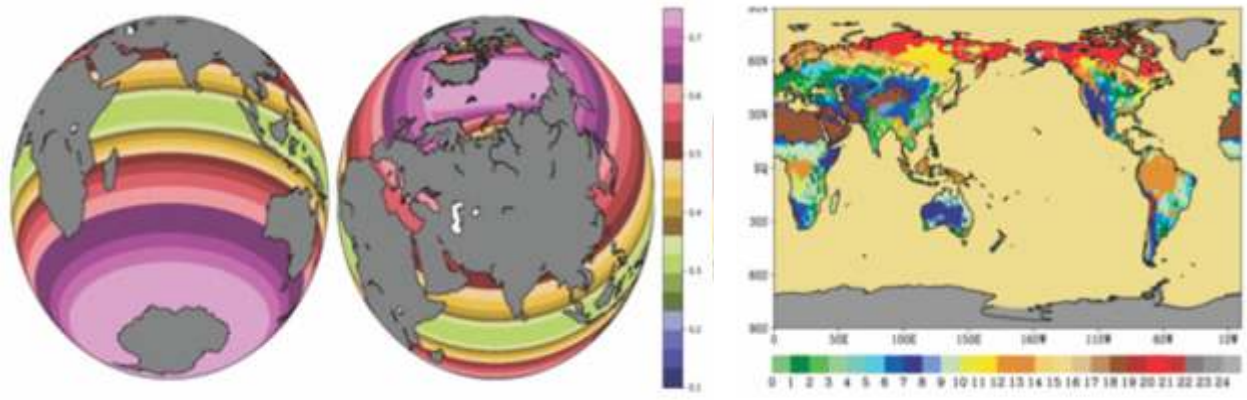


Fig. 1: *The new ocean grid developed for IITM-ESMv3 (left panel) and land-use land-cover data based on NRSC over the Indian region with 24-type vegetation types in IITM-ESMv3 (right panel).*

ART-CI, Silkheda (SKD), Bhopal: This site, located in Central India, falls under the core monsoon zone. Obtaining observations from this region will provide valuable information, enhancing understanding GHG emissions in this region. Multilevel measurements of GHG concentration, fluxes, radiation, and weather parameters are being observed at this site. With a 72-meter tall tower, GHG concentrations at three-levels, two-level eddy covariance measurements, PAR and Line PAR sensors, and multicomponent weather measurements have been conducted since March 2023. Multilevel measurements will facilitate information about the variation and mixing of GHGs within the first 100m of the boundary layer. **Figure 3** shows site locations and laboratories. Figure 3 shows the temporal variation of GHGs (CO_2, CH_4, and CO) at different heights over the Silkheda Bhopal during March 2023- Jan 2024. High CO_2 concentrations were observed during pre-monsoon and post-monsoon months, whereas low concentrations were observed during the monsoon and winter months. The maximum CH_4 and CO concentrations are observed in post-monsoon to winter months, with minimum concentrations observed during the summer monsoon months.

Sinhagad (SNG) site: The Sinhagad site has been operational since 2010, and air samples collected at weekly intervals analyzed using Gas chromatography at IITM, Pune. In Dec 2022, high temporal frequency (1Hz) GHG analyzer were installed to continuously monitor GHG concentrations, along with a weather and radiation sensor at Sinhagad site. **Figure 4** shows the temporal variation of GHGs at Sinhagad site during 2023. The 5th and 95th percentiles indicate local anthropogenic emission influences on increasing GHG concentrations over this site. The maximum CO_2 concentration is observed during pre-monsoon season, while the minimum is observed during the monsoon season. High concentrations of CH_4 and CO are observed during the post-monsoon to winter seasons, with low concentrations observed in monsoon season.

IITM Pune site: The Pune site has been operational since 2016, where isotopic analysis of CO_2, CH_4, and CO has been conducted using high-precision in-situ instruments at IITM Pune. Additionally, isotopic analysis of CO_2, ($\delta^{13}C$, ^{17}O, ^{18}O) has been carried out since 2018 using high-frequency in-situ instruments at IITM Pune.

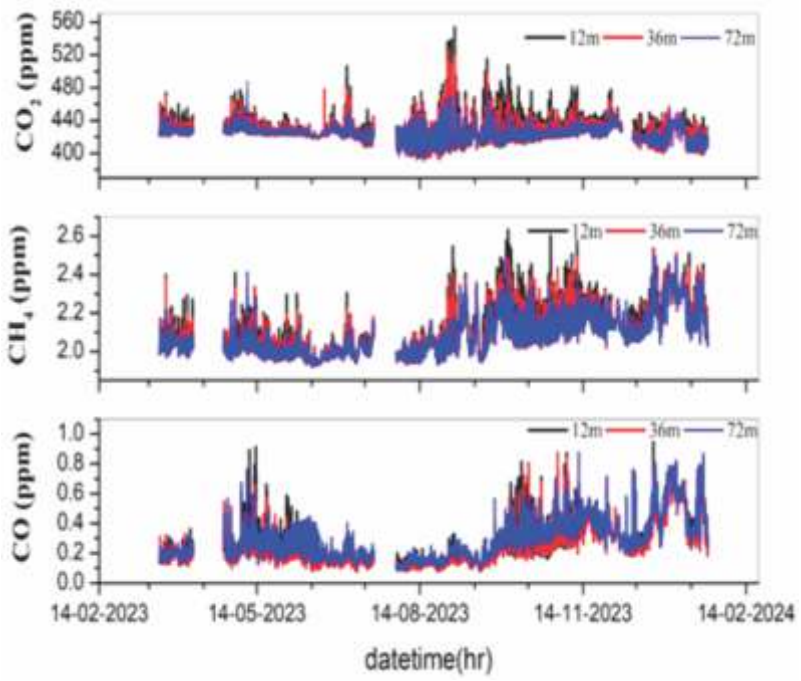


Fig.3: *Temporal variation of GHG concentration at different heights at 72-meter tower at ART Silkheda Bhopal.*

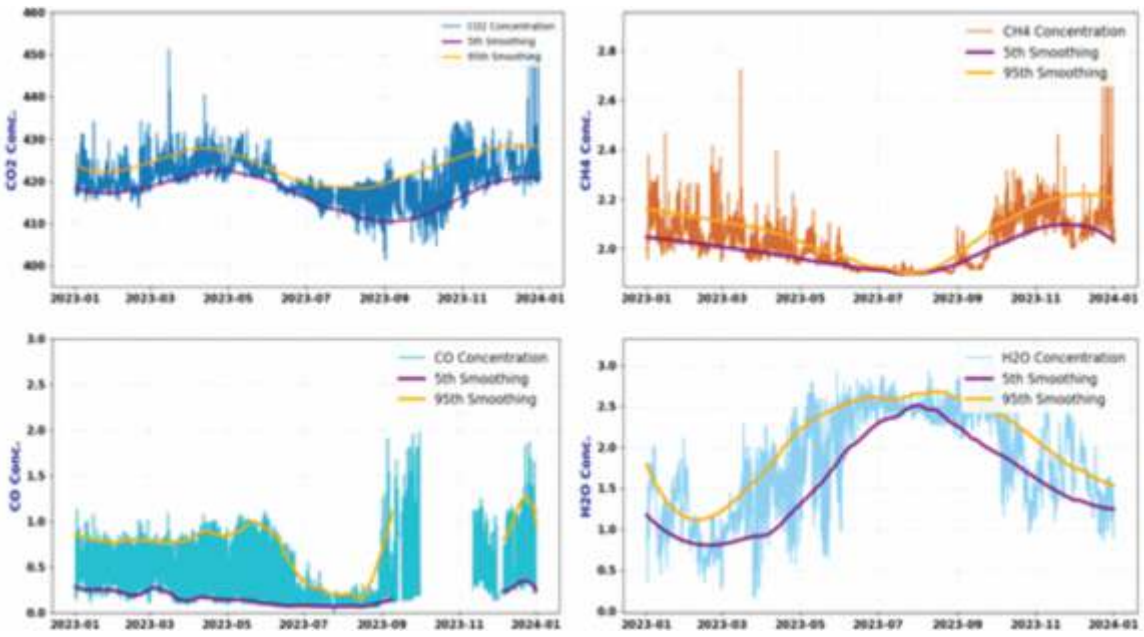


Fig.4: *Temporal variation of GHG concentrations (CO_2, CH_4, CO, and H_2O) at Sinhagad during 2023.*

Figures **5a-c** show time series of hourly averaged concentrations. A data gap for CO during 2018-2021 is due to instrument change. The CCGCRV method extracted annual means, trends, seasonal amplitudes. Over the study period, CO_2 rose from 407±3.77 ppm to 422.255±4.19 ppm, CH_4 increased from 1.9657±.07 to 2.0733±0.10 ppm, and CO rose from 0.26±0.13 to 0.40±0.10 ppm. All gases exhibited an upward trend, with CO_2 showing a more pronounced annual increase (2.5 ppm/year) compared to CH_4 (16.8 ppb/year). These trends indicate rising levels of these greenhouse gases, highlighting the need for monitoring and mitigation strategies to address their impact on the environment and climate.

As part of the Metflux project, IITM installed an Eddy Covariance system (CO_2-H_2O sensor, CH_4 sensor, Sonic Anemometer) along with weather sensors at the Pichavaram tower site. The installation has been completed at the National Centre for Coastal Research, Chennai. To ensure the smooth functioning of the Pichavaram, Port Blair, and Lakshadweep sites, IITM is collaborating with MoES institutes, as recommended by the national committee. Additionally, efforts are being made for site identification at the Coringa Mangrove

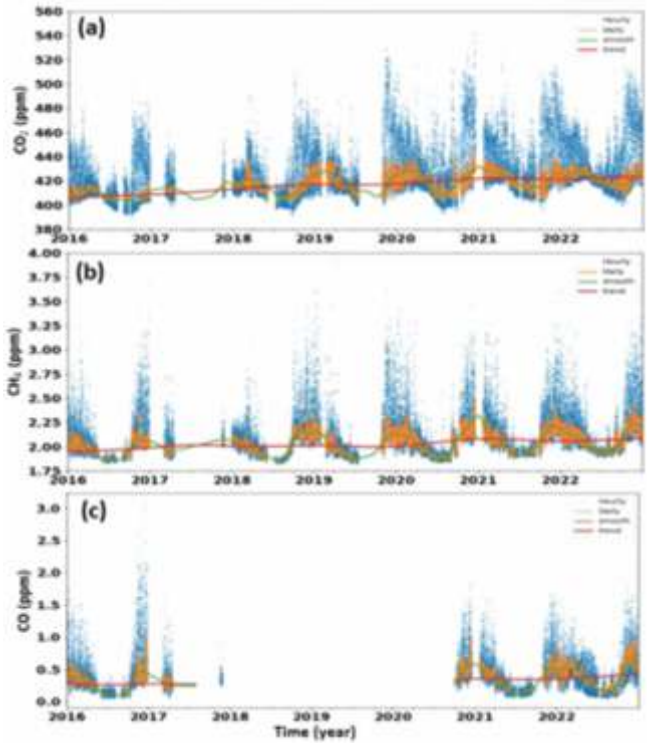


Fig.5: *In-situ observations of atmospheric (a) CO_2, (b) CH_4, and (c) CO concentrations at IITM Pune. Blue dots show hourly values; orange lines show daily averages; green is a smooth line; and red is a trend. Carbon Monoxide (CO) shows a data gap during 2018-2021 due to an instrument change that does not measure CO.*

Forest near Kakinada, Andhra Pradesh, to install a flux tower, with necessary permissions being pursued from the forest department.

In a bid to foster collaborative research on biosphere-atmosphere exchanges of greenhouse gases and energy fluxes being monitored at Kaziranga National Park, Assam, IITM signed an MoU with Tezpur University, Assam, on 15th July 2023.

Similarly, for the promotion of collaborative research on biosphere-atmosphere exchanges at Devasthal, near Nainital, Uttarakhand, IITM signed a MoU with Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital. An Eddy Covariance system (CO_2-H_2O sensor, Sonic Anemometer) has been installed at ARIES, Nainital.

Under the COSMOS program, a hydrometeorological observation system was set up at KBC-NMU, Jalgaon. As field-scale soil moisture (SM) observations using COSMOS are expensive and challenging for small to medium farmers in India, IITM's observational group developed reliable and cost-effective indigenous SM sensors for farmers. IITM also signed an MoU with Kavayitri Bahinabai Chaudhari North Maharashtra University (KBC-NMU), Jalgaon, to extend the SM sensor network. A fully functional SM sensor was installed at the Department of Earth Sciences at KBC-NMU, Jalgaon, which has been continuously monitoring and generating consistent data since its installation in September 2023.

In the context of Atmospheric Chemistry observational efforts, instruments were deployed at the Indian Antarctic base, Bharati, to monitor halogen compounds in the lower troposphere. Findings indicated that halogen compounds cause significant ozone depletion, though the concentrations are considerably lower compared to the West Antarctic. These data supported the validation of a new halogen emission parameterization developed within the CAM-Chem chemistry-climate model. Additionally, observations of climatically relevant trace gases were initiated at the Indian Arctic Station, Himadri. Long-term monitoring will focus on key species such as halogen compounds, oxidized volatile organic compounds, and sulfur dioxide, among others. It marks the first-time vertical profiles of these species are being measured in the Arctic lower troposphere on a long-term basis. These observations are expected to improve the understanding of atmospheric chemistry in the Arctic, offering quantitative insights into the effects of human-induced climate change on local emissions and the transport of long-range pollutants. These measurements will also complement similar observations in Antarctica, drawing attention to the contrasts between the northern and southern polar regions.

As part of a scientific collaboration with Germany, IITM conducted a high-altitude balloonsonde observational campaign in August 2023 at Nainital, India, located in the monsoon anticyclone zone and on the southern slopes of the Himalayas. Measurements of water vapor, ozone, aerosol backscatter, and meteorological parameters (wind, temperature, relative humidity) were carried out during the monsoon season to study the transport of water vapor into the lower stratosphere and its impact on the ozone layer. This campaign was coordinated with the "Phileas" aircraft campaign conducted over Syria in the UTLS monsoon outflow region by Forschungszentrum Jülich, Germany.

Basic Research

IITM Earth System Model: In addition to the development activities of IITM-ESM, studies are being carried out to understand the science of climate change using the IITM-ESM. North Atlantic teleconnection to South Asian summer monsoon is assessed using the pi-control simulation of IITM-ESM CMIP6 and reanalysis data sets. North Tropical Atlantic Sea Surface Temperature (NTA SST) anomalies emerge as a key driver of the whole El Niño Southern Oscillation–South Asian Summer Monsoon (ENSO–SASM) system. The evidences from observations and a Pi-Control coupled simulation using IITM-ESM demonstrate the pronounced biennial nature of the NTA–ENSO–SASM

system, thus suggesting the precursory role of the NTA SSTs in this biennial ENSO–SASM system through their capacitor effect. The spatial pattern of NTA from IITM-ESM is shown in **Figure 6**. The ensembles of short coupled sensitivity experiments using the IITM-ESM coupled model, as conducted by imposing observed warm (cold) SST anomalies over NTA, further support the key role of NTA SSTs in ENSO transitions and impacting the Indian summer monsoon rainfall.(***Sooraj K.P., Aswale A.M., Swapna P.,*** *Terray P.,* ***Sandeep N.S.,*** *Modulations in the Indian Summer Monsoon–ENSO teleconnections by the North Tropical Atlantic,* ***Climate Dynamics****, 61, November 2023, DOI:10.1007/s00382-023-06817-4, 4603-4622)*

A recent study addressed the sea level rise in the north Indian Ocean using the CMIP6 simulations from IITM-ESM and also other CMIP6 models. The results reveal that sea level rise in the north Indian Ocean is mainly driven by the anthropogenic increase in ocean temperature *(**Jyoti J., Swapna P., Krishnan R.,**North Indian Ocean sea level rise in the past and future: The role of climate change and variability,* ***Global and Planetary Change,*** *228: 104205, September 2023, DOI:10.1016/j.gloplacha.2023.104205, 1-13)*

METFLUX

Investigating terrestrial carbon uptake over India using multimodel simulations of gross primary productivity and satellite-based biophysical product

A study conducted by the Metflux team on Gross Primary Productivity (GPP) trends in India's ecosystems reveals projected growth rates varying from 4.9 to 21.95 gC m^{-2} y^{-2} across regions until 2100 **(Figure 7)**. Utilizing CMIP6 multi-model ensembles, the research underscores diverse carbon uptake patterns, with the Eastern Himalayas emerging as a dominant carbon sink. This comprehensive analysis provides critical insights into future carbon sequestration dynamics amidst climate change challenges. *(Uchale G.,* ***Deb Burman P.K., Tiwari Y.K., Datye A.,*** *Sarkar A., Investigating terrestrial carbon uptake over India using multimodel simulations of gross primary productivity and satellite-based biophysical product,* ***Journal of Geophysical Research: Biogeosciences****, 128: e2023JG007468, November 2023, DOI:10.1029/2023JG007468, 1-19)*

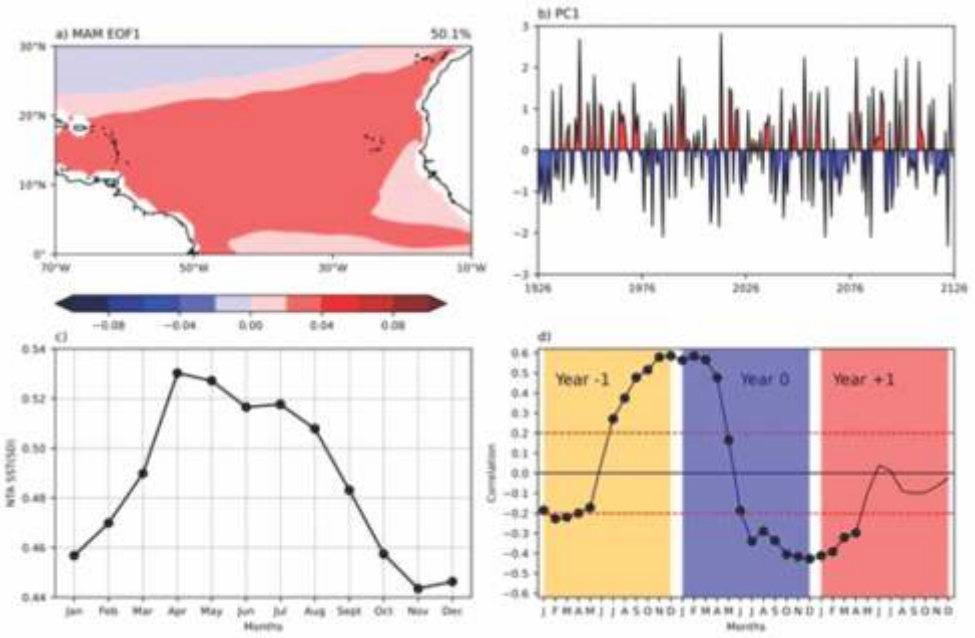


Fig.6*: The dominant mode of detrended SST anomalies over the North Tropical Atlantic (NTA) using Pi-Control simulation of IITM-ESM. an EOF1 for MAM SST anomalies (°C). b normalized principal component (PC1) corresponding to EOF1 for the MAM season. c Monthly SD of NTA (in °C). d Lead-lag correlation between the NTA Index (based on the normalised PC1 index for MAM season) and monthly Nino3.4 SST Index. In (d), black dots (red dotted lines), respectively, indicate the correlation values that are above the 90% (95%) significance confidence level according to a two-tailed Student's t-test.*

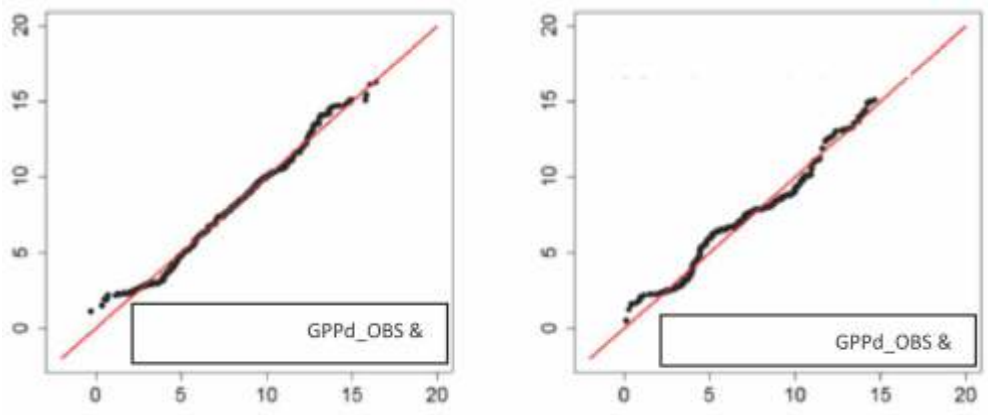


Fig.7: *Quantile-Quantile (QQ) plot among observed and simulated daily GPP (GPPd) (left) between GPPd_OBS and GPPd_ISAM_OBS in 2016, (right) between GPPd_OBS and GPPd_ISAM_OBS in 2018*

COSMOS:

Understanding the soil water dynamics during excess and deficit rainfall conditions over the core monsoon zone of India

Under the COSMOS activity of CCCR, a study on understanding the soil water dynamics during excess and deficit rainfall conditions over the core monsoon zone of India was conducted. Soil water dynamics and annual soil water budget were investigated using IMD station observations of surface (0-30 cm) and subsurface (30-60 cm) SM across the core monsoon zone (CMZ) of India during 2000 - 2021. Similar analysis is also carried out at the COSMOS-IITM, Pune site for the period of 2017-2021. Coupling between surface and sub-surface SM along with autocorrelation and ridgeline analysis is implemented to understand the influence of SM memory during the excess and deficit rainfall conditions on successive winter and pre-monsoon seasons. **(Fig. 8)** *(**Goswami M.M., Mujumdar M., Singh B.B., Ingale M.,** Ganeshi N., Ranalkar M.,Franz T.E., Srivastav P., Niyogi D., **Krishnan R.,** Patil S.N., Understanding the soil water dynamics during excess and deficit rainfall conditions over the core monsoon zone of India, **Environmental Research Letters**, 18: 114011, October 2023, DOI:10.1088/1748-9326/acffdf, 1-16)*

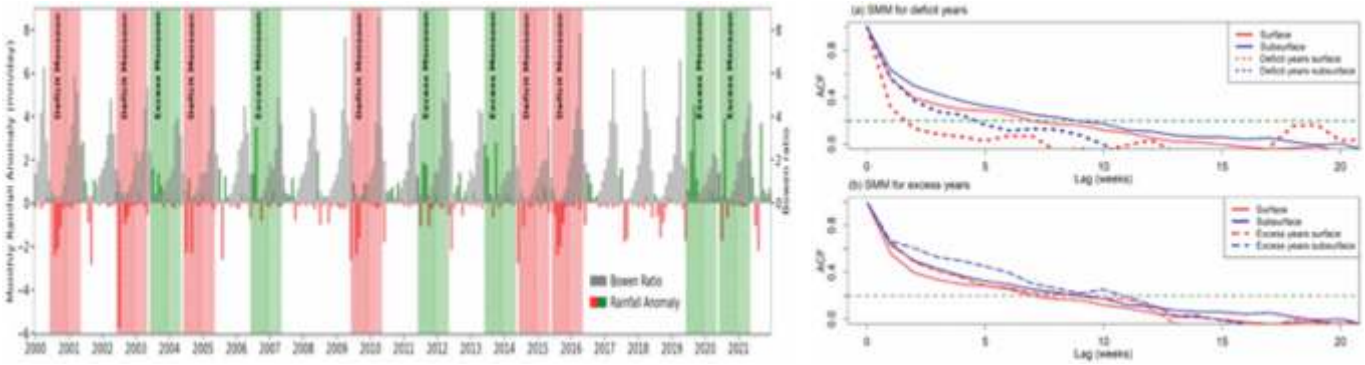


Fig.8: *(left) The deficit (excess) year, e.g., 2009 (2019) – red (green) strips with hatched region indicating June to December period, shows negative (positive) rainfall anomalies – red (green) bars, persisting for post-monsoon season induces stronger (weaker) surface – subsurface coupling and longer (shorter) SM memory (right a and b). This increases (decreases) the availability omutof surface SM during successive winter and pre-monsoon seasons (shaded red (green) strips). This in turn reduces (enhances) the Bowen ratio (grey bars) and thus can reduce (increase) convective activities.*

Paleoclimatology

The Indian monsoon variability during the last two millennia and links to the tropical equatorial Pacific

This study examines the variability of the Indian summer monsoon rainfall (ISMR) during the last two millennia using a near-annually resolved speleothem oxygen isotope record from Kadapa cave in peninsular India. The results show that the monsoon precipitation variations experienced a wet phase during the dark age cold period (DACP; ~250–800 CE) as evidenced from the progressive depletion of the δ18O values; followed by high amplitude variability during the medieval warm period (MWP; ~ 900–1300 CE), and drier monsoon conditions with enriched δ18O values during the edge of the little ice age (LIA; ~ 1500–1850 CE). It is further noted that the monsoon precipitation variability as observed in the Kadapa speleothem record during the last two millennia is corroborated by other speleothem and sediment records from the Indian subcontinent and adjoining oceanic areas. Analyses of reconstructed climate proxies, suggest that the intertropical convergence zone (ITCZ) during the DACP was stable and located relatively northward with pronounced La Niña conditions prevailing in the tropical Pacific. On the other hand, the high amplitude monsoon precipitation variations during the MWP appear to have resulted from multi-decadal fluctuations in the latitudinal position of the ITCZ, accompanied by enhanced activity of ENSO. (***Reddy A.P., Gandhi N.,*** *Yadava M.G.,* ***Krishnan R.,*** *The Indian monsoon variability during the last two millennia and links to the tropical equatorial Pacific,* ***Climate Dynamics****, 60, June 2023, DOI:10.1007/s00382-022-06513-9, 3645–3660)*

Dendroclimatology:

Tree-ring based runoff reconstruction for western Himalaya

High-resolution proxy records of tree ring-width chronologies from different sites of the western Himalayas are used to study climatic variation where observed climatic records are not available for a long period across the Himalayan region. The current study has considered total 4 sites (K1, K2, K3, and k4) residual chronologies **(Figure 9 and 10)**. Based on the significant CCs, the principal component (PC) analysis among the site chronologies for the common period is performed which regionally shows the coherency in tree

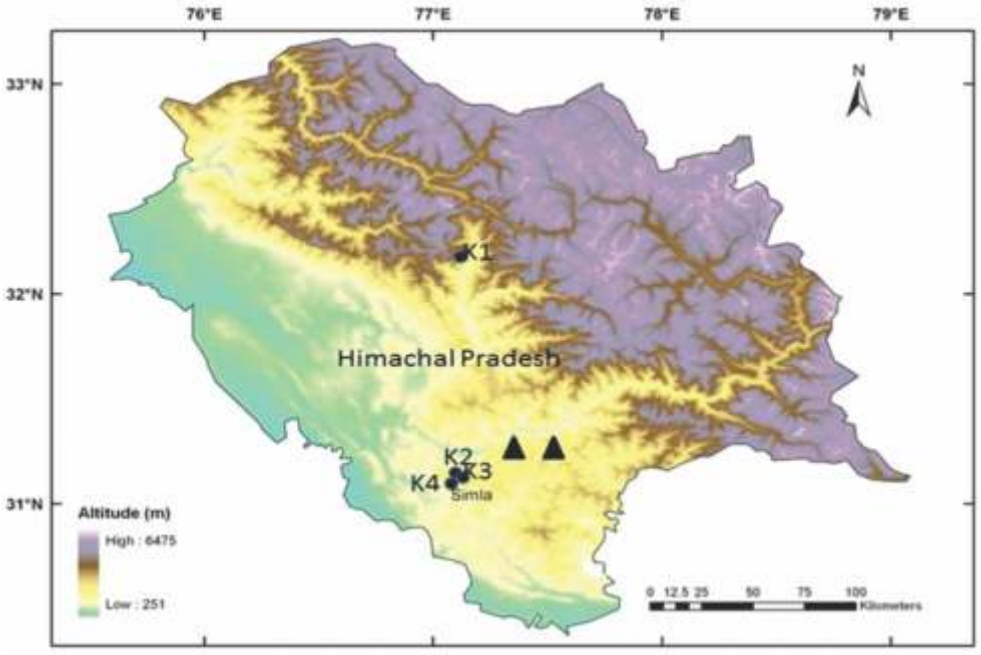


Fig.9: *Study area of sampling site; ●: tree ring-width;▲: grid point climate data*

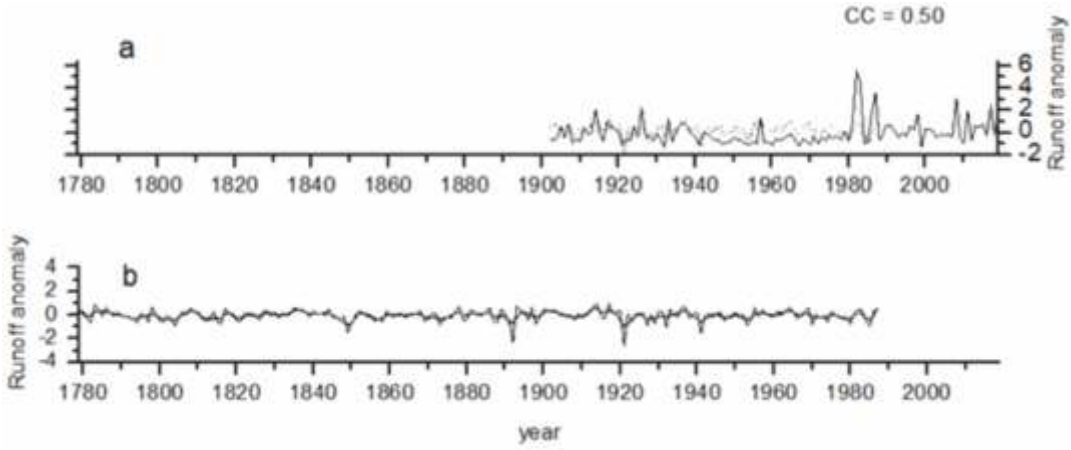


Fig. 10: *a Comparison between actual (solid line) for the period 1902-2019 and estimated regional runoff anomalies (dashed line) for the period 1902-1988 over the western Himalaya during summer season (April to June), CC is the correlation coefficient between actual and estimated runoff; b. reconstructed regional runoff anomaly back to 1779 over the western Himalayas. Smoothed black line in lower panel is a 10–year cubic smoothing spline fit.*

ring chronologies over the wide area of the Himalaya. The first principal component (PC1) explains 50% common variance is carried out here for further study. The 1st principal component performed based on the multi-species chronologiesshows that increases in runoff water over the region are found to have a positive impact in favoring the tree growth process during the winter and summer months. Meanwhile, the role of vapor pressure on tree growth during the summer (April-June) is not found to be conducive. The significant positive relationship of tree growth with regional runoff indicates that the increasing runoff water may be useful for tree growth. Reconstructed Runoff of Western Himalaya, and this record has been published. ***(Somaru Ram, Pandey U.,*** *Srivastava M.K., Tree-ring based runoff reconstruction for western Himalaya in India during the last two centuries,* ***Journal of the Indian Academy of Wood Science****, 20, June 2023, DOI:10.1007/s13196-022-00308-5, 12–17)*

Tree ring Climate relationship in Western Ghats

Instrumental data record a considerable spatiotemporal variation of rainfall amount along the Western Ghat (WG) mountain. Although Indian teak (Tectona grandis LF) samples from WG have been used earlier for reconstructing past monsoon rainfall, the effect of rainfall variation on the annual ring growth pattern along the mountain has not been extensively studied yet. To address this issue, tree-ring width data series from three locations-Dahanu (1763-1985), Nagerhole (1703-2016), and Tekkedy (1785-2003) are presented in this study. The locations are situated along WG from north to south. Monthly mean rainfall data obtained from the nearest observatories show a decreasing (increasing) rainfall amount from north to south during summer monsoon (pre and post-monsoon). We obtain a significant positive correlation between ring width indices and monsoon rainfall and a negative correlation with summer (especially May) temperature suggesting a contrasting response of summer temperature and monsoon rain on teak growth. The correlation between rainfall and ring width varies from southern to northern WG (both in significance level and the number of months with significant correlation). While the southernmost location exhibits positive (significant) correlations for both pre and summer monsoon months, the correlations are found for only two summer monsoonal months in the northernmost location. This spatial correlation trend reflects the variation of the pre-monsoon to monsoon rainfall ratio observed in our study locations. This observation is further substantiated by soil moisture-ring width relationship. Furthermore, our study shows that ring width indices respond to a variation of western equatorial Pacific sea surface temperature and vapor pressure deficit. Our study, therefore, suggests that the

Indian teak samples can be used for understanding regional and seasonal scale rainfall/soil moisture variation along the WG and teleconnection studies. (***Sengupta S.,Borgaonkar H., Datye A., Gajbe A.,*** *Deciphering climate response variation along the Western Ghats of India archived in teak ring width,* ***Theoretical and Applied Climatology, November*** *2023, DOI:10.1007/s00704-023-04590-2, 1-15).*

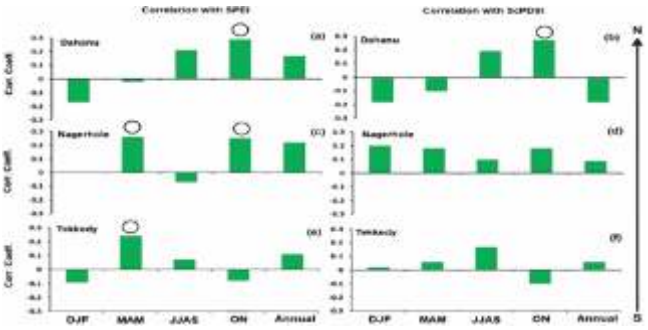


Fig. 11: *Figure* ***a, c, and e*** *Correlation analyses with tree-ring indices and gridded data of Standard Precipitation Evapotranspiration Index (SPEI) extracted over the study locations.* ***b****,* ***d****, and* ***f*** *Same analysis with self-calibrated Palmer Draught Severity Index (Sc-PDSI).*

Isotope studies

Quantifying Raindrop Evaporation Deficit in General Circulation Models from Observed and Model Rain Isotope Ratios on the West Coast of India

Raindrop evaporation is an important sub-cloud process that modifies rainfall amount and rainwater isotope values. Studies have shown that various general circulation models (GCMs) do not incorporate this process properly during the simulation of water isotope ratios (oxygen and hydrogen). This work has demonstrated that an inadequate estimation of this process for the Indian Summer Monsoon (ISM) results in significant biases (model-observed values) in the simulation of various GCMs on a monthly scale. However, a quantitative estimation was lacking. The present study aims to investigate the magnitude of the monthly scale variation in raindrop evaporation in the simulations and its causal connection with the corresponding variation in isotope biases. Towards this, an 11-year-long (1997–2007) dataset of rain isotope ratios (both oxygen and hydrogen) from an Indian station, Kozhikode (Kerala), were obtained under the Global Network of Isotopes in Precipitation (GNIP) programme of the International Atomic Energy Agency (IAEA) with the corresponding outputs of two isotope-enabled nudged GCMs—ISOGSM and LMDZ4. The raindrop evaporation fractions are estimated for 44 ISM months (June–September) of the study period using the Stewart (1975) formalism. Using a simple condensation–accretion model based on equilibrium fractionation from vapour, obtained from two adopted vapour isotope profiles, the liquid water isotope ratios at the cloud base. Considering this water as the initial rain, the raindrop evaporation fractions are estimated using the observed oxygen and hydrogen isotope ratios of Kozhikode surface rain samples. The estimated fractions show strong positive correlations with the isotope biases (R^2 = 0.60 and 0.66; **Fig. 12**). This suggests that

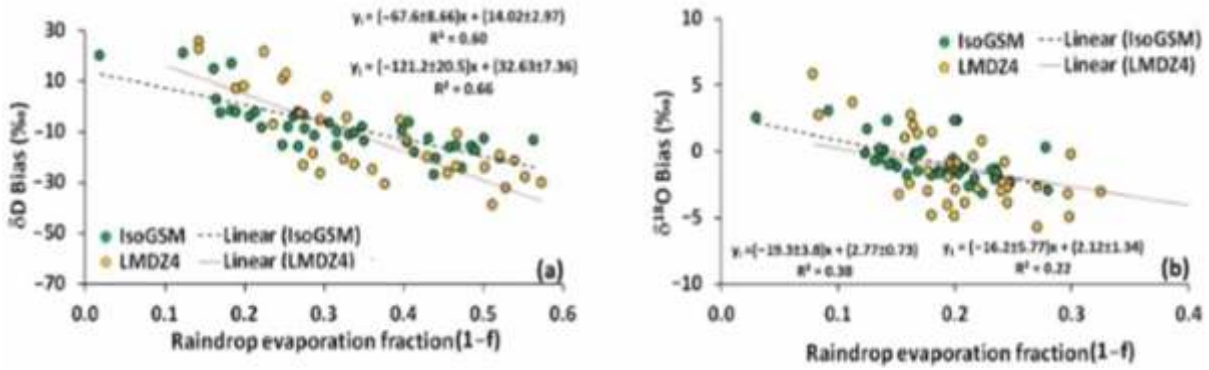


Fig. 12: *Estimated raindrop evaporation fraction and isotope biases for two GCMs –IsoGSM and LMDZ.*

lower estimates of raindrop evaporation could be responsible for the rain isotope biases in these two GCMs. *(**Sengupta S.,** Bhattacharya S.K., **Sunil N.S., Sonar S.,** Quantifying Raindrop Evaporation Deficit in General Circulation Models from Observed and Model Rain Isotope Ratios on the West Coast of India.**, Atmosphere,** 14: 1147, July 2023, DOI:10.3390/atmos 14071147, 1-18.)*

Atmospheric chemistry:

Atmospheric Chemistry modelling studies were carried out to: Understand the impacts of global volcanic eruptions during 2001-2015 on stratospheric dynamics based on simulations with and without volcanoes using the ECHAM6-HAMMOZ model. Moderate volcanoes that occurred during 2001-2015 show stratospheric heating caused by volcanic sulphate aerosols prolonged the easterly and westerly phases of QBO by 14 months. These results are based on the ECHAM6-HAMMOZ model simulations.

Air pollution reductions caused by the COVID-19 lockdown increased in snow cover (6–12 %) and mass (2–20 %) and a decrease in runoff (5–55 %) over the Hindukush Himalayas and Tibetan Plateau region. These results are based on the ECHAM6-HAMMOZ model simulations.

Comparison of ozonesonde measurements at Nainital with reanalysis and chemistry-climate-model data sets show an overestimation of ozone mixing ratios in these data sets in the troposphere (~20 ppb) and in the UTLS (~55 ppb).

Investigation of the coupled interactions of short-lived halogen chemistry with radiation using the Community Earth System Model 2 (CESM2) has been conducted. Mercury chemistry in CESM2 was also upgraded to include new mercury chemistry, including the photosensitized excitation of elemental mercury and subsequent oxidation by halogen compounds. Atmospheric sulphur chemistry was also upgraded to include the new reaction mechanism of hydroperoxy-methyl thioformate (HPMTF) and methane thiol (MeSH).

Year-round observations of halogen compounds were conducted at the Indian Antarctic base, Bharati. The results show that elevated BrO mixing ratios were found during spring (September), with a maximum value of 10.21 ± 4.38 pptv for clear sky conditions and 33.15 ± 2.23 pptv for cloudy conditions. BrO. bromine chemistry can deplete as much as 2.15 ppb of ozone in a day at the Bharati Station on clear days, which shows that it does not lead to complete ozone depletion events over Bharati *(**Wagh S.P., Joge S.D., Singh S., Mali P.,** Beirle S., Wagner T., Bucci S., Saiz-Lopez A., Bhawar R., **Mahajan A.S.,** Year-long ground-based observations of bromine oxide over Bharati Station, Antarctica, **Polar Science,** 38: 100977, December 2023, DOI:10.1016/j.polar. 2023.100977, 1-11)*

Observations show that iodine chemistry is less active than over the Weddell Sea, even during springtime, with IO mixing ratios below 2 pptv throughout the sunlit period. A slight increase in IO is observed in spring, although it is a factor of 10 lower than the Weddell Sea region. The study identified the variations in drivers in the different regions using sea ice concentrations, sea ice thickness and chlorophyll concentrations. Even at small concentrations, iodine can enhance ozone loss caused by bromine chemistry over east Antarctica, although this impact is lower than in the west Antarctic *(**Mahajan A.S., Wagh S.,** Fernandez R.P., **Singh Surendra,** Bucci S., Saiz-Lopez A., Differences in iodine chemistry over the Antarctic continent, **Polar Science**, 40: 101014, June 2024, DOI:10.1016/j.polar.2023. 101014, 1-9)*

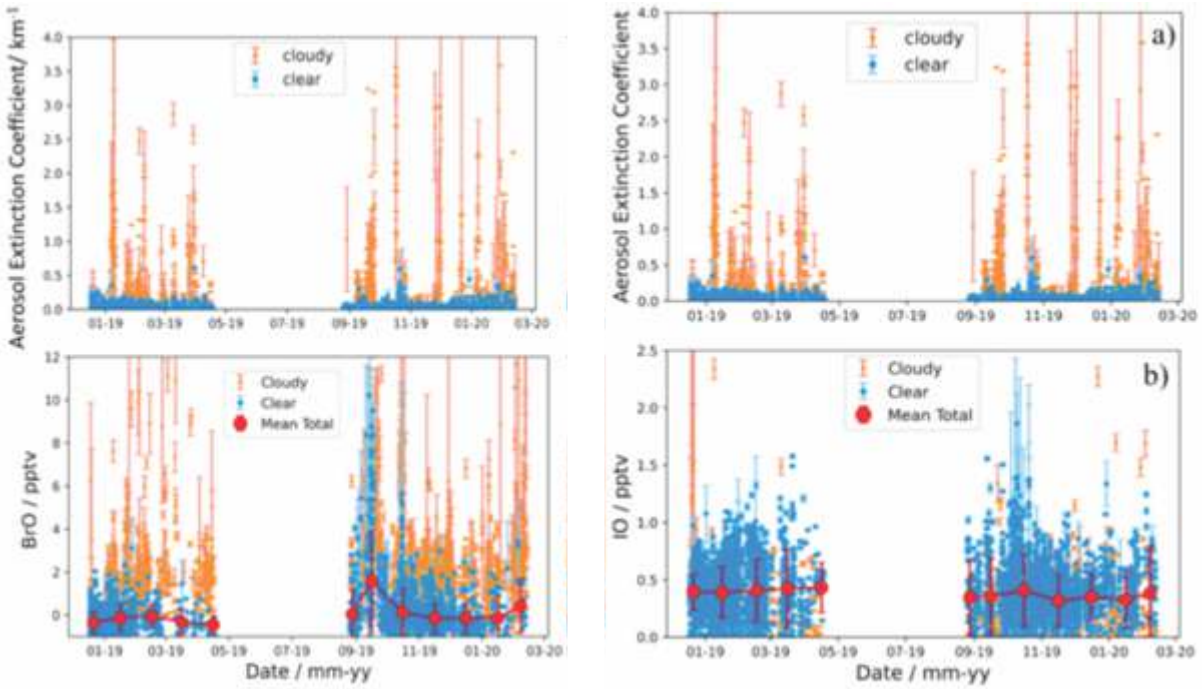


Figure 13: *Observations of reactive halogen compounds at Antarctica show that both bromine and iodine are present in this environment and can contribute to ozone depletion, but not as high as in the Wedell Sea.*

a) Installation of an Eddy Covariance system (CO_2-H_2O sensor, Sonic Anemometer) at the ARIES-Nainital campus. Furthermore, **b)** installation of an Eddy Covariance system (CO_2-H_2O sensor, CH_4 Sensor, Sonic Anemometer) along with weather sensors at the Pichavram Mangrove site.

Instrument setup at the Indian Antarctic base, Bharati, for measuring halogen compounds in the lower troposphere.

1.1.2. Physics and Dynamics of Tropical Clouds (PDTC)

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

Objectives

- To generate long-term observational data for understanding the boundary layer processes, aerosol, cloud and rainfall properties over the rain shadow region of India.
- To prepare a weather modification research strategy over the rain shadow region of India.
- To develop a laboratory for cloud seeding flare testing.
- To understand the boundary layer processes in a Fluid Dynamics Laboratory developed at IITM, Pune.
- To study the interaction of electrical, microphysical and dynamical properties of thunderstorms.
- To study lightning in different environmental conditions.
- To study lightning damages over India.

Highlights of Major Achievements

- Comprehensive Ground Observations at Solapur and Tuljapur: Continuous data collection on meteorological parameters, aerosol characteristics, cloud, and precipitation properties is ongoing, supported by advanced observational instruments like C-band radar, wind profilers, and automatic rain gauges. The network of 120 automatic rain gauges has been upgraded to ensure real-time monitoring.
- Deployment of Urban Meteorological Network in Delhi: Approved by the Ministry of Earth Sciences (MoES), this initiative focuses on establishing a comprehensive observational system in New Delhi. The project includes advanced instrumentation such as wind profilers, lidars, microwave radiometers, and X-band radar to monitor aerosols, clouds, and meteorological variables for urban weather forecasting.
- Pre-Monsoon Lidar Campaign for Aerosol Profiling: A lidar campaign was conducted in collaboration with SRM University to profile vertical aerosol distributions during the pre-monsoon season at Solapur. This study is critical for understanding aerosol-cloud interactions and their potential impacts on the monsoon transition period.
- Development of Wall-Turbulence Models and Monsoon Jet Simulations: The Fluid Dynamics Laboratory (FDL) developed a new theoretical framework for modeling friction in wall turbulence and established a wall-jet experimental setup to simulate the dynamics of the monsoon low-level jet. The lab also introduced an innovative technique for identifying turbulent-nonturbulent interfaces (TNTI) in wall jets.
- North East India Observational Network (NEION) Expansion: New observational sites equipped with micro-rain radars, automatic rain gauges, and disdrometers have been established across Assam and Arunachal Pradesh under the NEION project. These additions are essential for improving rainfall estimation and prediction capabilities in the complex terrains of North-East India.
- Quantifying Cloud Seeding Impact via CAIPEEX IV: The fourth phase of the CAIPEEX project

executed a cloud-seeding experiment in the rain-shadow region of the Western Ghats, resulting in up to a 46% enhancement in rainfall in seeded areas. This experiment provides valuable data on the effectiveness of cloud-seeding technologies in inducing precipitation under specific conditions.

- Seasonal Variations in Aerosol Hygroscopicity during Monsoon: Detailed analysis of CAIPEEX data from the 2018-2019 monsoon seasons indicated significant seasonal variability in aerosol hygroscopic properties, with notably lower hygroscopicity observed during active monsoon phases. These results offer critical insights into the role of aerosols in cloud formation and precipitation processes.
- Advances in Cloud Condensation Nuclei (CCN) Retrieval: A novel method was developed to estimate CCN concentrations using satellite and airborne data across the Indian monsoon region. The study identified significant seasonal variation in CCN levels, with peak concentrations occurring during the post-monsoon and winter periods, influencing cloud formation and precipitation efficiency.
- Monsoon Modulation of Aerosol-Cloud Interactions: The ongoing study of aerosol-cloud interactions using data from the CAIPEEX campaigns has revealed key mechanisms by which the monsoon modulates aerosol concentration and distribution. This has provided valuable insights into how aerosol properties affect cloud microphysics and regional precipitation patterns during different monsoon phases.
- Upgraded Rainfall Estimation Techniques in Complex Terrain: New methodologies for improving rainfall estimation using disdrometers and radar data in complex terrains like the North-East India region have been developed. This advancement is crucial for addressing challenges in accurately predicting localized precipitation in regions with high topographic variability.
- Long-term observational data is being collected to understand boundary layer processes, aerosol, cloud, and rainfall properties over India's rain shadow region.
- The Thunderstorm Dynamics research reveals that pre-monsoon thunderstorms show more intra-cloud lightning compared to monsoonal thunderstorms. The cold cloud depth is most prominently linked with the with the observed IC:CG ratio. The implication of these observed results has the importance of separating CG lightning flash from total and can be used in numerical models to give a proper prediction of CG lightning in hazard mitigation.
- Occurrence of lightning over India is being monitored by IITM's Lightning Location Network (LLN). The LLN data is being shared in real-time with IMD and NCMRWF for inclusion in their forecast models and shared with National Disaster Management Authority (NDMA) & disaster management authority of various States such as, Andhra Pradesh, Odhisa, Uttarakhand, Uttar Pradesh and Tamil Nadu for producing lightning alerts in respective State's weather alerts. The LLN has been augmented with addition of 9 sensors and upgradation of servers. The updated version of DAMINI- Mobile App provides Lightning alerts in 15 languages.

- IITM participated in India's first Arctic Winter Expedition, successfully installing equipment to study the Global Electric Circuit and lightning activity in the Arctic.
- A wind tunnel study showed that increasing electric fields reduce the probability of water drop coalescence, which impacts precipitation estimation in clouds. Relaxation time for coalescence is higher than that for the breakup. Higher collision kinetic energy has a tendency to increase the number of fragments of the sizes between 1.2 mm and 3.2 mm diameter. Hence, the effect of the electric field needs to be included in the estimation of drop growth and precipitation in clouds.
- Research has demonstrated that high Convective Available Potential Energy (CAPE) and cold, dry air entrainment are key factors influencing lightning activity during the Indian summer monsoon.
- A study observed a dramatic increase in positive cloud-to-ground lightning during the break period of the Indian summer monsoon, with potential hazard mitigation implications.
- IITM has established collaborations with universities and State Disaster Management Authorities for research on thunderstorms and lightning.

R&D Activities :

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

- Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)
- Thunderstorm Dynamics

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

Developmental Activities

CAIPEEX ground Observations:

CAIPEEX ground Facility observations at Solapur and Tuljapur Sites are ongoing with several instruments for measuring meteorological parameters, aerosol (physical and chemical properties), cloud and precipitation properties with several instruments including C-band Radar, wind profiles, automatic Rain Gauge network, Micro-rain Radar, etc. Daily radiosonde flights from Solapur are revived after obtaining necessary permissions from Civil Aviation Authorities and the Indian Air Force. These data are shared with NCMRWF for data assimilation in the daily forecasts. Maintenance of 120 Automatic Rain Gauge network at Solapur is completed in April 2023. Measures have been taken to protect the instruments from possible electrical surges.

Urban Meteorology Project in New Delhi:

The Urban Mesonet for Delhi has been approved by the Ministry of Earth Sciences (MoES) and aims to establish a cutting-edge observational network to monitor urban meteorological processes. This initiative will deploy a comprehensive array of instruments to measure aerosols, clouds, and other key atmospheric parameters, providing critical insights into the complex meteorological dynamics of urban environments. As part of this project, the CAIPEEX team has collaborated with industry experts to propose a series of advanced observational systems:

- Wind Profilers for continuous, high-resolution 3D profiling of wind velocities, critical for tracking atmospheric motion
- Wind lidar equipped with scanning capabilities to measure aerosols, cloud dynamics, and wind profiles using full 360-degree azimuth and elevation scans, ensuring high temporal and spatial resolution
- Ceilometers with dual-polarization to profile aerosols and cloud properties, with depolarization features for particle shape analysis
- Microwave Radiometers to capture atmospheric thermodynamic variables, crucial for understanding energy transfer processes and weather prediction
- A network of X-band radars, a dense array of Automatic Weather Stations (AWS), Meteorological Towers, Micro Rain Radars, and disdrometers will be strategically deployed across New Delhi and its surrounding areas to enhance data collection and accuracy.
- Additional instruments, such as dual-column Cloud Condensation Nuclei (CCN-200) counters, SP2-XR for black carbon measurements, and sun photometers, are also planned for installation.

The procurement process is currently underway, with ceilometers and disdrometers scheduled for installation between March and April 2024. This project represents a significant advancement in the capability to observe, model, and understand the unique meteorological conditions of urban settings like New Delhi.

LIDAR Campaign at CAIPEEX Solapur site:

CAIPEEX program successfully conducted a new observational campaign (with an aerosol LIDAR from the SRM University, Kattankulathur, Tamilnadu) at Solapur to investigate aerosol vertical profiles and cloud characteristics during pre-monsoon season (May-June). Fabrication of a cabin with special arrangements to operate a lidar system at CAIPEEX filed station, NBNSCOE, Solpaur in collaboration with SRM University is completed. This cabin is designed by the Civil Engineering Dept. of NBNSCoE, Solapur (during April 2023). A team of researchers from the SRM University installed the LIDAR system. Observations from co-located lidar, WPR, MWR & other aerosol & trace gases measurements were made in June 2023.

Agreements are established with SRM University, CUSAT, and IIST Trivandrum for collaborative research on CAIPEEX and joint field experiments, data assimilation, etc.

Fluid Dynamics Laboratory (FDL):

Some of the major development activities conducted under FDL are as follows:

- Generalized scaling and model for friction in wall turbulence: A new theoretical framework that accurately estimates friction experienced by a surface in turbulent flow has been developed.
- Development of new wall jet setup and papers being written on the long FOV wall jet data: The design and development of a new wall-jet facility are being carried out in the FDL lab. This facility aims to simulate the monsoon low-level jet in the laboratory to study the turbulence mixing within the flow.
- Preliminary TNTI investigations in wall jets and outer layer intermittency: A novel method to standardize the procedure for detecting TNTI has been developed, and experiments are being conducted to test this method. Multi-scale analysis of the structure of TNTI is being studied using concepts like fractal dimension.
- LES of truly and conventionally neutral ABLs: We are attempting to validate the lab predictive model using large eddy simulations (LES) for a particular class of ABLs known as truly neutral ABLs (TNABLs).

North East India Observational Network (NEION) Project:

North East India Observational Network (NEION) Project has been started. Under this observational program, CAIPEEX team has installed and made operational an impact disdrometer, Automatic Rain Gauge, Rain water collector, AWS and Micro Rain Radar at ST Radar Facility of Gauhati University, Assam. Apart from this, installation of four Automatic Rain Gauges and rain water collectors have been completed in March 2024 in Arunachal Pradesh.

Burning Chamber Facility for Flare characterisation:

Design and development of a Burning chamber to test and study the characteristics of seeding flares, to be used for cloud seeding, is under progress in collaboration with N. B. Navale Sinhgad College of Engineering, Solapur.

Data Sharing with NCMRWF:

CAIPEEX team took the initiative and had discussions with the scientists from NCMRWF, Noida for data assimilation purposes. The collaborative work for data assimilation is started by sharing sample data sets from the C-band radar, Wind Profiler, Radiosonde, Microwave radiometer and disdrometer observations with NCMRWF. Daily radiosonde data is uploaded to the server for data assimilation purpose.

Micrometeorological Measurements with 50m Tower:

50 m Eddy covariance tower has been relocated to a suitable location (due to the requirement of a more homogeneous site (the extensive building development activity around the current tower site has been noted) with better fetch in Solapur. The instruments are being refurbished and re-calibrated. A meteorological observations are conducted in June 2023 at the Solapur weather tower site during the Lidar campaign. Eddy Covariance sensors were installed during this campaign, which yielded invaluable weather and atmospheric data.

Training program: A training program was conducted at NBNSCoE Solapur, on Wind Profiler systems in collaboration with M/s Astra Microwave Products Ltd., Hyderabad, from 16-17 February 2023.

BASIC RESEARCH

CAIPEEX: Indian Cloud Seeding study:

In the fourth phase of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX IV, 2018-2019), a scientific investigation was conducted over a rain-shadow region of the Western Ghats mountains in India. The primary objective was to investigate the efficacy of hygroscopic seeding in

convective clouds and to develop a cloud seeding protocol for the Indian region. Followings are the major outcome of the study:

- The hygroscopic seeding material was detected in cloud droplets above the cloud base and key cloud microphysical processes in the seeding hypothesis were tracked.
- The formidable challenges of assessing seeding impacts in convective clouds and the results from 150 seed and 122 no-seed samples of randomized experiments are illustrated.
- Over 5,000 cloud passes from the airborne campaign provided details about the convective cloud properties as the key indicators for a seeding strategy and the evaluation protocol.
- The experimental results suggest that cloud seeding can be approached scientifically to reduce uncertainty.
- The results from this study should interest the scientific community and policymakers concerned with climate change's impact on precipitation and how to mitigate rainfall deficiencies

(***Prabhakaran Thara, Murugavel P., Konwar M., Malap N., Gayatri K., Dixit S., Samanta S.,Chowdhuri S.,Bera S.,Varghese M., Jaya Rao Y., Sandeep J., Safai P.D., Sahai A.K.,*** *Axisa D., Karipot A., Baumgardner D., Werden B., Fortner E., Hibert K.,* ***Nair S., Bankar S.,Gurnule D., Todekar K.,*** *Jose J.,* ***Jayachandran V.,Soyam P.S., Gupta A., Choudhary H.,Aravindhavel A., Kantipudi S.B.,*** *Pradeepkumar P.,* ***Krishnan R.,*** *Nandakumar K., DeCarlo P.F., Worsnop D., Bhat G.S., Rajeevan M.,* ***Nanjundiah R.,*** *CAIPEEX - Indian cloud seeding scientific experiment,* ***Bulletin of the American Meteorological Society,*** *104, November 2023, DOI:10.1175/BAMS-D-21-0291.1, E2095-E2120)*

Scan to read full BAMS article of CAIPEEX

CAIPEEX report, entitled **"Cloud Aerosol and Precipitation Enhancement Experiment CAIPEEX Cloud Seeding Experiment Results and Recommendations":**

The CAIPEEX seeding report was released to the scientific community by Hon'ble Minister of Earth Sciences (MoES) on 27th July 2023 during the MoES Foundation Day celebration at New Delhi.

The Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) is a state-of-the-art experiment conducted by IITM Pune to evaluate the efficacy of cloud seeding over arid regions. CAIPEEX followed the WMO recommendations for the scientific investigation of cloud seeding. The experiment has contributed to 267 randomized samples of convective cloud seeding. The cloud base (hygroscopic seeding) was conducted with aircraft, and radar and rain gauges were used to document the seeding impact. The report includes the evaluation of these experiments, outcomes, and recommendations.

CAIPEEX was executed in four phases and the lessons learned from the first three phases are used to plan and execute the fourth phase. CAIPEEX IV phase has shown that there is a relative enhancement of rainfall in the seeded samples compared to no-seed samples. The rainfall can be enhanced by up to ≅ 46±13 percent at some locations and on average based on the rain gauges, ≅ 18±2.6 percent in 100 square kilometers (km^2) area in the downwind of seeding location over the rain shadow region of Solapur, Maharashtra.

The report is available at https://www.tropmet.res.in/~lip/Publication/Technical-Reports/CAIPEEX-Report-July2023.pdf

Fig 14. *CAIPEEX Report released by HMoES on MoES Foundation Day, 27 July 2023*

Scan to read the full report

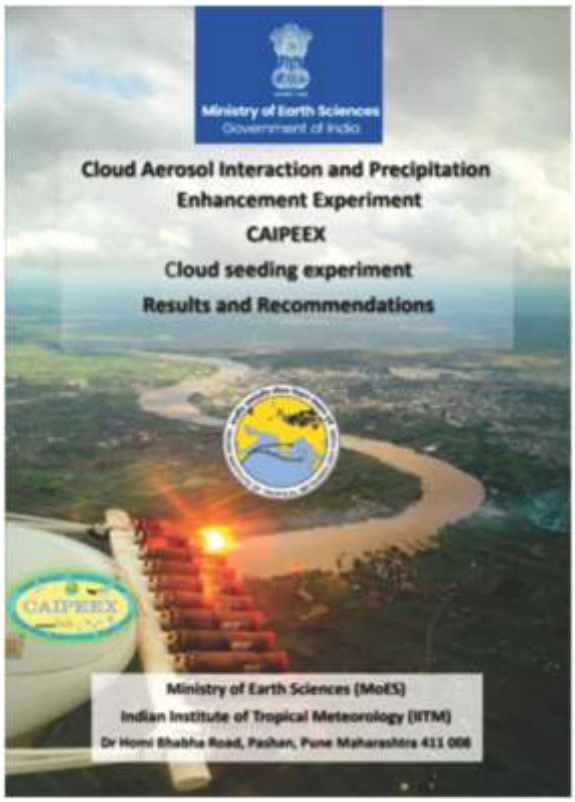


Fig.15*: Cover-page of CAIPEEX Report*

Generalized Scaling and Model for Friction in Wall Turbulence

This study presents a novel generalized scaling framework and predictive model for wall friction in turbulent flows. The scaling is derived from the dynamical equations, and total mean-flow kinetic energy and the velocity profile shape factor are used as surrogates for dynamical and boundary condition effects. Veracity of the present approach is assessed using data from the literature spanning unprecedented ranges of flow types, Reynolds numbers, accelerations, and history effects. Unlike previous models that solely apply to standard flows, the present framework reconciles nonstandard flows with standard flows and enables accurate estimates of wall friction in numerical simulations and experiments without resolving the viscous sublayer or using the law of the wall. *(**Dixit S.A., Gupta Abhishek, Choudhary H., Prabhakaran Thara,** Generalized Scaling and Model for Friction in Wall Turbulence, **Physical Review Letters**, 132: 014001, January 2024, DOI:10.1103/PhysRevLett.132.014001)*

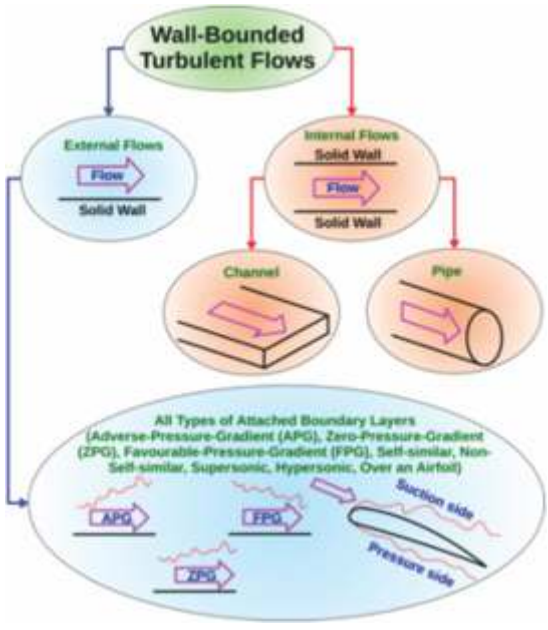


Figure 16*: Smooth-wall turbulent flows covered by this study. All flows are two dimensional in the mean. Internal flows are fully developed. External flows are different types of attached TBLs. Thick black lines indicate solid wall(s) and arrows indicate nominal flow direction. Thin red lines schematically indicate turbulent-nonturbulent interface, a measure of the thickness of TBLs.*

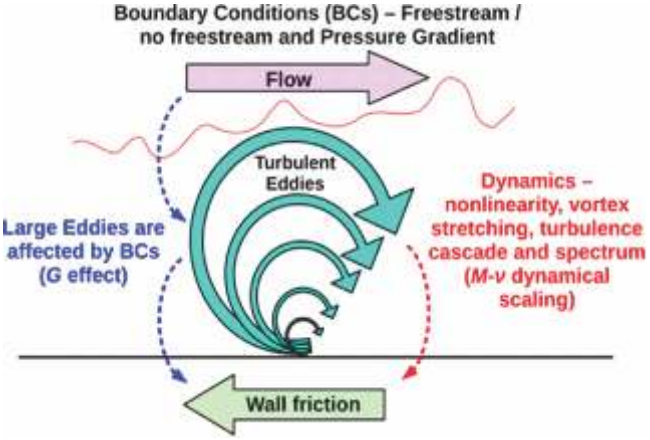


Fig. 17: *Schematic depicting roles of dynamics and BCs towards setting up and modulating eddies of turbulence that contribute to friction experienced by the flow at the wall. Dynamics contributes M–v scaling and effects of BCs are taken into account by Clauser's shape factor G, both together yielding generalized M–v–G scaling.*

Impact of monsoon on below cloud base aerosol hygroscopicity over a rain shadow region of India:

Vertically constrained observations of aerosol size distribution and hygroscopicity using the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) measurements during the monsoon seasons of 2018 and 2019 over a typical global climate model grid area are presented. Two regimes of aerosol loading - low and high, were identified within the season. Low aerosol loading is associated with active monsoon conditions and strong westerlies, while high aerosol loading occurs when the westerly airmass weakens or becomes continental. Aerosol hygroscopicity was the lowest (~0.08) during low aerosol loading days in 2019 and the highest (~0.3) during high aerosol loading days in 2018. Aitken mode aerosols control the bulk hygroscopicity on high aerosol loading days and at high supersaturation. The refractory Black Carbon (rBC) aerosols accounted for nearly 10% of the total aerosol number concentration during the monsoon. The internally mixed rBC aerosols had thicker coatings for smaller rBC cores and vice-versa. The cloud condensation nuclei (CCN) closure at the cloud base is established from the in situ observations. These observations are first-of-its-kind from the Indian region, covering two contrasting monsoon seasons, and are useful for studying aerosol-cloud interactions and constraining models. (***Varghese M., Malap N., Konwar M., Bera S.,*** *Jose J.,* ***Bankar S.P., Murugavel P., Prabhakaran Thara,*** *Impact of monsoon on below cloud base aerosol hygroscopicity over a rain shadow region of India,* ***Atmospheric Research****, 285: 106630, April 2023, DOI:10.1016/j.atmosres.2023.106630, 1-13)*

Retrieval and validation of CCN from satellite and airborne measurements:

The estimation of CCN concentration at the cloud base height is an essential constraint to aerosol-cloud interaction (ACI) studies and has been explored in this study. The study estimates the height-resolved CCN from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) using Optical Modelling of CALIPSO Aerosol Microphysics (OMCAM) algorithm and validated the results with airborne in-situ CCN measurements collected during the Cloud Aerosol Interaction and Precipitation Enhanced Experiment (CAIPEEX) at six locations over the Indian Summer Monsoon (ISM) region. Out of 40 CAIPEEX flight measurements collected in the year of 2009, 15 profiles were selected for the validation of CALIPSO-derived CCN number concentrations (NCCN). It is found that a reasonable agreement between CALIPSO and the in-situ measurements with a correlation coefficient of 0.72. However, the overall comparison suggests that the CALIPSO overestimates the NCCN by 54 ± 33%. Further, it is analyzed the CALIPSO-derived NCCN for the in-situ stations. A strong seasonal variation of NCCN at SS 0.4% is observed in all six stations. The mean NCCN is maximum (minimum) during the post-monsoon (pre-monsoon) for Pathankot 2592 ± 1026 cm^{-3} (1636 ± 809 cm−3), Bareilly 3618 ± 1326 cm^{-3} (2078 ± 792 cm−3) stations whereas maximum (minimum) during winter (monsoon) for Guwahati 3696 ± 1400 cm^{-3} (2661 ± 1096 cm^{-3}), Pune 3422 ± 1628 cm^{-3} (2241 ± 1086 cm^{-3}), Hyderabad 3765 ± 1366 cm^{-3} (2498 ± 1084 cm^{-3}) and Bangalore 2956 ± 1274 cm^{-3} (2401 ± 1071 cm^{-3}). (***Aravindhavel A.,*** *Choudhury G.,* ***Prabhakaran Thara, Murugavel P.,*** *Tesche M., Retrieval and validation of cloud condensation nuclei from satellite and airborne measurements over the Indian Monsoon region,* ***Atmospheric Research****, 290: 106802, July 2023, DOI:10.1016/j.atmosres.2023.106802, 1-15)*

OBSERVATIONAL CAMPAIGNS:

CAIPEEX 2023 Monsoon Experiment- Lidar experiment at Solapur CAIPEEX ground site:

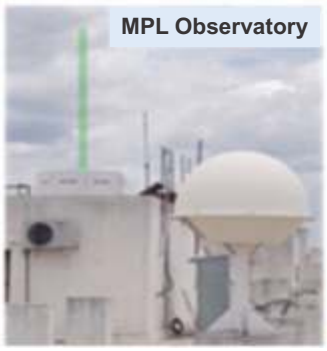
The CAIPEEX program is conducting a new observational campaign at Solapur to investigate aerosol vertical profiles and cloud characteristics. Though the observations on the ground are being carried out, the vertical variations of aerosols are not known. The satellite data gives the aerosol optical depth as an integrated value and cannot give details of the aerosol layering. The Calipso satellite can give details of vertical profiles of aerosols and characterization of different aerosol types.

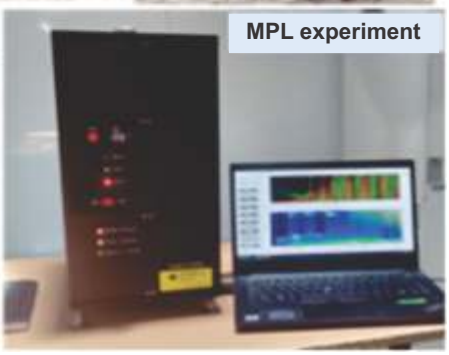
The intensive field campaign started in Solapur on 30th May 2023. An aerosol lidar from Atmospheric Observations and Modelling Laboratory, SRM Institute of Science and Technology (SRMIST), Kattankulathur, Tamil Nadu, India, is operated together with other observations ongoing at Solapur. This is a joint experiment with SRMIST which is funded by the MoES and SERB (Science and Engineering Research Board, Government of India) for the Lidar experiments.

The experiment is focused on different objectives to investigate the surface and boundary layer exchange processes, the role of low-level jet and moisture, aerosol transport over the region, the impact of clouds on the boundary layer processes, aerosols above clouds and cloud layers, estimates of radiative forcing, based on vertically constrained data from the in situ and Lidar observations. The experiment has collected valuable data during the dry-to-wet transitions during the monsoon onset over Solapur. It is expected that together with other ongoing observations at Solapur, new science will come out from this experiment.

Participation of CAIPEEX team in ASTRAL (Arabian Sea Transition Layer) cruise field campaign held from 9th to 26th June 2023 from Mormugao, Goa

The ASTRAL project is part of the EKAMSAT initiative (Enhancing Knowledge of the Arabian Sea Marine Environment through Science and Advanced Training) which is a joint research initiative between India (MOES) and the USA. The main goal of the EKAMSAT is to





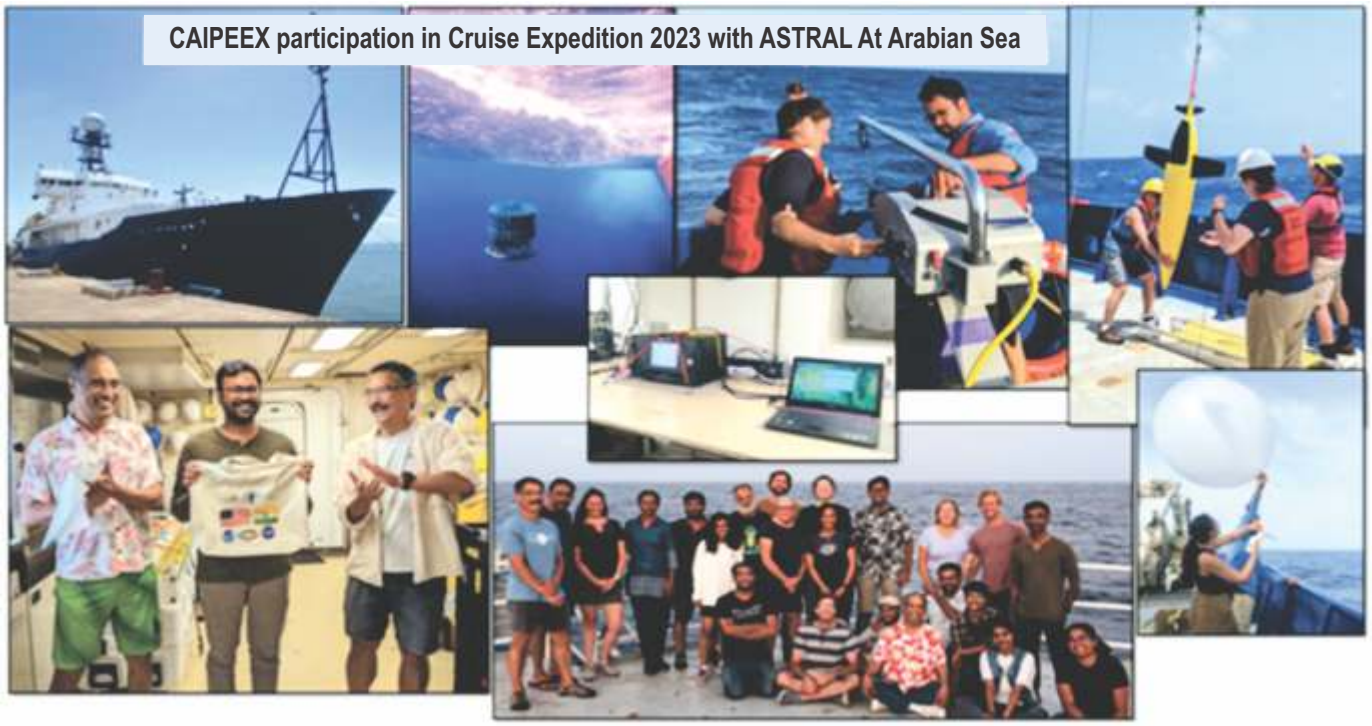
enhance the understanding of the air-sea interaction, and boundary layers processes over the Arabian Sea, which is crucial for the better prediction of monsoon dynamics.

A researcher from CAIPEEX has participated in the EKAMSAT/ASTRAL Cruise campaign (8 June 2023-26 June 2023) over the Arabian Sea and collected valuable datasets over the Arabian Sea of the black carbon aerosols. This is the first time that concurrent observations of BC are carried out over the Arabian Sea and the inland location Solapur and the first of its kind measurements during the summer monsoon period over the important geographical region. The atmospheric aerosol samples were also collected to understand its microphysical and chemical properties better. The above-mentioned datasets can give valuable insights into the radiative forcing over the region during the onset of monsoon. At the same time, particles deposited in the sea surface water were also collected to study wet scavenging of atmospheric black carbon and their role in warming sea surface temperature. The datasets can give valuable insights into the radiative forcing over the region during the onset of monsoon.

After successful participation of EKAMSAT/ ASTRAL (Arabian Sea Transition Layer) cruise field campaign during 8-26 June 2023 over Arabian Sea, the data analysis is being carried out.

Rainwater Chemistry Campaign-2023

The Indian Institute of Tropical Meteorology, New Delhi Branch has been engaged in air pollution and atmospheric chemistry studies for more than a decade in conducting and participating in various field experimental programmes. IITM- Delhi Branch Office (BO) initiated a campaign for Rainwater chemistry: A comprehensive understanding of nature of rainwater during the Monsoon-2023. The study was conducted initially at seven different locations over the Indo-Gangetic Plain, IGP (New Delhi, Ludhiana, Jaipur, Lucknow, Varanasi, and Ranchi) and over the foothills of Himalayas (Nainital) during the Monsoon-2023 (June-September 2023). This study has been conducted in



collaboration with different research Institutions/ Universities which are mentioned below (and also depicted in **Figure 18**).

i. New Delhi (IITM BO, a representative urban site over the western IGP)

ii. Ludhiana, Panjab (Gulzar Institute, a representative agriculture biomass site over the northwest IGP)

iii. Jaipur, Rajasthan (IIS University, a representative dust site)

iv. Lucknow, UP (IET, a representative urban site over the central IGP)

v. Varanasi, UP (BHU, a representative urban site over the central-eastern IGP)

vi. Ranchi, Jharkhand (BIT Mesra, a representative urban site over the eastern IGP)

vii. Nainital, Uttarakhand (ARIES, a representative high-altitude site (~1400 m) in the Himalayan foothills)

The study aims to understand the spatial distribution of major ionic species in rainwater along with its nature (acidic and/or alkaline). This study will provide atmospheric deposition of acidic and alkaline species and help to assess the atmospheric carrying capacity of the region from the emissions and air quality.

National and International collaborations:

Efforts are being made to collaborate with United Arab Emirates on rain enhancement research. In this regard, a meeting was held with Deputy Chief of Mission, The Embassy of United Arab Emirates, New Delhi on 20 Feb. 2023.

Apart from this, on national level, CAIPEEX team had scientific discussion on the on-going research activities for possible research collaborations with CUSAT, University of Hyderabad, CSIR-National Physical Laboratory (NPL) & IIST Thiuvanathapuram, VIT Velore.

CAIPEEX is working with the Indian Air Force (Meteorology) to formulate a collaboration in the cloud seeding/weather modification research.

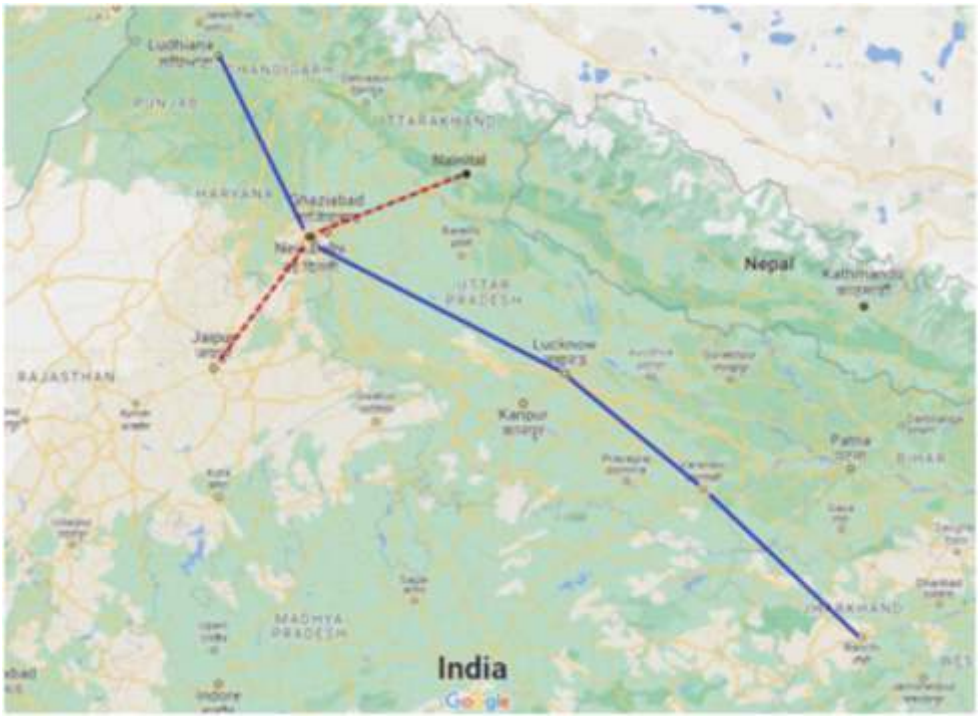


Figure 18: *showing the various locations for rainwater sampling carried out during the campaign.*

1.1.2.2 Thunderstorm Dynamics

DEVELOPMENTAL ACTIVITIES

A 10-meter-high Micrometeorological tower has been erected at Sanjay Ghodawat University Observation site. Eddy co-variance system and compact weather sensors (for s wind speed and direction, air temperature, relative humidity, atmospheric pressure and rainfall) are installed at 6m and 2m level respectively to study the surface layer characteristics including the turbulence.

A sensor of lightning network has been installed at Itanagar, ArunachaL Pradesh and integrated with the Central Processor at IITM.

IITM participation in the India's maiden Arctic Winter Expedition (18 December 2023 to 15 January 2024):

The IITM project proposal entitled "Study of lightning and global Electric circuit over Artic in Climate change scenario" has been approved for the Indian Arctic Expedition November 2023 –March 2024 by MoES with major objectives as: i) to understand the electrical structures of thunderclouds over Arctic through measurements of electric field and Maxwell current; and ii) to study the feedback of increasing lightning on Climate and Global electric circuit. The HMoES flagged off India's first winter scientific expedition to the Arctic from the MoES headquarters in New Delhi on 18th December 2023.

A researcher from this Group participated in the first Arctic Winter Expedition and reached Himadri station on 21st December 2023. IITM has successfully installed indigenously developed electric field mill, Maxwell current antenna at Indian station Himadri, Ny-Alesund, Svalbard (Arctic) Arctic for measurements of atmospheric electric current and electric field respectively (**Fig. 19**). These are operational now and data is being generated. These measurements are very much useful for understanding the changes in Global Electric Circuit (GEC). These measurements will be

***Fig. 19**: Set-up by IITM during the first Arctic Winter Expedition at Himadri station, Arctic*

continued for at least three years and patterns will be studied to understand the feedback of climate change to Global electric circuit and vice-versa. Long time continuous observations of atmospheric electric parameters will help in understanding the change in global electric circuit. Observations of electric field and current during lightning periods over the Arctic will provide an opportunity to understand the electrical properties of thunderstorms over the Arctic.

Thunderstorm Prediction: Modelling framework for thunderstorm/lightning prediction has been set up for operation based on a new approach using 'dynamical lightning parameterization' in WRF. The first version of the system/code is shared/ handed over to IMD for operational use.

Basic Research:

Wind Tunnel Study of binary Collisions of Water Drops in Presence of Horizontal Electric Fields

Effect of horizontal electric field (EH) = 0, 100, and 300 kVm^{-1} on the characteristics of binary collisions of small water drops (dS = 0.4–1.8 mm diameter) with large drops (dL = 3–3.5 mm diameter) has been investigated in a small vertical wind tunnel using a high-speed digital camera. The coalescence efficiency (EC) of 0.299 observed for average diameters (dL = 3.2 mm, dS = 1.2 mm) in EH = 0 decreased to 0.244/0.211 when EH is increased to 100/300 kVm^{-1}. The increase in the electric field reduces the probability of coalescence when a non-dimensional parameter, Weber number (We) is less than 1. However, an increase in We restricts the probability of coalescence when We ≥ 1. After a binary collision, the relaxation time for coalescence is higher than that for the breakup and increases from the filament to sheet to disk mode of breakup in all-electric field values. Fragment size distributions after the filament and sheet types of breakups differ. More violent collisions have a tendency to increase the number of fragments of the sizes between 1.2 mm and 3.2mm diameter. It is concluded therefore that, the effect of the electric field needs to be included in the estimation of drop growth and precipitation in clouds. *(**Bhalwankar R., Pawar V., Kamra A.K.,** Binary collisions of water drops in presence of horizontal electric fields: A wind tunnel study, Journal of Geophysical Research: **Atmospheres,** 128: e2022JD037543, April 2023, DOI:10.1029/2022JD037543, 1-18).*

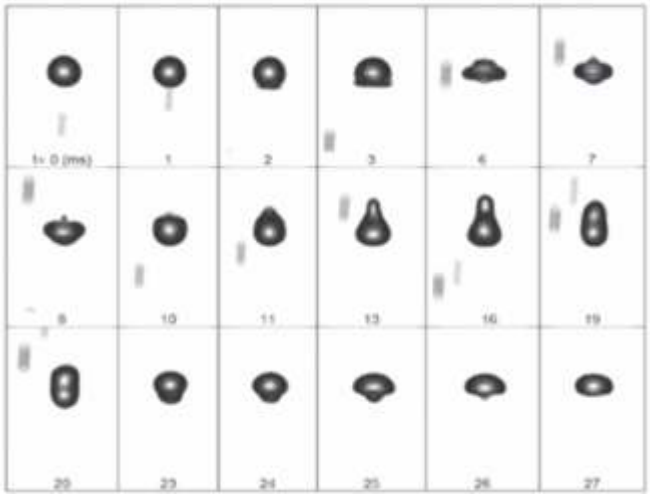


***Fig. 20:** Sequence of high-speed camera images showing coalescence after the collision of drop pair (dL=3.27mm; dS=0.789 mm) in the presence of EH=300 kVm^{-1}. The time shown indicates the evolution of breakup in ms. The smaller drops seen in the top/bottom/left side of the picture are not part of the coalescence.*

Seasonal and Regional Distribution of Lightning Fraction over Indian Subcontinent

Pre-monsoon thunderstorms exhibit more intra-cloud (IC) discharge than monsoonal thunderstorms; hence, the IC: cloud-to-ground (CG) ratio is also high in pre-monsoon. It is shown that CG lightning is approximately 20% of total lightning in pre-monsoon whereas 25% of total lightning in monsoon all over the Indian region. A stronger vertical updraft associated with high convective available potential energy enhances the cold cloud depth. It may expand the mixed phase region, which can broaden and uplift the size of the upper positive charge center inside a thunderstorm. In contrast, the middle negative charge center remains at the same temperature level. Therefore, this process may enhance IC discharge between the upper positive charge center and the middle negative charge center, increasing the IC:CG ratio of a thunderstorm (**Fig. 21**). ***(Ghosh R.,Pawar S.D., Hazra A.,** Wilkinson J**., Mudiar D.,Domkawale M.A.,** Gayatri Vani K., **Gopalakrishnan**

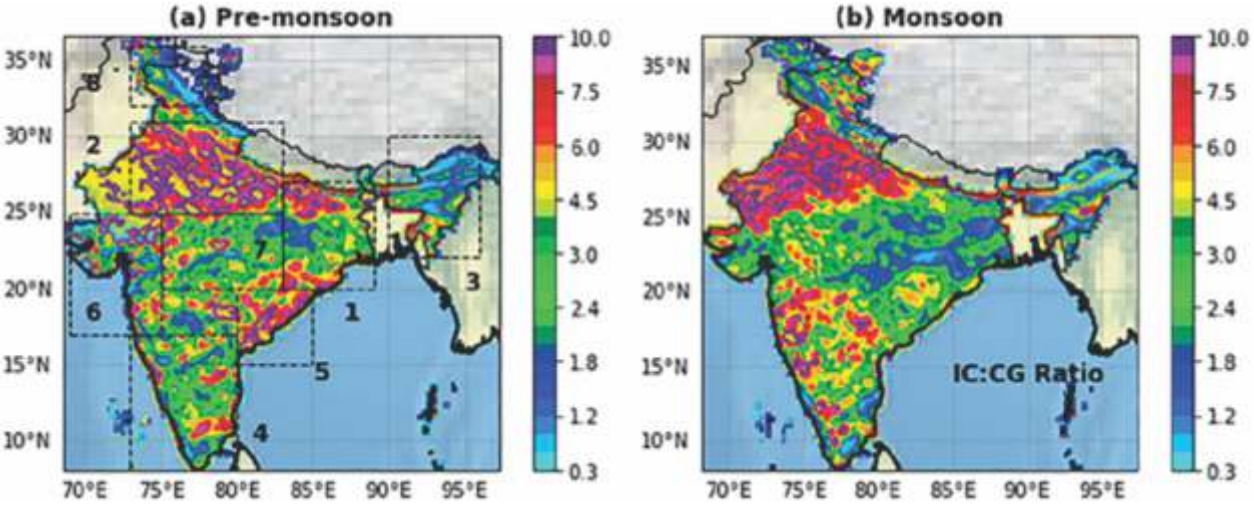


Fig. 21: *Climatological mean (0.25° bins) IC:CG ratio (Z) with estimated from 4 years (2019–2022) of IITM LLN observations over Indian land-mass (8°–35°N, 65°E–100°E) for Pre-monsoon season (March–May) and Monsoon (June–September) in (a and b) respectively. Different regions are marked in the figure (East India, GWB Region 1: 20°N–27°N,83°E–88°E; NorthWest India, Region 2: 25°N–32°N, 73°E–83°E; Northeast India Region 3: 22°N–30°N, 90°E–98°E;Southern Peninsular India, Region 4: 8°N–17°N, 73°E–80°E; Andhra Coast, Region 5: 15°N–20°N, 80°E–85°E; West India, Region 6:17°N–25°N, 72°E–78°E; Central India, Region 7:20°–25°N, 75°–83°E; J&K, Region 8: 32°–36°N, 73°–78°E).*

V., *Seasonal and regional distribution of lightning fraction over Indian subcontinent,* ***Earth and Space Science****, 10: e2022EA002728, June 2023, DOI:10.1029/2022EA002728, 1-19)*

Variability of lightning flash count and CAPE

Variability of lightning flash count and persistence of Convective Available Potential energy (CAPE) during onset-withdrawal and active-break phases of Indian southwest monsoon (ISM) over central India region has been examined for the period 2014–2019. Observed increased lightning activity over this region during onset and withdrawal phase of lightning suggests that when monsoon trough is over the region, both CAPE and lightning increase. Observed high CAPE and lightning over central India (monsoon trough region) during monsoon period can be explained by the dry and cold air entrainment over warm and moist air at the surface. Present results demonstrate that position and strengths of monsoon trough plays important role in the lightning activity over monsoon trough region by prompting the entrainment of dry and cold air coming from north. The analysis clearly suggests high CAPE is a necessary condition for formation of thunderstorms during ISM period (June to September). From the station based CAPE data, it is seen that lightning activity is higher at a station Nagpur (close to the monsoon trough region) compared to a station Hyderabad (far away from monsoon trough). Further, the monsoon trough region remains conditionally unstable which generates lightning producing storms over the study region during monsoon season. Observations suggest that when monsoon trough is strong, entrainment of cold and dry air in the lower level from north of monsoon trough interact with warm and moist air from south of monsoon trough and can make the atmosphere conditionally unstable that helps in formation of thunderstorms over the study region during ISM. (***Pawar V.S., Domkawale M.A., Bhalwankar R.V., Gopalakrishnan V., Pawar S.D.,*** *Lightning activity and Convective Available Potential Energy during different phases of Indian summer monsoon season over central region of India,* ***Meteorology and Atmospheric Physics****, 135: 32, May 2023, DOI:10.1007/s00703-023-00969-y, 1-10)*

Observation of a dramatic increase in the positive cloud-to-ground lightning in the Indian summer monsoon season

Observation of a dramatic increase in the positive cloud-to-ground lightning in the Indian summer monsoon season:Lightning is known for its meteorological importance and associated hazard potential. It is known that the polarity of cloud-to-ground flash (CG) can act as a prognosis of the storm's characteristics. Ground-based observation of lightning over the Indian region suggests that during the break period in the summer monsoon seasons, CG lightning of positive polarity increases dramatically relative to the pre-monsoon days. Here we propose that for thunderstorms forming in the wet season, the non-inductive charge separation happens in the presence of larger mean cloud liquid water in the mixed phase region of the storms. This facilitates the positive charging of graupel particles, thereby producing a large amount of positive CG lightning on these days. This observation is found to be consistent with the laboratory results of Takahashi (1978). The implication of these results has been discussed from the perspective of hazard mitigation associated with positive lightning over India. *(**Ghosh Rakesh, Mudiar D., Pawar S.D., Domkawale M. A., Syed H.A., Hazra A., Gopalakrishnan V.,** Observation of a dramatic increase in the positive cloud-to-ground lightning in the Indian summer monsoon season, **Atmospheric Research,** 298: 107119, March 2024, DOI:10.1016/j.atmosres.2023.107119, 1-14)*

Collaborations:

MoUs have been signed with Ahmedabad University, Shivaji University & Andhra Pradesh State Disaster Management Authority (APSDMA) for cooperation and research in the areas of thunderstorms and lightning.

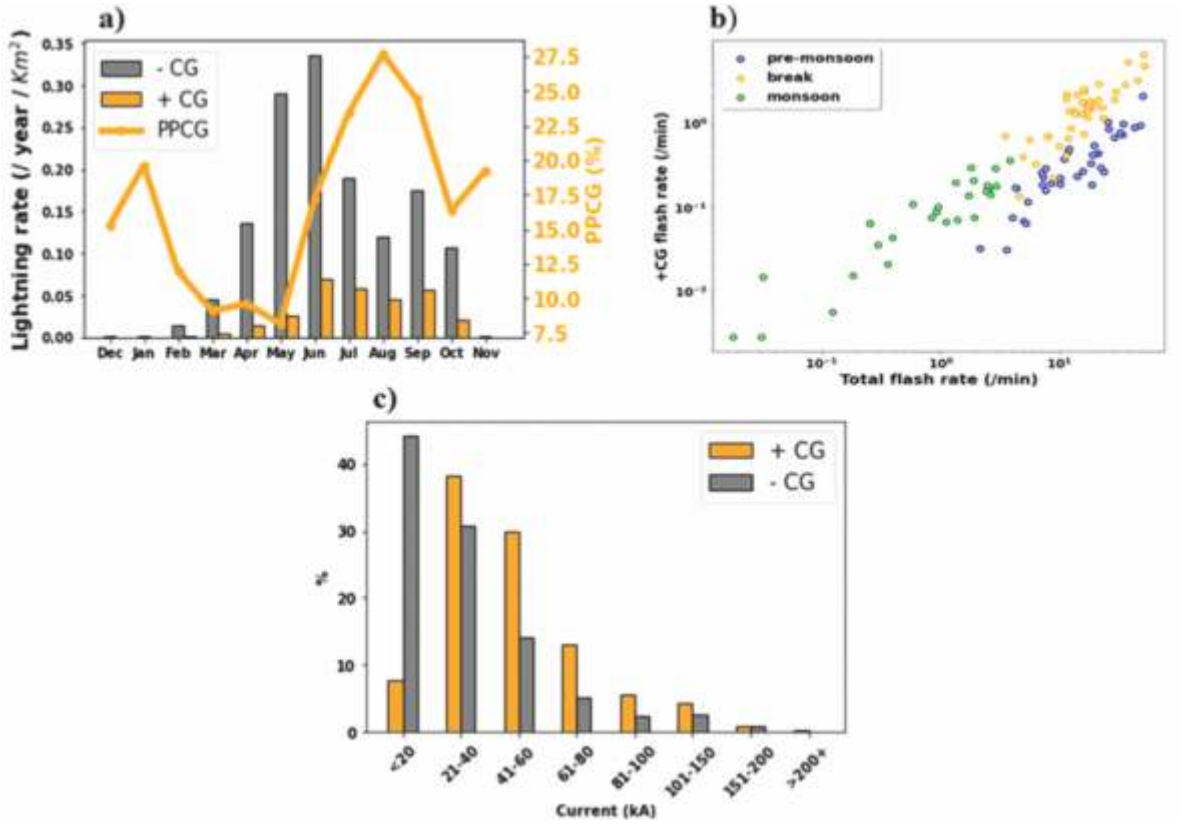


Figure 22: *From a ground-based lightning observation network, we have observed that the rate of positive cloud-to-ground (a-b) discharges (+CG), which are known for their large current (c) and associated hazard potential, dramatically increases during the break regime in summer monsoon season (June–September) compared to the pre-monsoon (March-May).*

1.1.3. Atmospheric Research Testbeds (ARTs)

Project Director: Dr. G. Pandithurai

Objectives

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

R&D Activities:

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

- Central India ART, Silkheda (Bhopal)
- Orographic ART (HACPL)
- Urban ART (Radar and Satellite Meteorology)
- Lower Atmospheric Research using Unmanned Aerial System Facility (LARUS)

Highlights of Major Achievements:

IITM established the Atmospheric Research Testbest (ART) facility in Central India on ~100 acres of land, deployed first phase of atmospheric instrumentation and put in operation. This includes i) Dual Polarization C-band Doppler Weather Radar, ii) Microwave radiometric profiler, iii) Ceilometer, iv) Micro rain radar, v) Disdrometer, vi) Radiosonde, vii) 72 m tall tower for GHG and flux measurements, viii) CCN counter, ix) Aethalometer. The physical infrastructure such as 33 KV electrical sub-station, internal roads connecting different observing facilities, boundary wall with main entrance gate, security cabins, solar streetlights, high mast lights for illuminating the campus etc. were established in the campus. This ART-CI facility has been virtually inaugurated by Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, on 12 March 2024.

Monsoon-2023 observational campaign has been conducted at ART-CI using an established set of sophisticated instruments such as C-band Dual Polarization Doppler Weather Radar, etc to study convective and microphysical properties in the monsoon core zone. The campaign was in coordination with IMD RS/RW sites (twice daily) in the Central Indian region. The datasets generated have been shared with NCMRWF, Delhi for data assimilation & preparation of initial conditions in modelling study.

Radiosonde campaign (twice a day) at ART-CI was conducted in coordination with IMD in the central Indian region during Monsoon-2023 to understand the thermal and dynamical structure of troposphere and lower stratosphere. The campaign was also coordinated with IMD Bhopal such a way that during IOPs, 4 soundings (0600 UTC and 1800 UTC from IITM; 0000 UTC and 1200 UTC from IMD) were conducted. Data also was shared with NCMRWF for assimilation purpose.

In conjunction with the radiosonde observation, the continuous C-band radar observations, MRR observations, aerosols measurements and various other met observations were also collected during the 15 June-15 October 2023. C-band radar operations have provided vertically-resolved polarimetric data on 3-D structures of convective and microphysical properties in the monsoon core zone.

Several observational studies and model sensitivity experiments of cloud and precipitation microphysical processes have been conducted at the **High-Altitude Cloud Physics Laboratory at Mahabaleshwar (Orographic ART)**. The Potential Aerosol Mass (PAM) oxidation chamber to investigate the oxidation of precursor gases have been implemented which produce secondary organic aerosol (SOA) mass and in turn its role on CCN activation.

As part of Mumbai MESONET, four short-range X-band dual-polarimetric radars in the form of a network is being set up over the Mumbai Metropolitan region to better capture the spatial and temporal variability of rainfall.

Established a disdrometer network for 10 cities for rainfall microphysics.

Under the **Lower Atmospheric Research Using Unmanned Aerial System Facility (LARUS), Unmanned Aerial Vehicle (UAV) mission flights** were conducted successfully with onboard instrumentation for boundary layer profiling of meteorological parameters and aerosol physical and chemical properties over Osmanabad.

Drone-based observational campaign was conducted at ART Bhopal in collaboration with NIOT Chennai using in-house designed mini GHG gas sensor system around 72m tower for inter comparison of CO_2 and CO. A portable mini Radiosonde Ground Receiver (mRGR) System was developed at IITM for meteorological data telemetry from a UAV/Drone/Balloon, and published as IITM Technical Report.

1.1.3.1. Central India ART, Silkheda (Bhopal)

Developmental Activities

ART- Central India facility: The ART-CI facility has been formally inaugurated by Hon'ble Minister Shri. Kiren Rijiju, MoES, GoI on March 12, 2024 virtually. The site was initialized in 2021 on ~100 acres of land at Silkheda village in the Sehore District of Madhya Pradesh to provide important observations for better understanding on processes related to convection, clouds and land-atmosphere interactions in the core monsoon zone region. The first phase of physical infrastructure and instrumentation was successfully completed in the year 2022. Guesthouse construction at ART is under progress.

Atmospheric Instrumentation Laboratory is established at ART-CI and state of the art instruments are commissioned viz., Dual-Polarization C-band Doppler Weather Radar, Microwave Radiometric Profiler, Ceilometer, Disdrometer, Micro Rain Radar, AWS, Tower (72 meters) with multi-level sensors and GHG monitoring, Radiation sensors and aerosol measurement facility have been augmented at the ART facility for collecting continuous and high-resolution measurements of aerosols, clouds, rainfall and radiation in the monsoon core region (**Fig. 23**). List of Instruments installed and operational since 2023 are given below

Dual-Doppler Analysis (DDA) to derive 3-D winds in precipitating cloud system

Doppler Weather Radar (DWR) is capable of observing, the internal structure of storm and heavy precipitation system at high spatial and temporal resolution. However, the direct measurements are limited to reflectivity, radial component of velocity, and spectrum width but there is no direct measurement of the complete three-dimensional (3D) wind field. An attempt has been carried out to retrieve 3D winds using dual-Doppler analysis with 3D variational framework (3DAVAR). A coordinated experiment was conducted using two different radars on 2-3 August 2023, for the range coverage of 250 km and range resolution of 500 m. Out of these radars, one DWR is S-band single polarization radar operated by India Meteorology Department (IMD) at Bhopal and other one is C-band dual polarization radar operated by IITM at Atmospheric Research Testbed (ART) facility at Silkheda, Sehore. The radial distance between both radar is 41 km. The chosen area of -150 km to 150 km for wind estimation has been divided into the rectangular grid, each grid having dimension of 0.5 km x 0.5 km and height interval of 500 m. The wind fields synthesis is carried out using 3DVAR based on dual-Doppler method on a region where two radars have overlapping scan coverage (**Figure 24**).

Table-1

	Instrument	Data
1	Suite of Radiation sensors	SW, LW, IR, UV, PAR, Direct, Diffuse.
2	CIMELSunphotometer	Aerosol optical depth, Single scattering albedo, Asymmetry parameter, Precipitable water vapor
3	Nephelometer	Aerosol scattering coefficient (3 wavelengths)
4	SMPS	Aerosol size distribution and total number concentration
5	ACSM	Non-refractive aerosol chemical composition.
6	SP2	Black carbon size distribution and concentration
7	Micro Rain Radar	Vertical profile (6 Km) of Rain rate, raindrop size distribution, and reflectivity.
8	Sky Imager	Cloud fraction, sky condition
9	Disdrometer	Rain rate, raindrop size distribution

Fig. 23: *The exterior (a) and interior (b) view of Atmospheric Instrument Laboratory (AIL) as established at ART, Silkheda facility during August, 2023. Figure (c) shows the suite of radiation sensors installed and commissioned during June 2023. Figure (d) shows the CIMEL sun photometer installed during January, 2024 for the in-situ measurement of AOD along with other derived parameters. Figure (e) describes the custom built common inlet system installed for various aerosol measurements.*

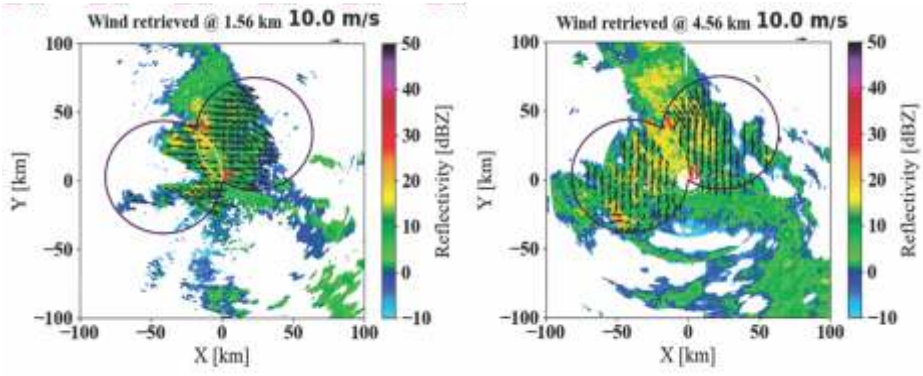


Fig. 24: *Retrieved winds in the overlapping dual-Doppler lobes at 1.5 km (left) and at 4.56 km (right).*

C-band dual-polarization (CPol) radar at ART facility was continuously operated throughout the year 2023 to observe the monsoon convection, pre-monsoon thunderstorms & hailstorms and convection induced by the Western disturbances during winter. CPol radar provides 3D-structure of precipitating systems over a large domain. With the availability of dual-polarization facility, the radar provides differential reflectivity (ZDR), differential phase (ϕ_{DP}), copolar correlation coefficient (ρ_{hv}) along with the conventional parameters, like, radar reflectivity (Z), Doppler velocity (V) and velocity spectrum width (W). Dual-polarization measurements are explored to infer the underlying ice and rain microphysical processes. The temporal and

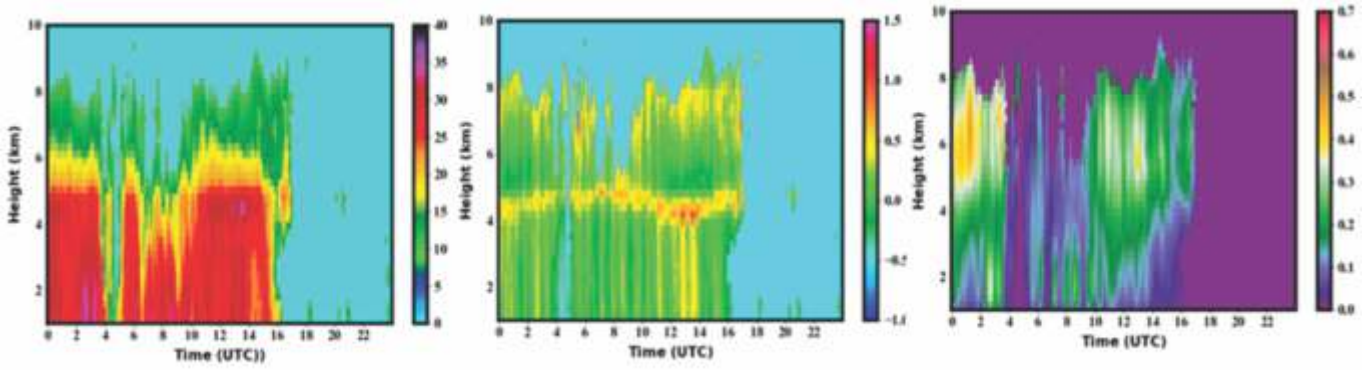


Fig. 25: *Time-height variations of radar reflectivity (left), specific differential phase (middle) and differential reflectivity (right) during the passage of an organized convective system at ART site.*

vertical cross-sections of the mesoscale convective system passed over central India as observed by the C-band radar is shown in the **Figure 25**. The remnants of the convective system during midnight to early morning hours (shallow convective systems during 6-10 UTC) and the development of stratiform rainfall during afternoon (11-16 UTC) is well captured in the vertical profiles of Z, ZDR and specific differential phase (KDP). From the dual-polarization measurements, the underlying ice and rain microphysical processes can be inferred. Riming and aggregation dominates during the stratiform precipitation (between 5 and 8 km). The collision-coalescence process leads to higher reflectivity (during 02-04 UTC, below 2 km) and hence larger raindrops during convective rain.

Radiosonde campaign (twice a day) at ART-CI was conducted in coordination with IMD in the central Indian region during Monsoon-2023 to understand the thermal and dynamical structure of troposphere and lower stratosphere. The campaign was also coordinated with IMD Bhopal such a way that during IOPs, 4 soundings (0600 UTC and 1800 UTC from IITM; 0000 UTC and 1200 UTC from IMD) were conducted. Data also was shared with NCMRWF for assimilation purpose.

Polarimetric radar-based objective quantification of rain-types and convective organization (clustering) over the monsoon core zone

The 6-minute volumetric 3D C-band polarimetric radar (CPol) data from the Atmospheric Research Testbed (ART) site during JJAS 2022 is used to study the evolution of convective clustering over the life cycle of convective entities. The radar observations during heavy rain events (rainfall > 64.5 mm) are first used to classify radar echoes into different types: convective, stratiform, mixed, isolated convective core, isolated convective fringe. **Figure 26** shows spatial structure of radar reflectivity and rain-types. Various clustering metrics were applied to radar-identified convective echoes to objectively determine degree of convective aggregation and their spatial distribution within a radar domain. These metrics measure the degree of organization for each snapshot of radar volume (6 min) with different parameters of clouds present in the radar domain, viz. number density, size, & distance bet convective objects. In **Figure 27**, as a depiction of the convective life cycle during heavy rain events, the composite time series of rain types, aggregation metrics, and related parameters (N, A, and D_0) averaged over the radar domain are made around the temporal maxima of observed precipitation (at t=0). Two distinct phases of convective clustering are observed, each lasting about 24 hours before (Phase 1) and after (Phase 2) the peak rain rate. In phase 1, convective clustering is accompanied by an increase in convective elements whereas phase 2 shows the prevalence of broad region of stratiform along with a decrease in convective elements. A phase-lag relationship amongst isolated convective core, convective, and stratiform echoes is noticed.

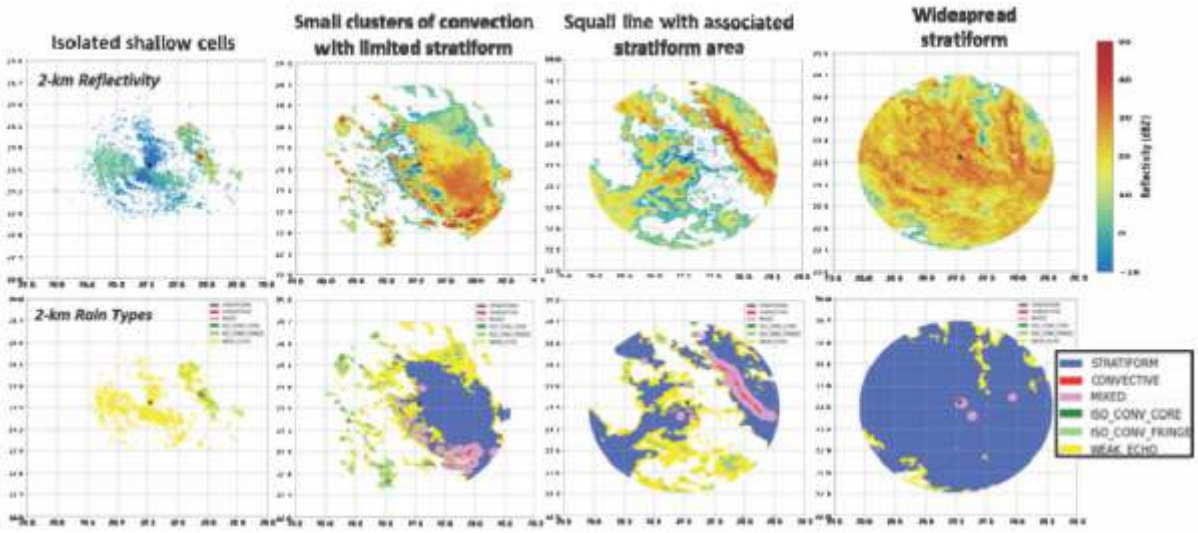


Fig. 26: *Typical scenes of convection during a heavy rain event as observed by C-band polarimetric radar at ART facility. Top and bottom panels show the spatial structure of radar and rain-type classification, respectively.*

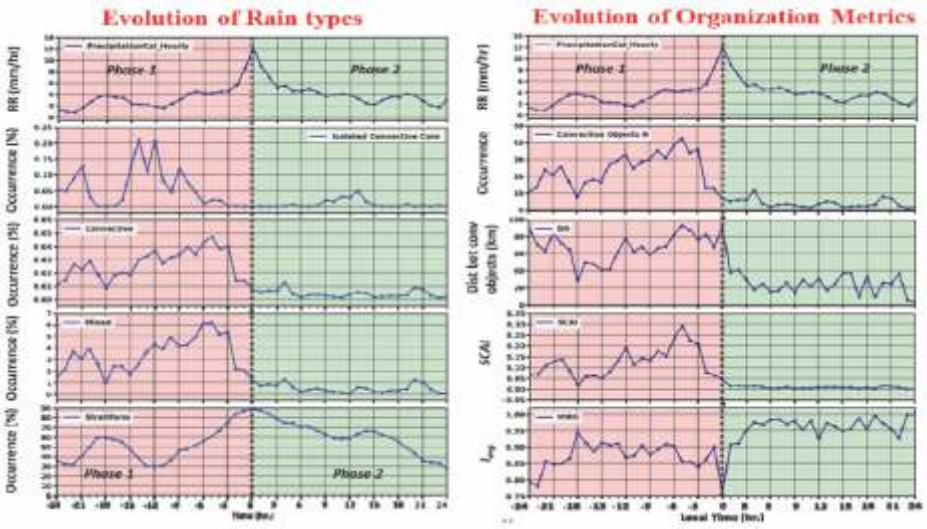


Fig. 27: *Evolution of rain types and organization metrics averaged over radar domain about temporal maxima of observed rain (at t=0) during 2-day heavy rain event.*

Radiosonde campaign in the central Indian region during Monsoon-2023 at ART-CI, Bhopal

1.1.3.2. Orographic ART (HACPL)

Developmental Activities

- Potential Aerosol Mass (PAM) Oxidation Flow Reactor is being implemented to study the aging processes that are responsible for the formation of potential cloud active nuclei. This system will also provide a unique opportunity to study the gas-to-particle conversion processes with the aging time scales of days within a time scale of minutes.
- A size-resolved aerosol hygroscopicity parameterization is developed utilizing size-resolved hygroscopicity data which is further incorporated into the regional scale model in order to conduct sensitivity study of aerosols hygroscopicity for cloud and precipitation formation processes.
- The realignment and recalibration of the optical detectors of Spectrometer for Ice Nuclei (SPIN) system were carried out and the instrument is resumed for the ice nuclei measurement at ART-HACPL facility.
- The time-of-flight power supply part of the TOF_ACSM instrument was repaired, and the instrument is now deployed at ART, Bhopal for online measurement of sub-micron aerosol chemical composition.

Potential Aerosol Mass (PAM) Oxidation flow chamber

Implemented Potential Aerosol Mass (PAM) Oxidation flow chamber at HACPL to create a highly oxidising environment that simulates oxidation processes on time scales of days in the atmosphere in few minutes (**Figure 28**). This will be used to study the secondary aerosol generation via gas phase hydroxyl (OH) radical or Ozone (O_3) oxidation of gaseous precursors. PAM in combination with other aerosol observing systems will be utilized:

- To study the potential SOA formation from individual VOCs, and mixture of VOCs.
- To estimate SOA potential mass from different combustion sources under different OH exposures (ageing time scales). Here dilutor will be utilized to maintain a desired aerosol number concentration.
- SOA formation from selected individual VOCs under the presence of different size selected seed particles (NH_4NO_3, NH_4SO_4, Black Carbon from Aquadaq) which will be generated through aerosol generator.
- Ambient measurement in different seasons to evaluate the ageing scales.

Fig.28: *Initial installation and commissioning of PAM instrument along with accessories with other state of the art equipment.*

Basic Research

Use of multiplatform in-situ observation to study vertical structure and microphysics of clouds during southwest monsoon over Western Ghats, India

Combination of radiosonde profiles with collocated in-situ ground and aircraft measurements is used for the first time to study the vertical structure and microphysics of clouds during southwest monsoon over the Western Ghats, India. The morphology of clouds is detailed with the help of radiosonde observations and classified as low, mid, and high-level clouds depending on the cloud base height. Radiosonde sounding profiles indicated occurrences of both single and multi-layered clouds with higher occurrences of single-layered (~35%) clouds during monsoon transition period (June and September) and two-layered (~42%) during core monsoon period (July and August). Dominance of low (~30%) and high-level (~60%) clouds were noticed compared to mid-level clouds over the observational site during the southwest monsoon. Warm cloud microphysics was investigated using collocated ground and airborne in situ measurements. Irrespective of the cloud type, the cloud liquid water content and the effective droplet diameter increased with altitude. One of the key results is the rapid broadening of the cloud droplet size distribution with height. The number concentration of droplets above 25 μm diameters showed a steep decrease at altitudes above 1800 m, suggesting active collision-coalescence. *(**Leena P.P., Varghese M.,** Kumar J.S., **Anil Kumar V.,Pandithurai G.,Patil R.D.,** Resmi E.A., **Prabhakaran Thara,** Use of multiplatform in-situ observation to study vertical structure and microphysics of clouds during southwest monsoon over Western Ghats, India, **Atmospheric Research**, 290: 106780, July 2023, DOI:10.1016/j.atmosres.2023.106780, 1-13)*

Characterization of rain microphysics on the leeside of the Western Ghats

This study evaluates the performance of four impact-type disdrometers installed at the Indian Institute of Tropical Meteorology, Pune, located on the leeside of the Western Ghats (WG). Further, seasonal variation of rain microphysical properties is studied during premonsoon (March–May), monsoon (June–September), postmonsoon (October–November), and winter (December–February). The four disdrometers exhibit comparable raindrop size distribution (DSD) patterns, though negligible differences are found at smaller drop diameters. The DSD shows higher concentrations of smaller (large-size) drops during monsoon (premonsoon and postmonsoon). Principal component analysis revealed three distinct modes of DSD characteristics. Monsoon DSDs are associated with a group of numerous smaller drops allied with shallow storm heights (warm rain). The premonsoon and postmonsoon DSDs are clustered in a group where ice-based processes dominate, resulting in higher median drop diameters (D0) and smaller normalized intercept parameters (Nw). The fitted gamma DSD model indicates higher mass-weighted mean diameter (Dm) during premonsoon, and higher intercept parameter during monsoon, whereas postmonsoon and winter have intermediate values. DSD stratified with rain rate shows that the Dm values increase with an increase in rain rate during winter, monsoon and postmonsoon, whereas in premonsoon, Dm increases initially and then decreases. Higher Dm and lower Nw are observed during convective rain in all seasons. The fitted slope–shape parameter relationships show a considerable seasonal variation. The DSD on the WG's leeside is notably different from the windward slopes and other WG locations. Different microphysical and dynamical mechanisms lead to seasonal differences in DSD characteristics. In monsoon, a considerable volume of water vapour advected from the Arabian Sea promotes the formation of raindrops through collision–coalescence processes, which may result in a higher proportion of smaller and midsized raindrops. The deeper clouds during pre-monsoon and post-monsoon indicate mixed-phase processes, which lead to mid and large-sized raindrops. *(**Murali Krishna U.V., Das Subrata Kumar, Kolte Y., Jha Abhishek, Konwar M., Deshpande S., Pandithurai G.,** Characterization of rain microphysics on the leeside of the Western Ghats, **Quarterly Journal of the Royal Meteorological Society**, 149, October 2023, DOI:10.1002/qj.4554, 3250-3269)*

1.1.3.3. Urban ART (Radar and Satellite Meteorology)

Developmental Activities

- **Urban Weather Radar Network:** Development of an urban weather radar network over the Mumbai Metropolitan region is underway. The radar's factory acceptance test (FAT) was conducted in mid-April 2023.The necessary infrastructure development, such as erecting tower structures for radar installation, is in progress.
- **Automatic Rain Gauge Network:** MESONET automatic rain gauges were operated in the Mumbai Metropolitan region to help the flood warning system. Rainfall information is disseminated through mobile applications to all the stakeholders.

Urban Radar Network, Mumbai: Establishment of Urban X-band Radar Network in Mumbai (4 no.) is under progress. The erection of towers and AC cabin base for RADAR is completed at three locations: 1) Amity University Mumbai, Panvel, 2) DJ Sanghvi College, Ville parle, 3) Vidya Vardhini College of Engineering, Vasai (**Figure 29**). The tower and AC cabin base fabrication work of tower is under progress at Kalyan cite. The radar consignments are safely stored at IIG, Colaba. This Urban Radar Network in Mumbai will be operational by May/June 2024.

Mumbai MESONET and Urban Radar Network: A MESO-scale rain gauge NETwork (MESONET) consisting of about 117 rain gauges distributed over the Mumbai region has been established to have real-time rainfall information. Real-time ARG's rainfall data from Mumbai MESONET disseminated in real-time to MoES institutes (viz., IMD-New Delhi, IMD-Pune, NCMWRF, NCCR), Maharashtra State Disaster Management and academic institutions, through Mobile Apps (Android and iOS) - useful for validating High-resolution satellite rainfall products. As part of Mumbai MESONET, four short-range X-band dual-polarimetric radars in the form of a network is being set up over the Mumbai Metropolitan region to better capture the spatial and temporal variability of rainfall.

For rainfall microphysics, IITM has established the network of **Disdrometers over 10 stations** of India (viz., New Delhi, Mumbai, Kolkata, Chennai, Pune, Mahabaleshwar, Kochi, Bhopal, Silkheda, Lakshadweep Island) which differ widely with respect to their geographical and climatic variations.

Basic Research

Radar observed convective storm characteristics at the eastern edge of the Indian summer monsoon trough

The summer monsoon trough (MT) is a dynamically active region of the quasi-stationary feature extending from

Fig. 29 : *Radar Tower and Radar control room platform at Amity University, Panvel. A similar setup is being equipped at other 3 sites (Vile Parle, Kalyan, Vasai) of radar network*

north-western India towards the Bay of Bengal (BoB). The eastern rim of the MT (EMT) is modulated by the embedded synoptic-scale monsoon low-pressure systems (LPSs) in north BoB. The spatiotemporal variability of the convective storm (CS) in the EMT region, which lies along the pathway of LPSs was examined. A Lagrangian-based objective-tracking method, Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN), was injected into Kolkata S-band radar observations of nine wet seasons (June–September, 2009–2017). CSs frequently occur near the onshore areas and is linked to the formation and propagation of LPSs in the BoB. By examining the relationship of CS top heights with reflectivity lapse rate and fractional volume of 40 dBZ or more, three vertical categories of CS have been identified as shallow (SCS) below 5 km, medium depth (MDCS), and deep CS (DCS). The land–ocean contrast in the spatial distribution of MDCS and DCS and the contoured frequency by altitude diagram shows continental convective vigor. Although short-lived smaller CSs account for most storms in EMT, the bulk of the precipitation (75%) contributed from the infrequent largest storms. A weak (strong) linkage between the precipitation flux and CS top (area-time integral) gives a clue on the importance of CS voluminous organization rather than the linkage of heaviest rainfall to tallest CS. While most CSs propagate inland following the mass-weighted mean winds, the largest CS propagate offshore steered by the mid-level wind at 700 hPa. *(**Jha A.K., Das Subrata Kumar, Deshpande S.M., Murali Krishna U.V.,** Radar observed convective storm characteristics at the eastern edge of the Indian summer monsoon trough, **Climate Dynamics,** 61, October 2023, DOI:10.1007/s00382-023-06759-x, 3633–3652)*

CloudSat inferred contrasting monsoon intra-seasonal variation in the cloud vertical structure over different regions in India

Earlier studies reported the contrasting cloud properties over central India during intraseasonal oscillation of the Indian summer monsoon (ISM). This intraseasonal ISM variation in the cloud vertical structure (VSC) over different parts of India is yet to be explored. To fIll this gap area, VSC derived from nine years of CloudSat measurements over geographically diferent but having homogenous ISM rainfall Indian regions are selected for the study. We investigated VSC, types of clouds, and microphysical properties during the intra-seasonal variation of ISM. Signifcant contrast was found in the mid-tropospheric cloud region during the ISM spells. Analysis of cloud types shows signifcant intra-seasonal variability with the presence or absence of mixed-phase clouds (As, Ns, and Ac). In ISM (active and break) spells, the core monsoon regions (CI, CE, WI) share similar VSC features (complete or void mid-levels). Hence, microphysical properties follow similar characteristics except for ice water content which difers profusely among them. Over these regions, ten times higher ice efective radius during active days indicates dominating ice process compared to break days. Larger-sized ice hydrometeors (>25 µm) are present at 5–6 km, which shows good interrelation with the ISM active and break spells above freezing level, and its size decreases with altitude. Whereas no diference in VSC is found during diferent ISM spells over the eastern part of India (WB and EI) except in the ice microphysical parameters, which are more dominant during break days. Further, irregular and discontinuous VSC over North and South India (NI and SI) could be due to their pertinent geographical conditions. Suppression of cloud processes at mid-tropospheric altitude is one of the most important reasons behind reduced precipitation over the core ISM regions. Mid-tropospheric drying is a remarkable sign of ISM break, which is the main source of suppressed convection and cloud activity over the core ISM region. This CloudSat study brought robust composite cloud vertical structure for the ISM intra-seasonal variability of cloud over diferent regions of India to improve the understanding of cloud-related processes and then increase the predictive capabilities of large-scale models. *(**Kalapureddy M.C.R., Sukanya P., Dhavale V., Nair M.R.,** CloudSat inferred contrasting monsoon intra-seasonal variation in the cloud vertical structure over Indian regions, **Climate Dynamics**, 61, August 2023, DOI:10.1007/s00382-022-06643-0, 1567–1589)*

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

Developmental Activities

A suitable data logging system with data telemetry capability is in-house designed and developed at IITM and integrated with sophisticated miniaturized gas sensors. Thus, the in_house designed prototype gas sensor system named as *mini GHG (mGHG) system* is suitable for using on a UAV/drone for air pollution measurements. This system is deployed on a Hexacopter and tested the performance of the sensors in air at NIOT, Chennai. The results are encouraging and more such experiments will be conducted in the boundary layer to assess the data quality *(Technical report under preparation)*.

Drone experimentation at ART-Bhopal:

Drone based experimentation was conducted at ART site Bhopal in collaboration with NIOT to explore the suitability of a Drone platform for feasible atmospheric measurements in the boundary layer. IITM in-house mGHG gas sensor system and other aerosol and meteorological sensors were deployed on a Hexacopter platform at acceptable positions. The experiment was conducted above the ground observatory and near the 72m tower at ART site and obtained the vertical profiles of trace gases, aerosol and met parameters covering the lower boundary layer (500m to 1000m). Unique data sets are collected. Data processing and inter comparisons are underway.

The drone experimentation was also conducted near the tower of 72m. On the tower, CO_2 and CO are measured at altitudes of 12m, 36m and 72m using Piccaro analyzer. The drone was hovered at those levels for few minutes for simultaneous measurements of CO_2 and CO. The inter-comparison of CO_2 and CO is within the acceptable range. Further, Calibration of mGHG system with known gases is attempted and data processing and interpretation of the results is in progress.

Technical report published: "***In-house built a portable mini Radiosonde Ground Receiver (mRGR) System for meteorological data telemetry from higher altitudes***" by Mahesh Nikam, Sanket Kalgutkar and Padmakumari B, *Technical Report No. TR-07, ESSO/IITM/ART/ TR/01(2023)/201*.

Fig. 30 : *(a) Testing of IITM mGHG gas sensor system on a Hexacopter. (b) Drone experimentation at ART-Bhopal*

1.1.4. Air Quality Early Warning System (AQEWS) and, Metropolitan Air Quality and Weather Services (MAQWS)

Project Director (MAQWS): Dr.B.S. Murthy, Scientist F (till November 2023)
Project Incharge (AQEWS & WIFEX): Dr. Sachin Ghude (till November 2023)
Project Director(AQEWS, MAQWS&WIFEX): Dr. Sachin Ghude (w.e.f. December 2023)

Objectives

- To develop a research-based integrated state-of-the-art air quality early warning system for air quality to provide accurate and timely air quality forecasts, assess health risks, and support policymakers, municipal bodies, and health agencies with actionable insights for targeted interventions.
- To investigate the meteorological, environmental, and chemical conditions driving fog formation, persistence, and dissipation; to improve fog prediction models by studying its dynamics and impacts on visibility and hazards; to collect high-resolution data on key variables across fog-prone areas; and to assess and mitigate fog's impact on transportation, public health, and daily activities by providing actionable insights and supporting decision-making in high-impact regions.
- To advance research on atmospheric processes governing the atmospheric chemical composition, air toxicity and air pollutants through modelling and observational network.
- To investigate the role of carbonaceous species (black carbon, organic carbon, brown carbon, etc.) in different atmospheric processes

The following major R&D activities are executed:

- Air Quality Early Warning System (AQEWS) for operational air quality forecasts
- Decision Support System (DSS) for operational assistance to the policymakers in managing air quality
- Winter Fog Experiment (WiFEX)
- SAFAR (MAQWS): Air Quality measurements and forecasting over four Metropolitan cities (Delhi, Pune, Mumbai and Ahmedabad)
- MAPAN (MAQWS): PAN India Air Quality Monitoring Network.
- MAPAN-2 : Air Quality Monitoring Network over Himalayan and oceanic region
- Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation (RASAGAM)
- EIACP/ENVIS: operates under the thematic area of Atmospheric Pollution and Climate Change as a Programme Centre Resource Partner to the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India

Highlights of Major Achievements:

- Air Quality Early Warning System (AQEWS): The AQEWS, operational since 2022, employs a high-resolution modeling approach at 400m spatial resolution to forecast air quality in Delhi NCR. This system integrates real-time data from various monitoring stations and utilizes advanced meteorological models to predict severe air quality events, thereby enabling timely alerts for residents and policymakers to take preventive measures against pollution.

- Decision Support System (DSS): Developed by the Indian Institute of Tropical Meteorology, the DSS enhances air quality management by quantifying contributions from local emissions and external sources, including biomass burning from neighboring states. It operates using a numerical model framework that assimilates data from ground-based and satellite sources, providing actionable insights for emission reduction strategies during critical pollution episodes.
- Winter Fog Experiment (WiFEX): The WiFEX campaign focuses on understanding fog dynamics and improving forecasting accuracy across the Indo-Gangetic Plain. Utilizing advanced remote sensing technologies and an Ensemble Probability Fog Forecast System, WiFEX provides real-time fog predictions, which are crucial for aviation safety and public health during winter months characterized by dense fog events.
- SAFAR Initiative: The System of Air Quality and Weather Forecasting and Research (SAFAR) offer comprehensive air quality monitoring across major Indian metropolitan areas. By integrating automated weather stations and air quality sensors, SAFAR provides real-time data and forecasts up to three days in advance, facilitating informed decision-making for urban authorities and the public.
- MAPAN Network: The Monitoring of Air Pollution Across the Nation (MAPAN) is a nationwide initiative aimed at expanding air quality monitoring beyond urban centers. This network captures data from diverse geographical regions, including rural and industrial areas, to assess overall air quality trends in India, thereby supporting targeted policy interventions for pollution management.
- RASAGAM Program: The Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation (RASAGAM) initiative focuses on identifying pollution sources through real-time monitoring. By analyzing the chemical composition of ambient air, RASAGAM aids in developing targeted mitigation strategies that address specific pollutants and their health impacts.
- DSS v1.0 Findings: The Decision Support System version 1.0 has demonstrated its utility in quantifying the impact of emission reductions on PM2.5 levels in Delhi. For instance, a projected 20% reduction in emissions could lead to a significant 12% decrease in PM2.5 concentrations, highlighting the system's capability to inform effective air quality management strategies.
- Fog Forecasting Improvements: Recent studies indicate that incorporating irrigation effects into weather prediction models significantly enhances fog event forecasts in northern India. This finding underscores the importance of considering agricultural practices in meteorological models to improve predictive accuracy regarding fog formation, which has implications for transportation safety and public health during winter months.

Air Quality Early Warning System (AQEWS) and Decision Support System (DSS):

The Indian Institute of Tropical Meteorology (IITM), under the Smart Cities Mission (NP15) of the Government of India, has successfully deployed an operational Air Quality Early Warning System (AQEWS) and Decision Support System (DSS) for the Delhi National Capital Region (NCR). The AQEWS, which operates at a high spatial resolution of 400 meters, employs a globally standardized modeling approach to deliver timely air quality forecasts for residents of the Delhi NCR region. This system's operational and public dissemination is facilitated through the dedicated website: https://ews.tropmet.res.in/. Key organizations, including IMD, MoES, CAQM, CPCB, MoEFCC, and DPCC, rely on this system for operational purposes. IITM continues to provide essential technical support to enhance forecast accuracy and ensure the system's maintenance. Since becoming operational in 2022, the DSS has been instrumental in providing quantitative data on emissions from various sources contributing to air quality degradation. Ongoing efforts focus on developing a public dissemination tool for this information. The DSS issues timely alerts for impending air quality events and predicts source contributions for the following five days, enabling swift decision-making in alignment with the Graded Response Action Plan (GRAP) of the Government of India. In 2022, the system provided critical research inputs to the Commission for Air Quality Management (CAQM), which informed the development of a new stubble-redistribution policy and offered insights into the contributions of various emission sources to Delhi's air pollution. Additionally, the DSS evaluated the effectiveness of GRAP initiatives in controlling air pollution, further supporting informed decision-making in advanced air quality management. This system is now extened to other cities of India such as Japur and soon will become operational for Mumbai.

Winter Fog Experiment (WiFEX):

The Winter Fog Experiment (WiFEX) campaign for the 2023-24 winter season was conducted from December 2023 to February 2024 at Indira Gandhi International Airport, New Delhi. This campaign involved the deployment of advanced remote sensing and in-situ instruments at the airport, alongside the implementation of a 21-member operational Ensemble Probability Fog Forecast System. This system provided real-time fog forecasts across the Indo-Gangetic Plain, with a particular focus on New Delhi and the surrounding NCR region. The WiFEX forecast system is utilized by multiple agencies, including the Airport Authorities, the New Delhi Airport Operator, the India Meteorological Department (IMD), and the National Centre for Medium Range Weather Forecasting (NCMRWF) for operational decision-making.

A retrospection meeting, chaired by Dr. K.J. Ramesh, was held to review WiFEX Phase-I (2015-2022) and discuss the research plan and scientific objectives for WiFEX Phase-II. The fog research review committee expressed satisfaction with the scientific achievements of the first phase and emphasized the need for targeted experiments and site-specific observations in the next phase. Following the committee's recommendations, WiFEX-II commenced in early November 2023, with the introduction of new instruments at the WiFEX lab to study aerosol chemical composition and its role in haze and fog formation. Additionally, WiFEX-II has been expanded to include the newly constructed Noida International Airport, located outside the urban canopy. This expansion aims to investigate the effects of the urban-rural contrast and urbanization on fog formation.

WiFEX (Winter Fog Experiment) delivers an ensemble probabilistic forecast system specifically designed to predict fog events for airports and the broader northern region of India. This advanced forecasting system operates at a high spatial resolution of 3 kilometers, enabling precise and localized predictions. The forecast system operates at a 3 km resolution, ensuring detailed and accurate predictions across the northern region of India, including key airports. This high resolution is particularly important for capturing the local-scale meteorological phenomena that contribute to fog formation, such as temperature inversions, humidity levels, and wind patterns. WiFEX forecasts are integrated into the decision-making processes of multiple

agencies, including the India Meteorological Department (IMD), airport authorities, and the National Centre for Medium Range Weather Forecasting (NCMRWF). These forecasts assist in making informed decisions about flight operations, ground services, and public safety measures during fog events. WiFEX's ensemble probabilistic forecasts play a critical role in mitigating the adverse effects of fog on air travel and daily life in northern India, providing essential data for timely and effective response actions.

Metropolitan Air Quality and Weather Services (MAQWS)

SAFAR: Air Quality Measurements and Forecasting Over Four Metropolitan Cities: The System of Air Quality and Weather Forecasting and Research (SAFAR) are an initiative by the Ministry of Earth Sciences (MoES) designed to provide real-time air quality information and forecasts for major metropolitan cities in India. SAFAR is a part of the larger Ministry's efforts under the Meteorological and Air Quality Weather Services (MAQWS) program, which includes a comprehensive network for air quality monitoring and forecasting. SAFAR is operational in four key metropolitan cities: Delhi, Pune, Mumbai, and Ahmedabad. The system provides real-time air quality data, forecasting for the next 1 to 3 days, and health advisories to the public. This initiative involves a high-resolution monitoring network with automated weather stations and air quality monitoring instruments deployed across these cities. The SAFAR program integrates these data streams to model and predict air quality, helping local authorities and the public take proactive measures to mitigate the adverse effects of air pollution. The system's outputs are accessible to the public via a dedicated website and mobile applications, ensuring that timely and accurate information reaches citizens, enabling them to minimize exposure to harmful pollutants.

MAPAN: PAN India Air Quality Monitoring Network

The Monitoring of Air Pollution Across the Nation (MAPAN) is a PAN India network under the MAQWS program that extends air quality monitoring beyond the metropolitan focus of SAFAR. This network is designed to provide a broader understanding of air quality across various geographical regions in India, capturing data from diverse environments such as urban, rural, industrial, and remote areas. MAPAN serves as a crucial tool in assessing the overall air quality scenario across India, identifying pollution hotspots, and understanding regional variations in air quality. The data collected through this network support policymakers in developing targeted strategies for air quality management across the country. The program is further revised as MAPAN-2 for Air Quality Monitoring Network over Himalayan and Oceanic Regions. MAPAN-2 expands the air quality monitoring efforts to more challenging and less studied environments, specifically the Himalayan region and oceanic zones. This network is designed to gather air quality data in these critical regions, which are often influenced by unique meteorological and topographical factors. In the Himalayan region, MAPAN-2 focuses on monitoring the impacts of transboundary pollution and the effects of local sources in high-altitude areas, which are crucial for understanding climate and environmental changes in these sensitive regions. Over the oceanic regions, the network contributes to the understanding of air-sea interactions and the transport of pollutants across the oceans. MAPAN-2 plays a significant role in filling the gaps in air quality data from these remote regions, providing a more comprehensive understanding of India's air quality dynamics.

Together, these initiatives under the SAFAR and MAPAN programs represent a significant effort by the MoES to monitor, understand, and forecast air quality across India, enabling better management of air pollution and protection of public health and the environment.

Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation (RASAGAM)

The Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation (RASAGAM) is a cutting-edge initiative aimed at identifying and quantifying the sources of air pollution in real time. This program is crucial for devising targeted strategies to mitigate the effects of air pollution in various regions across India. By

providing real-time data on the composition and sources of pollutants, RASAGAM enables authorities to implement more effective air quality management practices and reduce public exposure to harmful pollutants. In addition to source apportionment, RASAGAM also focuses on assessing the toxicity of the air we breathe, particularly the harmful effects of metals and microplastics present in the atmosphere. This aspect of the program is essential for understanding the health risks associated with exposure to various pollutants. The RASAGAM program is pivotal in providing a detailed understanding of the air pollution landscape in India, particularly in urban and industrial regions where pollution levels are often high. By combining real-time source apportionment with toxicity assessments, RASAGAM equips policymakers, environmental agencies, and health organizations with the information needed to implement effective air quality management and mitigation strategies. This program plays a critical role in safeguarding public health by addressing both the sources of pollution and their toxicological impacts.

DEVELOPMENTAL ACTIVITIES

(i) Air Quality Early Warning System (AQEWS) and Decision Support System (DSS):

Automation of AQEWS: The automation of the forecasting process was a significant milestone in our development activities. By streamlining operations and reducing manual intervention, we ensured the timely generation of accurate forecasts. The integration of chemical data assimilation for PM10 and PM2.5 further augmented the precision and reliability of our forecasts, enabling stakeholders to make informed decisions regarding pollution mitigation strategies.

Comprehensive Air Quality Forecasting System Development and Project Contributions

The development of the high-resolution Air Quality Forecasting system for major cities in West India was a meticulously planned and executed endeavour. Leveraging advanced computational models and data assimilation techniques, IITM embarked on the task of understanding atmospheric dynamics and pollutant dispersion patterns. Through extensive research and development efforts, it aimed to enhance our predictive capabilities and provide actionable insights for air quality management.

The AQEWS team continuously explored novel approaches to forecasting methodology. Projects like the AQEWS and the Jaipur Air Quality Early Warning System served as platforms for testing and refining the AQEWS models. Through collaborative research endeavours, various environmental parameters, enriching the understanding of air quality dynamics and refining the forecasting algorithms have been developed. Additionally, the IITM contributions to projects such as ARAI Delhi and the Jaipur Air Quality Early Warning System spurred advancements in emission ingestion techniques and forecasting setup development. These initiatives were instrumental in addressing the challenges posed by complex urban landscapes and diverse pollutant sources, thereby enhancing the accuracy and reliability of existing AQEWS forecasting systems.

Examination of HONO Chemistry

Nitrous acid (HONO) chemistry is examined for the first time, a pivotal factor in the formation of secondary aerosols in the troposphere. During the Winter Fog Experiment (WiFEx) campaign in the winter of 2017–2018 in Delhi, India, HONO was measured for the first time. A comprehensive study has been conducted on HONO temporal characteristics, as well as other gases (NO_x, O_3, NH_3, SO_2, and HNO_3), $PM_{2.5}$ aerosols, and meteorological parameters. The HONO sources and sinks during the fog period were investigated using a Tropospheric HAlogen Chemistry MOdel (THAMO). At the peak of HONO concentration, an OH formation rate of 1×10^7 molecules cm^3s^{-1} was estimated, highlighting that HONO photolysis emerged as the primary source of OH radicals, surpassing other traditional pathways and significantly impacting atmospheric oxidizing capacity.

Parameterisation of Secondary Organic Aerosols (SOA) in AQEWS modelling framework

The existing modeling framework of the AQEWS lacks the incorporation of Secondary Organic Aerosols (SOA).

In an effort to enhance the system's performance, especially during extreme pollution events, steps have been taken to parameterise the formation of SOA within the current setup while ensuring computational efficiency. This involves the adoption of a simplified parameterisation for SOA formation within the MOZCART chemical mechanism. The integration of this approach into the current setup significantly has the potential to improve the representation of SOA, specifically emphasising its formation from both biomass burning and anthropogenic volatile organic compound (VOC) emissions. This addition to the modelling framework could contribute to a more accurate and comprehensive portrayal of the feedback mechanisms associated with SOA.

Tuning of Visibility Embedded with Realistic Aerosol (VERA) model for Delhi:

The 'Visibility Employing Realistic Aerosols' (VERA) model is for visibility prediction by allowing aerosols to participate in the fog-droplet formation processes. The VERA-simulated visibility in Delhi during winter showed a large deviation from the observations. While in situ measurements show a multimodal dry aerosol size distribution over Delhi, VERA prescribes six different uni-modal configurations. We have initiated modifications in VERA by introducing a new observationally constrained dry aerosol size distribution for Delhi. We have developed an empirical model for aerosol (PM2.5) size distribution for Delhi during winter from the measured PM2.5 mass mixing ratio by employing the multi-modal log-normal size distribution following Hess et al. (1998).

Decision Support System (DSS) for air quality management in Delhi and its bordering districts in the National Capital Region:

This DSS is an air quality forecasting framework aimed at quantifying a) the source contribution to the fine particulate matter load, and b) the effects of source-level interventions on the same for the eight bordering districts of Delhi, including Jhajjar, Rohtak, Sonipat, Bagpat, Gautam Buddha Nagar, Ghaziabad, Faridabad, and Gurgaon. A similar system for the city of Delhi has already been developed by IITM in the year 2021.

Early Warning and Decision Support for Air Quality Management in Jaipur:

This air quality forecasting system has been developed to provide high-resolution (2 km grid spacing) air quality forecasts to the city of Jaipur. The system further has a DSS framework to quantify the contribution of the neighbouring districts, including Tonk, Ajmer, Nagaur, Sikar, Alwar, Dausa, Mahendrgarh, and Sawai Madhopur to the Jaipur district's fine particulate matter pollution.

(ii) Winter Fog Experiment (WiFEX):

Implementation of Ensemble Probability Fog forecast System (EPFS)

The operational Ensemble Probability Fog Forecast System (EPFS; 21 members) was developed at the Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, India. Additionally, an advanced automated system for comprehensive fog forecasting was developed and successfully implemented through the utilisation of shell scripting.

Implementation of deterministic Urban Fog Model

Implemented a coupled WRF-Urban Asymmetric Convective Model (WRF-UACM) for Delhi, India, integrating explicit urban physics with Sentinel-updated USGS land-use and urban morphological parameters derived from the UT-GLOBUS dataset. WRF-UACM reproduced the nighttime urban heat island effect within the city, showing realistic diurnal heating and cooling patterns that are important for accurate fog onset and duration.

(iii) Metropolitan Air Quality and Weather Services (MAQWS)

The **Modelling Air Pollution and Networking (MAPAN)** project is a pan India project with 21 Air quality monitoring stations across different parts of India. However, the stations have been non-operational after the COVID period. An inter-MoES committee was formed to look after the revival process of MAPAN

network. The committee has recommended primarily reviving 8 MAPAN stations in the 1st phase. Five stations viz. Mahabaleshwar, Bhopal, Thiruvananthapuram, Chennai, and Srinagar (J&K) will be repaired and retained in their present location. The remaining three, viz. Lucknow, Gorakhpur and Hyderabad will be shifted to Gangtok, Srinagar (Garhwal) and Rani chauri as part of forming a Himalayan air quality network. As part of MAPAN network over the Himalayan Region, MoU for real time monitoring of air pollutants have been signed with: i) Hemvati Nandan Bahuguna Garhwal University (HNBGU), Srinagar Garhwal, Uttarakhand, India in March 2024; ii) Sikkim University, Gangtok, Sikkim. Development of a directional particulate sampler which can be used for source-specific data collection or fence line monitoring.

IITM has developed Air quality Integrated system for Risk Warning and Safety Enhancement (AIRWISE) for Megacities. Operational support has been provided in existing daily Air Quality Forecasting systems (AQEWS) for Delhi and QATAR.

BASIC RESEARCH

AWQES

Decision Support System version 1.0 (DSS v1.0) for air quality management in Delhi, India

This paper presents the newly developed Decision Support System version 1.0 (DSS v1.0) designed for air quality management in Delhi, India. Beyond standard air quality forecasts, DSS offers insights into the contributions of Delhi, its surrounding districts, and stubble-burning fires in Punjab and Haryana to $PM_{2.5}$ levels in Delhi. Additionally, DSS evaluates the impact of local and regional emission-source-level interventions on pollution in Delhi. According to DSS, implementing a 20% (40%) reduction in anthropogenic emissions across all NCR districts would result in a 12% (24%) reduction in $PM_{2.5}$ levels in Delhi on a seasonal mean basis. *(Decision Support System version 1.0 (DSS v1.0) for air quality management in Delhi, India, (**Govardhan G., Ghude S.D.,** Kumar R., Sharma S., Gunwani P., Jena C., **Yadav P., Ingle S., Debnath S., Pawar P., Acharja P., Ja, R., Kalita G., Ambulkar R.,** Kulkarni S., Kaginalkar A., Soni V. K., Nanjundiah R.S., Rajeevan M., Decision Support System version 1.0 (DSS v1.0) for air quality management in Delhi, India, **Geoscientific Model Development,** 17, April 2024, DOI:10.5194/gmd-17-2617-2024, 2617–2640).*

Impact of dust aerosols on the Indian Summer Monsoon Rainfall on intra-seasonal time-scale

The study explored the impact of declining dust emissions on Indian monsoon rainfall using the WRF-Chem model, revealing a significant reshaping of the spatial distribution of seasonal mean monsoon rainfall. Altered aerosol loading conditions were observed to influence large-scale circulation patterns, strengthening convective rainfall over the Bay of Bengal and intensifying the 10–20 days sub-seasonal mode of the Indian Summer Monsoon, leading to enhanced westward propagation of rain-bearing systems and substantial rainfall across the Indian subcontinent. *(**Debnath S., Govardhan G., Saha Subodh K., Hazra A., Pohkrel S.,** Jena C.,Kumar Rajesh, **Ghude S.D.,** Impact of dust aerosols on the Indian Summer Monsoon Rainfall on intra-seasonal time-scale, **Atmospheric Environment**, 305: 119802, July 2023, DOI:10.1016/j.atmosenv.2023.119802, 1-13)*

Forecasting of an unusual dust event over western India by the Air Quality

This study presents the successful implementation of an operational Air Quality Early Warning System (AQEWS) to forecast an unprecedented dust storm in western India from January 21-24, 2022. The system accurately predicted the storm's outbreak over the Arabian Sea on January 21 and its subsequent movement towards the Indian landmass, leading to a substantial dust loading during January 23-24, 2022. The incorporation of chemical data assimilation significantly improved predictions of elevated levels of PM_{10} in various West Indian cities. ***(Kalita G., Yadav P.P., Jat R., Govardhan G., Ambulkar R.,** Kumar Rajesh, Gunwani P., **Debnath S.,** Sharma P., Kulkarni S., Kaginalkar A., **Ghude S.D.,***

Forecasting of an unusual dust event over western India by the Air Quality Early Warning System, ***Atmospheric Environment,*** *311: 120013, October 2023, DOI:10.1016/j.atmosenv.2023.120013, 1-11)*

AQEWS (collaborative)

Harnessing deep learning for forecasting fire-burning locations and unveiling PM2.5 emissions

Harnessing deep learning for forecasting fire-burning locations and unveiling PM2.5 emissions: Climate change and human activity have increased fires in India. Fine particulate matter is released into the atmosphere by stubble burning in Punjab and Haryana and forest fires in the north-eastern and central areas of the country. Accurate short-term estimates are essential to protect human health and reduce acute air pollution. However, global air quality forecasting methods grapple with a persistent assumption of fire emissions. They use near-real-time fire emissions throughout the prediction cycle. Air quality forecasts are prone to inaccuracies and biases due to fire emissions' dynamic nature. IITM has employed spatiotemporal deep learning techniques, specifically ConvLSTM and ConvGRU, to forecast fire emission locations up to three days in advance. Through this evaluation, it is found that ConvLSTM outperforms ConvGRU in terms of prediction accuracy and performance. The chosen model provides a very good correlation coefficient for the 1st day forecast and a moderate value (0.5 - 0.55) for subsequent 2nd and 3rd days forecasts. The predictors NDVI, temperature, wind, surface pressure, and total cloud cover are included to this model training to improve these correlations. In Punjab-Haryana, wind input improves results. This fire burning location prediction method could improve air quality forecasting. This deep learning model can improve forecasts by revealing the complex interactions of components and reflecting fire emissions' dynamic nature. This research may help improve air quality forecasts in the face of rising fire events, protecting communities across the Indian subcontinent. (***Gaikwad S., Kumar Bipin, Yadav P.P., Ambulkar R., Govardhan G.,*** *Kulkarni S.H., Kumar Rajesh,* ***Chate D.M., Nigam N., Rao Suryachandra A., Ghude S.D.,*** *Harnessing deep learning for forecasting fire-burning locations and unveiling PM2.5 emissions,* ***Modeling Earth Systems and Environment****, 10, February 2024, DOI:10.1007/s40808-023-01831-1, 927-941)*

WiFEX: Walk into the Warm Fog over the Indo-Gangetic Plain Region

This study offers an overview of the Winter Fog EXperiment (WiFEX) campaign and synthesises selected observational and modeling/findings. Spanning the winters from 2015 to 2020 at the Indira Gandhi International Airport, New Delhi, the field experiments utilised a range of in-situ instruments to collect simultaneous observations of micrometeorological conditions, radiative fluxes, turbulence, droplet/aerosol microphysics, aerosol optical properties, fog water chemistry, and vertical thermodynamical structure of fog layer, illuminating the environmental stability conducive to fog formation. These observations, which encompassed over 90 dense fog events, aided in interpreting the strengths and weaknesses of the numerical modelling framework. This article presents and discusses four scientific objectives of the Winter Fog Experiment: (i) understanding the life cycle of optically thin and thick fog, (ii) examining microphysical properties in the polluted boundary layer, (iii) investigating fog water chemistry and gas–aerosol partitioning during the fog life cycle, and (iv) enhancing numerical prediction capabilities for fog. *(****Ghude S.D.,*** *Jenamani R.K.,* ***Kulkarni R.,Wagh S., Dhangar N.G.,Parde A.N.,Acharja P.,Lonkar P., Govardhan G., Yadav P., Vispute A., Debnath S.,Lal D. M., Bisht D.S.,*** *Jena C.,* ***Pawar P.V.,*** *Dhankhar S.S., Sinha V.,* ***Chate D.M., Safai P.D., Nigam N., Konwar M., Hazra A., Dharmaraj T ., Gopalkrishnan V., Padmakumari B.,*** *Gultepe I., Biswas M., Karipot A.K.,* ***Prabhakaran Thara,*** *Nanjundiah R.S., Rajeevan M., WiFEX: Walk into the Warm Fog over Indo-Gangetic Plain Region,* ***Bulletin of the American Meteorological Society****, 104, May 2023, DOI:10.1175/BAMS-D-21-0197.1, E980–E1005)*

Forecasts of fog events in northern India dramatically improve when weather prediction models include irrigation effects

Forecasts of fog events in northern India dramatically improve when weather prediction models include irrigation effects: Dense wintertime fog regularly impacts Delhi, severely affecting road and rail transport, aviation and human health. Recent decades have seen an unexplained increase in fog events over northern India, coincident with a steep rise in wintertime irrigation associated with the introduction of double-cropping. Accurate fog forecasting is challenging due to a high sensitivity to numerous processes across many scales, and uncertainties in representing some of these in state-of-the-art numerical weather prediction models. This study shows fog event simulations over northern India with and without irrigation, revealing that irrigation counteracts a common model dry bias, dramatically improving the simulation of fog. Evaluation against satellite products and surface measurements reveals a better spatial extent and temporal evolution of the simulated fog events. Increased use of irrigation over northern India in winter provides a plausible explanation for the observed upward trend in fog events, highlighting the critical need for optimisation of irrigation practices. *(Daniel D.K. Smith, Reka S., Dorling S.R., Ross A.N., Renfrew I.A., Jayakumar A., Anurose T.J., **Parde A.N.,Ghude S.D.,** Rumbold H., Forecasts of fog events in northern India dramatically improve when weather prediction models include irrigation effects, **Communications Earth and Environment**, 5: 141, March 2024, DOI:10.1038/s43247-024-01314-w, 1-10)*

MAQWS

Spatio-temporal variability and possible source identification of criteria pollutants from Ahmedabad-a megacity of Western India

Spatio-temporal variability and possible source identification of criteria pollutants from Ahmedabad-a megacity of Western India: This study addresses the spatio-temporal variability and plausible sources of criteria air pollutants in the Western Indian city-Ahmedabad. The air pollutants PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO have been analyzed at ten locations in Ahmedabad from 2017 to 2019. The seasonal variability indicates that the air pollutant concentration is highest during winter, followed by pre-monsoon, post-monsoon, and monsoon seasons. The concentration of PM2.5 (59.52 ± 16.68–89.72 ± 20.68) and PM10 (107.25 ± 30.43–176.04 ± 38.34) crosses the National Ambient Air Quality Standards (NAAQS) in all seasons. However, the seasonal difference from winter to pre-monsoon is not highly significant ($p > 0.05$), indicating that the pollution remains fairly similar during these two seasons. The spatial variability of air pollutants over Ahmedabad indicates that the concentration is highest in the south and central region of Ahmedabad and lowest at the east location. The Ventilation Coefficient (VC) has been used to understand the dispersion of air pollutants. The different locations identified were industrial, residential, and traffic which mainly contribute to the air pollutants in Ahmedabad city. The health risk assessment indicates PMs are the leading pollutant and causing excess risk (ER > 1) at all the locations. With the help of the different statistical techniques, it helps in ascertaining the hotspots of air pollution in a region which will be beneficial in studying health exposure and for policymakers to adopt mitigation strategies. *(Bano S., **Anand V.,** Kalbande R., Beig G., Rathore D.S., Spatio-temporal variability and possible source identification of criteria pollutants from Ahmedabad-a megacity of Western India, **Journal of Atmospheric Chemistry**, 81: 1, March 2024, DOI:10.1007/s10874-023-09456-5, 1-25)*

Long-term SAFAR observations at Mumbai reveal the following:

- NO_2 is directly associated with $PM_{2.5}$ concentrations.
- SO_4 is the leading ion among ions, especially in winter.
- Variability and peak concentration of $PM_{2.5}$ is highest in winter (APR-2023).

National and International Collaborations:

- Kalinga Institute of Industrial Technology (KIIT) (ongoing; MoU signed on 10 March 2023): This research project is funded by NERC South Asian Nitrogen Hub (SANH) between KIIT in collaboration with IITM. The project uses country-specific NH_3 and NO_x emission inventories, a global HCl emission inventory, and the updated EDGAR V6 emission inventory. It also includes an inter-comparison of NH_3 measurements over Delhi and features IITM's higher version of WRF-Chem for comprehensive air quality analysis across South Asia.
- Automotive Research Association of India (ARAI) (on-going, signed on 06 January 2023)
- This project aims to understand the effects of ethanol-blending of petrol on the ozone concentrations in Delhi, India. The study is being carried out using a regional chemistry transport model "WRF-Chem".
- Rajasthan Pollution Control Board (RSPCB) (ongoing, signed on 26 March 2023)
- This project is related to the development of an early warning and decision support system for air quality management in Jaipur, Rajasthan. A high-resolution air quality forecasting framework will be developed for Jaipur, with the ability to carry-out real-time source apportionment of the fine particulate matter load in Jaipur.
- MoU has been signed with HNB Garhwal University, Srinagar and Sikkim University, Gangtok, for the operation of MAPAN stations in April 2024.
- MoU has been signed with NIO, Goa, for aerosol optical measurements. Under this, a sky radiometer was installed in May 2023.

Products/ Services: Following products are being generated which are helpful for the end users viz., India Meteorological Department (IMD), Commission for Air Quality Management (CAQM) in the National Capital Region and Adjoining Areas, Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC), Ministry of Environment, Forest and Climate Change (MoEFCC), Rajasthan Pollution Control Board (RSPCB), Automotive Research Association of India (ARAI).

- Operational air quality forecast for all of India at 10 km grid spacing, with 2 km grid spacing for the National Capital Region and 400m grid spacing for the national capital, New Delhi.
- Operational probabilistic fog forecasts from Ensemble Probability Fog Forecast System (EPFS) over the IGP region at 4 km grid resolution. The EPFS product facilitated the probability forecast of visibility with four different categories (CAT2, CAT3A, CAT3B, and CAT3C) at five main airports in the IGP region. In addition, EPFS provide a spatial probability forecast of dense fog (Vis < 200 m) over the IGP region
- Operational Decision Support System for Air Quality Management in Delhi, launched in October 2021 and continued till date.
- The MAPAN observations of various particulate and gaseous pollutants will be used for the study of basic processes of aerosol and gaseous chemistry. The observations will also be used in model validations and studies on the impacts of air pollution in the Himalayan environment.
- Compiled Infographics on various topics useful for daily life to the public and students which have been provided through the Environmental Information, Awareness, Capacity Building and Livelihood Programme (EIACP) at IITM outreach program.

OBSERVATIONAL CAMPAIGNS:

A significant aspect of research on emissions from biomass burning impacting Delhi's air quality was conducted involving a targeted survey in farm regions near Delhi, including locations like Karnal, Panipat, Kaithal, and Sonipat, from October 31st to November 2nd, 2023. The survey aimed to document observations on agricultural crop patterns and burned fields, which are crucial for compliance with regulations set by the

Commission for Air Quality Management in the National Capital Region and Adjoining Areas (CAQM).

Under **the MAQWES project**, a month-long campaign was conducted during April-May 2023 to decipher the particulate pollution in an urbanizing region using a gravimetric sampler at Vadu in the Pune Metropolitan Region (PMR).

Under the **WiFEX and RASAGAM** Project, an Aerosol Lab has been set up at the India Meteorological Department, New Delhi, which aims to provide real-time ambient aerosol monitoring and serve as a supersite for aerosol microphysics observation for WiFEX. This lab is equipped with high-end instruments, such as an aerosol mass spectrometer for measuring aerosol chemical composition, a Humidified Tandem Differential Mobility Analyzer (HTDMA) to study aerosol hygroscopic growth during heavy pollution episodes and its role in severe haze formation. A meteorological parameter measurement set-up along with a visibility meter has also been installed at the lab for continuous measurements. During the WiFEX intense observation period (IOP), several experiments were conducted at the lab to better understand fog-aerosol interaction.

Under the **WIFEX Phase-II,** various observational activities have been conducted:

a) A supersite for WiFEX has been established at New Delhi airport. A 20-meter meteorological tower was populated with several sensors at different levels, viz., 2m, 10m, and 20m. A fog monitoring device (FM-120) was installed to measure fog microphysical properties. Two remote sensing devices for fog layer studies, viz., ceilometer and microwave radiometer, were also deployed during the campaign period.

b) A fog observatory has been established at the upcoming NOIDA International Airport site at Jewar (UP). This observation setup consists of basic meteorological sensors (temperature, relative humidity, wind speed, wind direction, wind speed, and radiation) and soil parameters (soil moisture, temperature, and soil heat flux).

c) According to the roadmap suggested by the Fog Research Review Committee, fog microphysics observations were carried out at various locations to understand fog microphysics. Locations such as Jewar, Srinagar (Uttarakhand), and Hisar (Haryana) were considered. A mobile fog observation setup was deployed at observation sites. The setup consists of the fog monitoring device (FM-120) and basic meteorological parameters, such as temperature, wind, radiation, and visibility.

WiFEX; fog observation campaign at Noida International Airport, Jewar (UP)

1.1.5 Climate Variability and Prediction (CVP)

Project Director: Dr. C. Gnanaseelan

Objectives

- To understand the decadal and internnual climate variability and predictability with emphasis on the Indian monsoon and the Indian Ocean.
- To develop a decadal prediction system based on the in-house Earth System Model for enabling the capability to predict the Indian monsoon and Indian Ocean temperature, sea level etc. about 1-10 years ahead of time.
- To develop interannual and decadal prediction and variability products for different stakeholders/ sectors such as agriculture, water resource, energy, etc.

Highlights of major achivements:

- CMIP6 decadal hindcasts show improved skill in predicting extreme rainfall events over the Indian landmass.
- Quantile mapping approach improves representation of rainfall variability and intensity in CMIP6 DCPP hindcasts.
- Models predict an increase in small and medium-area extreme rainfall events over the monsoon core region for 2019-2028.
- A new approach using CFSv2 model improves seasonal prediction skill for Indian Summer Monsoon.
- Exp initialization strategy reduces model initial shocks and improves monsoon teleconnections.
- Unusual subseasonal variability in Indian summer monsoon rainfall occurred in 2020 due to westward-propagating atmospheric Rossby waves.
- CFSv2 model fails to capture westward extension of WNP anticyclone, impacting July rainfall prediction.
- Intra-decadal variability of Meridional Heat Transport impacts rainfall over Southern Africa during austral summer.
- Decadal variability in sea surface salinity and stratification over the tropical Indian Ocean is influenced by upper ocean salinity, temperature, and equatorial currents.
- Climate modes like Indian Ocean Dipole and Interdecadal Pacific Oscillation modulate TIO stratification through precipitation and evaporation modulation.

DEVELOPMENTAL ACTIVITIES

- **Developed high resolution IITM-DCPSv1 (Decadal Climate Prediction System version 1)** by improving the IITM-DCPS version 0 (IITM-DCPSv0).
- **IITM-DCPSv1 decadal hindcasts and forecasts participated in the WMO Lead Centre Annual-to-Decadal Climate Prediction update.**
- Replaced the default University of Maryland (UMD) 13 vegetation categories with United States Geological Survey (USGS) 24 categories for more realistic portrayal of the model's surface characteristics in IITM-DCPSv1.
- Refined the model representation of land-atmospheric coupling in IITM-DCPSv1.

- Utilized high-resolution representation of land surface boundaries, including deep soil temperature, surface roughness length, orography, soil, and vegetation type in IITM-DCPSv1.
- A time-varying monthly mean green vegetation fraction dataset has been prepared based on CMIP6 protocol using the Land-Use Harmonization 2 (LUH2) datasets in IITM-DCPSv1.
- **Ocean initial conditions compatible for the IITM-DCPSv1 are prepared in-house**.
- Daily precipitation, surface air temperature and SST from CMIP6 DCPP hindcasts and projections have been successfully downscaled and explored its representation of extreme precipitation, heat and cold waves, and marine heat waves.

IITM-Decadal Climate Prediction System (IITM-DCPS)

The Decadal Prediction System (DPS), also known as IITM-DPS, has been developed at IITM for near-term climate prediction, utilizing the IITM-Earth System Model (IITM-ESM). This system incorporates time-varying components such as monthly and annual vegetation fractions, greenhouse gases, solar forcing, ozone, and stratospheric aerosol forcing, all aligned with the CMIP6 protocol. To mitigate initial shocks from simultaneous component initialization, ocean initial conditions are first stabilized through subsurface temperature and salinity nudging from ORAS5. Meanwhile, atmospheric initial conditions are prepared by NCMRWF using the Ensemble Kalman Filter method.

Extreme rainfall hindcasts over Indian region by IITM-DCPS relative to CMIP6 hindcasts

Evaluating the ability of global climate models to capture extreme weather events is crucial. In this context, the Decadal Climate Prediction Project (DCPP) models, including those from the Coupled Model Intercomparison Project phase-6 (CMIP6), are compared with IITM-DCPS. **Figure 32** displays the spatial distribution of R95 values over India in IITM-DCPS and CMIP6 models. Observations reveal extreme rainfall thresholds of approximately 140 mm/day over the Western Ghats, 120 mm/day in eastern India, and 70 mm/day in central India. However, DCPP models

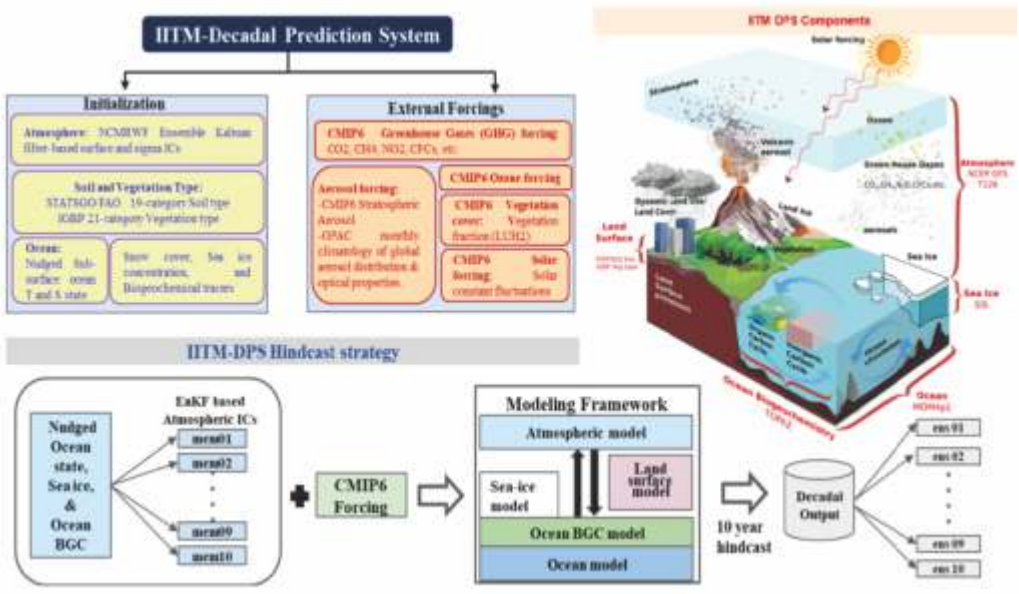


Figure 31: *The schematic illustrates IITM Decadal Climate Prediction System (DCPS) modeling framework, hindcast strategy and its components.*

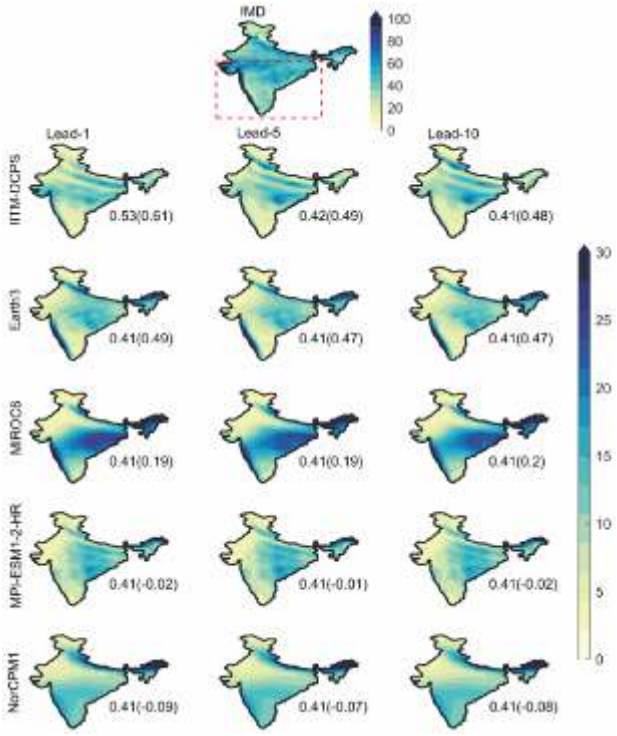


Fig.32: *Spatial distribution of extreme (R95) thresholds over the Indian landmass for observed (IMD), IITM-DCPS, EC-Earth3, MIROC6, MPI-ESM1-2-HR, and NorCPM1 decadal hindcast models of Lead-1, 5, and 10 years. Values shown adjacent to panels represent the spatial correlations averaged over the Indian land mass (over the Indian land mass south of 25°N or over the red box; 68 to 90°E; 7 to 25°N).*

significantly underestimate these thresholds. Notably, IITM-DCPS outperforms other models in capturing the spatial distribution of R95 thresholds over India, with higher spatial correlations (Figure 32). While IITM-DCPS accurately captures regional extreme rainfalls over the monsoon trough, Western Ghats, and eastern India, it exhibits a southward shift of rainfall extremes near the Himalayan foothills, a challenge to be addressed.

Climate Variability Studies

BASIC RESEARCH

Improvement in the skill of CMIP6 decadal hindcasts for extreme rainfall events over the Indian land mass

Decadal climate predictions have been widely used to predict the near-term climate information relevant for decision-making at multi-year timescales. In the present study, we evaluate the quality of the CMIP6 DCPP hindcasts in capturing the extreme rainfall events over the monsoon core region during Indian summer monsoon season up to lead years 1-10. For the first time, in this study, we have used quantile mapping approach to downscale and bias correct the CMIP6 DCPP rainfall simulation/hindcast for the better representation of EREs. Detailed analysis suggests that the models in general strongly underestimate the rainfall variability over the summer monsoon region. However, after the downscaling and bias correction, the representation of rainfall variability and intensity improved multifold. The bias-corrected decadal hindcasts in fact show ~80% improvement in capturing the frequency, intensity, and spatial distribution of rainfall associated with the EREs. Present study brought out a downscaled DCPP product, with potential prediction skill for EREs over India. It is important to highlight that the models predict an increase in the small and medium-area EREs as compared to the large-area EREs over the monsoon core region for the decade 2019-2028 (**Fig.33**). *(**Konda G., Chowdary J.S., Gnanaseelan C., Parekh A.,** Improvement in the skill of CMIP6 decadal hindcasts for extreme rainfall events over the Indian summer monsoon region, **Scientific Reports,** 13: 21737, December 2023, DOI:10.1038/s41598-023-48268-1, 1-13)*

A New Approach for Seasonal Prediction of Indian Summer Monsoon Using CFSv2

Predicting Indian Summer Monsoon (ISM) is challenging due to its complexity and nonlinear interactions. Improving seasonal prediction skill would greatly benefit the population and economy. Three hindcast experiments (9 months each) were conducted for 1993-2019 using NCEP-CFSv2, differing in initialization: FebIC (February), MayIC (May), and Exp (ocean initialized in February, atmosphere reinitialized monthly up to May). Exp better represents mean tropical Indo-Pacific SST, Walker circulation, monsoon circulation, and moisture transport to India. ISM rainfall prediction skill improves in Exp over central India, Indian landmass, and extended monsoon region. Exp's initialization strategy reduces model initial shocks in upper ocean heat content and SST over the Indo-Pacific region (**Figure 34**), offering a cost-effective approach.

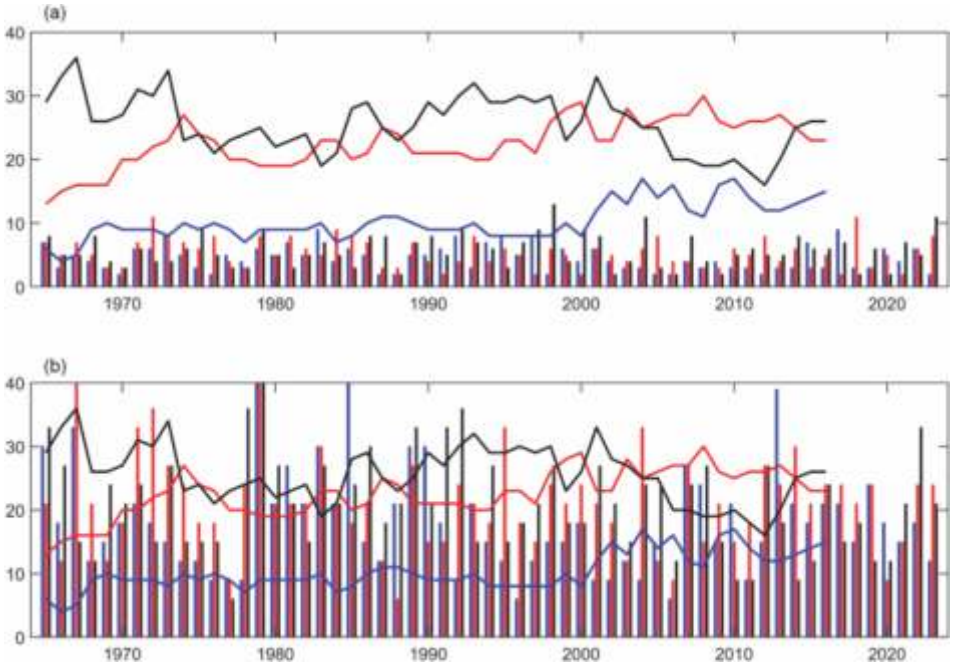


***Figure 33**: Number of extreme days over the monsoon core region for 10-year-average from 1965 to 2023 in MME, (**a**) before DBC (downscaling and bias correction) and (**b**) after DBC, blue bars for large area, red for medium area, and black for small area extreme days. Similarly, lines represent the extreme days in the observations.*

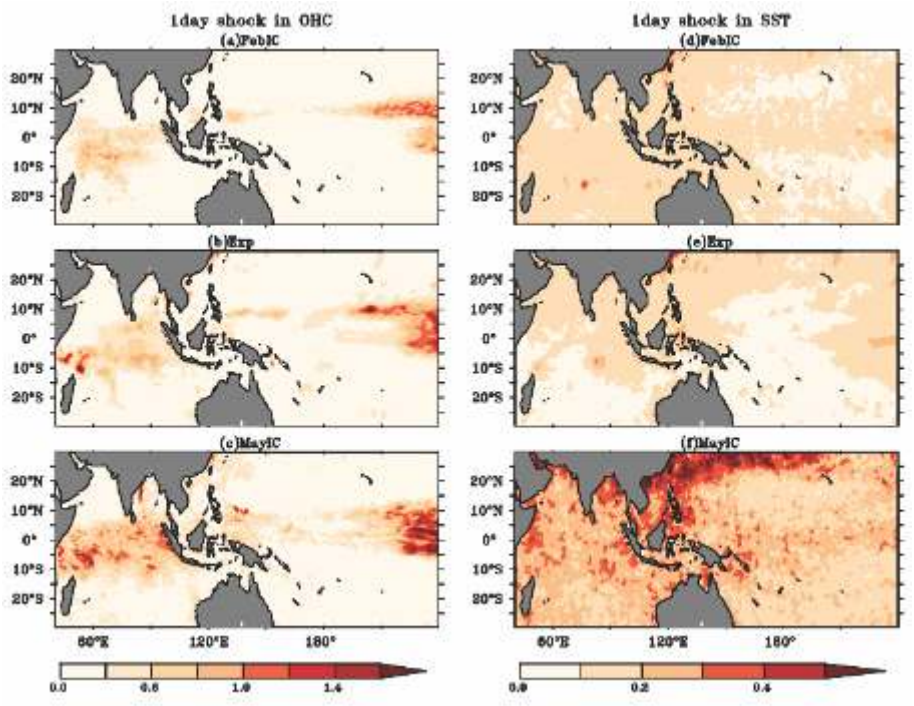


***Figure 34**: Composite 1-day initial shock in the mean upper ocean (0–100 m) heat content ($OHC_{100} \times 10^8$ $Jm^{-2}day^{-1}$) during 1st to 10th February in (a) FebIC, 1st to 10th May in (b) Exp and (c) MayIC. Panels (d)–(f) are the same as (a)–(c) but for 1-day shock in SST (°C day^{-1}) for the period 1993–2019. The composite initial shocks are computed as the root mean square of 1-day change over all the ensemble members and years of hindcasts, and called 1-day shock.*

Exp also reduces the cold tongue SST bias over the equatorial Pacific and improves monsoon teleconnections, reducing ISM rainfall's overdependence on El Niño Southern Oscillation. (***Fousiya T.S., Gnanaseelan C., Halder S.,Kakatkar R., Chowdary J.S., Patekar D., Parekh A.,*** *A new approach for seasonal prediction using the coupled model CFSv2 with special emphasis on Indian Summer Monsoon,* ***International Journal of Climatology,*** *43, September 2023, DOI:10.1002/joc.8126, 4944-4964)*

Unusual Subseasonal Variability of Indian Summer Monsoon Rainfall in 2020

India received above-normal summer monsoon rainfall in 2020, with 109% of its long-period average. However, July 2020 saw deficit rainfall, despite being the peak monsoon month. This study investigates the mechanisms behind this unusual variability. Analysis reveals that strong low-level moisture divergence, caused by a westward-propagating atmospheric Rossby wave, induced by suppressed western North Pacific (WNP) convection, led to the July rainfall deficit. The WNP suppressed convection is linked to anomalous low-level anticyclonic circulation, maintained by tropical Indian Ocean warming-induced atmospheric Kelvin waves and strong low-level convergence. Unlike July, the WNP anticyclone and TIO warming are weaker in June and August. The Climate Forecast System version-2 (CFSv2) model predicts strong positive rainfall anomalies over India in July, contrasting with observations. The model fails to capture the westward extension of the WNP anticyclone, impacting July rainfall prediction. A CFSv2 sensitivity experiment, imposing strong negative sea surface temperature anomalies over the WNP region, captures the westward extension of the WNP anticyclone and suppressed rainfall over the core monsoon region in July. The experiment supports the role of the WNP anticyclone in inducing reduced rainfall in July 2020 over the monsoon trough region (**Figure 35**). (***Darshana P., Chowdary J.S., Parekh A., Gnanaseelan C., Fousiya T.S., Vibhute A., Halder Subrota, Prem Singh, Kakatkar R.,*** *2024,* ***Quarterly Journal of the Royal Meteorological Society****, February 2024, DOI:10.1002/qj.4675, 1-18)*

Impact of intradecadal variability of meridional heat transport on the rainfall over Southern Africa during austral summer

This study examines the impact of intra-decadal variability of Meridional Heat Transport (MHT) associated with Indian Ocean Shallow Meridional Overturning Circulation (SMOC) on rainfall variability over Southern Africa during austral summer. Century-long ocean reanalysis, atmospheric reanalysis, and

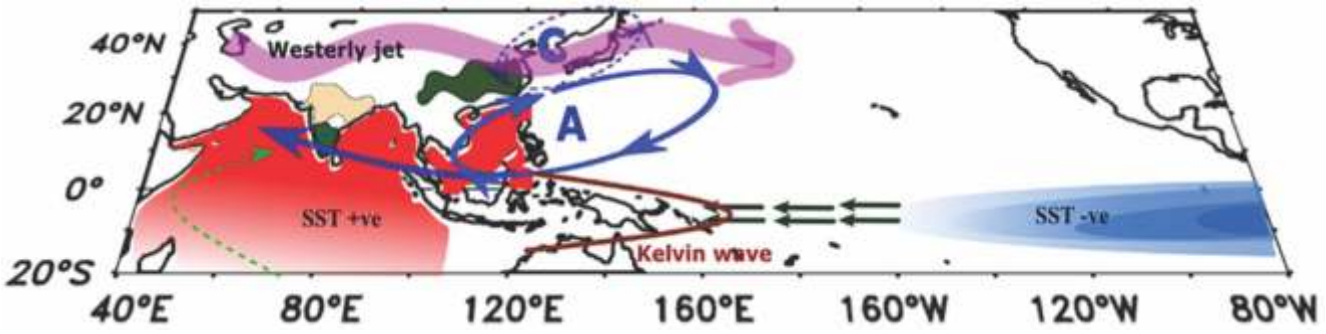


Figure 35: *Schematic diagram illustrating the physical mechanisms associated with abnormal Indian summer monsoon (ISM) precipitation during July 2020. Shading in the Indian Ocean and south China sea represents basin-wide warming and in eastern equatorial Pacific it represents weak La Nina conditions. Dark and light shading over Asian region shows positive and negative precipitation anomalies (mm·day^{-1}) during July 2020. Vectors over the equatorial central Pacific represent low-level easterlies, Thin dashed curved arrow over western Indian Ocean denotes cross-equatorial flow, Arrow over the southern parts of India shows easterlies extending from western north Pacific anticyclone. A- Anticyclone (solid); C-Cyclonic circulation (dashed).*

rainfall observations are used. Spectrum analysis reveals significant intra-decadal (5-7 years) variability in MHT index and rainfall anomaly. Strong (weak) MHT years show reduced (increased) Sea Surface Temperature (SST) in the southwest Indian Ocean, out-of-phase with net heat flux but in-phase with ocean circulation. This leads to anomalous circulation, subsidence (convection), and below (above) normal moist static energy, resulting in negative (positive) rainfall anomalies over Southern Africa (**Figure 36**). The study reports the association between intra-decadal MHT variability and Southern African rainfall for the first time, potentially enhancing predictability of intra-decadal rainfall variability. (***Pai R.U., Parekh A., Halder S., Chowdary J.S., Gnanaseelan C.,*** *Impact of intra-decadal variability of meridional heat transport on the rainfall over Southern Africa during austral summer,* ***International Journal of Climatology****, 43, December 2023, DOI:10.1002/joc.8263, 7256-7273).*

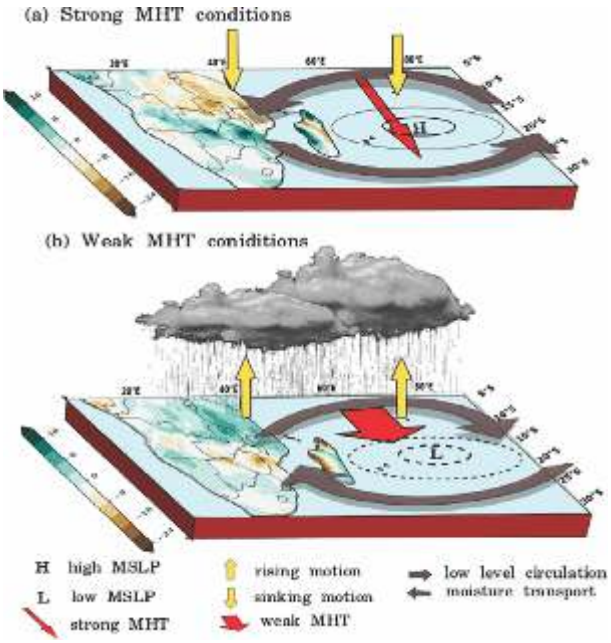


Figure 36: *Schematic of mechanism displaying the impact of MHT associated with SMOC on the austral summer rainfall over south Africa at intra-decadal timescale during (a) strong and (b) weak MHT conditions. (Shades over the land are filtered rainfall anomaly [mm_month^{-1}] for the respective phases).*

What drives the decadal variability in sea surface salinity and stratifcation over the tropical Indian Ocean?

The study examines decadal variability in surface salinity and stratification over the tropical Indian Ocean (TIO) from 1979-2017 using analysis, reanalysis, and ocean model simulations. Results show upper ocean stratification exhibits decadal and multidecadal variability in the eastern equatorial Indian Ocean (EEIO), southwestern tropical Indian Ocean (SWTIO), and head Bay of Bengal (**Figure 37**). The forced ocean model simulates decadal variability in stratification, consistent with analysis and reanalysis products, though with some amplitude underestimation. Upper ocean salinity influences EEIO stratification variability, while SWTIO stratification is affected by upper ocean temperature through Rossby wave propagation. Equatorial currents modulate EEIO stratification, especially in recent decades. Subsurface ocean dynamics impact stratification over EEIO and SWTIO by modulating subsurface temperature and salinity. Model sensitivity experiments reveal river runoff modulates decadal variability in stratification and surface salinity over the head Bay of Bengal. Climate modes, such as the decadal Indian Ocean Dipole and Interdecadal Pacific Oscillation, modulate TIO stratification through precipitation and evaporation modulation. *(**Mohapatra S., Gnanaseelan C., Fousiya T.S., Dandapat S.,*** *What drives the decadal variability in sea surface salinity and stratification over the tropical Indian Ocean?,* ***Theoretical and Applied Climatology,*** *152, May 2023, DOI:10.1007/s00704-023-04429-w, 1129-1145)*

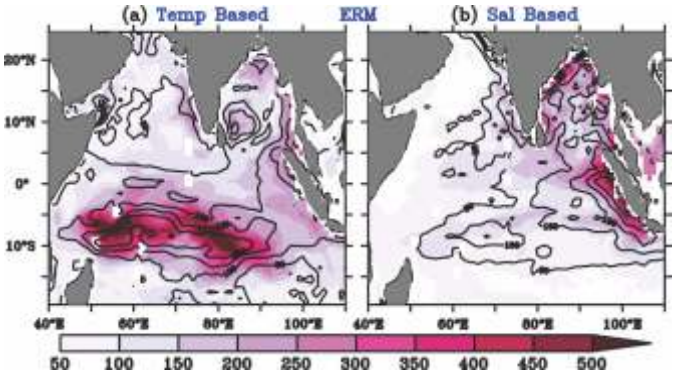


Figure 37: *Decadal Standard deviation in* ***a)*** *ERM (temp-based: based on climatological salinity, J/m^2),* ***b)*** *ERM (sal-based: based on climatological temperature, J/m.^{2}) for the period 1983–2013 from ORAS5 (shaded) and CTL (contour)*

1.2 Monsoon Mission

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

Objectives

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

- To build a working partnership between the academic and R&D organisations both national and international, and MoES to improve the operational monsoon forecast skill over the country and develop relevant climate applications for agriculture, hydrology and power sectors.
- To develop and improve the state-of-the-art dynamical modelling framework for improving the prediction skill of (a) seasonal (months to season) (b) extended-range (10 days to a month) and (c) short-to-medium range (up to 10 days)
- To develop a coupled ensemble extended range prediction system and post-processing techniques for improving the sub-seasonal prediction skill up to 4 weeks.
- To develop a high resolution (~12 km – 6 km) short-range ensemble forecast and to improve the parameterisation of physical processes of the model for improving the short-range forecast of monsoon and high-impact weather.
- To establish a met hub at IITM to promote Indian start-ups in weather/climate data/ forecast services.
- To support regional climate activities for south Asia.
- To support International Monsoons Project Office (IMPO).

R&D Activities:

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

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

Highlights of Major Achievements:

- The Monsoon Mission aims to improve the prediction of the Indian monsoon across all time scales, specifically by developing partnerships between national and international academic institutions, R&D organizations, and the Ministry of Earth Sciences (MoES).
- A key goal is to develop a state-of-the-art dynamical modeling framework, focusing on improving prediction skill for Seasonal and Extended range (S2S) predictions as well as Short and Medium range (up to two weeks) forecasts.

- The IITM High-Resolution Global Forecast Model (HGFM), launched under the "Make in India" initiative in November 2023, has been run daily on an experimental basis since June 2022. A thorough evaluation is underway, and it is set to be handed over to the India Meteorological Department. The experimental forecast is accessible online, and a short film on the model was presented during the India International Science Festival- 2022 at Bhopal in Jan. 2023.
- IITM has developed the Extreme Forecast Index (EFI) based on 10 years of Global Ensemble Forecast System (GEFS) climatology. The EFI provides a 5-day lead time for extreme weather events, capturing potential extremes well in advance, and has been handed over to IMD for daily operational forecasts.
- The GEFS T1534 ensemble forecasts accurately predicted the tracks, intensity, and landfall of tropical cyclones in 2023, including "MOCHA," "BIPARJOY," "TEJ," "HAMOON," "MIDHILI," and "MICHAUNG." These forecasts were used by IMD to generate final operational predictions.
- IITM's 6.5 km HGFM (Tco1534) model also accurately predicted the track, intensity, and landfall of cyclonic systems. Both GEFS and HGFM forecasts were shared with IMD, and ensemble tracks are available on IITM's website for public access.
- A bias-corrected GFS quantitative precipitation forecast has been developed for efficient flood forecasting in river basins across India. Wind and solar forecasts are also provided to public and private stakeholders.
- IITM signed an MoU with the Defence Research Development Organization's Armament Research and Development Establishment (ARDE) in October 2023. Under this collaboration, IITM provides GFS model forecast data for strategic defense locations based on ARDE's requirements.
- Revised cloud processes in the CFSv2 model at T126 (~100 km) resolution have improved the simulation and prediction of Indian summer monsoon rainfall, with better representation of cloud hydrometeors. This has led to improvements in rainfall variability and the northward propagation of rainfall bands.
- The Global Ensemble Forecast System (GEFS T1534) showed reasonable skill in predicting cyclonic disturbances over the North Indian Ocean during 2020-2021. The model accurately forecasted the genesis, track, intensity, and landfall of cyclonic disturbances with reduced track and landfall errors, providing critical insights for operational use.
- Accurate convection parameterization is crucial for minimizing model biases in simulating extreme events.
- New-Tiedtke scheme excels in predicting extreme precipitation events due to better representation of convection and low clouds.
- Cold wave (CW) events in India occur from November to February, with a new criterion and multi-model ensemble system used for monitoring and prediction.
- The multi-model ensemble system predicts CW events effectively up to 2-3 weeks in advance despite decreasing confidence for longer leads.

- Initialization errors impact monsoon onset phase forecasting, with differences in land surface conditions and observation numbers affecting model performance.
- Soil moisture plays a significant pre-conditioning role during active monsoon phases, influencing rainfall and boundary layer MSE.
- CFS model fails to capture realistic soil moisture feedback, contributing to rainfall dry bias.
- Analysis of large-scale convection and circulation changes during ISM 2022 reveals distinct patterns in precipitation and circulation between active and break phases.
- Development of a high-resolution (12-6 km) short-range ensemble forecast system is underway, with enhanced model parameterizations to improve forecasting of the Indian monsoon and high-impact weather events.
- Under Monsoon Mission-III, notable R&D advancements include the operationalization of the COARE 3.0 bulk flux algorithm with diurnal ocean skin temperature parameterization in CFSv2 to enhance model accuracy.
- The MMCFSv2 (Monsoon Mission Coupled Forecast System version 2.0) has significantly upgraded key components such as the atmospheric model (switching from Eulerian to Semi-Lagrangian dynamical core) and the ocean model (from MOM4 to MOM6), improving resolution and parameterization of physical processes.
- A new lightning parameterization scheme was developed for the Global Climate Model (GCM), improving the prediction of extreme weather events related to lightning by incorporating aerosol-cloud interactions and advanced physical processes.
- International collaborations with organizations such as JAMSTEC, NTU Taiwan, and the UK Met Office (under the WCSSP program) have enhanced research on intra-seasonal variability and the simulation of Monsoon Intraseasonal Oscillations (MISOs), with a focus on correcting biases in monsoon rainfall predictions.
- Research under the Monsoon Mission has demonstrated that including river-routing models in CFSv2 improved sub-seasonal variability, particularly enhancing the representation of low-pressure systems (LPS) and MISO northward propagation by accurately simulating oceanic processes and air-sea interactions, which are vital for better monsoon predictions.

1.2.1 Short and Medium Range

DEVELOPMENTAL ACTIVITIES

- The "Make in India" Model which was launched in Nov 2023, **IITM high-resolution global forecast Model (HGFM)** has beenrun in real-time on daily basis since June 2022 on an experimental basis. Presently a thorough evaluation of HGFM model is being carried out considering every aspect of summer monsoon and associated synoptic systems. It will be handed over to India Meteorological Department and it will be handed over to India Meteorological Department at the earliest. The forecast is made available at: https://srf.tropmet.res.in/srf/hires_gefs/index-tco.php. This indigenous IITM HGFM helps to reach forecast to a scale smaller than block level. A short film on this product was prepared and screened during the India International Science Festival- 2022 in Bhopal (Jan 2023) and available on IITM YouTube : https://www.youtube.com/watch?v=dxacESa28bY
- Development of Extreme Forecast Index (EFI): IITM has developed the Extreme Forecast Index (EFI) using the 10 years of climatology of Global Ensemble Forecast System (GEFS). The EFI was generated for 5 days lead time and was handed over to IMD for operational implementation on daily operational forecast. It is evident that the possibility of the extreme is well captured 5 days in advance based on EFI.
- The GEFS T1534 based ensemble forecasts provided accurate forecast of ensemble tracks, strike probability, intensity and landfall for the tropical cyclones that were seen over the Arabian Sea and the Bay of Bengal throughout the year 2023 viz., "MOCHA" during 9-15 May 2023, "BIPARJOY" during June 2023, "TEJ" and "Hamoon" during October 2023, "MIDHILI" during 15-18 November 2023, "MICHAUNG" during 1-5 December 2023.
- The experimental forecast from the 6.5 km IITM HGFM (Tco1534) model also predicted the track, intensity and landfall of the systems accurately. Both the forecast products were communicated to IMD. Forecasts of ensemble tracks from GEFS are made available on IITM website. The forecasts have been extensively utilized by IMD in generating the final operational forecast.
- A bias corrected GFS quantitative precipitation forecast has been developed for the river basins in India for efficiently forecasting floods. Accurate wind and solar forecasts are being issued to different stakeholders (public and private).
- An MoU has been signed with Defence Research Development Organization Armament Research and Development Establishment (ARDE), Pune on 9 October 2023 for collaboration and utilization of weather forecast for defence applications. Under this collaboration,IITM has started to share GFS model forecast data for different strategic locations as per the requirement from ARDE.

BASIC RESEARCH:

Revised cloud processes to improve the simulation and prediction skill of Indian summer monsoon rainfall in climate forecast system model

The performance of six-class weather research forecasting (WRF) single moment (WSM6) cloud microphysical scheme in the National Centre for Environmental Prediction (NCEP) Climate Forecast System version 2 (CFSv2) at T126 (~100 km) horizontal resolution in the simulation and prediction skill of the Indian summer monsoon (ISM) is investigated with 34 years of hindcast runs with 10 ensemble members. The results reveal that the revised version of CFSv2 (EXPT) shows relative improvement in summer monsoon precipitation, its variability, rainfall annual cycle, rainfall

probability distribution function, synoptic and intraseasonal variance, etc. over ISM region compared to standard CFSv2 (CTRL). Robust representation of cloud hydrometeors in the WSM6 microphysics scheme leads to better large-scale precipitation distribution compared to CTRL simulation which resulted in realistic northward propagation of rainfall bands in the EXPT. The interannual variability of rainfall in EXPT simulation suggests improved prediction skill of summer monsoon than CTRL run and comparable to higher resolution (T382; ~38 km) version of CFSv2. The above improvements are mainly attributed to the better simulation of vertical and spatial distribution of cloud hydrometeors in the EXPT simulation. Further, the cold bias in sea surface temperature (SST) in CTRL simulation is replaced with slightly warm bias in EXPT run which has resulted in wet bias in precipitation over the tropical oceanic region. Introduction of more physically based cloud physics parameterization helps to improve the cloud hydrometeor, cloud variability, and the rainfall variability (**Fig. 38**). *(**Phani M.K.R., Ganai M., Tirkey S., Mukhopadhyay P.,** Revised cloud processes to improve the simulation and prediction skill of Indian summer monsoon rainfall in climate forecast system model, **Climate Dynamics**, 61, September 2023, DOI:10.1007/s00382-023-06674-1, 2189–2210)*

Evaluation of the Global Ensemble Forecast System (GEFS T1534) for the probabilistic prediction of cyclonic disturbances over the North Indian Ocean during 2020 and 2021

With increasing number of cyclonic disturbances (CDs) over the North Indian Ocean, the prediction of pre-genesis, along with the accurate forecast of the track and intensity, is the need of the hour. The present study evaluates the skill of prediction of genesis as well as the verification of CDs (total of 16 cases are considered) that occurred during the year 2020–2021, using Global Ensemble Forecast System (GEFS) T1534. Different initial conditions with longer lead hours are analysed for

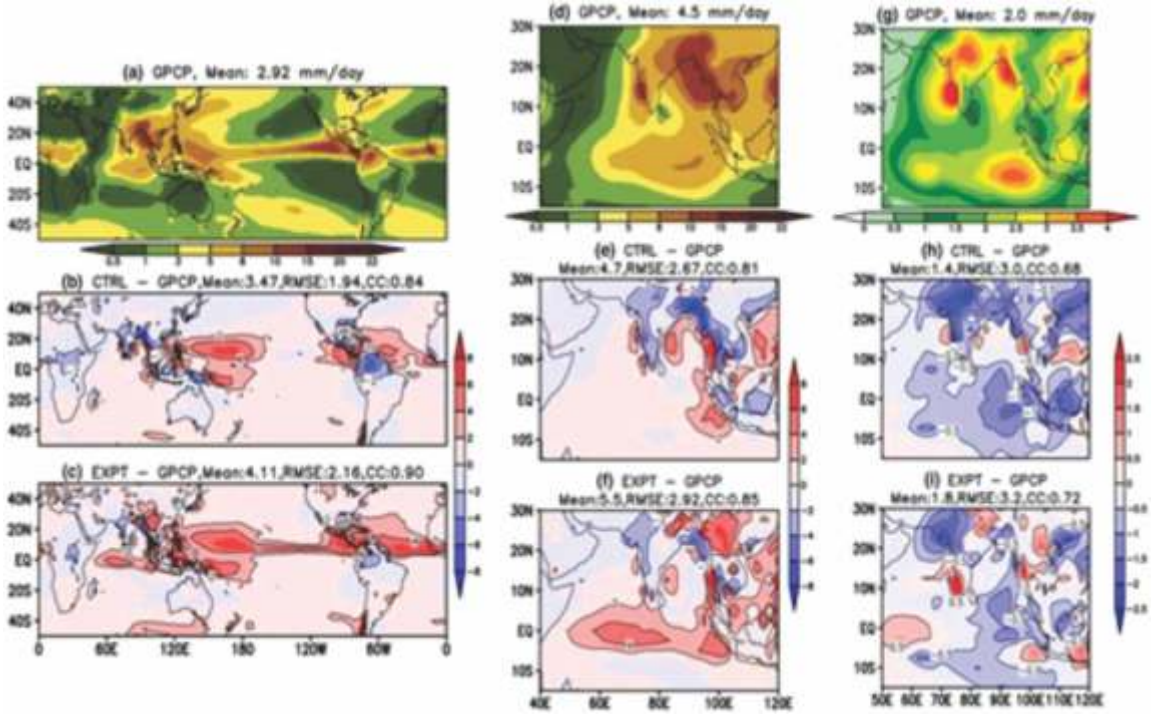


Fig. 38: *a) The spatial distribution of a mean precipitation (mmday^{-1}) from GPCP and corresponding model biases with respect to GPCP from b) CTRL and c) EXPT simulations over global tropics during JJAS. d–f) Similar analyses but over the Indian summer monsoon domain. g–I) represents similar analyses as d–f but for standard deviation of rainfall (mm day^{-1}). The domain-averaged mean, RMSE and spatial CC are mentioned in all the bias plots.*

genesis, track, intensity and landfall errors. The model has the ability to predict genesis location with error of about ~200 km at day 2 lead. Verification of all CDs indicates that the landfall in terms of time and position is well predicted by the model. In general, the model shows the northward bias in genesis location error for the initial 12 hours and after that southwestward bias. From depression till dissipation, the track error for ensemble mean is less than that of the control run. The track error is less than 150 km for ensemble mean till day 3 and is about 220 km on day 4. The model shows northward bias in predicting the track of CDs. For predicting the landfall locations, southwestward bias is shown by model. The probabilistic ensemble skill scores are also evaluated for GEFS T1534, which shows reasonable skill. *(**Kanase R., Tirkey S., Deshpande M., Phani M.K.R.,** Johny C.J., **Mukhopadhyay P.,** Iyengar G., Mohapatra M., Evaluation of the Global Ensemble Forecast System (GEFS T1534) for the probabilistic prediction of cyclonic disturbances over the North Indian Ocean during 2020 and 2021, **Journal of Earth System Science**, 132: 143, August 2023, DOI:10.1007/s12040-023-02166-2, 1-14)*

Fidelity of WRF model in simulating heat wave events over India

Fidelity of WRF model in simulating heat wave events over India:The evaluation of Weather Research and Forecasting (WRF) model has been performed for simulating episodic Heat Wave (HW) events of 2015 and 2016 with varied horizontal resolutions of 27 km for the entire India (d01), 9 km for the North West (NW (d02)) and South East (SE (d03)) domain. Study compares the maximum temperature (Tmax) simulated by WRF model, using six different combination of parameterization schemes, with observations from the India Meteorological Department (IMD) during the HW events. Among the six experiments, Exp2 (i.e., combination of WSM6 microphysics (MP) together with radiation parameterization CAM, Yonsei (PBL), NOAH land surface and Grell-3D convective schemes) is found closest to the observations in reproducing the temperature. The model exhibits an uncertainty of ± 2 °C in maximum temperature (Tmax) for both the regions, suggesting regional temperature is influenced by the location and complex orography. Overall, statistical results reveal that the best performance is achieved with Exp2. Further, to understand the dynamics of rising HW intensity, two case studies of HW days along with influencing parameters like Tmax, RH and prevailing wind distribution have been simulated. Model simulated Tmax during 2015 reaches up to 44 °C in NW and SE part of India. In 2016, HW is more prevailing towards NW, while in SE region Tmax reaches upto 34–38 °C with high RH (60–85%). The comparative research made it abundantly evident that these episodic events are unique in terms of duration and geographical spread which can be used to assess the WRF performance for future projections of HW. (*Gupta P., Verma S., **Mukhopadhyay P.,** Bhatla R., Payra S., Fidelity of WRF model in simulating heat wave events over India, **Scientific Reports**, 14: 2693, February 2024, DOI:10.1038/s41598-024-52541-2, 1-19*

1.2.2 Sub-seasonal Range / Extended Range Prediction

BASIC RESEARCH

Convection Parameterization Sensitivity to the Background Scale Interaction in Simulating Extremes

Accurate representation of real-atmospheric processes in physical parameterization is crucial for minimizing biases in models, particularly for extreme events. This study examines the inconsistent simulation of event genesis in small and large-scale environments across multiple convection parameterizations. While some inherent errors exist, most selected schemes predicted the Uttarakhand heavy rains 10-15 days in advance, with the best performances from runs without convection schemes, new-Tiedtke, and BMJ schemes. However, all schemes except new-Tiedtke struggled to predict the Mount-Abu flood from 5-day advance initialization. Further analysis revealed new-Tiedtke's superiority in simulating extreme precipitation events due to its better representation of convection and low clouds. The better representation of convection, especially shallow convection, and low clouds in this scheme makes it superior to other schemes for simulating extreme precipitation events. Results are further extended for a few other cases, confirming new-Tiedtke's efficiency. This study highlights the importance of accurate convection parameterization in simulating extreme events (**Fig 39**). *(**Kaur M., Joseph S., Phani M.K.R., Sahai A., Dey Avijit, Mandal R.,** Impact of genesis conditions on regional simulations of extreme rainfall: A convection parameterization sensitivity study, **Mausam,** 74, April 2023, DOI:10.54302/mausam.v74i2.5983, 467–482)*

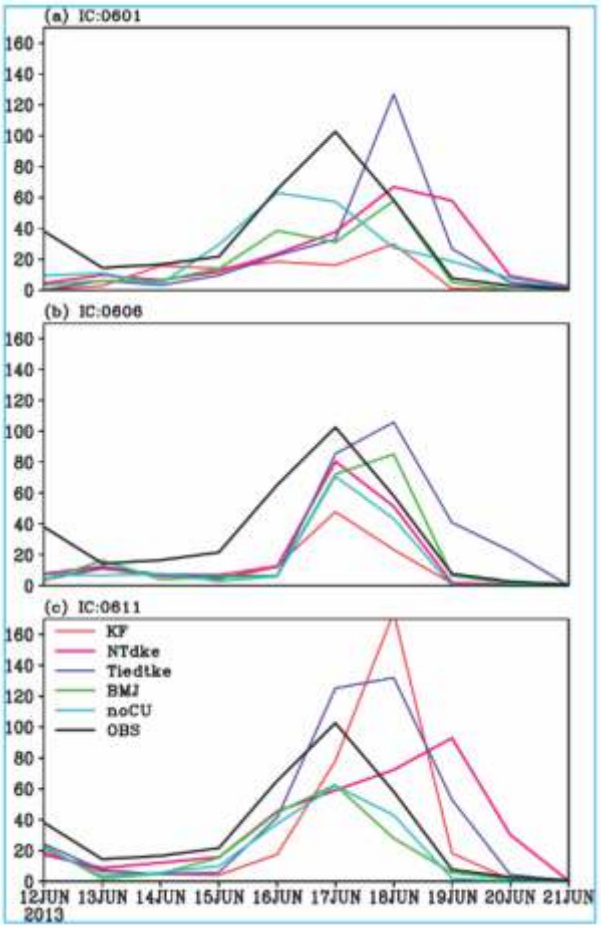


Fig. 39: *Time-series of area-averaged rainfall (mm/day) during Uttarakhand event (17th June, 2013) from observation (black) and physics simulations (multi-color) from (a) farthest IC (0601), (b) far IC (0606)and(c) near IC (0611).*

Diagnostics and real-time extended range prediction of cold waves over India

Cold wave (CW) events across India typically occur during the boreal winter months from November to February. This study introduces an objective criterion using actual, departure from normal, and percentile values of daily gridded minimum temperature (Tmin) data for monitoring CW events over India, and assesses its applicability in a multi-model ensemble extended range prediction system. The large-scale features associated with CW events are also discussed. Utilizing this criterion and considering the average number of CW days per year over the study period and recent decades, the CW-prone region is identified. The time series of standardized area-averaged Tmin anomalies (over the CW-prone region) from 1951-2022 identifies CW events. Temporal variability analysis reveals no compromise in CW occurrences despite overall warming trends. Long CW events (> 7 days) are favored by La-Nina conditions, while short CW events (≤ 7 days) are

favored by neutral Pacific conditions. A blocking high to the northwest of Indian longitude with slow westerly trough movement eastward is associated with long CW events, while for short events, the blocking high is less significant. The multi-model ensemble prediction system shows reasonable skill in predicting CW events in the CW-prone region up to 2-3 weeks in advance, though confidence decreases with longer leads. Forecast verifications indicate that, despite uncertainties in time and space, this forecasting system effectively provides early indications of forthcoming CW events. *(**Mandal R., Joseph S., Sahai A.K., Dey Avijit, Phani M.K.R., Pattanaik D. R., Kaur M.,** Karmakar N., Diagnostics and real-time extended range prediction of cold waves over India, **Climate Dynamics**, 61, September 2023, DOI:10.1007/s00382-023-06666-1, 2051–2069)*

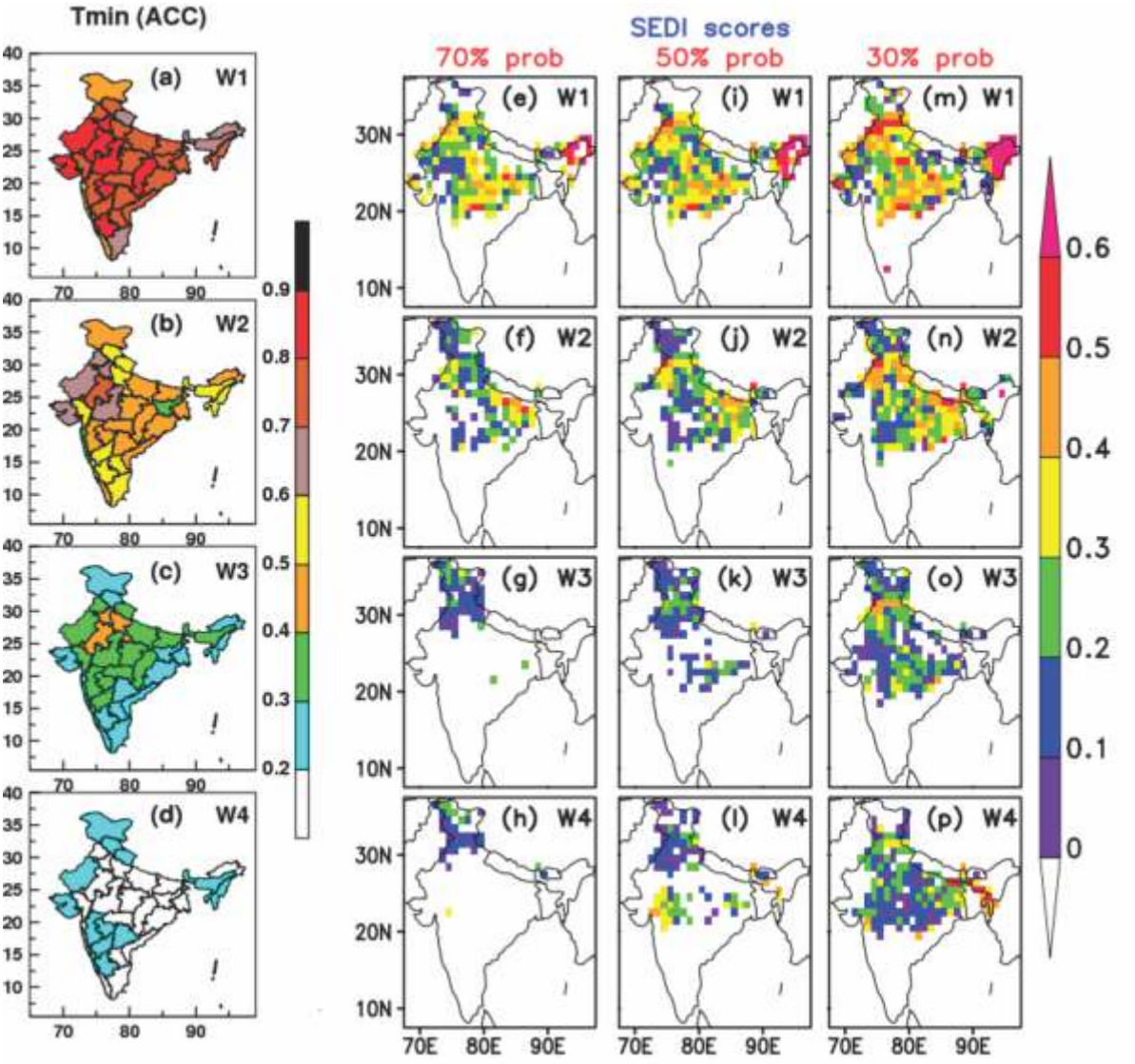


Figure 40: *Skill of the Extended Range Prediction System of IITM-IMD in predicting cold waves. (a–d) Anomaly Correlation Coefficient (ACC) of minimum temperature (Tmin); (e–h) SEDI values for 70% CW probability; (i–l) SEDI values for 50% CW probability; and (m–p) SEDI values for 30% CW probability for different week leads (W1 to W4) during NDJF for the hindcast period 2003–2017. ACC above 0.2 is significant at a 5% level using a hypothesis test for the population correlation coefficient (or r-test) with about (or more than) 100 independent samples spatially for each sub-division and for each week lead during the season. [Here, W1, W2, W3 and W4 represent the week-1, week-2, week-3 and week-4 leads]*

Coupled Model Biases and Extended Range Prediction Skill during the Onset Phase of the Indian Summer Monsoon with Different Initializations Related to Land Surface and number of Observations

The significance of initialization in monsoon onset phase forecasting in the extended range (beyond ten days lead time) and the impact of displacement or shift in initial conditions (IC) on the extended range forecast is examined. Two displacement errors are considered: (a) the initial error due to a change in land surface initial conditions and (b) the initial error due to a change in the number of observations. For the first part (a), we analyze and compare the prediction skills in the United Kingdom Met Office (UKMO) GloSea5 forecasts run with two different land surface IC configurations. In one configuration, the IC is prepared using a monthly land surface climatology; in the other, it is based on daily land surface reanalysis. In the second part (b), we use the IITM_CFS model with two different ICs (NCEP and NCMRWF, differing in the number of observations over the Indian land region). Both runs indicate a shift in the initial condition, manifesting as a displacement error. (***Gautam P., Chattopadhyay R., Joseph S.,*** *Martin G.M.,* ***Sahai A.K.,*** *Coupled model biases and extended-range prediction skill during the onset phase of the Indian summer monsoon with different initializations related to land surface and number of observations,* ***Quarterly Journal of the Royal Meteorological Society,*** *149, July 2023, DOI:10.1002/qj.4475, 1650-1673)*

Intraseasonal oscillation of land surface moisture and its role in the maintenance of CTCZ during the active phases of the Indian summer monsoon:

The role of soil moisture in maintaining the continental tropical convergence zone (CTCZ) during the active monsoon phase is explored using soil moisture datasets from ERA5 reanalysis, validated with other datasets. The analysis reveals that soil moisture, like rainfall, exhibits significant intraseasonal oscillation, with distinct sub-seasonal and seasonal features. During the summer monsoon, the seasonal mean maximum soil moisture occurs over the western coastal regions, central India, and the northeastern Indian subcontinent. However, during sub-seasonal active phases, the maximum positive soil moisture anomaly shifts to northwestern India. This suggests that soil moisture plays a pre-conditioning role during active monsoon phases in India's monsoon core zone, depending on the region's soil type and climate patterns. Analyzing the moist static energy (MSE) budget during active phases shows that soil moisture feedback influences the boundary layer MSE and rainfall. Evaluating this feedback in the Climate

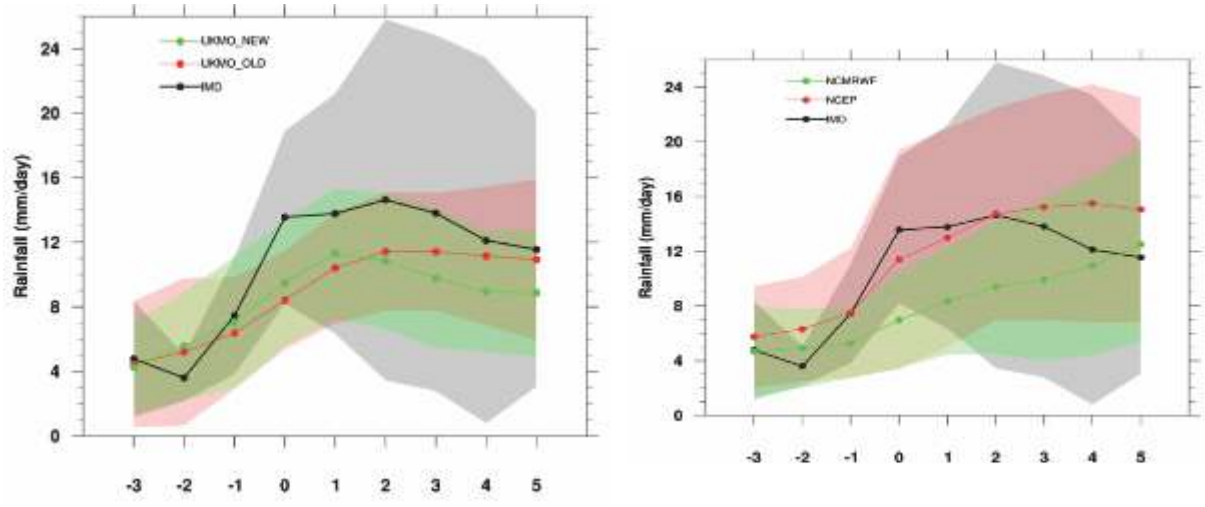


Fig.41: *Evolution of rainfall(mm) over a larger southern box(8°-14°N;70°-82°E) from the UKMO model(a) and IITM-CFS(b) during three days prior and five days later monsoon onset days, where day 0 represents monsoon onset days for the period 2003-2015.*

Forecast System (CFS) model-free run highlights that CFS does not realistically capture soil moisture's pre-conditioning role and its feedback on rainfall, contributing to the model's rainfall dry bias. The study also finds that soil texture significantly affects soil moisture and rainfall's intraseasonal patterns. A WRF regional model experiment demonstrates that pre-conditioning of soil moisture over sandy soils increases precipitation during the active monsoon phase (**Fig. 42**). (***Gautam P., Chattopadhyay R.,*** *Martin G.,* ***Joseph S., Sahai A.K.,*** *Intraseasonal oscillation of land surface moisture and its role in the maintenance of CTCZ during the active phases of the Indian summer monsoon,* ***Climate Dynamics,*** *Online, March 2024, DOI:10.1007/s00382-023-07070-5, 1-17)*

Large-scale features during active and break phases of Indian summer monsoon 2022

The large-scale changes in convection and circulation during the active-break periods of rainfall in the Indian Summer Monsoon (ISM) 2022 are analyzed. The spatial structure of rainfall and circulation changes between an active (9-15 July 2022) and break (26 August – 3 September 2022) spell is isolated from precipitation anomalies, wind anomalies at 850hPa, GPH at 200hPa, divergence anomalies at 200hPa, and the latitude-pressure section of vertical velocity (omega) averaged over Indian longitudes (73°-82°E) depicting Hadley circulation. These are separately analyzed for active and break spells, along with the difference (active-break) spell (**Figure 43** (a-o)). Precipitation anomalies show a 'quadrupole' structure with enhanced (decreased) precipitation over central India, extending over the Bay of Bengal and equatorial west Pacific, while decreased (enhanced) precipitation is observed over the southeastern tropical Indian Ocean (SETIO) and northwest tropical Pacific during the active (break) phase. The low-level monsoon circulation, monsoon trough, and the cross-equatorial jet over Somali are

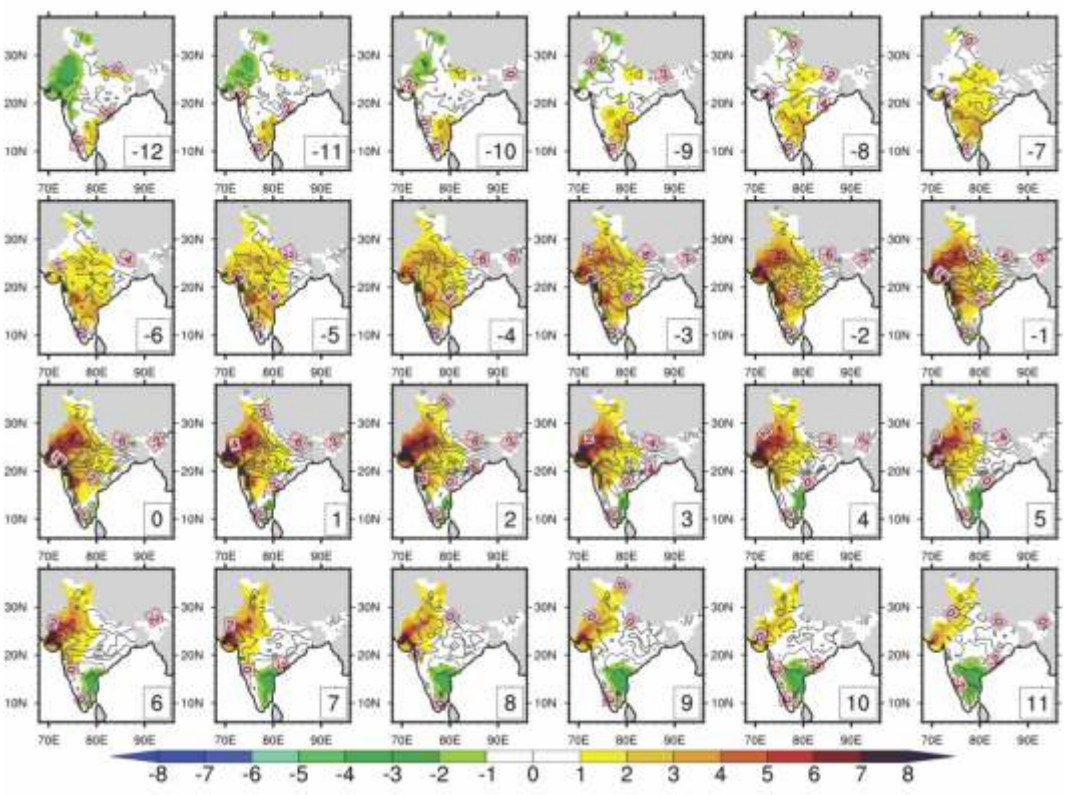


Fig. 42: *Spatial Distribution of anomalous ERA5 soil-moisture *0.01m^3/m^3) (shaded) in the days before, during and after the peak of the active phase (lag 0).Rainfall(mm/day) is shown as contours.*

strengthened (weakened) in the active (break) phase, while low-level anomalous anticyclonic circulation over the head Bay of Bengal (BOB) reduces precipitation during the break.

In the upper troposphere, the local circulation during the active phase is characterized by an extended Tibetan anticyclone (TA) with a two-cell core structure. The extent of TA is reduced in the break spell compared to the active spell. The intensified TA reinforces strong upper-level horizontal divergence, initiating convection over India during the active phase. This divergence is enhanced over the core monsoon zone, extending southeastward to central and southeast BOB, the Maritime continent, and equatorial west Pacific in the active phase, while during the break phase, it is enhanced over south peninsular India, southwest Arabian Sea, and SETIO. The locations of strong positive upper-level divergence anomalies correspond with increased precipitation anomalies. The intensified (weakened) lower and upper tropospheric flow over the monsoon domain corroborates the substantial strengthening (weakening) of the large-scale Hadley circulation during the active (break) phase. The enhanced low-level cyclonic (anticyclonic) circulation anomaly in the monsoon trough region during an active (break) condition is associated with enhanced (decreased) ascending motion, leading to increased (decreased) precipitation over the monsoon trough region and decreased (enhanced) ascending motion and precipitation over the equatorial warm waters. Thus, the regional Hadley circulation oscillates between a northern position around the monsoon trough region and a southern location over an equatorial ocean between an active (break) phase. *(**Mandke,** Sujata. Large-scale features of active and break phases during Indian summer monsoon 2022, Research activities in Earth system modelling. Working Group on Numerical Experimentation. Report No. 53. July 2023, **WCRP Report No.6/2023.** Edited by E. Astakhova, WMO, Geneva, 2-11).*

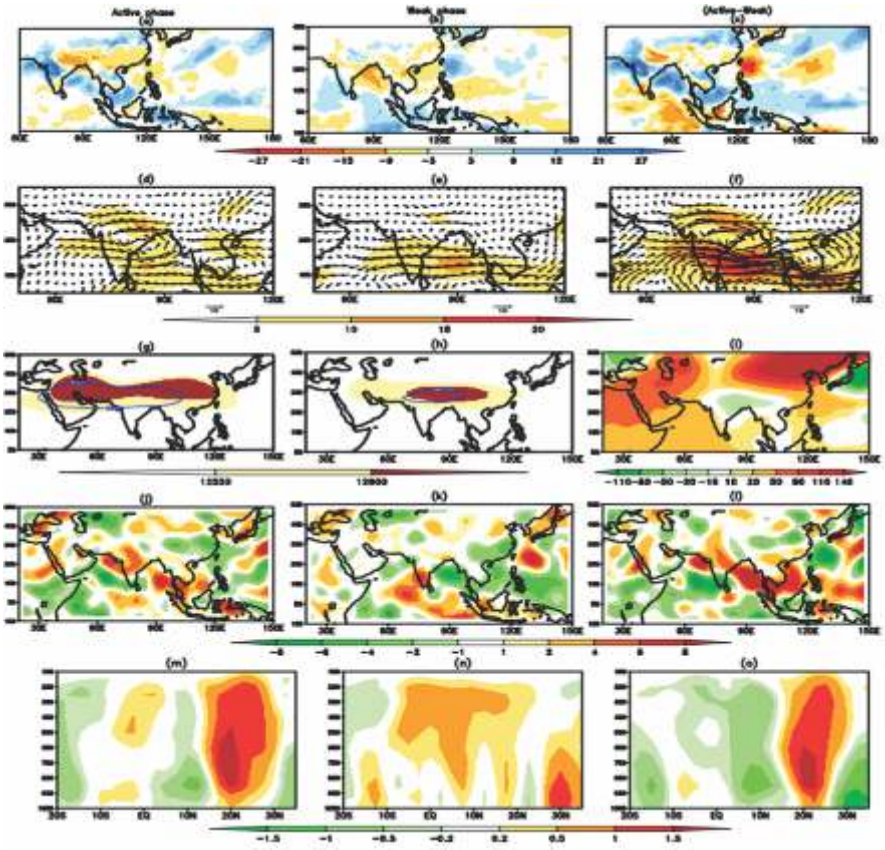


Fig.43: *Precipitation anomaly during (a) Active spell (b) Break spell (c) Difference (Active-Break). (d, e, f) are same as (a, b, c) respectively, except wind anomaly at 850hPa. (g, h, i) are same as (a, b, c) respectively, except Geopotential height at 200hPa (shaded) overlaid by climatology (blue contour). (j, k, l) are same as (a, b, c) respectively except divergence anomaly at 200hPa (*10^6*). (m, n, o) are latitude-pressure section of vertical velocity (omega*-10) averaged over Indian longitudes (73°-82°E).*

1.2.3. Seasonal Scale

Developmental Activities

- Implementation of COARE 3.0 bulk flux algorithm with diurnal ocean skin temperature parameterization in CFSv2 is completed.
- Improvement of S2S predictions of ISM rainfall have been carried out by developing convective and microphysical processes.
- Developed and operationalized dynamical system for lightning prediction. Improvements of extreme events associated with lightning by developing aerosol-cloud interaction, aerosol hygroscopicity, new INP and ratio of ICCG have been done based on process study using observation. Operational forecast simulations are carried out from 2019 to till date.
- New lightning parameterization is developed for GCM. Evaluation of lightning parameterization schemes to simulate lightning flash counts over different parts of India has been done.
- Improved sub-seasonal variability in CFSv2 by coupling a river-routing model
- Developed Mission Coupled Forecast System version 2.0 (MMCFSv2) model which substantially upgrades the present operational MMCFSv1 (version 1) at the India Meteorology Department. The primary individual model components of MMCFSv1 which are upgraded in MMCFSv2 are as follows:
    - The use of Semi-Lagrangian dynamical core in the Global Forecast System (GFS) spectral model (as the atmospheric model) in place of the Eulerian dynamical core in MMCFSv1.
    - MMCFSv1 uses the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 4p0d (MOM4) as the ocean model. It has been upgraded to MOM6 in MMCFSv2. This has resulted in scale aware parameterizations in the ocean model. The ocean model resolution has also increased both vertically and horizontally.
    - MMCFSv1 uses a three-layer (one layer of snow and two layers of sea ice) interactive sea-ice mode, which is an improvement over the Semtner three-layer model. This component model has been upgraded to the Los Alamos CICE5 in MMCFSv2.
- Marine heat waves forecast products created and shared with INCOIS for their feedback.
- New model hindcast data with initialized with April ICs have been shared with IMD for verification and operationalization.

National and International collaborations

- The MoES and JAMSTEC collaboration is extended to explore the capability of both the models for the prediction of intra-seasonal variability such as the active and break phase of monsoon. In this direction efforts were initiated to exchange the required model simulations and analysis are being carried out in constant collaboration between the members of Seasonal Prediction group and JAMSTEC. Drs. Swadhin Behera and Takeshi Doi from JAMSTEC have shared the SINTEX-F2 hindcast simulations with IITM Seasonal Prediction group and analysis is being carried out focusing Monsoon Intraseasonal Oscillations.
    - National scientific collaboration with NCMRWF and IITM (without MOU)
    - International collaboration with National Taiwan University (NTU), Taiwan (without MOU) and UKMO (under **the Weather and Climate Science for Service Partnership WASSP**program).

Under the program WCSSP India, in collaboration with the UK Met Office, following development activities have been carried out: **a)** Development of

Indian summer monsoon precipitation biases in two seasonal forecasting systems and their response to large-scale drivers; **b)** the pre-cursors to Indian Ocean Dipole and its simulation in coupled models.

Basic Research

Monsoon Mission Coupled Forecast System version 2.0: model description and Indian monsoon simulations

This study presents the Monsoon Mission Coupled Forecast System version 2.0 (MMCFSv2) model, which substantially upgrades the present operational MMCFSv1 (version 1) at the India Meteorology Department. The latest 25 years (1998–2022) of retrospective seasonal coupled hindcast simulations of the Indian summer monsoon with April initial conditions from Coupled Forecast System Reanalysis are discussed. MMCFSv2 simulates the tropical wind, rainfall, and temperature structure reasonably well. MMCFSv2 captures surface winds well and reduces precipitation biases over land, except over India and North America. The dry bias over these regions remained like in MMCFSv1. MMCFSv2 captures significant features of the Indian monsoon, including the intensity and location of the maximum precipitation centers and the large-scale monsoon circulation. MMCFSv2 improves the phase skill (anomaly correlation coefficient) of the interannual variation of Indian summer monsoon rainfall (ISMR) by 17 % and enhances the amplitude skill (normalized root mean square error) by 20 %. MMCFSv2 shows improved teleconnections of ISMR with the equatorial Indian and Pacific oceans. This 25-year hindcast dataset will serve as the baseline for future sensitivity studies of MMCFSv2 (**Fig. 44**). *(**Jain D., Rao Suryachandra A., Dandi R.A., Pillai P. A., Srivastava Ankur, Pradhan M., Gangadharan K.V.,** Monsoon Mission Coupled Forecast System version 2.0: model description and Indian monsoon simulations, **Geoscientific Model Development,** 17, January 2024, DOI:10.5194/gmd-17-709-2024, 709-729)*

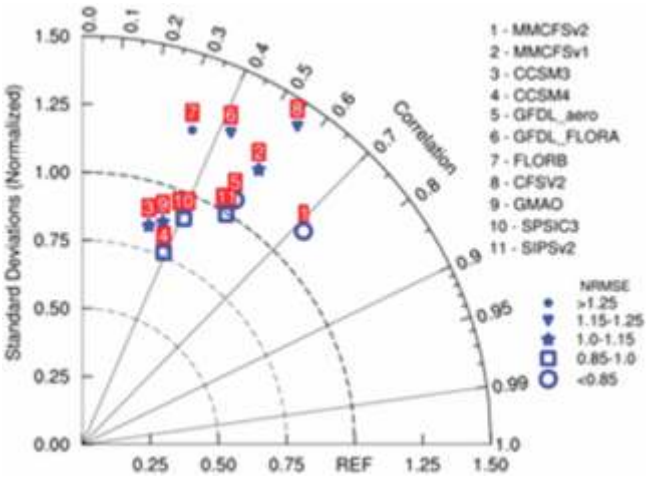


Fig. 44: *Taylor diagram showing the normalized RMSE pattern correlation coefficients and normalized standard deviation of the JJAS mean ISMR of the MMCFS and NMME models with respect to GPCP observations. The NMME model simulation period is 1998–2021 and the MMCFS period is 1998–2022.*

Role of mean, variability and teleconnection of clouds behind Indian summer monsoon rainfall

Skilful prediction of the seasonal Indian summer monsoon (ISM) rainfall (ISMR) at least one season in advance has great socio-economic value. The ISM is a lifeline for about a sixth of the world's population. The ISMR prediction remained a challenging problem with the subcritical skills of the dynamical models due to a limited understanding of the interaction among clouds, convection and circulation. In this study, we have analysed the seasonal mean of high cloud fraction, ice mixing ratio and ice cloud fraction from satellite and reanalysis and demonstrated their importance for ISM. The variability of the mixing ratio of cloud ice in different time scales (3–7 days, 10–20 days and 30–60 days bands) is also examined from reanalysis during ISM. Here, we have shown the teleconnection of different cloud variables over the ISM region with global sea surface temperature. We found that they are tied with slowly varying forcing (e.g., El Niño and Southern Oscillation). Besides, the correlation of cloud ice with different indices (Niño, Pacific Decadal Oscillation, North Atlantic Oscillation and Extratropics) may enhance the potential predictability of ISMR. The representation of deep convective clouds, which involve the ice-phase processes in a coupled climate model, strongly modulates ISMR variability in association with

global predictors. The results from the two sensitivity simulations using coupled global climate model (CGCM) demonstrate the importance of the cloud ice on ISM rainfall predictability. Therefore, this study provides a scientific basis for improving the simulation of the seasonal ISMR by developing the physical processes of the cloud on a subseasonal time scale and motivating further research in this direction. *(**Hazra A., Dutta U., Chaudhari H.S., Pokhrel S., Konwar M.,** Role of mean, variability and teleconnection of clouds behind Indian summer monsoon rainfall, **International Journal of Climatology**, 43, July 2023, DOI:10.1002/joc.8076, 4099-4118)*

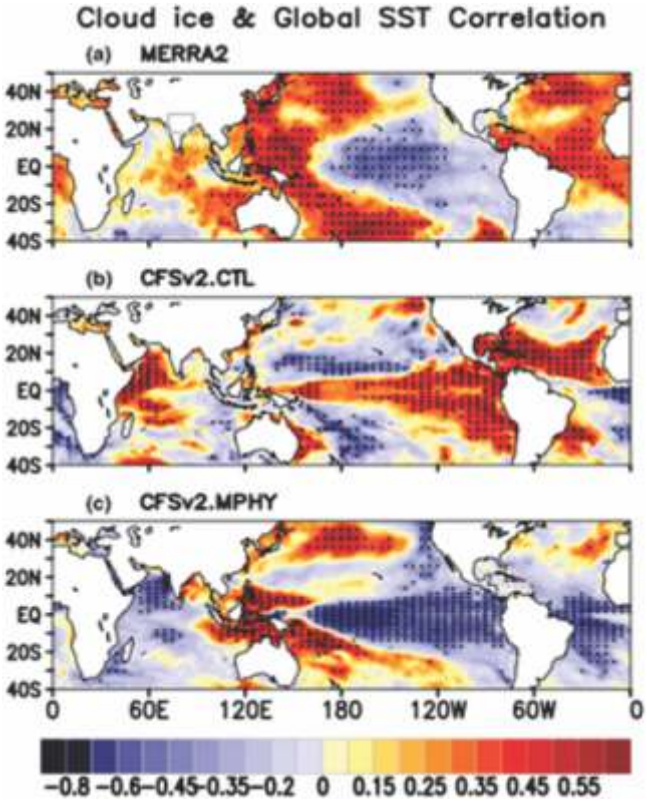


Fig. 45: *Correlation of central India averaged ice mixing ratio (IMR) with global SST (HadiSST) at each grid point. (a) MERRA2, (b) CFSv2.CTL, (c) CFSv2.MPHY. The correlation values greater than 95% significance are stippled*

Improving the subseasonal variability of the Indian summer monsoon in a climate model

Many global climate models, including the Climate Forecast System version 2 (CFSv2), have a biased representation of subseasonal modes of variability of the Indian summer monsoon. For instance, they simulate a weaker summer mean monsoon low-pressure systems (LPS) climatology, faster than observed northward propagation of monsoon intraseasonal oscillations (MISOs), and a systematic dry bias over Indian landmass. The Bay of Bengal (BoB), with its shallow mixed layers and unique thermal stratification, significantly modulates the convective activity in this region at subseasonal-to-seasonal timescales through modulation of sea surface temperature. The highly stratified upper ocean in the BoB is due to the enormous freshwater it receives from rains and rivers. A river routing model is coupled to the CFSv2 to account for the riverine freshwater and the improvements in modelling the upper-ocean structure are analysed. Model simulations indicate that inclusion of temporally varying riverine freshwater improves the upper-ocean state in the BoB and the observed mixed-layer temperature gradients in the Bay are simulated reasonably after incorporating the time varying river runoff. This resulted in increased LPS lifetime and track density, and enhanced rainfall over central India. Better representation of the upper-ocean stratification in the model leads to larger post-convection shoaling of mixed layers at intraseasonal timescales, thereby forming thick barrier layers. Enhanced air–sea interactions restricted to the shallow mixed layer are associated with stronger vorticity, specific humidity and low-level convergence to the north of the intraseasonal convection band. This enhanced low-level moisture convergence north of the convection centre results in realistic northward propagation of MISO and aids LPS activity. It is demonstrated that better simulation of the upper-ocean structure in coupled climate models can improve the representation of subseasonal modes of

monsoon variability. These results bear important implications for operational forecasting. *(**Srivastava Ankur, Rao Suryachandra A.,** Ghosh S., Improving the subseasonal variability of the Indian summer monsoon in a climate model, **International Journal of Climatology**, 43, September 2023, DOI:10.1002/joc.8142, 5227-5247)*

Towards a realistic MISO simulation: impact of rectification

State-of-the-art coupled models have several limitations in representing the phase and amplitude characteristics of monsoon intra-seasonal oscillations (MISO). Specifically, the models' deficiencies in predicting stronger active spells have been widely reported in earlier studies. In the present study, efforts have been made to overcome this limitation by improving the representation of the diurnal cycle of the sea surface temperature and the associated feedback processes. In the present study, it is demonstrated that resolving the diurnal cycle rectification along with implementing a modern bulk surface-flux algorithm in a global coupled model improves the simulation of MISO characteristics. The present analysis showcases how rectification in the presence of a revised turbulent flux algorithm and diurnal skin temperature parameterisation can modulate the oceanic, atmospheric, and interfacial properties so that the coupled model can better simulate stronger active monsoon spells. The essential requirements for the coherent northward propagation mechanisms of MISOs are pronounced in the presence of intra-seasonal rectification by diurnal SSTs and air–sea interactive flux feedbacks. *(**Pradhan M., Rao Suryachandra A.,** Bhattacharya A., Towards a realistic MISO simulation: impact of rectification, **Climate Dynamics**, Online, January 2024, DOI:10.1007/s00382-023-07053-6, 1-19)*

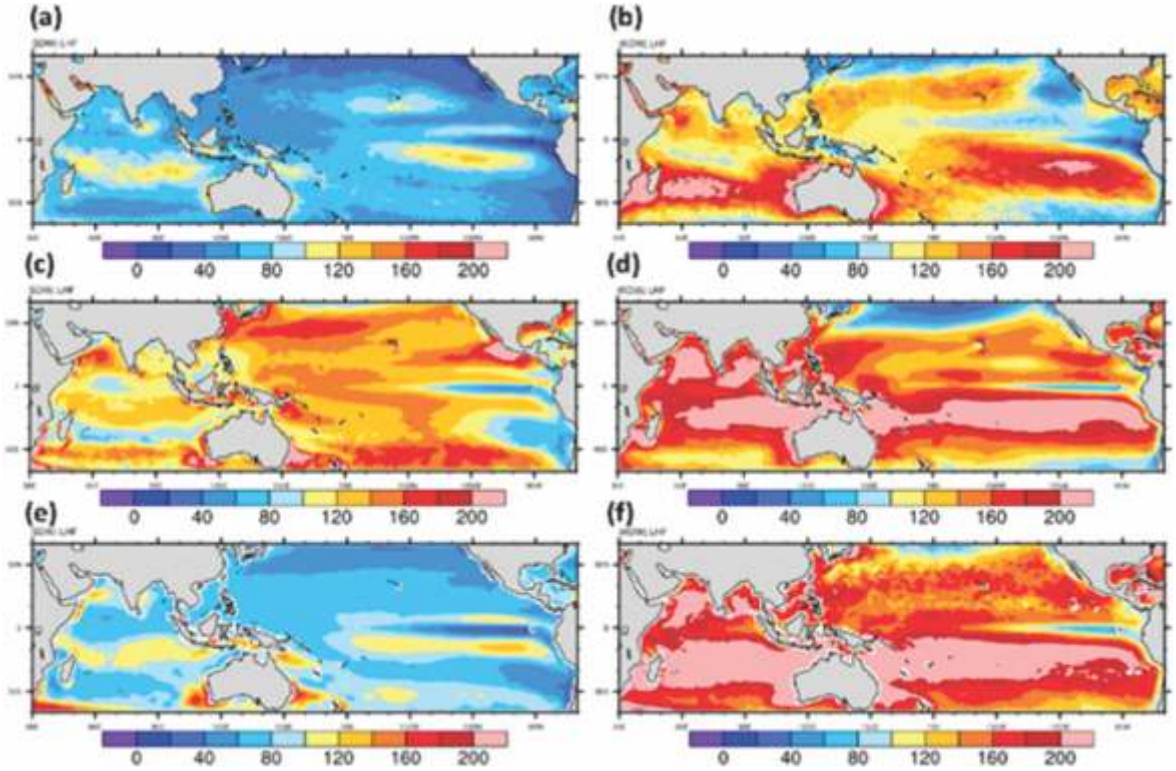


***Fig. 46**: Composite of observed Latent Heat Flux (W/m^2) during **a** Strong Diurnal Warming (SDW) events, and **b** Weak Diurnal Warming (WDW) defined for each grid point events. **c–f** are same as **a**, **b** but for CTL and SEN simulations respectively*

1.2.4. Unified model framework for Monsoon Variability and Predictability (Monsoon Mission-UMVP)

OBJECTIVES

To understand the monsoon variability and predictability in a unified system, where physical processes at various scales (i.e. diurnal to MISOs) and their interactions with slowly varying boundary conditions (i.e. land, ice, oceanic states) shape the weather and climate.

Highlights of Major Achievements

- The Monsoon Mission-UMVP project has made notable advancements in improving the land model component of the CFS climate model. By increasing soil depth to 10 layers (totalling 10 meters), the project enhances the model's ability to simulate soil temperature and moisture, leading to a more accurate representation of land-atmosphere interactions. Additionally, the introduction of the Ball-Berry transpiration scheme improves the portrayal of plant physiology and evapotranspiration, resulting in more realistic rainfall predictions for the monsoon season.
- IITM's research has uncovered a significant link between spring land surface temperatures in the Western Third Pole region and June rainfall across the Asian monsoon zone. This relationship underscores the role of land surface processes in shaping monsoon variability. However, current climate models, including the IITM CFS, need to improve their ability to capture this teleconnection, particularly the impact of spring temperatures on subsequent monsoon rainfall, as highlighted by the LS4P project.

DEVELOPMENTAL ACTIVITIES:

- Under this project, improvements in land model component of coupled model- CFS have been targeted. Soil depth is increased (10 layers, total 10m depth) in land model Noah to improve simulation of soil and surface temperature. The choice to augment the soil depth to 10 layers, resulting in a total depth of 10m, was made with the specific aim of enhancing the portrayal of soil characteristics within the model. Deeper soil layers can better capture the vertical distribution of soil properties and improve the simulation of soil temperature and moisture content. This could lead to more accurate depiction of land-atmosphere interactions. Replacing the Jarvis scheme with the Ball-Berry transpiration scheme is implemented with a specific interest in improving the representation of plant physiology and its impact on evapotranspiration. The Ball-Berry transpiration scheme is known for its more sophisticated representation of stomatal conductance, which plays a crucial role in the exchange of water vapor between vegetation and the atmosphere. This change could lead to more realistic estimations of evapotranspiration, and it may lead to better depiction of rainfall in coupled climate model- CFS.

BASIC RESEARCH

Remote effects of Tibetan Plateau spring land temperature on global sub seasonal to seasonal precipitation prediction and comparison with effects of sea surface temperature: the GEWEX/LS4P Phase I experiment

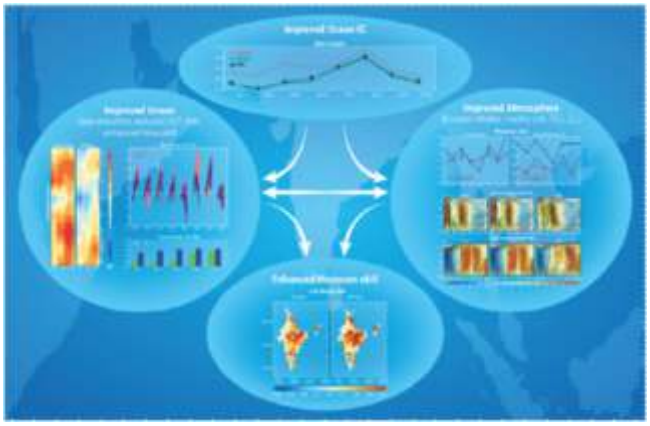
Subseasonal-to-seasonal (S2S) precipitation prediction in boreal spring and summer months, which contains a significant number of high-signal events, is scientifically challenging and prediction skill has remained poor for years. Tibetan Plateau (TP) spring observed surface temperatures show a lag correlation with summer precipitation in several remote regions, but current global land–atmosphere coupled models are unable to represent this behavior due to significant errors in producing observed TP surface temperatures. To address these issues, the Global Energy and Water Exchanges (GEWEX) program launched the "Impact of Initialized Land Temperature and Snowpack on Subseasonal-to-Seasonal Prediction" (LS4P) initiative as a community effort to test the impact of land temperature in high-mountain regions on S2S

prediction by climate models. More than 40 institutions worldwide, including our group from IITM, are participating in this project.

In the present study, we have identified a dominant mode of variability in June rainfall over the entire Asian monsoon region. This mode is found to be linked with the spring (April, May) land surface temperature (LST) of the areas centred around the Western Third Pole (WTP). The WTP region is also home to many glaciers and steep mountains, and spring LST of this region has a strong inverse relationship with snow water equivalent (r=-0.65), suggesting a seminal role of land surface processes in the first phase of ASM variability. Evaluation of models participating in the LS4P project reveals that land-surface processes in IITM CFS needs to be improved to capture the found teleconnection between spring LST over WTP and June precipitation over India. (***Saha Subodh K.,*** *Xue Y., Krishnakumar S., Diallo I., Shivamurthy Y., Nakamura T., Tang Q.,* ***Chaudhari H.S.,*** *A dominant mode in the first phase of the Asian summer monsoon rainfall: role of antecedent remote land surface temperature,* ***Climate Dynamics,*** *61, September 2023, DOI:10.1007/s00382-023-06709-7, 2735–2751 and*

Xue Y., Diallo I., Boone A.A., Zhang Y., Zeng X., Lau W.K.M., Neelin J.D., Yao T., Tang Q., Sato T., Koo M.-S., Vitart F., Ardilouze C., ***Saha Subodh K.,*** *... et al., Remote effects of Tibetan Plateau spring land temperature on global subseasonal to seasonal precipitation prediction and comparison with effects of sea surface temperature: the GEWEX/LS4P Phase I experiment,* ***Climate Dynamics****, Online, August 2023, DOI:10.1007/s00382-023-06905-5, 1-26)*

Role of Improved Ocean Initial State in the Seasonal Prediction of Indian Summer Monsoon: A Case Study has made as an effort to show the impact of improved ocean initial conditions (ICs) in a coupled forecast system (CFSv2) simulation on the seasonal prediction of Indian summer monsoon rainfall (ISMR). CFSv2 is used as an operational dynamical model for the seasonal prediction of ISMR. An improved ISMR skill has been shown by initializing the ocean component of CFSv2 using new improved ocean ICs based on Global Ocean Data Assimilation System (GODAS) analysis. This new analysis is better than the NCEP GODAS, which uses the earlier-generation ocean model MOM4p0d and assimilates observed temperature and synthetic salinity using the 3DVar assimilation scheme. However, the new, improved GODAS analysis uses the MOM4p1 ocean model and assimilates observed salinity instead of synthetic salinity. Twin sets of nearly identical model experiments have been performed by differing only in their ICs, with one set using NCEP ICs and the other using the new ICs (NIC). The NIC experiment consistently shows better El Niño–Southern Oscillation prediction skill than the NCEP IC experiment. This advancement leads to improvement in the ISMR skill. It is found that the substantial improvements in both oceanic and atmospheric variables in a coupled feedback system contributed to the improved ISMR skills. The enhanced ISMR skill score of the NIC experiment might be the result of improved teleconnections, better depiction of large-scale monsoon circulations, and reduced model drift. (***Pokhrel S.,*** *Rahaman H.,* ***Saha Subodh K., Chaudhari H., Hazra A.,*** *Ravichandran M., Role of Improved Ocean Initial State in the Seasonal Prediction of Indian Summer Monsoon: A Case Study,* ***Ocean-Land-Atmosphere Research****, 3: 0034, January 2024, DOI:10.34133/olar.0034, 1-21)*



COLLABORATION:

Collaborated in the international project "Impact of Initialized Land Temperature and Snowpack on Subseasonal-to-Seasonal Prediction (LS4P)" initiated by Global Energy and Water Exchanges (GEWEX) program. About 40 institutions worldwide (including IITM's UMVP) have participated in this project.

1.2.5. International Monsoons Project Office (IMPO)

Executive Head: Dr. E. N. Rajagopal

The International Monsoons Project Office (IMPO), hosted at IITM w.e.f. 30 July 2021, contributes to WMO's monsoon research coordination activities under WWRP and WCRP. IMPO is established through an agreement between IITM and WMO, with support from MoES. IMPO was formally launched through an online event on 28 February 2022, by the honorable Minister of Earth Sciences Dr. Jitendra Singh, in the presence of Dr. M. Ravichandran, Secretary, MoES, and dignitaries of WMO, WCRP, WWRP & MoES and Director, IITM.

Important activities by International Monsoons Project Office (IMPO):

- International Monsoons Project Office (IMPO) provided key support to the CLIVAR/ GEWEX Monsoons Panel (MP) in preparation of Annual Reports, new Membership recommendations, issuing appointment letters to new members, organising online meetings of MP and WG on Asian-Australian Monsoons, etc.
- IMPO has provided key support to the Monsoon Panel's three regional Working Groups on Asian Australian Monsoons (WG-AAM), African Monsoons (WG-AFM) and American Monsoons (WG-AMM).
- IMPO successfully organized the **International Project Offices (IPO) & WCRP Secretariat Group** online meeting on 18th April 2023 for the first time. Participated and presented updates on IMPO's activities in the subsequent meetings held on 6th July 2023, 22nd September 2023 and 4th March 2024
- **Joint WCRP/WWRP Monsoons Panel Webinar Series:** IMPO played a key role in the successful organization of the three webinars of the series on:
  - "Global Monsoon", 13th September2023.
  - "Asian-Australian Monsoon", 30th November 2023
  - "African Monsoons", 6th March 2024

  The video recording of the three webinars have been made available in the IITM YouTube Channel by IMPO for wider publicity.
- IMPO successfully organized the **5th Session of the Monsoons Panel (MP) along with a meeting between MP and Working Group on African Monsoons (WG-AFM)** in Hybrid mode on 27th October 2023 at Kigali, Rwanda.
- **IMPO participated in the WCRP's Open Science Conference (OSC-2023**), Kigali, Rwanda during 23-27 October 2023 with the following activities:
  - Supported CLIVAR/GEWEX Monsoons Panel in the organization of the Session S03 on "Global and Regional Monsoons".
  - Supported WCRP in the organization of OSC-2023 as Session Support in 3 sessions.
  - Providing CLIVAR's travel funds to 2 MP members and GEWEX's travel funds to 2 WG-AFM members for participation in the OSC
  - Organized and participated in four online meetings of the Convenors of "Global and Regional Monsoons" session in OSC-2023. Issued the invitation letters to the identified Keynote Speakers of the session.
  - Actively involved in drafting contributions from Concept Paper on Regional and Global Monsoons for the OSC Kigali Declaration, which is Co-lead by MP Co-chairs.
  - A 5-minute video on MP & IMPO was created for display at the WCRP Booth during the OSC in Kigali
  - Supported WCRP in the online poster (session S03) presentations on 11th October as Moderator.
- IMPO together with the Working Group on Tropical Meteorology Research (WGTMR) successfully

organized a 2-hour **Online Meeting with Stakeholders for identifying the Needs and Gaps in S2S Monsoon Prediction in Agriculture Planning** on 28th April 2023.

- IMPO participated in the **WWRP/WCRP S2S Summit 2023** held for celebrating 10 years of the Subseasonal to Seasonal Prediction Projectduring 3-7 July 2023 at University of Reading, UK and was actively involved in the following activities:
  - Chairing the session on "Predictability and Processes: Precipitation and Tropical Waves" on 7th July 2023.
  - Delivered an oral talk on "Development of a Multi-physics Multi-ensemble system for efficient subseasonal prediction" in the session Modelling: M2 Ensembles & Processes on 6th July 2023
  - Presented a poster on "Diagnostics and real-time extended range prediction of cold waves over India" in the Poster: Session 2 on 4th July 2023.
- IMPO has been involved in the planning and organization of the **International Workshop on Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX)** to be held at IITM, Pune during 02-07 June 2024.
  - IMPO contributed for the finalization of the Concept Note, securing WWRP/IMPO's funds (15000 USD) towards travel support to the invited international speakers, participation in discussion meetings with WCRP & SPARC, finalization of workshop logo, flier and website, etc. and publicising the workshop through IMPO webpage, WCRP Academy Catalog, etc.
- **IMPO has been involved in activities related to 9thGlobal Energy and Water Exchanges (GEWEX) Open Science Conference OSC-2024** to be held during 7-12 July 2024 at Sapporo, Japan**.** Inputs on "GEWEX OSC Program: Sessions and Themes" were collected from MP & WGs and submitted to IGPO. Introduced a new session on "Monsoon - Atmospheric-Land and Atmospheric-Ocean Interactions" with Dr. Suryachandra Rao and Dr. Hiroshi Takahashi of MP as Session Conveners.
  - Publicised the event through IMPO webpages.
  - Proposed an In-person meeting of MP and WG-AAM during GEWEX OSC with travel support from CLIVAR and GEWEX. Both CLIVAR and GEWEX agreed to support with 5000 USD each.
- IMPO has played a key role in bringing the **Eighth WMO International Workshop on Monsoons** (**IWM-8**) to India and it will be organized at Pune during 17-21 March 2025, jointly by IITM, the Ministry of Earth Sciences (MoES), Government of India, the WWRP's Working Group on Tropical Meteorology Research (WGTMR) and the WCRP's CLIVAR/GEWEX Monsoons Panel in cooperation with the India Meteorological Department and the International Monsoons Project Office (IMPO).
  - Dr. R. Krishnan, Director IITM and Prof. Yali Luo, NUIST, China are the Co-chairs of International Scientific Committee (ISC) of IWM-8

2. High Performance Computing (HPC) System

Project Director: Dr. A. Suryachandra Rao

OBJECTIVES:

- Establish a multi-petaflop computing facility for MoES institutes to support numerical modeling requirements in weather and climate forecasting, fundamental research, and observational studies.
- Provide computational resources to the academic and R&D communities to enhance operational forecasting systems and improve forecast skills.
- Develop a robust computational and visualization infrastructure to support advanced Big Data Analytics and AI/ML applications in Earth science.
- Establish and maintain a MoES Atmospheric Research Data Center, ensuring streamlined access to research data for the scientific community.
- Promote research in weather and climate applications with a focus on integrating AI/ML technologies.

Highlights of Major Achievements:

- **Pratyush HPC:** A 4 Petaflop HPC system is the only HPC system (has worldwide rank 201 on top500.org) available for R&D purpose at this moment for IITM and other MoES institutes.

  The uptime Percentage: **99.5;** System issues resolved: **651;** User application issues handled: **521**
- **Atmospheric Research Data Center (ARDC):** Large data about **1.2 Petabytes** of data has been uploaded on the ARDC server and **238** users have registered to download the required data.
- **MoES AI/ML virtual Center:** The AI/ML in Weather and Climate Prediction session was chaired by IITM Scientist Dr. Bipin Kumar during Tropmet2023, Birla Institute of Science and Research, Jaipur during 22-25 November 2023.

Developmental activities in AI/ML Virtual Center

- **Climate Downscaling and Prediction:** Key advancements in applying deep learning for climate downscaling and weather prediction, including high-resolution urban precipitation models and global precipitation forecasting.
- **Deep Learning for Weather Prediction in global scale:** Novel methods are introduced for global precipitation prediction. This modified approach enhances the forecasting process, showing significant potential for creating efficient digital twins for real-time weather simulations.
- **Urban Modeling with AI-Generated Data:** AI frameworks were designed to provide urban canopy parameters for models like WRF, utilizing machine learning to generate functional urban building datasets from open-source data, beneficial for urban climate studies.
- **Advancements in Long-Term Urban Data Series:** Bridged the data gaps and extend valuable urban datasets for continued urban studies.

Pratyush HPC activities:

Application software: A list of applications and libraries installed (or upgraded) during Apr 2023- Mar, 2024 by the Pratyush Team is provided as a Table 1.

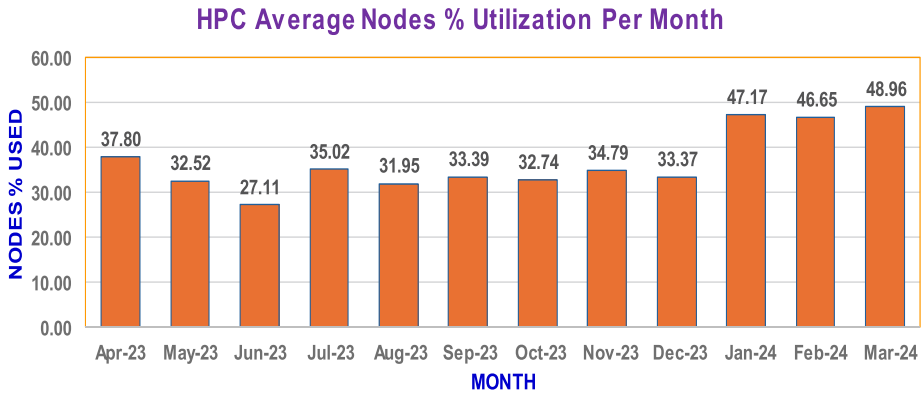


Fig.47: *The average utilization of the compute nodes during each month.*

Figure 47 presents the monthly compute node utilization for the specified period. Peak utilization was observed during the months of January, February, and March, primarily due to the execution of seasonal forecast models. The overall system performance was influenced by the high disk storage usage from multiple user groups. The Pratyush HPC disk utilization has increased, with 90% of the total allocated disk space being occupied across all user groups, as indicated in **Figure 48. Figure 49** provides a detailed breakdown of individual group-wise disk space utilization, demonstrating that several operational and research groups have exceeded 80% of their allocated storage capacity.

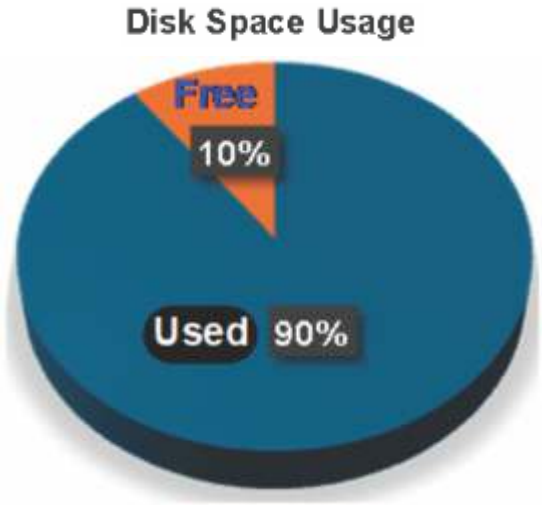


Fig.48*: Details of the disk space used. Only 10% space is left in the disk*

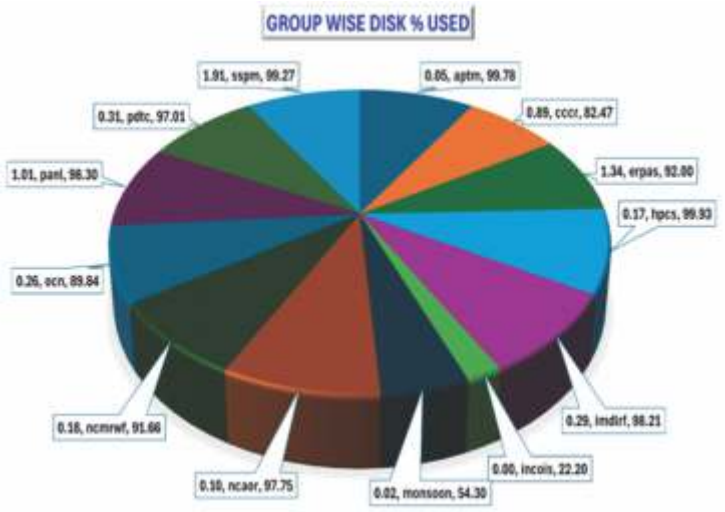


Fig.49*: Group-wise Node utilization of Pratyush HPC system (Percentage utilization of total system utilization).*

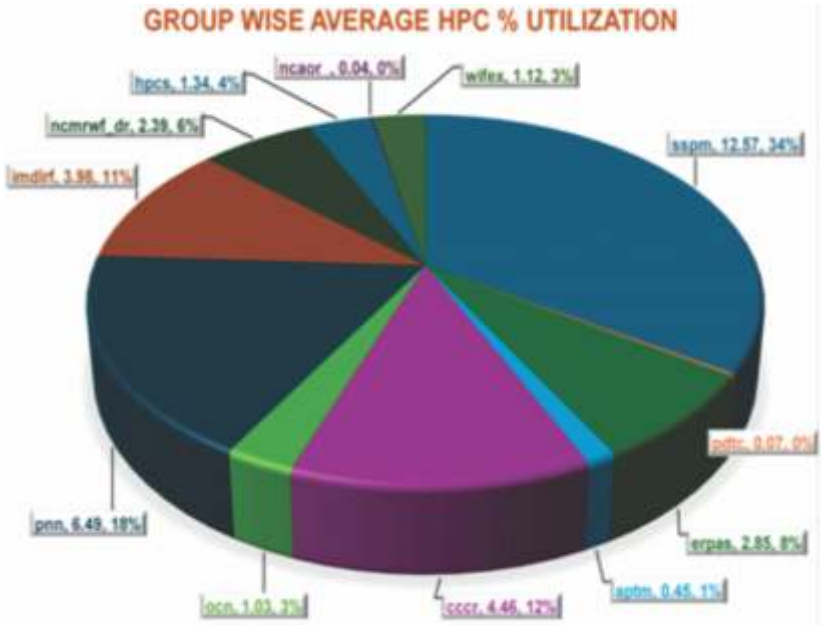


***Fig.50**: Space utilization of Pratyush in Percentage utilization out of allocated. Numbers in parenthesis denotes total allocation in PB*

Figure 50, shows the group wise node utilization of the Pratyush HPC system for the financial year. Few groups shown in the figure have used their utilization more than the allocated nodes. The percentage denotes the overall usage of the nodes from the total cluster utilization. There are 530 user application issues solved by the Pratyush Support. **Figure 51**, shows the number of issues (application) resolved from various user groups of MoES.

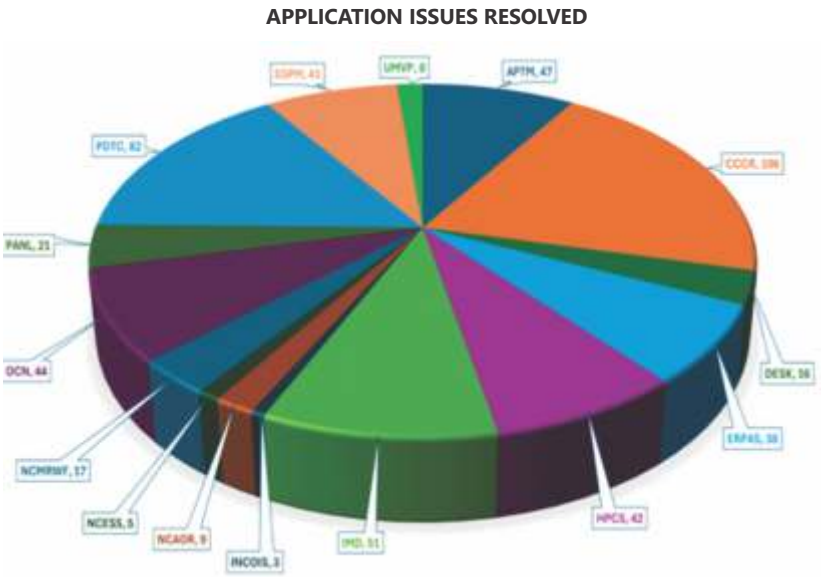


***Fig.51**: User application issues resolved from different groups of Pratyush HPC system*

System updates

The details of the applications installed on Pratyush during financial year are:.

No.	Update	Group Requested
1	Total 181 applications installed	APTM (14), OCN (15), CCCR (40), SSPM(30),PDTC(26), NCPOR(2),ERPAS(13), HPCS(15), PANL(6), IMD(11),UMVP(2),DESK (2)NCMRWF(1), CVP(2), NCESS(1)
2	Installed CDT version 18.04 and 18.12	NCMWRF
3	Installed Totalview 2018.0.5	NCMRWF
4	Upgraded IDL to version 8.8.2	HPCS
5	Installed Matlab 2023a	HPCS
6	Installed Profiling Tools: Paraver, Extrae, Clustering, & Dimemas	HPCS
7	Installed Spark in Apollo	HPCS
8	Installed MongoDB in Apollo	HPCS
9	Installed LLAMA Model in Apollo	HPCS
10	Installed WRF-WVT	UMVP
11	Installed MOM4p1 Regrid	OCN
12	Installed RStudio-GUI	ERPAS, APTM

Table 1: Details of applications installed during financial year

03. Human Resource Development and Capacity Building

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

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

3.2. Academic Cell

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

Project Director: Dr. V. Valsala

Objectives

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

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

Highlights of Major Achivements:

- IITM collaborates with universities to offer academic courses like M.Sc., M.Tech., and PhD, enhancing expertise in weather and climate sciences.
- DESK, under the REACHOUT programme, provides specialized training through JRF/SRF programmes and organizes workshops on targeted atmospheric science topics.
- The MoES Research Fellowship Programme (MRFP) successfully trained and recruited 12 JRFs in 2023 through an online selection process, preparing them for research in various institutes.
- Annual Progress Review Meetings were held in 2023 for 32 MRFP Fellows from Batches I-III, providing feedback to students and their supervisors.
- MRFP students have published 59 research papers since 2019, with contributions to high-impact journals and collaborative research.
- MRFP candidates actively engage in academic conferences and workshops, with a total of 94 in-person and 81 online events attended.
- DESK organized several national training workshops and webinars in 2023, with topics ranging from climate impacts of carbonaceous aerosols to Weather Research and Forecasting (WRF).
- PhD registration for MRFP Batch-II was completed, with eight students conducting research on diverse topics, including ocean-atmosphere interactions, primary productivity modeling, and earthquake genesis.

MoES Research Fellowship Programme (MRFP)

DESK is successfully implementing the MRFP programme. The Fourth batch of 12 JRFs was recruited in 2023 through a nationwide online process. The ab-initio training of four months for this batch was conducted online, with the following subjects:

(a) Introduction to Earth System Sciences

(b) Research Methodology

(c) Computer Programming and Data Analysis/ Visualization

IITM scientists/project scientists contributed to this training as faculty. All 12 students (JRFs) have joined their respective research institutes after the training.

BATCH III

Institutes at which MRFP JRFs are recruited to:	Number of MRFP JRFs
NCCR	1
NCMRWF	1
CMLRE	2
NCESS	2
NCS	3
BGRL	1
IMD-Pune	2
Total	12

The Annual Progress Review Meetings for all **12 MRFP Fellows for Batch-III** and all 09 MRFP fellows for Batch-IV were conducted from October to December 2023. The review committee's recommendations were communicated to students and their guides/ coordinators of the respective MoES institutes. The Annual Progress Review Meetings for all 16 MRFP Fellows for Batch-1 and all 09 MRFP fellows for Batch-2 were also conducted during 2023-24. The review committee's recommendations were communicated to students and their guides/coordinators of the respective MoES institutes.

The Annual progress of all the 32 MRFP Research Fellows of the Batch-I, II and III was reviewed during September and October and Ph.D registration certificates of MRFP Batch-II have been received.

13 peer reviewed research papers have been published/accepted by MRFP research fellows in 2023-24. The following chart shows the performance of the candidates recruited since 2019. The data for 2024 is until March 2024 only. The figure clearly shows that the

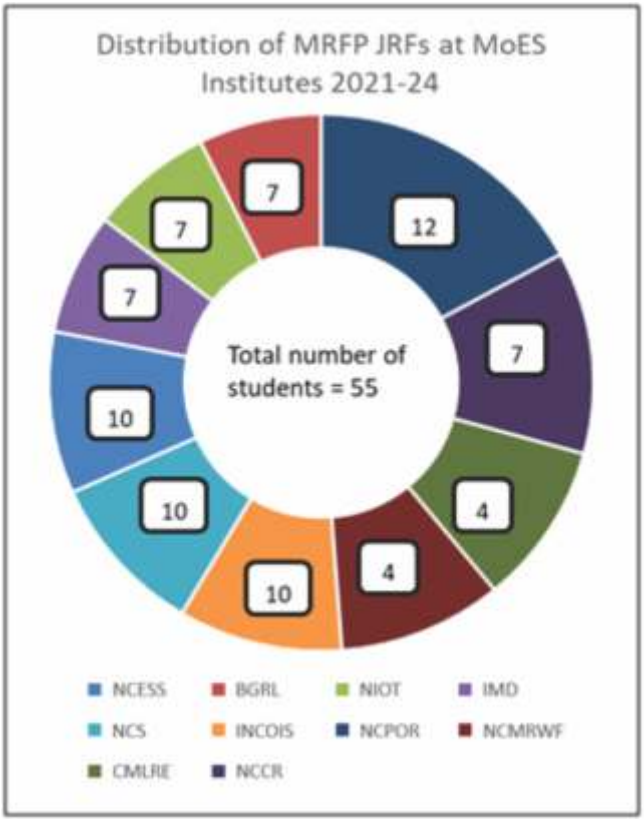


Fig.52: *Number of MRFP students in each institute*

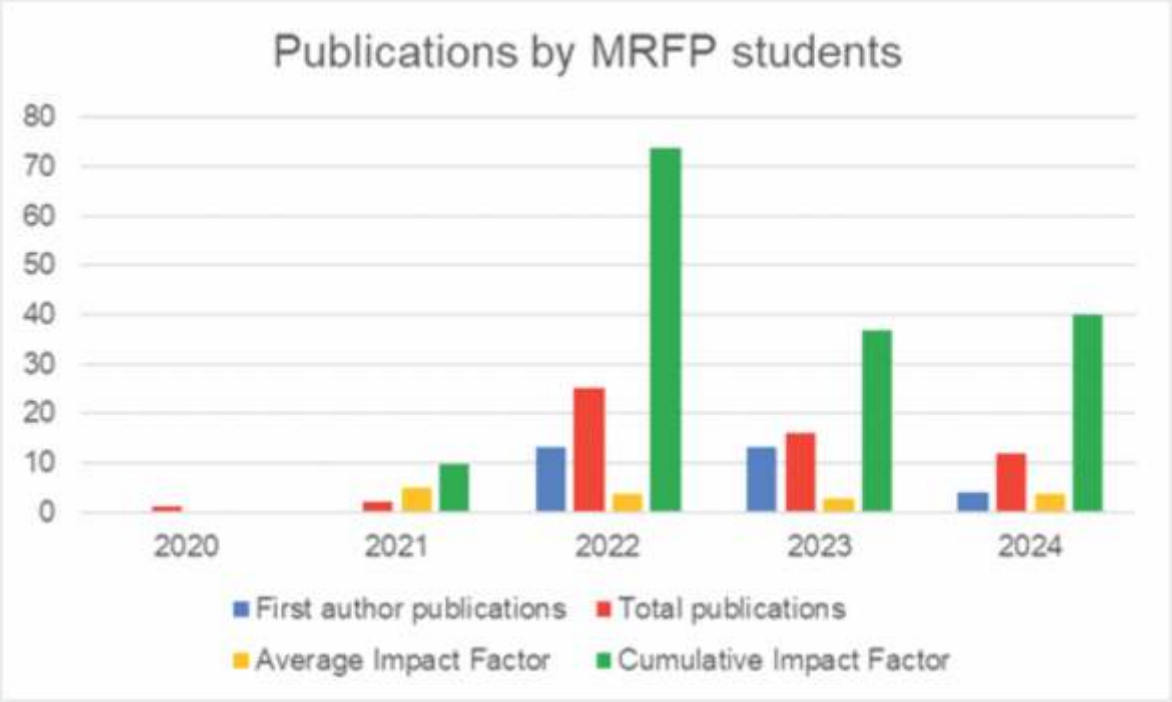


Fig.53*: Performance of MRFP students in terms of publications and Impact Factor*

candidates are publishing papers in high-impact journals; it also shows that they are collaborating in their work as they have a high number of papers other than first-author papers too. The total number of publications so far from MRFP candidates is 59.

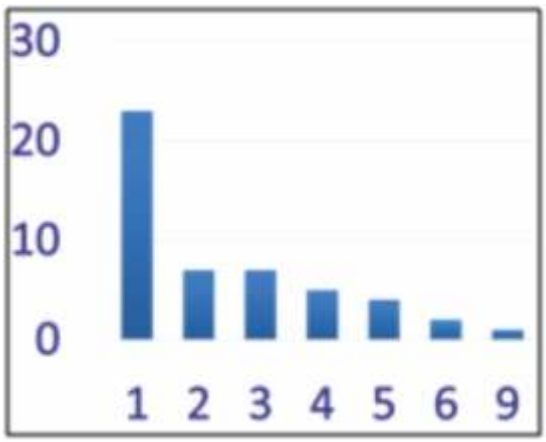


***Fig.54**: Number of publications vs authorship for MRFP students*

The students have actively participated in conferences and workshops. 94 workshops have been attended in person and 81 have been attended online cumulatively by MRFP candidates.

DESK has conducted various training programs and talks in 2023-24 with help of the Library, Information and Publication Division (LIP) and Computer Division.

MoES webinars and short-term training programmes organized.

- 2nd Training workshop of Indian Air Force (IAF) Officers during 3-7 October 2023.
- National Training workshop on Climate impacts of carbonaceous aerosols and measurements (NT-CCAM), 04-07 December 2023 (43 participants)
- Comprehensive one-week hands-on Weather Research and Forecasting (WRF) training program, 11-15 March 2024
- Several special lectures and seminars on different topics, and virtual talks under the Cloud and Precipitation Physics and Dynamics lectures series**, National Atmospheric Chemistry Seminar Series NACSS (introduced in February 2023- Monthly Seminar series),** Prof. R. Ananthakrishnan Seminars/Colloquium, lectures and talks by invited speakers were organized. Details are available in the chapter on Seminars. All the videos are available for the public online through IITM YouTube channel.

Basic Research

A contrast in biennial variability of rainfall between central India and the Western Ghats and its mechanisms:

The Western Ghats (WG) of Peninsular India, an integral part of the Indian summer monsoon rainfall, receives three times the average of all India rainfall. The averaged rainfall over WG is characterized by an intense tropospheric biennial oscillation (TBO) of 2–3 years of periodicity. The rainfall anomalies over WG are almost uncorrelated to rainfall over Central India (CI) in the TBO window. This study characterizes the WG and CI biennial rainfall variability and their governing mechanisms using observation and reanalysis datasets for 1980–2020. A zonally symmetric build-up of heat anomalies from the Iranian Plateau (IP) to the Tibetan Plateau (TP) extending from the surface to the mid-troposphere governs the TBO rainfall of CI. On the other hand, localized heating (cooling) over the IP and Pak-Afghanistan region (PA) and cooling (heating) over the TP governs the phases of TBO rainfall over WG. An increase (decrease) in anomalous heat build-up in the vertical column causes an increase (decrease) in anomalous moist static energy during positive (negative) WG TBO years extending over the IP (TP) region. Increased heating (cooling) over the IP and PA (TP) during positive WG TBO years can shift the center of near-surface cyclonic circulation, anchored over the Indian subcontinent and surrounding areas during the positive CI TBO years, to move westward. This shift in rainfall anomalies and the center of cyclonic circulation is because of the westward shift in anomalous moisture convergence from CI and significant moisture loss along southeastern Peninsular India. Considering the growing number of extreme rainfall events over the WG regions recently, the present work is an attempt to understand the mechanism through which TBO modulates WG and CI rainfall. ***(Arora Anika, Valsala V., Pillai P.A.,*** *A contrast in biennial variability of rainfall between central*

India and the Western Ghats and its mechanisms, ***Dynamics of Atmospheres and Oceans****, 103: 101383, September 2023, DOI:10.1016/j.dynatmoce.2023. 101383, 1-18)*

Revisiting the effect of increasing horizontal resolution on the evolution of El Niño in a coupled model

The ENSO (El Niño southern oscillation) in the tropical Pacific plays a crucial role in regulating the Indian summer monsoon. Many mechanisms have been proposed to explain the positive and negative feedback associated with the ENSO through air-sea interaction in the tropical Pacific. Historical run data at varying oceanic and atmospheric resolutions from the MPI-ESM model is analyzed and compared with observations to determine the possible reasons for the much earlier onset and delayed withdrawal of ENSO in the coupled model. Increasing the resolution of the oceanic and atmospheric components of the coupled model helps in well-resolving the annual cycle of sea surface temperature in the tropical Pacific. There is a significant improvement in the early onset and late withdrawal of El Niño in the coupled model with increasing horizontal resolution of the model components. The weak subsurface propagation along the 20 °C isotherm in the equatorial Pacific improves on increasing the horizontal resolution of the coupled model. Similar to observations, there is a clear eastward extension of convection, 20° east of the dateline, in the equatorial tropical Pacific in the coupled model during ENSO years. Increasing the resolution of the oceanic and atmospheric components of the coupled model improves the simulation of convective activity over the western Pacific along with the improved magnitude of anomalous zonal wind strength during El Niño years. However, the presentation of convective activity over the equatorial Pacific deteriorated on increasing atmospheric resolution further to T255 due to the enhanced value of the interannual amplitude of intraseasonal zonal wind around the international dateline. Also, the coupled model does not capture the accurate eastward propagation of the Madden Julian Oscillation envelope over the western Pacific. While higher resolutions showed improvement in the representation of El Niño events in terms of their number and duration, challenges persisted in accurately capturing the frequency of these events and their related triggering mechanisms. Understanding the intricate interplay of factors influencing the evolution of El Niño requires further research and progress in modeling strategies. *(**Arora A.**, Revisiting the effect of increasing horizontal resolution on the evolution of El Niño in a coupled model,* ***Global and Planetary Change,*** *230: 104256, November 2023, DOI:10.1016/j.gloplacha.2023.104256, 1-18)*

First International Summer School on Marine Heatwaves

A key component of the summer school was the introduction of an innovative approach called SDA2 (Skill Development, Awareness, and Application). This framework was designed to help ECSs build long-term and productive collaborations, both among themselves and with their mentors. This article published in BAMS provided an overview of the themes addressed during the summer school, the SDA2 approach, and the benefits and insights gained by the participants.

In response to the growing awareness of marine heatwaves (MHWs) and their impacts, the international Climate Variability and Predictability (CLIVAR) program and the International Centre for Theoretical Physics (ICTP) in Italy, with support from the World Climate Research Programme (WCRP), U.S.-CLIVAR, and U.S. agencies NASA, NOAA, and NSF, organized the Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts. The primary goal of the summer school was to share the latest understanding of the mechanisms, predictability, and impacts of MHWs, and to provide practical tools and training for early career scientists (ECSs), particularly from under-resourced countries, to enhance their ability to detect and predict these events.*(**Singh, S.,** J. Sprintall, A. Capotondi, and R. Rodrigues, First International Summer School on Marine Heatwaves,* ***Bulletin of the American Meteorological Society,*** *2024, 105, E742–E748,* https://doi.org/10.1175/BAMS-D-23-0288.1 (Summary of Event)

3.2. Academic Cell

Chairman: Dr. Shivsai A. Dixit

Objectives

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

M.Tech. (Atmospheric and Space Sciences) programme

M.Tech. (Atmospheric and Space Sciences) is a joint academic programme of IITM and the Department of Atmospheric and Space Sciences (DASS) of S.P. Pune University (SPPU), Pune. Five (05) students were admitted to this programme for the academic session 2023-25. Their classes were conducted at DASS, SPPU. The 2nd year students (03) of the M.Tech. 2022-24 batch are doing their project work at IITM.

M.Sc. (Atmospheric and Space Sciences) programme

Under this IITM and Department of Atmospheric and Space Science (DASS) of S.P. Pune University (SPPU), Pune collaborative M.Sc. (Atmospheric Science) Programme,11students were admitted for the academic session 2023-25. The M.Sc. second-year students (07) of the batch 2022-24 are doing their project work at IITM and DASS, SPPU.

IITM JRF batch 2023-24: A total of 08 candidates joined as IITM Junior Research Fellows at IITM. 03 candidates joined as AcSIR PhD students at IITM. Currently, they are doing their coursework at IITM (Semester I; September 2023 - February 2024). Details of Semester-I core coursesare as below:

Semester-I Core Courses		
No.	**Core Subject**	**Faculty**
C1	Dynamics of Atmosphere & Ocean	Dr. Ramesh Vellore, Dr. Jasti Chowdhury and Dr. Bhupendra B.S.
C2	Physics & Chemistry of the Atmosphere	Dr. Gaurav Govardhan, Dr. Anoop S. Mahajan and Dr. Siddharth Kumar
C3	General Circulation of Atmosphere	Dr. Sabin T.P. and Dr. Prasanth Pillai
C4	Mathematics and Statistics	Dr. Shivsai Dixit, Dr. Shikha Singh and Dr. Siddharth Kumar
C5	Observational Methods for Atmosphere & Ocean	Dr. Ananth Parekh, Dr. Madhuchandra Reddy, Dr. Naveen Gandhi and Dr. Yogesh Tiwari

(Semester II from March 2024 to July 2024) Details of Semester-II courses are as below:

No.	**Core Subject**	**Faculty**
C6	Data Analyses and Advanced Computing	Dr. Phani, Dr. Malay Ganai, Dr. Snehalata Tirkey and Dr. Madhusudan Ingle
C7	Science communication	Dr. Anoop S. Mahajan, Dr. Chaitri Roy and Shri. Mriganka Biswas
E1B	NWP and Modelling	Dr. Sahadat Sarkar
E1E	Satellite Meteorology	Shri. M. Mahakur

PhD Degree Awarded by Different Universities/Institutes during 2023-24:

S. No.	Student	Guide and Co-guide	Name of University	Thesis Title
1	Mr. Boragapu Raja	Dr. Maheskumar R.S. and Dr. Padma Kumari B.	SPPU	Aerosol impact on the regional scale aspects of South Asian monsoon and its variability
2	Ms. Thomas Lois	Dr. Bipin Kumar	SPPU	Numerical studies of turbulence impacts on growth of cloud droplets
3	Mr. Sarkar Sahadat	Dr. Mukhopadhyay P., Dr. Dutta S. and Dr. Pandithurai G.	SPPU	Study of cloud and convective processes associated with different phases of intra seasonal oscillation using observations and General Circulation Model
4	Mr. Mandal Raju	Dr. Joseph Susmitha and Dr. Sahai A.K.	SPPU	Development of Extended Range Prediction strategy of extreme temperature events over Indian region for societal benefits
5	Ms. Sneha Sunil	Dr. Padma Kumari B. and Dr. Naidu C.V.	Andhra University, Visakhapatnam	Study of Cloud Properties and their Radiative Effects: Implications to Climate System
6	Mr. Narayanasetti Sandeep	Dr. Panickal Swapna and Dr. Krishnan R.	SPPU	Teleconnections of the North Atlantic with the Asian monsoon in a warming climate
7	Ms. Roy Chaitri	Dr. Fadnavis Suvarna and Dr. Krishnan R.	SPPU	Variability of ozone and its precursors in the upper troposphere and lower stratosphere (UTLS) over the Asian region
8	Mr. Singh Bhupendra Bahadur	Dr. Srivastava Manoj K., Dr. Krishnan R. and Dr. Vellore Ramesh	Banaras Hindu University	Investigations of Asian summer monsoonal links to water vapor variability in the upper troposphere and lower stratosphere
9	Ms. Nimmya S.S.	Dr. Sengupta Saikat	SPPU	Process Modeling of stable water isotopes during Indian summer monsoon in connection to paleoclimate interpretation
10	Ms. Lekshmi Mudra B.	Dr. Sabin T.P. and Dr. Krishnan R.	SPPU	Monsoon prediction response over the Indus Valley to mid-Holocene forcing

S. No.	Student	Guide and Co-guide	Name of University	Thesis Title
11	Mr. Pradhan Maheswar	Dr. Bala-subramanian Sridhar, Dr. Bhattacharya Amitabh, Dr. Rao Suryachandra A.	Indian Institute of Technology Bombay, Mumbai	Improving Air-Sea Interaction in Couples Models
12	Prajeesh A.G.	Dr. Krishnan R., Dr. Panickal Swapna	SPPU	Indian ocean dipole variations in a warning climate and associated linkages to monsoon and marine primary productivity

PhD Theses Submitted to Different Universities during 2023-24:

S. No.	Name of PhD Student	Guide	Name of Univ.	Title
1	Mr. Abirlal Metya	Dr. S. Chakraborty and Dr. Yogesh K. Tiwari	SPPU	Source-sink characterization of carbon dioxide and methane in urban and natural environments of India based on their concentration and isotopic time series
2	Mr. Sagar Vinod Gade	Dr. Sreenivas Pentakota and Dr. Suryachandra A. Rao	SPPU	Impact of Coupled Ocean-Atmospheric Data Assimilation on Seasonal Prediction of Monsoon
3	Mrs Sreyashi Debnath	Dr. Sachin Ghude	SPPU	Understanding atmospheric chemistry-climate interaction over the Indian sub-continent
4	Mr. Sunil Sonbawne	Dr. G. Pandithurai, Dr. Suvarna Fadnavis and Dr. Abhilash S. Panicker	SPPU	Impact of Coupled Ocean-Atmospheric Data Assimilation on Seasonal Prediction of Monsoon
5	Ms. Pallavi S. Buchunde	Dr. P.D. Safai, Dr. Devendraa Siingh and Dr. G. Pandithurai	SPPU	Carbonaceous aerosols over a high altitude location: Temporal variation and the formation ofnew particles and associated cloud condensation nuclei
7	Mr. Prithviraj Mali	Dr. Anoop S. Mahajan	SPPU	Retrieval of aerosol and trace gas vertical profiles using multi-axis differential optical absorption spectroscopy (MAX-DOAS) observations

Research Guidance to Students for Project Work

IITM is committed to offering its expertise in Weather and Climate Sciences and extending its state-of-the-art facilities to aspirants seeking knowledge or a career and hands-on experience in these areas of expertise. Therefore, IITM generously admits meritorious undergraduate (UG) and post-graduate (PG) students for their internship/project work. During the year 2023-24, 57 studentsof different UG/PG courses in science and engineering from various colleges, universities and institutions across the country have completed or are working on their short-term/long term project/ internship under the guidance of IITM scientists through remote/online or on-campus mode.

04. Important Events and Activities

- **Visit of HMoES (Hon'ble Minister of Earth Sciences)**: Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, along with Dr. M. Ravichandran, Secretary, MoES, visited IITM on 15 July 2023,. Shri Rijiju toured several R&D facilities and laboratories, interacted with scientists and research scholars, and reviewed ongoing projects. Dr. R. Krishnan, Director, IITM presented the Institute's scientific and outreach activities. During the visit, two MoUs were signed with Tezpur University and Aryabhatta Research Institute of Observational Sciences (ARIES) for the Metflux Project of CCCR. Shri Rijiju and Dr. Ravichandran also released the latest issue of IITM's in-house Rajbhasha magazine, 'Indradhanush.

- **CAIPEEX Report Released by HMoES**: On the 17th Foundation Day of the Ministry of Earth Sciences (27 July 2023), Shri Kiren Rijiju Hon'ble Minister of MoES released the CAIPEEX report, titled "Cloud Aerosol and Precipitation Enhancement Experiment CAIPEEX Cloud Seeding Experiment Results and Recommendations." This report details the outcomes of the CAIPEEX-IV experiment conducted in Solapur, Maharashtra, showcasing the feasibility and effectiveness of cloud seeding as a strategy to enhance rainfall under suitable conditions. The Report is available on IITM website (https://tropmet.res.in/399-news_details).

- **ICRC-CORDEX 2023 Conference**: The International Conference on Regional Climate – Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX 2023) was jointly organized by the Centre for Climate Change Research at IITM, Pune the Ministry of Earth Sciences, the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy, the Swedish Meteorological and Hydrological Institute (SMHI), and the World Climate Research Program (WCRP). Conference was held in hybrid mode from 25-29 September 2023, with physical hubs in Pune, India, and Trieste, Italy, the conference covered various topics from scientific discussions to user impacts and applications, aiming to connect climate science with solutions. Dr. M. Ravichandran, MoES Secretary, Dr. Kamaljit Ray, MoES Advisor, and Dr. M. Mohapatra, DGM, India Meteorological Department, were the Chief Guests. The conference had 67 offline and 36 online participants and included an extraordinary session titled "Leveraging Climate Research and Modeling for Action in the Indo-Pacific region."

- **S20 Extended Discussions and Symposium**: IITM hosted the S20 Extended Discussions and Symposium on "Fostering Science, Technology, and Innovation Ecosystem for Sustainable Development," on 03 October 2023, organized by Vidnyan Bharati Pune in association with the Indian National Science Academy (INSA) and IITM.

- **Visit of HMoES (Hon'ble Minister of Earth Sciences)**: Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, visited the High Altitude Cloud Physics Laboratory (HACPL) at Mahabaleshwar on 05 October 2023. The visit included lab tours, interactions with scientists, a selfie point, a felicitation program for safai karmacharis, and a tree plantation drive as part of Special Campaign 3.0.

- **Swachhta Hi Seva:** Special Campaign 3.0: IITM conducted various activities under Swachhta Abhiyan, including the "Swachhta Hi Seva - Ek Tarikh Ek Ghanta" drive, Swachhanjali Programs, a Swachhta pledge, lawn development, beautification, tree plantation, and more such activities during October 2023.

- **IITM 62nd Foundation Day Celebrations**: IITM celebrated its 62nd Foundation Day on 17 November 2023 in a befitting manner. Shri Nilesh M. Desai, Director, Space Application Centre (SAC), Ahmedabad, was the Chief Guest, and

Prof. Janardhan Padmanabhan, INSA Senior Scientist, Physical Research Laboratory, Ahmedabad, and Prof. Trenton Franz, Associate Professor at the University of Nebraska, Lincoln, USA, were the Guests of Honor. Dr. R. Krishnan, Director, IITM In his inaugural address, highlighted the important work being done at the Institute during the year 2023 and the recent achievements in the field of weather and climate research and services to the Nation. Dr. M. Ravichandran, Secretary, MoES, presented the opening address and guided the institute to have an ambitious approach to achieve weather management within the year 2047 during Amrit Kaal (Virtual mode). Shri Nilesh M. Desai presented the foundation Day lecture on "Indian Space Missions for Meteorology and Future Perspective". In inaugural address Prof. Janardhan Padmanabhan, presented a special lecture on "Explosive Solar Events-A Looming Threat to Our Modern Way of Life". Prof. Trenton Franz, Associate Professor at the University of Nebraska, Lincoln, USA, delivered the Foundation Day lecture (Online) on "Revolutionizing Land Surface Soil Water Monitoring: Pioneering a National Scale Operational Network with Cosmic-Ray Neutron Sensors Across India". Best employees awards 2023 were presented for 5 categories viz. Research category, Administrative staff category, Scientific support staff category, Project staff category and for Hindi outstanding contribution: 2023. The celebration concluded with a simple and colourful cultural programme in the evening. Several ex-employees and special invitee, in addition to the existing employees and their families, attended the function. Complete program was live streamed via IITM YouTube channel: https://www.youtube.com/watch?v=nivAGxeDaSc

- Presentation of Best Employee Award 2023 in Research category was presented to Dr. B.S. Murthy, Shri. V. Gopalakrishnan, Dr. (Smt) Padma Kumari, Dr. H.S. Chaudhari, Shri P. Murguvel, Dr. M. N. Patil, Dr. Prashant Pillai, Dr. Sabin T.P. and Dr. (Kum.) Rashmi A. Kakatkar for their outstanding contribution to weather and climate science.
- Presentation of Best Employee Award 2023 in Scientific Support Staff category was presented to Shri Ashish R. Dhakate for the outstanding contribution to monsoon mission activities.
- Presentation of Best Employee Award 2023 in Administrative staff category was presented to Shri Ajit Prasad for the exemplary Administration, Shri Shafi Sayyed for outstanding contribution to Finance Management, Smt. Manini Das for outstanding contribution in Establishment matters and Shri P.P. Vyawahare for outstanding contribution in Hospitality matters.
- Presentation of Best Employee Award 2023 in Project staff category was presented for outstanding contribution to their respective projects to Shri Pamod Kori for Metropolitan Air Quality and Weather Forecasting Services, Shri Yogesh Kolte for Test Bed in Central India, Shri V Anil Kumar for High Altitude Cloud Physic Laboratory, Dr. Faseels S.P for Development of Skilled Manpower in Earth System Sciences, Shri Shivdas Bankar for Cloud Aerosol Interaction and Precipitation Enhancement Experiment, Dr. Radhika Kanse for National Monsoon Mission, Ms. Abida Chowdhry for Thunderstorm Dynamics, Shri Mangesh Goswami for Center for Climate Change Research, Shri Rajmal Jat for Air Quality Early System, Dr. Rajesh P.V. for Climate Variability Prediction and Dr. Buddhi Jangid Prakash for National Monsoon Mission.
- Presentation of Best Employee Award 2023 was presented to Dr. (Smt) Thara Prabhakaran, Dr. P Mukhopadhyay, Dr. Vinu Valsala, Dr. Medha Deshpande, Dr. Rahul Reddy, Shri Yogesh Pawar, Shri Sandeep Gothwal, and Smt. Ashwini Pendharkar for their outstanding contribution in Implementation of Official Language: 2023.

- **National Training Workshop on Climate Impacts of Carbonaceous Aerosols and Measurements (NT-CCAM)**: A workshop focusing on the climate impacts of carbonaceous aerosols and measurement techniques during 4-7 December 2023 was organized at IITM. The workshop included lectures, a field visit to Mahabaleshwar HACPL laboratory, and hands-on training for early career researchers and master students

- **Mini-Workshop on MoES vision document for Amrit Kaal (2047)**: A mini-workshop for preparation of vision document was conducted during 12-14 February, 2024 at IITM, Pune, to discuss and brainstorm about Weather and Climate Science and Services, including observing systems, modelling and prediction systems, services to society, the current status, knowledge gaps, future pathways for improving the accuracy of weather and climate forecasts on different space and time scales, such as the monsoons, tropical atmosphere- ocean coupled phenomena, severe weather and extreme events, air-quality, etc and charting new avenues for research & development, such as Weather Management, Urban Meteorology, Tropical Bio-Meteorology, Applications of Artificial Intelligence and Machine Learning (AI-ML) approaches for hyper-local weather and climate information, etc. Heads of MoES Institutions and several experts participated in the mini-workshop. Prof. Jagadish Shukla, George Mason University, USA, was invited as an expert on Weather and Climate modelling and prediction.

- **Inauguration of "Atmospheric Research Testbed (ART) Facility"**: Shri Kiren Rijiju, Hon'ble Cabinet Minister of Earth Sciences, remotely inaugurated the "Atmospheric Research Testbed (ART) Facility" at Silkheda, Madhya Pradesh on 12 March 2024, marking a milestone in atmospheric research and forecasting in India. The inauguration was live-streamed on IITM's YouTube channel https://www.youtube.com/watch?v=d-MAbIjla1M. A Press Release is made available on IITM website: https://www.tropmet.res.in/other-pdfs/PressRelease_ART_facility-12March2024.pdf.

- **International Women's Day 2024**: IITM celebrated International Women's Day on 7 March 2024, with yoga and meditation sessions, an inaugural address by Dr. R. Krishnan, and a keynote speech by Dr. Kamaljit Ray. The celebration included talks on women's empowerment, the inauguration of an outdoor gymnasium, and a fun fitness activity.

Important Meetings/Events held at/by IITM

- **Indian Air Force (IAF) Officers Training**: IITM conducted 2nd Training workshop of Indian Air Force (IAF) Officers during 3-7 October 2023. Lectures were delivered by IITM scientists on various topics. The participants were taken to Thunderstorm electricity lab, field mill lab, Lightning network lab, HPC, Fluid Dynamics Lab and HACPL, Mahabaleswar Lab and had interaction with IITM scientists.

- The second Scientific Review and Monitoring Committee (SRMC) meeting (Hybrid mode) under Monsoon Mission Phase-III was organized at IITM during 23-24 February 2023.

- WCSSP Annual Science meeting was held on 23 February 2023 at IITM.

- Under Monsoon Mission Phase-III, the third Scientific Review and Monitoring Committee (SRMC) meeting (Hybrid mode) and the second Scientific Steering Committee (SSC) were organized at IITM on 13 March 2023. SRMC and SSC approved eight projects under Monsoon Mission Phase-III and accordingly, the Mission Directorate issued sanction orders.

- Brainstorming meeting on Tropical Biometeorology Program Document Development was held at IITM, Pune on the 12 January 2024. A total 40 people participated in this meeting.

- The IMD-IITM-IMSP meeting was held at IITM, Pune on 16 February 2024, during this meeting, "Bulletin of IMSP (BIMSP)", Vol. 22, No. 4-9 was released at the

hands of Director IITM, President IMS, Chairman IMSP, Managing Editor of BIMSP and other dignitaries.

- **ISMP Annual Monsoon Workshop (AMW) and National Symposium on "Understanding the science of heatwaves under the warming scenario and challenges ahead"** jointly organized by Indian Meteorological Society, Pune Chapter (IMSP), India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and Ocean Society of India (OSI) on 18 March 2024 and 19 March 2024 respectively at IITM.

Science Popularisation Activities

- **World Ocean Day – 2023** was celebrated at IITM, Pune on 8 June 2023. The event was organized by the Ocean Society of India (OSI) Pune Chapter. Dr R. Krishnan, Director of the institute inaugurated the event. An online lecture by Dr. Rajiv Nigam, retired scientist, NIO, Goa and an in-person presentation by Dr. Vinu Valsala, IITM on different facets of oceanography were arranged.
- **Mission LiFE Campaign:** IITM-EIACP (RP-PC) organized various outreach activities under Mission LIFE campaign on different occasions for spreading awareness among students and public for adopting 'Lifestyle for Environment' through informative talks and competitions. Students were also given a certificate and a badge as encouragement for taking the Climate Change Action Pledge.
    - **Earth Day 2023:** Activities for E-waste Reduction, based on Mission LiFE were held at Paradise English Medium School & Jr. College, Narhe, Pune on 24 April 2023.
    - **World Migratory Bird Day 2023** (12 May 2023): National Level Online Drawing Competition for students and the public on the theme of "Water: Sustaining Bird Life" was organized. Around 150+ participants from almost all states of India participated in this competition and shared their views through art.
    - **World Environment Day 2023** (05 June 2023): An online talk on "Good practices of handling and various ways of recycling E-waste" by Mr. Manoj Mehta, Chief Managing Director, Mahalaxmi E Recyclers Pvt. Ltd., Pune, drives viz. E-Waste Collection, Tree Sapling Plantation & Distribution, Display of Mission LiFE posters and drawings made by students were arranged at IITM.
    - **Haryali Saptah/Van Mahostav 2023**: various awareness activities were conducted as part of the environmental protection drive at the Biodiversity Park, Baner Hill, Pune on 7 July 2023. The aim of the event was to spread awareness of Mission LiFE movement and Environmental Protection and Conservation towards sustainable lifestyle for better future.
    - **E-waste Campaign** was held at Panditrao Aagashe Highschool, Pune on 24 July 2023.
    - **Engineer's Day** (15 September 2023): an interaction session on 'Air Pollution" was conducted for final year Civil Engineering students of Indira Engineering College, Wakad, Pune at SAFAR Control room, IITM.
    - **Ozone Day Celebration:** A talk by Dr. B S Murthy, PD-MAQWS followed by a short quiz based on the talk was arranged at Modern College of Arts, Science and Commerce, Ganeshkhind, Pune on 15 September 2023. Competition prizes were distributed to the winners and a Selfie Booth on Mission Life was launched at the college. In the Sad Samvad live telecast by All India Radio (AIR), Pune; interview was condcuted with Ms. Mugdha Kulkarni, Program Officer, IITM-EIACP at Aakashvani, Pune on 16 September 2023
    - **International E-waste Day 2023:** Students of Environment Science, SPPU visited the E-waste Recycling Plant at Mahalaxmi E-waste Recycler, Pune on 12 October 2023 was arranged. Also, value-added products were distributed on "Reduce E-waste" to everyone. Around 50 students and 11 staff

participated in this Campaign. All participants took pledge and captured photos with Selfie Booth.

- **National Pollution Control Day 2023**: An Online Script Writing Competition for Students and common public was conducted on 10 December 2023.
- **Sensitization event on Reduce E-waste**: Sensitization event on E-waste theme under at Maruti Mahadu Sutar Vidhyalaya, Sutarwadi, Pune was organized on 19 December 2023.
- **Mission Llife National Mega Event**: Exhibition of different models and knowledge products of different centres was arranged at India Gate, Delhi, 9-10 February 2024.
- **International Women's Day 2024**: was celebrated on 08 March 2024.
- **International Day of Forests 2024**: Pamphlet on theme "Forests and Innovation: New Solutions for a Better World" was circulated on all social media platforms through online mode on 21 March 2024 to spread awareness on importance of the forest to students, parents, faculties and common public.
- **World Water Day 2024**: A post with the theme "Water for Peace" was issued on 21 March 2024 on all social media platforms to raise awareness about the importance of water.

- **9th India International Science Festival (IISF) 2023**: IITM participated in the Mega Science and Technology Exhibition (Expo), during 17-20 January 2024, Faridabad (Haryana).
- **National Science Day 2024**: IITM celebrated National Science Day on 28 February 2024 at its premises in a befitting manner. On this occasion, an open day was observed for students, the general public and the media persons. Students and other visitors were taken around the institute in groups to see the working of scientific instruments and experimental activities at the institute's various laboratories and to interact with scientists. IITM scientists and researchers demonstrated and explained different aspects of weather and climate sciences to the visitors. An introductory presentation about the institute was also given. Students were also guided about the various career opportunities available in the field.
- **National Science Day Celebrations at GMRT, Narayangaon**: A team of women researchers from IITM participated in the two days Science Expo at the Giant Metrewave Radio Telescope (GMRT) observatory at Narayangaon during 28-29 February 2024. A big stall was set up where IITM's popular scientific exhibits and specimens were displayed for the general public and students. Many schools and college students/faculty and the general public visited the exhibition stall. An effort was made to popularize Atmospheric Sciences and sensitize students opting for a career in the same. The visitors were explained science through exhibits and demonstrations. Institute's publicity material was also distributed among interested students and visitors.
- **World Meteorological Day 2024:** IITM celebrated World Meteorological Day on 22 March 2024 by organizing Special Lecture on "Climate Knowledge for Climate Action" by **Dr. Rupa Kumar Kolli** President, Indian Meteorological Society; Honorary Scientist at International Monsoons Project Office (IMPO), IITM; Former Executive Director, IMPO; Former Chief, World Climate Applications & Services Division, WMO). The lecture was in line with the theme of World Meteorological Day 2024 'At the Frontline of Climate Action'.

Special Days/Weeks Observed

- **World Blood Donor Day:** As part of World Blood Donor Day, following the Health Ministry's instructions, and on the occasion of Azadi Ka Amrit Mahotsav IITM organized a blood donation camp for the Indian Army in association with the Armed Forces Medical College (AFMC), Pune on 12 June 2023.

- **Har Ghar Tiranga - Azadi Ka Amrit Mahotsav**': As a part of 'Har Ghar Tiranga - Azadi Ka Amrit Mahotsav', all employees of IITM recited the National Anthem at Flag Post on 1st Monday of every month, till August 2023.
- **International Day of Yoga**: IITM celebrated 9th International Yoga Day on 21 June 2023 with great enthusiasm.
- **Vigilance Awareness Week** was observed during 30 October - 5 November 2023. Various competitions like essay, poster, online quiz and debate competition were arranged during the week. As a prelude to the Vigilance awareness campaign (16 August to 15 November 2023) and a part of capacity building, trainings on "Purchase Procedure by officials of Purchase Section" on 11 October 2023 and "E-office file management system" by Ms. Nikita Yeole of E-office support team, on 19 October 2023; Shri Hans Pratap, Hindi Officer, IITM on 7 November 2023 gave a talk on "Prevention of Sexual Harassment at the Workplace (POSH) Act". Cyber Security Awareness online quiz was conducted by National Critical Information Infrastructure Protection Centre (NCIIPC) during 20-31 October 2023. On the Concluding function on 03 November 2023, Ambassador Shri. V. Ashok, Indian Foreign Service (IFS), Retired in the rank of Secretary, Government of India delivered a talk on "Say no to corruption; commit to the Nation" and winners of the competitions were felicitated.
- **Khadi Mahotsav**: A stall of Khadi Products was set up at the Institute by Central Bee Research Training Institute (CBRTI), Pune on 30 October 2023. Employees were encouraged to take e-pledge of Khadi Mahotsav to promote Khadi, handloom, handicraft and other local products in spirit of Vocal for Local and for building Atmanirbhar Bharat. Various competitions (quiz, slogan, essay writing, short films etc.) were organized by Khadi and Village Industries Commission on MyGov platform https://www.mygov.in/campaigns/khadi-mahotsav/
- **Constitution Day (Samvidhan Diwas)** was celebrated on 28 November 2023. The Preamble of the constitution of India was read on this day. Employees of the Institute were encouraged to participate in an Online quiz competition on " Bharat: Loktantra ki Janani" at the link https://constitutionquiz.nic.in/. A webinar by **Dr. Ravi Mishra,** Sci-E, NCPOR, Goa was organized on this occasion.
- **National Voters' Day:** On the occasion, all the employees of the Institute took the pledge on 25 January 2024. National Voters Day 2024.
- **75th Republic Day** was celebrated at IITM on 26 January 2024. Director, IITM, Pune hoisted the flag and National Anthem was sung. Director addressed the employees of the institute and felicitated the winners of IITM Sports Meet 2024 held during 8-25 January 2024.
- **Martyrs' Day**: IITM observed two minutes' silence on 30 January 2024 in memory of those who sacrificed their lives during the struggle for India's freedom.
- **Health Check-up Camp** (Wellness Activities) for all the IITM staffs was organized by IITM Recreation Club in association with Sahyadri Hospital from 8-9 February 2024. Also, a Health Talk Session on "How to keep your Heart healthy?" was delivered by Dr. Priya Palimkar, MD (Medicine), DNB (Cardiology), Fellow of the European Society of Cardiology (FESC), Fellowship in the American College of Cardiology (FACC) on 8 February 2024.

Infrastructure Development at IITM

Completed work

- Installation of 72 Meter Tower and porta-cabins including related civil works at Atmospheric Research Test-bed (ART) facility, Silkheda, Sehore, Madhya Pradesh.
- Setting up of a seating arrangement (cubical room) for Metflux project and Thunderstorm Dynamics in calibration lab at RITURANG building.

- Construction of shed for terrace pumps in RITURANG building through CPWD.
- Providing and fixing aluminum sliding windows and storage unit at IITM office building.
- Furnishing carpet flooring in Aryabhatta hall.
- Renovation of LAURUS lab workshop.
- Renovation of the old bus garage to set up drinking water treatment system and water bottles refilling plant at the IITM Office Campus.
- Replacing of Indian water closet by new European water closet in residential quarters at IITM colony.
- Providing and fixing mosquito proof wooden framed shutter for main door, M.S. fabrication work for open balcony and dry balcony for ground floor's Shishir quarter at IITM colony.
- Installation of polycarbonate roof and fabrication work for Day Care center at the IITM colony campus,

Work under progress

- Site preparation works viz. M.S fabricated towers and A.C container resting platforms for installation of radar at four locations in Mumbai through CPWD, Mumbai.
- Development of Horticulture work and its maintenance, construction of road (Phase-1), guest house building, shed for vehicle parking, radio sonde storage & launching platform at ART, Bhopal.

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 35 journals (31 foreign and 04 Indian) with online access to 31 foreign and 4 Indian journals for the year 2023 (costing approx. Rs.43.54 lakhs). Subscription to 21 journals [17 foreign (online access) and 04 Indian] for the year 2024 (costing approx. Rs.20.21 lakhs) has been processed. In addition to these, access to 131 foreign journals published by Elsevier, Nature Publishing Group, 165 journals collection package on 'Earth & Environment Science' by Springer, 12 Journals published by Wiley, 1 journal published by AAAS, and the 'Web of Science' database has been made available under the National Knowledge Resource Consortium through Ministry of Earth Sciences (MoES). Access to 30 journals (12 Indian and 18 foreign) are available either complimentary/free online or against life membership to this institute. Print version of Nine (9) books covering majority of the institute's research areas (costing approx. Rs.0.57 Lakhs) were purchased. Subscribed to the 'Grammarly Premium' software (writing support tool) for the year 2024 (costing Rs. 4.86 lakhs). Online IP based institutional access to (i) Earth and Environment Sciences Package of the e-book resources of Springer for the copyright years 2005-13 (ii) 49 titles of springer (single title model) and (iii) 56 titles of Cambridge e-books are working satisfactorily at IITM. Payments for article processing charges for two (2) papers of the institute's scientists were approx. Rs. 5.13 lakhs.

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

The division is tracking news-clippings on the institute and archiving the same on DSpace (in-house developed institutional repository for news-clippings) and MOES Knowledge Resource Portal. LIP Division is constantly contributing toward further refinement of the MoES-KRCNet portal and enriching the portal by adding IITM contents viz., e-resources, events, etc.

Several User Education sessions were coordinated and conducted online with the help of MoES and different Service Providers for effective utilization of products/ tools under the National Knowledge

Resource Consortium through Ministry of Earth Sciences (MoES) viz., JGate, Web of Science, RemoteXs, Springer and Nature Journals, Elsevier training sessions on Scopus and Science Direct.

The LIP Division has managed and contributed throughout the period towards outreach by highlighting institute's research and development achievements, Rajbhasha, social and other activities of the institute on digital platforms viz., IITM bilingual website (www.tropmet.res.in) and social media sites such as Facebook, Twitter, Instagram (introduced in 2024), MoES Knowledge Resource Portal (MoES KRCNet), Lectures/ videos/ documentaries/ training sessions/ events through IITM YouTube channel. All digital platforms are accessible through dedicated QR codes also.

In addition to this, the Division has designed and developed websites for National & International Events hosted by IITM.

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

The division is involved in the documentation and compilation of various reports including the Annual Reports, Research Advisory Committee (RAC) Report and IITM e-Newsletters (Quarterly).

LIP provides support to DESK and MoES for conducting webinars, and public outreach activities. Notifications of awards, seminars, symposia, conferences, etc. received from other organisations were provided to the scientists of the institute. Centralised technical services like photocopying, photography, video recording, printing, binding, publicity materials such as Posters/ Flyers/ Brochure etc are 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 & World Meteorological Day. The Division also arranged institute's participation in scientific exhibitions of other organisations.

Management

IITM Society

- The Ministry of Earth Sciences, Govt. of India has reconstituted the IITM Society with the Hon'ble Minister, Ministry of Earth Sciences as the ex-officio President and Director, IITM as the ex-officio Member Secretary vide Order No. MoES/27/ 01/2017-Estt dated 16 March 2022. Details of all the new members of the Society are given in the starting pages of this report. A meeting of the IITM Society was held on 8 November 2022.

Governing Body

- As per the Notification No. O.M. No.25/10/2006 dated 19 July 2006 from the President of India, the Indian Institute of Tropical Meteorology (IITM), Pune has been transferred from the Department of Science and Technology (Ministry of Science and Technology) to the Ministry of Earth Sciences, Government of India with effect from 12 July 2006. The Ministry of Earth Sciences, Govt. of India has reconstituted the GC of IITM as the IITM Governing Body (GB) with the Secretary, MoES being the ex-officio Chairperson and Head/In-charge of Administration at IITM as the ex-officio Member-Secretary vide Order No. MoES/27/01/ 2017-Estt dated 16 March 2022. Details of the members of the GB are given in the starting pages of this report. During the year 2023-24, GB had its 106th and 107th meeting on 17 June and 21 November 2023 respectively.
- The Institute maintains close collaboration and interaction with other organisations working in the

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

Research Advisory Committee

- The Governing Council, at its 69th meeting held on 26 December 2003, formed a Research Advisory Committee (RAC) for the Institute, which consists of four scientists from various disciplines of meteorology and atmospheric sciences, one of whom will be one of the scientist members of the Governing Council. The Chairperson is nominated by the Governing Council. The senior most scientist of the Institute is the Member Secretary. The roles and functions of the Research Advisory Committee are (i) to advise and recommend thrust areas and research programs of the Institute and to monitor and evaluate its programs from time to time, (ii) to recommend, in general, the allocation of funds to various activities of the Institute to enable it to achieve academic excellence, (iii) to recommend new areas of research to be undertaken by the Institute, and (iv) to advice upon and recommend the creation of posts for priority areas of research. Consequent to the of the RAC by the MoES vide Order No. MoES/27/01/2017-Estt dated 16 March 2022, Dr. L.S. Rathore, Former DG, IMD, is the Chairperson of the RAC. Details of the members of RAC are given in the starting pages of this report. The 18th meeting of the Research Advisory Committee for the year 2023-24 was held during 08-09 June 2024 under the Chairmanship of Dr. L. S. Rathore. Director, IITM presented about the scientific activities of the Institute and scientific presentations on topical scientific issues were also made. RAC members also interacted with scientists and students over poster sessions.

Administration

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

Employment of Ex-servicemen

- Reservation for Ex-servicemen is made at 10% in Group-C posts of the Institute. The Percentage of Ex-Servicemen at the Institute via-a-vis total number of employees in group C is 14%.

Status of SC/ST/OBC/Reservation as on 31 March 2024:

Category	SC	ST	OBC	Total
Research	15	7	32	54
Scientific Support Staff	4	3	3	10
Technical Support Support Staff	2	0	0	2
Isolated Staff	0	0	0	0
Administrative Support Staff	3	4	9	16
MTS	3	2	1	6
Total	**27**	**16**	**45**	**88**

Staff Changes

Appointments: Scientific Staff

- Dr. U.V. Murali Krishna, Scientist-C, 11 April 2023.
- Dr. (Smt) Priya P., Scientist-C, 12 April 2023.
- Ms. Aathira Maria Jose, Senior Scientific Assistant, 25 April 2023.
- Mr. Nandi Priyabrata, Senior Scientific Assistant, 26 April 2023.
- Mr. Sunil Kumar, Senior Scientific Assistant, 28 April 2023.
- Dr. Praveen V. Thekuzhiyil, Scientist-D, 08 May 2023.
- Mr. A.K. Abhishek, Senior Scientific Assistant, 01 May 2023.

Personnel Profile as on 31 March 2024:

Category	Sanctioned	Filled	Vacant
Research Category	164	133	31
Scientific Support Staff	51	13	38
Technical Support Staff	19	2	17
Administrative Staff	53	37	16
Multi Tasking Staff	32	9	23
Total	**319**	**194**	**125**

- Mr. Ropulu Raviteja, Senior Scientific Assistant, 02 May 2023.
- Dr. Umakanth Uppara, Scientist-B, 15 June 2023.
- Dr. Moumita Bhowmik, Scientist-B, 13 June 2023.
- Dr. Jeni Victor N., Scientist-B, 09 June 2023.
- Dr. Rupraj Biswasharma, Scientist-B, 09 June 2023.
- Mr. Harikrishna Devisetty, Scientist-B, 16 June 2023.
- Mr. Sachin Patil, Scientist-B, 09 June 2023.
- Dr. Nellipudi Rao, Scientist-B, 09 June 2023.
- Dr. Saikat Pramanik, Scientist-B, 28 June 2023.
- Ms. Neelam Malap, Scientist-B, 12 June 2023.
- Mr. Manoj Domkawale, Scientist-B, 09 June 2023.
- Dr. Himabindu Hanumanthu, Scientist-B, 16 June 2023.
- Dr. Aravindhavel A., Scientist-B, 09 June 2023.
- Mr. Sandip Prakash Ingle, Scientist-B, 09 June 2023.
- Dr. Nagalakhmi Katru, Scientist-B, 16 June 2023.
- Dr. Sandeep Dnyadeo Wagh, Scientist-B, 09 June 2023.
- Mr. Sreenivas Gaddamidi, Scientist-B, 09 June 2023.
- Dr. Deewan Singh Bisht, Scientist-B, 12 June 2023 (A/N).
- Mr. Vijay Kumar Sagar, Senior Scientific Assistant, 30 August 2023.
- Mr. Arun VS, Senior Scientific Assistant, 08 September 2023

Appointments: Administrative Staff

- Mr. Sainath Chandrakant Ghogare, Upper Division Clerk, 13 April 2023.
- Mr. Sachin Bhimrao Babhale, Upper Division Clerk, 26 April 2023.
- Mr. Samir B. Ambekar, Upper Division Clerk, 12 May 2023.
- Mr. Umesh D. Ghatal, Upper Division Clerk, 15 May 2023.
- Mr. Rajendra Saraf, Upper Division Clerk, 30 June 2023.
- Mr. Venkata Ramesh K., Upper Division Clerk, 03 July 2023.
- Mr. Vishal Popat Sanap, Upper Division Clerk, 09 February 2024.

Appointments: Administrative Staff (On deputation/ absorption basis)

- Mrs. B.N. Naik, Section Officer, 21 August 2023.
- Mr. I.A. Pathan, Section Officer, 21 August 2023.

- Mr. D.E. Shinde, Section Officer, 21 August 2023.
- Mrs. Kavita Bharati, Section Officer, 21 August 2023.

Retirement on Superannuation

- Mrs. S.P. Iyer, Coordinator Grade-V, 30 April 2023.
- Mr. D.K. Trivedi, Scientist -E, 31 July 2023.
- Mr. Saumyendu De, Scientist -E, 31 July 2023.
- Mr. K.D. Barne, Coordinator Grade-V, 31 August 2023.
- Mr. M.S. Waghela, MTS, 31 August 2023.
- Mr. R.S.K. Singh, Scientific Assistant Grade 'C', 30 November 2023.
- Mr. H.K. Trimbake, Technician Grade 'F', 30 November 2023.
- Dr. B.S. Murthy, Scientist-F, 30 November 2023.
- Dr. Mrs. A.A. Deo, Scientist-E, 29 February 2024.

Resignations

- Mr. A.K. Abhishek, Senior Scientific Assistant, 25 July 2023.
- Mr. Ropulu Raviteja, Senior Scientific Assistant, 31 July 2023.

Technical Resignation

- Dr. Deewan Singh Bisht, Junior Scientific Officer Technical, 12 June 2023.
- Dr. Appala Ramu Dandi, Scientist-D, 10 May 2023.
- Dr. Abhay Singh Rajput, Scientist-E, 21 July 2023.

Policy decisions and the activities undertaken for the benefits of persons with disabilities

IITM is increasingly prioritizing accessibility for physically handicapped individuals, ensuring for their mobility and independent functioning, a user friendly environment is created by ensuring hassle free access to building. The institute has created special facilities in each of their building such as ramps, rails, special toilets, elevators and wide doorways to accommodate wheelchairs to suit the special needs of persons with disabilities. Further, a wheel chair has been placed in the entrance of the Institute for the convenience of physically handicapped visitor.

As per Govt of India orders posts are kept reserved for PwBD candidates. At the time of interview special care is taken that they are interviewed in the way they are comfortable i.e in the case of deaf candidate, the questions are written on the black board for easy understanding etc.

Government of India concession as amended from time to time are being implemented.

There is no separate allocation, release and utilization of funds under various schemes for the benefits of persons with disabilities. The benefits to the persons with disabilities (double transport allowance) are absorbed in the core grant budget of the institute. Also, the Income Tax exemption for persons with disabilities is allowed as per extant rules.

The number of beneficiaries with disabilities is 3 and their percentage in relation to the total number of beneficiaries (8) is 37.5%.

Finance

Finance Committee

Finance Committee (FC) constituted by the Governing Council meets twice in a year and reviews the financial performance of the institute and provides guidance for improvement of the performance. Consequent upon the reconstitution of the FC of IITM by the Ministry of Earth Sciences, Govt. of India vide Order No. MoES/27/01/2017-Estt dated 16 March 2022, Financial Adviser, MoES is now the Chairperson (Ex-Officio) of the FC. The Finance Committee held its 44th and 45th meetings on 16 June 2023 and 20 November 2023 respectively.

Budget

The Auditors appointed by the Governing Body M/s. A.R. Sulakhe & Co. conducted the audit for the year 2023-24. The abstract of the report is enclosed at the end of this report.

The grant received and the actual expenditure incurred for the period 2023-24 are as follows (in Crores):

Purchase and Stores

Sr. No.	Schemes	Opening Balance	Funds received	Total Funds available	Cash Expenditure	Closing Balance
A	**ACROSS**					
1	Monsoon Convection Clouds & Climate Change (Mc4)	7.28	90.26	97.54	96.50	1.04
2	High Performance Computer System	1.15	21.60	22.75	16.18	6.57
3	Monsoon Mission Phase III	3.22	3.36	6.58	6.71	-0.13
4	National Facility for Airborne Research (NFAR)	0.12	0.00	0.12	0.07	0.05
	TOTAL (A)	**11.77**	**115.22**	**126.99**	**119.46**	**7.53**
B	**REACHOUT**					
1	DESK	0.18	3.61	3.79	3.59	0.20
	TOTAL (B)	**0.18**	**3.61**	**3.79**	**3.59**	**0.20**
C	**ASSISTANCE TO AUTONOMOUS BODIES**					
1	IITM Operations & Maintenance	3.11	86.17	89.28	88.40	0.88
	TOTAL (C)	**3.11**	**86.17**	**89.28**	**88.40**	**0.88**
D	**SPONSORED PROJECT**	0.86	1.34	2.20	1.12	1.08
	TOTAL (D)	**0.86**	**1.34**	**2.20**	**1.12**	**1.08**
	TOTAL (A+B+C+D)	**15.92**	**206.34**	**222.26**	**212.57**	**9.69**

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

Particulars	Institute Funds	Project Funds	Total
Non-Consumables-Equipment	₹35,43,80,470.80	₹ 4,24,380.00	₹35,48,04,850.80
Dead Stock	₹38,25,562.14	₹ 0.00	₹38,25,562.14
Consumables	₹ 4,95,22,191.62	₹ 0.00	₹ 4,95,22,191.62
Total	**₹ 40,77,28,224.56**	**₹ 4,24,380.00**	**₹ 40,81,52,604.56**

Official Language Implementation

- Under the aegis of NARAKAS, Pune (Office-2) Solo Song Singing Competition was organized at IITM on 21 April 2023, 32 employees from Central Government offices in Pune participated enthusiastically.
- Rajbhasha Seminar Series at IITM:
  - Administrative topic – "Weeding out process", Mr. Y.S. Belgude, 19 May 2023.
  - Earth's atmosphere and role of CAIPEEX", Mr. Abhishek Gupta, 29 May 2023.
  - "Components of Poetry", Mr. Dinesh Kumar Trivedi, 28 July 2023.
  - "LTC Process", Shri Yogesh J. Pawar, 01 December 2023.
  - "Climatology – A Brief Introduction", Dr. Siddharth Kumar, 06 March 2024.
- Rajbhasha workshops at IITM:
  - Hindi Quarterly Report and Unicode Typing, 06 April 2023.
  - Official Language Policy and Implementation, 08 August 2023.
  - Official Language Policy and Use of Simple Hindi in Correspondence, 13 December 2023.
  - Hindi Unicode Typing, 27 December 2023.
  - Official Language Policy and Constitutional Provisions, 21 March 2024.
- The quarterly meetings of the Official Language Implementation Committee were held on 30 June 2023, 30 September 2023, 28 December 2023 and 23 March 2024.
- The In-House magazine of the Institute "Indradhanush" was released by the Minister of Earth Sciences, Honourable Kiren Rijiju ji on 15 July 2023.
- **National Rajbhasha Seminar-2023** was organised at the Institute on 13 September 2023 on the topic "Indian Culture, Literature and Environmental Science" in which 20 speakers from all over the country expressed their views.
- **Hindi Pakhwada-2023** was celebrated in the Institute from 13-27 September 2023. A Hindi Sukti was sent via email on all working days in September 2023 to celebrate Hindi Pakhwada. Various competitions (Essay Writing, Noting and Drafting, Antyakshari, Poetry Recitation, Solo Song-Singing, Quiz) were organised. The closing Ceremony was held on 20 October 2023 and winners of the competitions were announced.
- **World Hindi Day-2024** was organized in the Institute on 10 January 2024. On the occasion two competitions viz. Chitra Vichar Lekhan and Extempore Speech Competition were organized on 05 and 10 January 2024 respectively.
- **IITM participation in Rajbhasha Meetings/ Event**s
  - Half-yearly meeting of Narakas, Pune (Off. - 2), National Chemical Laboratory (NCL), Pune, 28 June 2023.
  - Meeting of Rajbhasha Liaison Officers, Hindi Teaching Scheme, Pune, 28 June 2023.
  - Joint Official Language Scientific Seminar, Agharkar Research Institute, Pune, 19 July 2023.
  - 3rd All India Official Language Conference-2023, Pune, 14-15 September 2023.
  - One day National Hindi-Scientific Seminar, National Centre for Polar and Ocean Research (NCPOR), Goa, 27 September 2023.
  - Joint Regional Official Language Conference-2023, Central and Western Region, Mumbai, 23 November2023.
  - Half-Yearly meeting of Narakas, NCL, Pune, 05 December 2023.

- One-Day Official Language Workshop, Regional Ayurveda Research Institute (RARI), Pune, 19 March 2024.

- Hindi version of the Institute's Annual Report: 2022-23 has been completed.
- The Hindi Pakhwada-2023 report was sent to the Ministry of Earth Sciences.
- "International Women's Day-2024" celebration report of IITM, Pune was translated into Hindi.
- Total seven Rajbhasha Workshops were conducted in the institute for various college Students during 2023-24.
- Books were purchased for the Hindi library during the financial year 2023-24 and the list of the books was uploaded on the Rajbhasha Patal of the Institute's website.

5. HONOURS AND AWARDS

IITM Scientists are listed in the World Online Ranking of Top Scientists in the field of Environmental Sciences given by the Research.com 2023 at the link https://research.com/scientists-rankings/environmental-sciences.

Dr. R. Krishnan

- Member, Joint Scientific Committee (JSC) for the World Climate Research programme, 1 January 2023 to 31 December 2024 (extended for two years).

Dr. Suryachandra Rao

- Co-Chair of CLIVAR/GEWEX Monsoons Panel of WMO.
- Co-Chair of CLIVAR/GEWEX Monsoons Panel (MP) of WCRP this year, in addition to his role in the Working Group on Asian-Australian Monsoons (WG-AAM) of MP.

Dr. C. Gnanaseelan

- Member, Decadal Climate Prediction Project (DCPP) panel of WCRP.

Dr. Thara Prabhakaran

- Member, Programme Advisory Committee (PAC) of the SERB-SURE scheme.
- Member (invitee), Steering Group (SG) of the Integrated Hydrology and Precipitation project of WWRP.
- Invited by The Secretary General of the International Association of Meteorology and Atmospheric Physics IAMAS (https://www.iamas.org/) to lead a group of international scientists to develop the new International Commission on Tropical Meteorology (ICTM) under IAMAS.

Dr. G. Pandithurai

- Associate Editor, the Journal Meteorological Applications, Royal Meteorological Society
- Chairman, Evaluation Committee for measurements and simulations carried out in CARS project "Investigation of Atmospheric Aerosol Physico-Chemical Properties for Laser-based Technologies: Ambient Observations and Numerical Simulation" funded by DRDO, CHESS, Hyderabad.
- Chaired scientific sessions in India Radar Meteorology Conference (iRAD-2024), IIT Indore, 10-12 January 2024.

Dr. Suvarna Fadnavis

- Coordinator, International Workshop on Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX-2024), IITM, Pune
- Editor, the Journal of Atmospheric Chemistry and Physics (ACP).
- Guest of Honour, 2nd International Conference on the Asian Summer Monsoon Anticyclone, SRM Chennai, 11-13 September 2023

Dr. P. Mukhopadhyay

- Coordinator, International Workshop on Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX-2024), IITM, Pune.
- Elected as the Fellow of Indian Academy of Sciences, Bengaluru in 2022 (effective from 2023).
- Member, Working Group on Tropical Meteorology Research of the World Weather Research Programme (WWRP) w.e.f. 20 February 2023.

Dr. Padmakumari

- Member, "Board of Studies in Meteorology & Oceanography Andhra University, Visakhapatnam".
- Member, 'Use of Drones in meteorological and environmental observations and applications' committee constituted by Director-General of Meteorology, New Delhi.

Dr. Anoop Mahajan

- Editor, Atmospheric Chemistry and Physics (ACP) – Journal of EGU (European Geophysical Union).
- Selected as one of the youngest editors for Atmospheric Chemistry and Physics (ACP), an esteemed EGU (European Geophysical Union) journal.

Dr. Sachin Ghude

- Member, Expert Group constituted by Commission for Air Quality Management (CAQM) to examine the suggestions before finalisation of the policy to curb air pollution in Delhi-NCR.
- Member, operationalization of Revised Graded Response Action Plan (GRAP), Commission for Air Quality Management (CAQM).
- LEAD Expert Team Urban Services (ET-US) Working Group on WMO - Regional Association II.

Mr. Somnath Mahapatra

- Awarded "Appreciation and Recognition" by the Indian Meteorological Society Pune Chapter (IMSP), during National Symposium on "Understanding the science of heatwaves under the warming scenario and challenges ahead", organized jointly by IMSP, IITM & IMD at IITM, Pune on 19 March 2024.

Dr. Susmitha Joseph

- Member, Vayumandal Editorial Board.

Dr. Swapna Panickal

- Member, Scientific Steering Committee of Scenario Model Intercomparison Project (ScenarioMIP) of CMIP7, WCRP.
- Member, Sea Level Rise Working Group, WCRP Safe Landing Climates (SLC) Lighthouse Activity.

Dr. Roxy Mathew Koll

- Member, WCRP CLIVAR Scientific Steering Group (SSG), 2023-2036.
- Member, CLIVAR Research Foci group on Marine Heatwaves in the Global Ocean.
- Member, Expert Panel on Global Freshwater Cycle Advisory Board of Schmidt Futures.
- Member, Board of Studies in Atmospheric Sciences, Cochin University of Science and Technology, Kochi, for the period 2024-2027.
- Editor, Ocean-Land-Atmosphere Research (OLAR), an open access journal published by the American Association for the Advancement of Science (AAAS).
- Co-Chair, Science Theme on 'Extreme events and their impacts on ecosystems and human populations' under the Second International Indian Ocean Expedition (IIOE2).
- Chief Guest and Key Resource Person, at the 'Climate Cafe', organized by the Meenachil River and Rain Monitoring Network, Visib Centre, Kodumpidy, Kerala, 1 June 2023.
- Represented the World Climate Research Program (WCRP) CLIVAR, as Directors of the 'ICTP-CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts', the International Centre for Theoretical Physics (ICTP), Trieste, Italy, 24-29 July 2023.
- Panellist, virtual conference on 'Heritage-Based Climate Action' organized by the United Nations International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM), 26 March 2024.

Mrs. Shompa Das

- Member, National Knowledge Resource Consortium NKRC (joint Consortium – CSIR, DST & MOES) and IITM Nodal Officer for Social Media sites of MoES

Mr. S.M.D. Jeelani and **Dr. Phani Murali Krishna**

- Awarded, the Dr. APJ Abdul Kalam HPC Group Award 2023 by Hewlett Packard Enterprise (NYSE: HPE) for efficient deployment, administration & management of the largest HPC system in India.

Dr. Kaustav Chakravarty

- Chaired the Session "Radar Meteorology and Hydrology" at the National Space Science

Symposium (NSSS-2024), Goa University, 26 February – 01 March 2024.

Dr. Sabin T.P. and **Dr. Gaurav Govardhan**

- Awarded, "Associate Fellow of the Indian Meteorological Society" at the IMS workshop for their outstanding contribution in Advancing Atmospheric and Climate.

Dr. Yogesh K. Tiwari

- Member, Steering Committee of the Integrated Global Greenhouse Gas Information System (IG3IS) and invited as an expert on the integrated long-term GHG observations in India.

Dr. Amita Prabhu

- Jury member, Young Polar Scientist Meet (YPSM) Poster Evaluation, National Conference on Polar Sciences (NCPS), National Centre for Polar and Ocean Research (NCPOR), Goa, 16-19 May 2023.

Mr. M. Mahakur

- Member, Executive Council Indian Remote Sensing Society, Pune Chapter.

Dr. Atul Kumar Srivastava

- Member, Ph.D. Advisory Committee of the Department of Environmental Studies, University of Delhi, New Delhi.
- Resource Person, 5-day training Course on "Hydro-meteorological Data Analysis for Climate Change Studies", the National Institute of Hydrology, Roorkee, 20 November 2023.

Mr. Bhupendra Bahadur Singh

- Appointed as Associate Editor of Geophysical Research Letters (GRL) (published by American Geophysical Union (AGU).
- Elected, the Vice-chairman of the Ocean Society of India, Pune Chapter, 17 April 2023.
- Second Prize, self-composed Poetry Recitation competition, half-yearly meeting of Town Official Language Implementation Committee (TOLIC), National Chemical Laboratory (NCL), Pune, 28 June 2023.
- Guest of Honor for the National Conference on "Advancements in Environment, Earth and Atmospheric Research" (AEEAR-2024) organized by the School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, 5 March 2024.

Dr. Shikha Singh

- Represented the World Climate Research Program (WCRP) CLIVAR, as Directors of the 'ICTP-CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts', at the International Centre for Theoretical Physics (ICTP), Trieste, Italy, 24-29 July 2023.

Ms. Aditi Modi

- Council Member, Ocean Society of India (OSI) Pune Chapter, 2023-2025.
- Member, National Decade Coordination Committee (NDCC) with effect from 19 January 2024.

Mrs. Smarati Gupta

- 1st Prize, Essay competition, half-yearly meeting of Town Official Language Implementation Committee (TOLIC), National Chemical Laboratory (NCL), Pune, 28 June 2023.

Dr. Deewan Singh Bisht

- Associate Editor for Springer Nature Journal "Water, air and soil pollution".

Mrs. Rohini Ovhal

- Member, National Knowledge Resource Consortium NKRC (joint Consortium – CSIR, DST & MOES)

Dr. A.K. Sahai

- Bestowed with IMS Fellowship at National Symposium "TROPMET-2023" by Indian Meteorological Society, Birla Auditorium, Jaipur, 22-24 November 2023.

Dr. Ipsita Roy

- Awarded, DST-SERB International Travel Scheme for attending and presenting her research at the XXI-INQUA Congress in Rome, Italy between 13-20 July2023.

Dr. Abhishek Gupta and Dr. Shibani Bhatt

- Received International Travel Scheme (ITS) grant from Science and Engineering Research Board (SERB) and travel support for attending 76th Annual Meeting of the American Physical Society (APS) Division of Fluid Dynamics (APSDFD) Conference, Washington DC, 19-21 November 2023.

Ms. Chandrima Mallik

- Young Scientist Award, National Symposium "TROPMET-2023" for the paper "Seasonal predictability of lightning over the global hotspot regions" by Mallick C., Hazra A., Saha Subodh K., Chaudhari H.S., Pokhrel S., Konwar M., Dutta U., Mohan G.M., Vani K.G., published in Geophysical Research Letters, 49: e2021GL096489, January 2022, DOI:10.1029/2021GL096489.

Ms. Shruti Saini

- First Prize Award, "Student Paper Competition", 6th Conference on India Radar Meteorology (iRAD 2024), Indian Institute of Technology (IIT), Indore, 10-12 January 2024.

Ms. Manisha Tupsoundare

- Third Prize Award, "Student Paper Competition", 6th conference on India Radar Meteorology (iRAD 2024), Indian Institute of Technology (IIT), Indore, 10-12 January 2024.

Ms. Pratibha Gautam

- Dr. S.K. Memorial Young Scientist Award-2024 for third-best paper, National Space Science Symposium, Goa University, 26 February to 01 March 2024.

Mr. Abhijith Raj

- Received the prestigious AGU Paros Fellowship in Instrumentation at American Geophysical Union Annual Meeting (AGU23), San Francisco, California, USA, 11-15 December 2023.

Ms. Pooja Pawar

- Selected as one of the Early Career Researchers (ECRs) from India to attend the Sixth session of the United Nations Environment Assembly (UNEA-6) at the United Nations Environment Programme (UNEP) headquarters in Nairobi, Kenya, from 26 February to 1 March 2024 by the National Environmental Research Council (NERC) South Asian Nitrogen Hub (SANH) with full funding support for her outstanding Ph.D work in 9th International Nitrogen Conference (N2024), 8 February 2024.

Dr. U.V. Murali Krishna

- Best Paper Award on Atmospheric Observations and Technologies (Formerly J. Das Gupta Award) for 2021-22 at National Symposium "TROPMET-2023", Indian Meteorological Society, Birla Auditorium, Jaipur, 22-24 November 2023.

Mr. Abhijeet Gangane

- Best Poster Presentation Award on "Positive Cloud to Ground (CG) lightning in Convective Dust storms over Northern parts of India", National Symposium "TROPMET-2023", Indian Meteorological Society, Birla Auditorium, Jaipur, 22-24 November 2023.

Ms. Archana P. Sagalgile

- Best Oral Presentation Award, National Symposium "TROPMET-2023", Indian Meteorological Society, Birla Auditorium, Jaipur, 22-24 November 2023.

Mr. Anurag Chaudhary

- Third prize, Best Poster Presentation, Annual Monsoon Workshop and National Symposium on Heat waves by Indian Meteorological Society at IITM, Pune, 18-19 March 2024.

6. VISITORS

International

- **Prof. Deepti Singh,** Washington State University (WSU), Vancouver, **USA,** 06 June 2023.
- **Dr. Evgueni Victorovich Poliakov,** Consultant, World Bank and FAO, **USA,** 19 June 2023
- **Mr. Siddhant Kerhalkar,** PhD Scholar, University of Massachusetts, **USA,** 11 July 2023
- **Prof. Mark Mahalingam Baskaran,** Department of Environmental Science and Geology, Wayne State University, Detroit, MI, **USA**, 14 July 2023.
- **Prof. Ralf Toumi,** Co-director, Grantham Institute-Climate Change and Environment, Imperial College, London, **UK**, 25 July 2023
- **Dr. Jothiram Vivekanandan,** Senior Scientist, Earth Observing Laboratory, NCAR, Boulder, Colorado, **USA,** 31 July 2023
- **Dr. Sharmila Sur,** Hydro climate Research Scientist, The Bureau of Meteorology, **Australia,** 05-08 August 2023
- **Ms. Anja Katzenberger,** Doctoral Researcher, Potsdam Institute for Climate Impact Research, **Germany**, 07-15 August 2023.
- **Dr. Nitin Chowdhary,** Researcher, Department of Physical Geography and Ecosystem Science, Lund University, **Sweden**, 08 August 2023
- **Mr. Gautam Martanda,** Institute for Atmospheric Physics Johannes Gutenberg University, **Germany,** 03-05 September 2023.
- **Prof. Toru Terao,** Faculty of Education, Kagawa University, **Japan,** 18 September 2023.
- **Dr. Grisa Mocnik,** Head, Centre for Atmospheric Research, University of Nova Gorica, **Slovenia,** 11 December 2023.
- **Mr. Antonio Rodriguez,** Camel Electronique, **France,** 12 December 2023
- **Dr. Ankur Srivastava,** University of Technology, Sydney, **Australia**, 07-10 January 2024.
- **Ms. Taina Dyckhoff,** First Secretary and Head, Division of Environment at Embassy of Federal Republic of **Germany** at New Delhi, ?? January 2024.
- **Dr. Tani Satyanarayana**, Project Senior Scientist and Coordinator Styria State Hail Mitigation Operations, **Austria,** 15-16 February 2024.
- **Dr. Elizabeth A. DiGangi,** Lightning Scientist, Earth Networks, Gaithersburg, Maryland, **USA**, 29 February 2024
- **Prof. Pinaki Chakraborty,** Okinawa Institute of Science and Technology (OIST), **Japan,** 01 March 2024.
- **Dr. Vivek Mugundhan,** Postdoctoral Fellow, KAUST, **Saudi Arabia,** 21 March 2024.
- **Ms. Monica Rao,** Student, Environmental Science and Management, University of Rhode Island, **USA**, 21 March 2024.
- **Dr. Steven Dobbie,** Associate Professor, University of Leeds, **UK,** 26 March 2024.
- **South African Government Delegates,** 28-31 March 2024 (visited ART Silkheda Bhopal).

National

- **Dr. Kondapalli Niranjan Kumar** and **Dr. Mohana Satyanarayana Thota**, National Centre for Medium Range Weather Forecasting (NCMRWF), 05 April 2023.
- **Dr. Anil Kulkarni,** Research Advisory Committee (RAC) Member, MoES and Distinguished visiting Scientist, IISc Bangalore, 13 April 2023.
- **Dr. Papiya Mandal,** Principal Scientist, CSIR-NEERI, Delhi, 03 May 2023 (visited IITM Delhi Branch Office)

- **Dr. Kaveri Srinivas Venkatesh,** Centre National de la Recherche Scientifique (CNRS), India, 24 May 2023
- **Mr. Alex Mathew,** Campbell Scientific, Delhi, 07 June 2023.
- **MoES Officials,** 09 June 2023.
- **Mr. D. Senthil Pandyan,** Joint Secretary and Chief Vigilance Officer, Ministry of Earth Sciences (MoES), 20 April and 14 June 2023.
- **Dr. Satyajith Ghosh,** FRMetS, School of Earth and Environment, University of Leeds, U.K. School of Mechanical Engineering, VIT, Chennai, 21-26 June 2023.
- **Mr. Parimal Singh**, Project Director, Maharashtra Project on Climate Resilient Agriculture (PoCRA), 7 July 2023.
- **Mr. Kiren Rijiju,** Hon'ble Cabinet Minister of Earth Sciences (MoES) and **Dr. M. Ravichandran,** Secretary, MoES, Govt. of India, 15 July 2023.
- **Dr. Vijay Kanawade,** Assistant Professor, University of Hyderabad, Hyderabad, 17 July 2024 (visited Branch Office).
- **Dr. Sumit Kumar Mishra,** Principal Scientist, CSIR-NPL, Delhi, 21 July 2023 (visited Branch Office).
- **Dr. V. Narayanan,** Director**,** LPSC, ISRO and Colleagues, 25 September 2023.
- **IAF Officers,** 04 October 2023.
- **Mr. Kiren Rijiju,** Hon'ble Cabinet Minister of Earth Sciences (MoES), 05 October 2023 (visited HACPL, Mahabaleshwar).
- **Naval Officers,** School of Naval Oceanology & Meteorology Naval Base, Kochi, 12 October 2023.
- **Mr. Nilesh M. Desai,** Director, Space Application Centre (SAC), Ahmedabad and **Prof. Janardhan Padmanabhan**, INSA Senior Scientist, Physical Research Laboratory (PRL), Ahmedabad, 17 November 2023.
- **Mr. Akshay Singhal**, IISER, Bhopal, 01 December 2023
- **Dr. Bishakhdatta Gayen,** Assistant Professor, CAOS, IISc, Bengaluru, 11-12 December 2023.
- **Mr. Sanjeev Sanyal,** Member, Economic Advisory Council to the Prime Minister (EAC-PM) of India, 16 December 2023.
- **Prof. Ashik Paul,** Head, Institute of Radio Physics and Electronics, University Calcutta, 21 December 2023.
- **Dr. Subhadeep Halder,** Professor, Banaras Hindu University (BHU) Varanasi, 05-08 February 2024.
- **Prof. Deepu Joseph,** Assistant Professor, Nirmalagiri College, Kerala, 17 February 2024 (visited HACPL Mahabaleshwar).
- **Dr. Kamaljit Ray,** Scientist-G & Program Manager, MoES, 20 February 2024.
- **Dr. Bipin Kumar G. Nair,** Professor and Dean, Amrita School of Biotechnology, Amrita Vishwa Vidyapeetham, Kerala, 04 March 2024.
- **Wing Commander Birendra Nepal**, Indian Air Force, 11-13 March 2024. Visited CAIPEEX field station, NBNSCOE, Solapur, 12 March 2024.
- **Dr. Dipankar Sarma** and **Mr. Piyush Bora** delegates of National Workshop, Kaziranga National Park and Tiger Reserve (KNP) visited IITM flux (CCCR-Metflux) tower site, Kaziranga National Park, 13 March 2024.
- **Mr. Sameer Banarjee,** Alumnus of IITB, 18 March 2024.
- **Mr. Vilas Rabde** and **Mr. Makarand Vaidya,** Tech Forum, 28 March 2024.
- **Visitors from Schools/Colleges/Universities**: as part of the science outreach, IITM allows students of different backgrounds to visit the Institute to have a look at R&D facilities and interact with scientists. For this guided tours of IITM are arranged many groups of students and faculty from different schools, colleges and universities visited IITM during the year

7. SEMINARS

By Visitors

Dr. Kaveri Srinivas Venkatesh, Centre National de la Recherche Scientifique (CNRS) India

- Presentation of the French National Centre for Scientific Research, 24 May 2023.

Dr. Satyajith Ghosh, FRMetS, School of Earth and Environment, University of Leeds, U.K. School of Mechanical Engineering, VIT, **U.K.**

- Consciousness of the Built Environment: Averting the 'New Terraforming' in this Era of the Anthropocene through Meteorological Applications, 26 June 2023.

Mr. Siddhant Kerhalkar, PhD Scholar, University of Massachusetts, Dartmouth, **USA**

- Lateral gradients in Diurnal Warm Layers in the Bay of Bengal, 11 July 2023.

Dr. Sharmila Sur, Hydro climate Research Scientist, The Bureau of Meteorology, **Australia**

- Predicting ENSO events and their regional impacts in Australia beyond a year, 07 August 2023.

Ms. Anja Katzenberger, Doctoral Researcher, Potsdam Institute for Climate Impact Research, **Germany**

- Indian summer monsoon under global warming: Updates from the Latest Generation of Climate Models (CMIP6) and an idealized Monsoon Planet, 10 August 2023.

Mr. V. Ashok, Ambassador, Indian Foreign Service (IFS), Retired in the rank of Secretary, Government of India

- Say no to corruption; commit to the Nation, 03 November 2023 (Vigilance Awareness Lecture).

Dr. Grisa Mocnil, Head, Center for Atmospheric Research, University Nova Gorica, **Slovenia**

- In-situ measurements of the aerosol absorption coefficient with the photo-thermal interferometer: standardization, laboratory and field studies of bare and coated soot, 11 December 2023.

Mr. Antonio Fernando Almansa Rodríguez, Cimel Electronique, **France**

- Brief Introduction to the Sun Sky Lunar Photometer & Aerosol Measurement, 12 December 2023.

Dr. Priya Palimkar, MD (Medicine), DNB (Cardiology), Fellow of the European Society of Cardiology (FESC), Fellowship in the American College of Cardiology (FACC)

- How to keep your Heart healthy?, 8 February 2024.

Dr. Elizabeth A. DiGangi, Lightning Scientist at Earth Networks, Gaithersburg, Maryland, **USA**

- Lightning Detection Network, 29 February 2024.

Dr. Rupa Kumar Kolli, President, IMS; Honorary Scientist at IMPO, IITM; Ex-Executive Director, IMPO; Former Chief, World Climate Applications & Services Division, WMO)

- Climate Knowledge for Climate Action, 22 March 2024 (World Meteorological Day Lecture).

By IITM Employees

Dr. Harshita Narkhede, IITM Medical Consultant,

- Awareness of "Sickle Cell Anemia", 19 October 2023.

Mr. Hans Pratap, Hindi Officer

- Prevention of Sexual Harassment at the Workplace (POSH) Act, Vigilance Awareness Week, 07 November 2023.

National Atmospheric Chemistry Seminar Series (NACSS)

Dr. Manish Naja, ARIES, DST, Nainital

- Trace gases over South Asia: Present and Future Scope, 26 April 2023.

Dr. Neeraj Rastogi, Physical Research Laboratory

- Deeper Insights into Sources and Processes Affecting Ambient Carbonaceous Aerosols using Dual Carbon Isotopes, 03 November 2023.

IITM Monsoon Discussion Forum (IMDF)

Dr. P. Mukhopadhyay

- Short range prediction and extreme forecast, 1st Seminar, 03 August 2023.

Dr Avijit Dey

- Extended Range Prediction, 1st Seminar, 03 August 2023.

Dr. Ankur Srivastava

- Seasonal Prediction of 2023 Summer Monsoon, 1st Seminar, 03 August 2023.

Dr. Ramesh Kumar Yadav

- Ocean states during monsoon 2023, 1st Seminar, 03 August 2023.

Prof. R. Ananthakrishnan Seminars/Colloquium

Prof. Mark M. Baskaran, Professor and Chair, Department of Environmental Science and Geology, Wayne State University, Detroit, MI, **USA**

- Radon and its Progeny as Atmospheric Tracers, 14 July 2023.

Prof. Ralf Toumi, Co-Director, Grantham Institute - Climate Change and Environment, Imperial College, London, **UK**

- The Dependence of Tropical Cyclone Pressure Tendency on Size, 25 July 2023.

Dr. Jothiram Vivekanandan, Senior Scientist at Earth Observing Laboratory, NCAR, Boulder, Colorado, **USA**

- Identification of Hydrometeor Particle Types and Estimation of Liquid Water Content from Cloud Radar and Lidar Measurements, 31 July 2023.

Dr. Nitin Chaudhary, Researcher, Department of Physical Geography and Ecosystem Science, Lund University, Lund, **Sweden**

- Modelling peatland carbon dynamics and their influence on the Earth's radiative balance in the past and future climates, 8 August 2023.

Mr. Akshay Singhal, IISER, Bhopal

- A decision-making experiment for impact-based forecasting of extreme hydro-meteorological events, 01 December 2023.

Dr. Bishakhdatta Gayen, Professor, CAOS, IISc

- The dominant role of convection and turbulence in the ocean: a new understanding of the global ocean circulation, 12 December 2023.

Prof. Ashik Paul, Head Institute of Radio Physics and Electronics, University Calcutta

- Features of near-Earth atmosphere as studied using University of Calcutta VHF Radar in the Indian low latitudes, 21 December 2023.

Dr. Ankur Srivastava, Postdoctoral Research Fellow, University of Technology Sydney, Sydney, **Australia**

- nfluence of Orographic Precipitation on Coevolving Landforms and Vegetation in Semi-Arid Ecosystems, 09 January 2024

Prof. Somnath Baidya Roy, IIT-Delhi

- Representing wind farms in weather and climate models: A 20 year journey,11 January 2024

Dr. Tani Satyanarayana, Project Senior Scientist and Coordinator, Styria State Hail Mitigation Operations, **Austria**

- Innovative methodologies for assessing crop hail damage & executing cloud seeding operations to enhance hail mitigation strategies, 16 February 2024.

Prof. Pinaki Chakraborty, Okinawa Institute of Sci. & Technology (OIST), **Japan**

- Surprising thermodynamics of landfalling hurricanes, 01March 2024

Dr. Vivek Mugundhan, Postdoctoral Fellow, KAUST, **Saudi Arabia**

- High-Speed Volumetric Measurements of Turbulent Flow through a Contraction using Lagrangian Particle Tracking Velocimetry, 21 March 2024

Dr. Steven Dobbie, Associate Professor, University of Leeds, **UK**

- Selected recent works on dust outbreaks, flooding, and crop failures, 26 March 2024.

Virtual lecture series on Cloud and Precipitation Physics and Dynamics)

Mr. Gautam Martanda, Institute for Atmospheric Physics Johannes Gutenberg University, **Germany**

- Experimental Studies on Retention of Secondary Organic Aerosol (SOA) Precursors, 05 September 2023.

Seminar on PhD Synopsis

Mrs. Roja Chaluvadi

- Understanding atmospheric chemistry-climate interaction over the Indian sub-continent, 31 August 2023.

Mr. Prithviraj Mali

- Retrieval of aerosol and trace gas vertical profiles using multi-axis differential optical absorption spectroscopy (MAX-DOAS) observations, 31 August 2023.

Mr. Mriganka Sekhar Biswas

- Study of Oxygenated VOCs over India: geographical distribution and atmospheric impacts, 02 November 2023.

Mr. Sreeraj P.

- Mean and Extreme Sea Level Response of the Indian Ocean to Climate Change, 02 November 2023.

Mr. Praveen Kumar

- Development of online modeling framework for carbonaceous fine particulate matter over Indian region, 02 November 2023.

Mr. Emmanuel Rongmie

- Investigation of Physical Processes Leading to the Genesis of Tropical Cyclones over the North Indian Ocean, 27 February 2024.

Seminar on PhD Proposal

Mr. Sankirna Devidas Joge

- Dimethyl sulfide (DMS) emissions and its impact on global climate, 24 May 2023.

Mr. Kethavath Lakshma

- Interannual to Decadal Variability and Predictability of Surface Air Temperature over India, 24 May 2023.

Mr. Shubham Waje

- Role of Stratosphere-Troposphere interaction in the Subseasonal Prediction of the Indian Monsoon, 06 June 2023.

Ms. Priya Kumari

- Characteristics of the Intertropical Convergence Zone (ITCZ) over Indian monsoon domain in a changing climate, 09 June 2023.

Ms. Shruti Saini

- Radar Observations of Convective Storms and their Relationship with Convectively Coupled Waves, 14 June 2023.

Ms. Arya Pisharody

- Investigation of Aerosol-Cloud Interaction using Cloud Residue Measurements and Numerical Modelling, 14 June 2023.

Ms. Priyanka Maraskolhe

- Understanding the relationship between Azores High and Indian summer monsoon on sub-seasonal to decadal time scale, 15 June 2023.

Ms. Shrayasi Samanta

- Polar Ice Melt and its impacts on the Global Climate, 15 June 2023.

Mr. Shubhajyoti Roy

- A study on teleconnection between the upper troposphere-lower stratosphere over Asia and the Arctic region, 16 June 2023.

Mr. Anurag Chaudhary

- Arctic amplification and its impact on the dynamics and thermodynamics of large-scale meridional circulation, 16 June 2023.

Mr. Arindam Das

- Understanding the role of aerosol size and chemistry on CCN activation and cloud microphysics over Western Ghats, India, 19 June 2023.

Mr. Md Kaif

- Monsoon Climate in the Younger Dryas and Holocene warm period: Insights from Paleo-reconstructions and Climate Model Simulations, 19 June 2023.

Mr. Sumit Kumar

- Understanding the drivers of surface radiation budget over urbanized regions in the IndoGangetic Plains in a modeling framework, 20 June 2023.

Lectures Delivered Outside

Dr. R. Krishnan

- Earth's Climate System and Indian Monsoon, World Earth Day, AMITY Global Warming Climate Change Cluster, AMITY University, 22 April 2023.
- Climate Change and the Arctic Sea Ice: Lessons Learned and Future Strategies, SaGAA 7 Conference on 'The Future of Arctic Ice: An Indo-Pacific Connect', New Delhi, 27-28 April 2023.
- Declining Arctic Ice and its implications on the South Asian monsoon in a changing climate, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany, 10 July 2023.
- Monsoon Mission, 17th Foundation Day, Ministry of Earth Sciences (MoES), New Delhi, 27 July 2023.
- Extreme rainfall events over India – Do these point to climate change?, Indian Express (Explained, Live), 29 July 2023 (Online).
- Understanding Regional Monsoon Precipitation Response to Global Climate Change, Indian Aerosol Science and Technology Association (IASTA) Monthly Lecture Series, 31 July 2023.
- Climate Impacts in India, Media Dialogue on Climate Change: Towards COP28 – Equity, Science and Policy, M.S. Swaminathan Research Foundation, Chennai, 04-05 September 2023.
- Understanding the behaviour of the Indian summer monsoon cross-equatorial flow in a warming climate, 3rd International Workshop on Equatorial Plasma Bubbles, Indian Institute of Geomagnetism, Mumbai, 15 September 2023.
- Water Cycle Changes in a Globally Warming Climate, International Conference on Water Security and Climate Adaptation, Indian Institute of Technology (IIT) Madras, Chennai, 04-07 October 2023.
- Earth's Climate System and Indian Monsoon, Defence Institute of Advanced Technology (DIAT), Pune, 08 November 2023.
- Water Cycle Changes in a Globally Warming Climate, Defence Institute of Advanced Technology (DIAT), Pune, 08 November 2023.
- Water Cycle Changes in a Globally Warming Climate, TROPMET-2023, National Symposium on "Changing Dynamics of Arid Region and Impact on Weather and Climate over Indian Subcontinent", Birla Institute of Science and Research, Jaipur, 22-24 November 2023 (Plenary Talk).
- Water Cycle Changes in a Globally Warming Climate, ISG-ISRS National Symposium on 'Exploring the Geospatial Ecosystem, Trends and Innovations', Symbiosis International University Campus, Lavale, Pune, 28-30 November 2023 (Plenary Talk).
- Water Security for Agriculture Sector, National Council for Climate Change Sustainable Development and Public Leadership (NCCSD), Ahmedabad, 22 December 2023.
- Air-Sea Interactions and Climate Models, Intensive Course on Ocean Science and Modelling – Energy-related Environment and Living Resources, CSIR-4PI, Bengaluru, 16-20 January 2024 (Invited Guest Lecture).
- The Changing Indian Ocean and Monsoon Circulations – Challenges and Opportunities. Indian Ocean Conference 2024 (IO Con-2024), INCOIS, Hyderabad, 1-3 February 2024.
- Role of large volcanic eruptions on the ENSO and Indian Monsoon Coupling. Joint Webinar Series IIT Madras, India and PIK, Potsdam, Germany, State-of-

the-art in Complex Systems Theory, 26 February 2024.

- The Changing Indian Ocean and Monsoon Circulations – Challenges and Opportunities, World Ocean Science Congress (WOSC-2024) – Sustainable Utilization of Oceans in Blue Economy, IIT Madras Research Park, 27 – 29 February 2024.
- Earth's Climate System and the Indian Monsoon – Challenges and Opportunities in a Warming World. National Space Science Symposium (NSSS-2024), Goa University, Goa, 26 February – 01 March 2024
- Predictive understanding of extreme precipitation over the Himalayan region under global warming. Workshop on Projection and Mitigation of Mega Geo Disasters Under Changing Climate, Tribhuvan University, Kathmandu, Nepal, 14-15 March 2024 (Keynote Talk).

Dr. Thara Prabhakaran

- Microphysics-dynamics interaction in deep convection: Insights from CAIPEEX observations, Aerosol, Cloud, Precipitation, and Climate (ACPC) Workshop, Texas Southern University, Houston, 17-19 May 2023 (online).

Dr. G. Pandithurai

- How do we observationaly investigate the effect of aerosol on cloud and precipitation, 2nd Aerosol Winter School MANTHAN (Minds on Air quality human health & climate Nexus)-2024, Central University of Jammu, 28 February 2024.
- Size resolved aerosol hygroscopicty measurements and its role on CCN activation, 2nd Aerosol Winter School MANTHAN (Minds on Air quality human health & climate Nexus)-2024, Central University of Jammu, 28 February 2024.

Dr. Suvarna Fadnavis

- Variability of Asian Summer Monsoon Anticyclone (ASAM) and its impacts over South Asia, 2nd International Conference on the Asian Summer Monsoon Anticyclone, SRM University Chennai, 11 September 2023.

Dr. P. Mukhopadhyay

- ·Basics of Meteorology and forecasting models, Training program on Demand and RE forecasting, WRLDC, Grid India, Mumbai, 17 August 2023.
- Role of Physical Parameterization on Model forecast, Applications Oriented WRF Training School, CDAC, Pune, 21 August 2023.
- Development of lightning prediction system over Indian region using regional mesoscale and global model, 2nd International conference on 'Lightning electromagnetics and applications of semiconducting materials (ICLEASM)', SALNET and SAMA, Nepal, 04 October 2023.
- Predication of extreme events and cloud parametrization, Workshop on Cutting edge Research frontiers in Earth System Science in 21st century and on AI/ML applications in Earth system Science, Department of Geophysics, Benaras Hindu University, Varanasi, 16 October 2023.
- The NWP model fidelity of predicting extreme events over India: Latest developments, Symposium on "TRACing moisture sources of extreme rainfall over India – a tool for Better monsoon pRedIction at Synoptic TImescales (TRAC-BRISTI), 23-24 November 2023.
- Challenges of Forecasting Weather Extremes: A combined approach of AI and NWP, IEEE CSS-IMS Chapter, Kolkata, IET Kolkata Local Network, Applied Physics Department, Calcutta University, 12 December 2023.
- Extreme weather forecasting with emphasis to thunderstorm and lightning, Bangabasi College, University of Calcutta, 13 December 2023.
- Convective parameterization deadlock and possibilities to overcome the challenges, Centre for Atmospheric and Oceanic Sciences, IISc, Bengaluru, 07 March 2024.
- Performance of GFS/GEFS forecast (at 12km resolution) and performance of experimental forecast of High resolution global forecast model

(HGFM) at 6.5 km resolution for monsoon 2023, Annual Monsoon Workshop and National Symposium on Understanding the science of heatwaves under the warming scenario and challenges ahead, IITM, Pune, 18 March 2024.

Dr. Vinu Valsala

- Is Amundsen-Bellingshausen Sea Low affecting trace gas air-sea fluxes in the Antarctic Ocean?, National Conference on Polar Sciences (NCPS), NCPOR ,Goa, 19 May 2023.

Dr. Ramesh Vellore

- Climate change and monsoon rainstorms, International Conference on 'Climate Change and Agroecosystems: Threats, Opportunities And Solutions' INAGMET-2024, Banaras Hindu University, Varanasi, 08-10 February 2024.

Dr. Anoop Mahajan

- Changing emissions of climatically sensitive gases in the Polar Regions through the Anthropocene in a conference on Engaging with Polar Regions: Science, Human Ecology and Geopolitics (EPR-2023) ICPS, Mahatma Gandhi University, Kerala, 28 October 2023.

Dr. Sachin Ghude

- AIRWISE: Enhancing Air Quality Management in Megacities - Air Quality Warning and Integrated Decision Support System for Emissions, India Clean Air Summit Bengaluru (ICAS), 24 August 2023.
- Applications of WRF: Air Quality, C-DAC, Pune, 25 August 2023.

Dr. Milind Mujumdar

- Agrometeorology in strengthening agricultural adaptation :Field-scale soil moisture monitoring, US-India Climate Action And Finance Mobilization Dialogue (CAFMD), Adaptation and Resilience Pillar, Adaptation and Resilience Pillar, Virtiual Roundtable, 27 April 2023.
- Importance of field-scale soil moisture monitoring for Agro-Hydrological system, National Training Program on Concept of Agro-meteorology and Crop Weather Models, Mahatma Phule Krushi Vidyapeeth, Department of Agricultural Meteorology Pune, 01 December 2023.
- Tech-scientific aspects of climate change, Training programme on 'Building Local Resilience in a Changing Climate' for Women Scientists & Technologists working in the Government sector, Lal Bahadur Shastri National Academy of Administration, Mussoorie, 28 February 2024.

Dr. Swapna Panickal

- Glacier Melting and Sea Level Rise, SAGHAA 7 conference, Delhi during 27-28 April 2023.
- Extreme Sea Level Rise along Indian Ocean Coastline, Japan Geoscience Union Meeting 2023, 23 May 2023 (online).
- Climate Change and the Changing Water Cycle: Perspectives for Kerala, Keraleeyam, Government of Kerala, J.M. Stadium, Thiruvananthapuram, Kerala, 5 November 2023.

Dr. Roxy Mathew Koll

- Compound Coastal Floods in a Changing Climate, National Workshop on Rising Impacts of Climate Change and Coastal Ecosystem Responses, National Institute of Oceanography, Kochi, 6 April 2023 (online).
- The Indian Ocean Observing System COVID impacts and the way forward, National Science Workshop on Indian Ocean Biogeochemistry, Centre for Marine Living Resources & Ecology (CMLRE), Kochi, 27 April 2023.
- The dominance of climate change on global circulations and its impact on heatwaves and marine heatwaves, National Workshop on Heatwaves, climate change and its impacts on health, economy and energy policies of India, Climate Trends, Bangalore, 28 April 2023.
- Climate Change Challenges and Opportunities (inaugural lecture as the Chief Guest and Key Resource Person), Climate Cafe, Meenachil River and

Rain Monitoring Network, Visib Centre, Kodumpidy, Kerala, 01 June 2023.

- Climate Proofing Coastal Cities - Challenges and Way Forward (inaugural lecture), G20 Global Coastal Cities Summit, A global conversation on Climate solutions for Coastal Cities, Mumbai First, Taj Mahal Palace Hotel, Mumbai, 02 June 2023.
- The Impact of Marine Heatwaves on the Atmosphere, ICTP-CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts, International Centre for Theoretical Physics (ICTP), Trieste, Italy, 26 July 2023.
- Climate Proofing Mumbai - Challenges and Way Forward, Roundtable Meeting with the German Minister of Culture and Media, Claudia Roth, Mumbai First, Taj Mahal Palace Hotel, Mumbai, 23 August 2023.
- Marine heatwave research in IITM, WCSSP India Forum on coupled process interactions, UK Met Office, 23 November 2023.
- Compound Climate Extremes in the Indian Ocean Region, CORDEX Southeast Asia workshop, representing WCRP/MCR Indo-Pacific hub at IITM, 23 November 2023.
- Heatwaves over India, NDMA Brainstorming Workshop on Heatwave, National Disaster Management Authority, 09 January 2024 (online).
- Heatwaves over India - Observed changes, future projections, and compound risks at the National Heatwave Workshop, National Disaster Management Authority, Vigyan Bhawan, New Delhi, 13 February 2024.
- Introduction on climate change and what are its impacts on human settlements, Climate-Culture Nexus Course, United Nations International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM), 19 February 2024 (online).
- El Niño-Southern Oscillation (ENSO), ocean warming, and the monsoon, South Asia Forecasters Forum, Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), 22 February 2024 (online).
- Monsoons, marine heating and other changes, Anil Agarwal Dialogue 2024, Centre for Science and Environment (CSE), 28 February 2024 (online).
- Extreme events and their impacts on ecosystems and human populations, IIOE-2 International Steering Committee meeting, International Indian Ocean Science Conference 2024, Indonesia, 05 March 2024.
- Coordinated Early Career Researcher activities in the Indian Ocean region, Indian Ocean Region Panel meeting, International Indian Ocean Science Conference 2024, Indonesia, 06 March 2024.
- Marine Heatwaves, Tropical Cyclones, and Terrestrial Heat Waves Cascading in a Changing Climate, National Symposium on Understanding the science of heatwaves under the warming scenario and challenges ahead, IITM, Pune, 19 March 2024.

Dr. Bipin Kumar

- Utilization of AI/ML algorithms in Atmosphere and Ocean science, IISER, Pune, 5 April 2023.
- Role of Direct Numerical Simulation (DNS) in understanding small scale cloud processes, IIT Delhi, 29 August 2023.
- Utilization of AI algorithms in Atmosphere science, International Conference & Symposium on AI Advancement in Hyperbolic PDEs (ICS-AIPDEs23), Department of Mathematical Sciences, UNIST, South Korea, 20-22 October 2023.
- Real-Time Pollution Estimation and Traffic Monitoring using Deep-Learning algorithm, TROPMET-2023, National Symposium on "Changing Dynamics of Arid Region and Impact on Weather and Climate over Indian Subcontinent", Birla Institute of Science and Research, Jaipur, 22-24 November 2023 (lead talk).
- Application of AI algorithms for Understanding and Predicting the Atmosphere and Ocean processes, Conference on Advances in Fluid Solid Interactions

using AI/ML with special reference to numerical weather prediction and smart farming using IoT, IIT Dhanbad, 12-16 February 2024.

- Deep Neural Networks as a Dynamic Alternative to Linear Interpolation, Conference on Advances in Fluid Solid Interactions using AI/ML with special reference to numerical weather prediction and smart farming using IoT, IIT Dhanbad, 12-16 February 2024.
- Small Scale Numerical Simulation to Understand Droplet and Aerosol Dynamics, Conference on Advances in Fluid Solid Interactions using AI/ML with special reference to numerical weather prediction and smart farming using IoT, IIT Dhanbad, 12-16 February 2024.
- AI Methods for Understanding and Predicting Monsoon and Other Atmosphere Processes, NSM Brainstorming meeting, CDAC Delhi, 23 February 2024.
- Benchmarking turbulence models to represent entrainment processes in warm clouds, 5th International Workshop on Cloud Turbulence, Nagoya Institute of Technology, Japan, 14 -15 March 2024.

Dr. Kaustav Chakravarty

- Unravelling the contrasting features of clouds and precipitation for the extreme weather events over the urban coastal city of Mumbai, International Conference CODEC-2023, Department of Radio Physics and Electronics, University of Calcutta, Kolkata, 14-16 December 2023.

Dr. Yogesh K. Tiwari

- Earth Climate System and Carbon-Climate Nexus in India", in a Earth day celebration event organized by Centre for Research in Environment, Sustainability Advocacy and Climate Change, SRM University, Chennai, 22 April 2023.
- GHG observation and modelling activities at IITM Pune, a joint meeting, ISRO-SAC Ahmedabad, 18 October 2023.

Dr. Jasti Chowdary

- Triple-dip La Niña contributes to Pakistan-northwest India flooding and southern China drought in summer 2022, Global Ocean Summit 2023, Qingdao, China, 25-27 September 2023.

Dr. Sabin T.P.

- Climate Change, Climate Modeling, and Sustainability, Maharashtra State Faculty Development Academy (MSFDA), Pune, 09 January 2024.
- Science of Climate Modeling, UGC-MMTTC Refresher Course on Climate Change and Human Health, KBCAOS, University of Allahabad, 19 January 2024.

Dr. Amita Prabhu

- Potential linkages of Greenland Sea ice and Arctic oscillation on the South and East Asian summer Monsoon in the recent, National Conference on Polar Sciences (NCPS), National Centre for Polar and Ocean Research (NCPOR), Goa 16-19 May 2023, 17 May 2023.
- ''How does Arctic Oscillation, Eurasian Snow and Atlantic SSTs influence summer monsoon rainfall variability over the North East regions of India?, Open Science Conference- National Conference on Polar Sciences (NCPS):, National Centre for Polar and Ocean Research (NCPOR), Goa 16-19 May 2023, 18 May 2023.

Dr. Medha Deshpande

- Tropical cyclones and it's Prediction, School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University (KBC NMU), Jalgaon, 17 October 2023.
- Research Methodology: Basic statistical tools in research and data analysis, School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University (KBC NMU), Jalgaon, 17 October 2023.
- Advanced weather analysis and forecasting: Ensemble prediction system, Advanced

meteorological training course (AMTC) Batch 183, Semester II, Meteorological Training Institute (MTI), IMD, Pune, 13-15 June 2023 (online).

- 'चक्रीवादळे' (in Marathi), organized jointly by Marathi Vidnyan Parishad Pune Vibhag and the Institution of Engineer Pune Local Centre, 20 June 2023.

Dr. Atul Kumar Srivastava

- Atmospheric aerosols: Unraveling the characteristics and its role in climate forcing, Certificate Course on Green Technology for Mitigating Climate Change, conducted jointly by Amity Institute of Environmental Sciences, Amity University, Noida and IMD, New Delhi, 21 September 2023 (Guest Lecture).
- Trends in aerosol characteristics over India: Implication to climate forcing, Faculty Development Program on "Bridging Climate Change and Environmental Security: Pathways to Resilience", Department of Environmental Science, Integral University, Lucknow, 26 September (Guest Lecture).
- वायु प्रदूषण: मानव स्वास्थ्य और पर्यावरण पर प्रभाव, Akashvani Delhi, 19 October 2023, broadcasted on 22 October 2023.
- Atmospheric aerosols: Small particles with big climate effects, Training Course on Hydro-meteorological Data Analysis for Climate Change Studies, National Institute of Hydrology (NIH), Roorkee, Uttar Pradesh, 20 November 2023 (Guest Lecture).
- Absorption characteristics of aerosols at an urban megacity over the western IGP, TROPMET-2023, National Symposium on "Changing Dynamics of Arid Region and Impact on Weather and Climate over Indian Subcontinent", Birla Institute of Science and Research, Jaipur, 22-24 November 2023 (Lead Talk).
- Carbonaceous aerosols: Tiny particles with large climatic implications, National Training Workshop on Climate impacts of Carbonaceous Aerosols and Measurements (NT-CCAM), IITM, Pune, 04-07 December 2023, 04 December 2023.
- उत्तर भारत के दिल्ली शहर में काले और भूरे कार्बन की अवशोषण विशेषताओं और स्रोत विभाजन का अध्ययन, One-day Seminar on "Environmental and Human Health: Current Challenges" (in Hindi), CSIR-NPL, New Delhi, 15 March 2024.
- Atmospheric aerosols: Tiny particles with large climatic implications, International Workshop and Winter School on "Instrumentation and Analytical Techniques for Atmospheric Aerosol Measurements, Source Apportionment and Prediction over Bharat, HNB Garhwal University, Srinagar, Uttarakhand, 18-22 March 2024, 18 March 2024 (Keynote Talk).

Dr. Bhupendra Bahadur Singh

- Climate change: Global and regional estimates, Indian Meteorological Society (IMS), Varanasi chapter, Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi, 18 August 2023.
- Weather, Climate and aspects of Climate Change over India, Department of Geology, Institute of Science, Banaras Hindu University, Varanasi, 19 August 2023.
- Soil moisture induced land-atmosphere interactions in the evolution of extreme temperature over India, National Symposium on 'Understanding the science of heatwaves under the warming scenario and challenges ahead', Indian Institute of Tropical Meteorology (IITM), Pune, 19 March 2024.

Mr. Sandeep Narayanasetti

- Overview of climate system, climate variability and indicators, IIRS Dehradun, 19 March 2023.

Ms Aditi Modi

- Revealing the Colors of the Indian Ocean: Filling Gaps in Ocean Color Data and Quantifying Climate Change Impact on Marine Primary Productivity, Brainstorming sessions by the Ministry of Earth Sciences (MOES), National Science Workshop on Indian Ocean Biogeochemistry (NSWIO-BGC), CMLRE, Kochi, 26-28 April 2023.

- Revealing the Colors of the Indian Ocean: Filling Gaps in Ocean Color Data and Quantifying Climate Change's Impact on Marine Primary Productivity, National Aeronautics and Space Administration (NASA), USA, 20 July 2023.
- Impact of Climate Change on the Marine Ecosystem in the Indian Ocean, International Training Programme on "Machine Learning-based Species Distribution Modelling", Indian National Center for Ocean Information Services (INCOIS), Hyderabad, 11-22 September 2023.
- Remote Sensing: Data Repositories and Access, International Training Programme on "Machine Learning-based Species Distribution Modelling", Indian National Center for Ocean Information Services (INCOIS), Hyderabad, 11-22 September 2023.
- Introductory Lectures on Python and Jupyter Notebook, International Training Programme on "Machine Learning-based Species Distribution Modelling", Indian National Center for Ocean Information Services (INCOIS), Hyderabad, 11-22 September 2023.
- Initiatives and Current Activities by the Early Career Scientists Network (ECSN) IIOE-2, Brainstorming on the future road map for International Indian Ocean Expedition, Indian National Center for Ocean Information Services (INCOIS), Hyderabad, 28-30 November 2023.

Mrs. Smrati Gupta

- Exploring terrestrial carbon sink trends in India, INAGMET-2024, Banaras Hindu University, Varanasi, 8-10 February 2024 (oral presentation).
- A comparative study on understanding the long-term variability in carbon sequestration of different biospheres over the Indian Region, World Climate Research Programme- Open Science Conference 2023, Rwanda, 23-27 October 2023 (poster presentation - online).
- भारत में विभिन्न पारिस्थितिक तंत्रों में कार्बन-संग्रहण सूचक और प्रवत्ति का अध्ययन, One day National Hindi-Scientific Seminar, National Centre for Polar and Ocean Research (NCPOR), Goa, 27 September 2023.

Dr. Pramit Kumar Deb Burman

- Carbon and Water Cycles in the Context of Climate Change at the World Environment Day 2023 celebration organised by the Department of Environmental Science, University of Calcutta in Kolkata on 05 June 2023.

Dr. Rupraj Biswasharma

- Microphysical and Thermodynamical Properties of Lightning Producing Storms, International workshop 'Atmospheric Aerosol Measurements, Source Apportionment and Prediction over Bharat', Garhwal University, Uttarakhand, 18–22 March 2024.
- Microphysical Properties of Lightning Producing Convective Systems over the Monsoon Core Region of India, TROPMET-2023, National Symposium on “Changing Dynamics of Arid Region and Impact on Weather and Climate over Indian Subcontinent”, Birla Institute of Science and Research, Jaipur, 22-24 November 2023.

Dr. Deewan Singh Bisht

- Tethered balloon vertical profile observation of Carbonaceous aerosols and particulate matter, National Training Workshop On: Climate impacts of Carbonaceous Aerosols and Measurements (NT-CCAM), IITM, Pune, 04 December 2023 (Guest Lecture).
- Physical and chemical properties of atmospheric aerosol in the central Himalayan region, International Workshop and Winter School on Hands-on-training on Instrumentation and Analytical Techniques for Atmospheric Aerosol Measurements, Source Apportionment and Prediction over Bharat, HNB Garhwal University, Srinagar, 18 March 2024.

Mr. Hans Pratap Singh

- Parliamentary Official Language Committee and Promotion of Official Language). One-Day Official Language Workshop, Regional Ayurveda Research Institute (RARI), Pune, 19 March 2024.

Dr. Ashish Soni

- Changes in Light Absorption Properties with the Changes in Molecular Forms of Atmospheric Carbonaceous Aerosols over Eastern Part in India, NCAP-COALESCE science meeting, IIT Bombay, 25-26 April 2023 (online presentation).

Dr. Gaurav Govardhan

- Decision Support System for Air Quality Management: a tool in a sustainable world, five days faculty development program on "Building a Sustainable Future with Green Technology: Innovations, Opportunities and Challenges", Amity University, Noida, 26 May 2023 (online).
- Air quality forecasts and decision support to policymakers in Delhi, India, 5th ACAM workshop, organized by IGAC and University of Dhaka, Dhaka, 08 June 2023.

Dr. Gayatry Kalita

- Air mass back trajectory calculation, Advanced Meteorological Training course, Meteorological Training Institute, India Meteorological Department (IMD), Pune, 05 July 2023.
- Dust concentration estimation, Advanced Meteorological Training Course, Meteorological Training Institute, India Meteorological Department (IMD), Pune, 06 July 2023.

Mrs. Pooja Pawar

- Work package 4.2 "Modeling of ammonia over South Asia using new emission inventory, UKRI South Asian Nitrogen Hub (SANH) Annual Meeting, SANH, Peradeniya, Sri Lanka, 04 October 2023.
- Chemistry of atmospheric ammonia over South Asia: a source of nitrogen pollution, 9th International Nitrogen Conference (N2024), International Nitrogen Initiative (INI), Guru Gobind Singh Indraprastha University, New Delhi, 05-08 February 2024.

Mr. Avinash Parde

- Numerical Simulation Fog: Forecasting and R&D Prospective, Job training program, Meteorological Watch Office (MWO, IMD), 06 December 2023 (online).
- Analysis of Fog Lifecycle: Insights from Observations to Forecasting, Indian Air Force Met Officers Training, IITM, Pune, 18 January 2024.

Ms. Vrinda Anand

- Santa Barbara Distort Atmospheric Radiative Transfer model, International Workshop and Winter School on Hands-on-training for Atmospheric Aerosol Measurements, Source Apportionment and Prediction Over Bharat, Department of Physics, Hemvati Nandan Bahuguna Garhwal University at Srinagar, Garhwal, Uttarakhand, 18 March 2024.

Ms. Aditi Rathod

- Hands on Training on SBDART and OPAC model, International Workshop and Winter School on Hands-on-Training on Instrumentation and Analytical Techniques for Atmospheric Aerosol Measurements, Source Apportionment and Prediction over Bharat, HNB Garhwal Central University Srinagar, Uttarakhand, 18 March 2024.

8. DEPUTATIONS ABROAD

Dr. R. Krishnan

- Participation, 44th session of the WCRP JSC Meeting, as a Member, Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP), WMO/IOC/ISC, Climate Centre, Brussels, **Belgium**, 08-15 May 2023.
- Participation, Berlin Summit for International Cooperation for improved climate service and science, Berlin, Germany, 03-07 July 2023 and Monsoon research collaboration with Potsdam Institute for Climate Impact Research (PIK), Potsdam, **Germany**, 08-11 July 2023

Dr. Anguluri Suryachandra Rao

- Participation, 35th GEWEX Scientific Steering Group Meeting (SSG-35) Global Energy and Water Exchange (GEWES0, Santiago, **Chile**, 01-04 May 2023.
- Participation, WCRP Open Science Conference 2023 and CLIVAR Scientific Steering Group Meeting, Kigali, **Rwanda**, 21-28 October 2023

Dr. S.D. Pawar

- Participation, 2nd International Conference on "Lightning Electromagnetics and Applications of Semiconducting Materials" (ICLEASM), **Nepal**, 04-06 October 2023.

Dr. Thara Prabhakaran

- Participation, 28th General Assembly of the International Union of Geodesy and Geophysics (IUGG), Berlin, **Germany**, 11-14th July, 2023

Dr. Anupam Hazra

- Participation, Scientific discussion, Department of Atmospheric Sciences, National Taiwan University, Taipei, **Taiwan**, 15 April to 15 July 2023.

Mr. Gopalkrishnan

- Participation, 2nd International Conference on "Lightning Electromagnetics and Applications of Semiconducting Materials" (ICLEASM), **Nepal**, 04-06 October 2023.

Dr. Suvarna Fadnavis

- Chair a session and Paper Presentation, 20th Annual Meeting of the Asia Oceania Geosciences Society (AOGS), **Singapore**, 30 July to 04 August 2023
- Participation, Team Meeting on "Perspectives on Stratospheric aerosol observation" as a steering committee member of "Stratospheric Sulfate and its Role in Climate (SSiRC), Bern, **Switzerland**, 11-13 October 2023

Dr. P. Mukhopadhyay

- Participation, WWRP TMR-TCPFP Meeting, Miami, **USA,** 09-11 May 2023.
- Participation, WMO Sub-seasonal to Seasonal (S2S) Summit, University of Reading, Reading, **UK**, 03-07 July, 2023
- Participation, Symposium on "TRACing moisture sources of extreme rainfall over India – a tool for Better monsoon pRedIction at Synoptic TImescales (TRAC-BRISTI)", National Oceanography Centre, University of Southampton, **UK**, 23-24 November 2023.

Dr. Subodh Kumar Saha

- Invited talks and oral presentation, AGU23 Meeting, San Francisco, **USA**, 11-15 December 2023.

Dr. Anoop Mahajan

- Research stay at Department of Atmospheric Chemistry and Climate, Institute of Physical Chemistry Rocasolano, CSIC, Madrid, **Spain**, 01 May - 30 June 2023
- Participation, the Indian Arctic Expedition 2023, Svalbard, **Norway**, 27 July - 22 August 2023

Dr. Sachin D. Ghude

- Participation, 9th International Conference on Fog, Fog Collection and Dew, Colorado, **USA**, 23-28 July 2023

- Participation, IGAC Scientific Steering Committee (SSC) Meeting as an iLEAPS liaison, **Singapore**, 26-28 September 2023,
- Participation, UKRI GCRF Asian Nitrogen Hub (SANH) Annual Meeting, **Sri Lanka**, 02-06 October 2023.
- Participation, Tenth meeting of WMO Regional Association (RA) II (Asia) Working Group on Weather, Climate, Water and Related Environmental Services and Applications (RA II WG-Services), Chongqing, **China**, 14-16 November 2023.

Dr. S.A. Dixit

- Participation, 75th Annual Meeting of the American Physical Society's Division of Fluid Dynamics (APS DFD), Indianapolis, IN, USA, 20-22 November 2022 and Presentation at Princeton, **USA**, 23 November 2022.
- Participation and Oral Presentation, KUSAT Workshop on "Outstanding challenges in wall turbulence and lessons to be learned from pipes", King Abdullah University of Science & Technology (KAUST), **Saudi Arabia**, 26-28 February 2024

Dr. Milind Mujumdar

- Participation, '2023 Water for Food Global Conference', University of Nebraska-Lincoln (UNL), USA, 08-11 May 2023 and Scientific interaction with students, faculty, and staff, Discovery Partners Institute (DPI), University of Illinois System, Chicago, **USA,** 12-15 May 2023.

Dr. Susmitha Joseph

- Participation and Oral Presentation, WWRP/WCRP S2S Summit 2023, University of Reading, **UK,** 03-07 July 2023

Dr. Swapna Panickal

- To deliver talk, JpGU Meeting, Chiba, Japan and JAMSTEC, **Japan**, 22-25 May 2023.
- Participation, WCRP Earth System Modelling and Observation (ESMO) and Working Group on coupled Modelling (WGCM) Meeting, Hamburg, **Germany**, 18-22 March 2024.

Dr. Roxy Mathew Koll

- Participation, ICTP-CLIVAR Summer School on Marine Heatwaves as a Director/ Organizer, Summer School as an invited Lecturer and Mentor and the first Research Foci Meeting as the CLIVAR Regional Foci Member, ICTP, Trieste, **Italy**, 23-29 July, 2023
- Participation, CLIVAR Scientific Steering Group Meeting, WCRP EMCR Symposium, WCRP Open Science Conference 2023 and side event on Computing for Climate Science, Kigali, **Rwanda**, 21-28 October 2023
- To Chair and participation, IIOE-2 International Steering Committee Meeting and the Indian Ocean Meetings (IOGOOS, IORP, IRF) as part of the International Indian Ocean Science Conference 2024 (IIOSC 2024), Lombok, **Indonesia**, 04-09 March 2024.

Dr. Bipin Kumar

- To deliver a lecture, 5th International Workshop on Cloud Turbulence and to attend the satellite meeting on "Turbulence", Nagoya Institute of Technology, **Japan**, 14-16 March 2024

Dr. Sachin M. Deshpande

- To conduct a factory acceptance test of X-band radars to be deployed in Mumbai Metropolitan region, Enterprise Electronics Corporation (EEC), Alabama, **USA**, 10-21 April 2023.

Dr. Kaustav Chakravarty

- Participation and Paper presentation, 12th International Workshop of Precipitation in Urban Areas, Pontresina, **Switzerland**, 29 November to 02 December 2023

Dr. Yogesh Tiwari

- Participation, Workshop on "Observations within the Global Greenhouse Gas Watch" as an expert on the integrated long-term GHG observations in India and a member of the Steering Committee of the Integrated Global Greenhouse Gas Information system, Geneva, **Switzerland**, 03-05 October 2023

Dr. Jasti Sriranga Chowdary

- Participation, 3rd Global Ocean Summit 2023, Qingdao, **China**, 25-27 September 2023

Dr. Naveen Gandhi

- Poster presentation, General Assembly 2023 of EGU, Vienna, **Austria**, 23-28 April 2023.

Dr. Abhilash S. Panicker

- Participation, 21st International Conference on Nucleation & Atmospheric Aerosols (ICNAA), Brisbane, **Australia**, 26-30 June, 2023

Dr. Ayantika Dey Choudhury

- Participation, disciplinary expert in the Berlin Summit for building Earth Visualization Engine, Berlin, **Germany**, 03-07 July 2023.
- Participation, WCRP Open Science Conference 2023, Kigali, **Rwanda**, 23-27 October 2023
- Participation and Invited talk in a symposium, National Oceanography Centre, Southampton, **U.K.**, 22-25 November 2023.

Mr. Bhupendra Bahadur Singh

- Participation, Joint SPARC DynVar – SNAP Meeting on "The Role of Atmospheric Dynamics for Climate and Extremes", Munich, **Germany**, 09-13 October 2023

Dr. Sandeep Narayansetti

- Participation, Berlin Summit for building Earth Visualization Engine, Berlin, **Germany,** 03-07 July, 2023
- Oral presentation, WCRP Open Science Conference 2023, **Rwanda**, 23-27 October 2023

Mr. Maheswar Pradhan and **Mr. Ankur Srivastava**

- Participation, WCRP Open Science Conference 2023, 23-27 October 2023 and WCRP-SPARC Training School on Climate Data Science and Artificial Intelligence, Kigali, **Rwanda**, 28-31 October 2023.

Mrs. Snehlata Tirke

- Oral presentation, 9th NOAA Ensemble Users workshop, Maryland, **USA,** 22-24 August 2023.

Mr. Raju Mandal

- Paper presentation, WMO Sub-seasonal to Seasonal (S2S) Summit, University of Reading, Reading, **UK**, 03-07 July, 2023.

Dr Avijit Dey

- Poster presentation, WCRP Open Science Conference 2023, Kigali, **Rwanda**, 23-27 October 2023.

Dr. Chaitri Roy

- Poster Presentation, GEIA Conference, Brussels, **Belgium**, 19-23 June, 2023.
- Participation and presentation, IAGOS users Meeting, Brussels, **Belgium**, 14-16 November 2023.
- Participation and Oral poster presentation, American Geophysical Union Annual Fall Meeting (AGU23), San Francisco, California, **USA**, 11-15 December 2023.

Dr. Shikha Singh

- Participation, ICTP-CLIVER Summer School on Marine Heat Waves: Global Phenomena with Regional Impacts, Trieste, **Italy**, 24-29 July 2023

Ms. Aditi Modi

- Participation and Oral presentation, Trevor Platt Science Symposium, Plymouth, **UK,** 09-11 August 2023
- Participation and, Oral and Poster presentation, WCRP Open Science Conference 2023 and Participation, AI for Climate risk mitigation and Computing for climate science, and WCRP–OSC's EMCR Symposium, Kigali, **Rwanda**, 21-28 October 2023

Dr. Manmeet Singh

- Participation, Berlin Summit for building Earth Visualisation Engine, Berlin, **Germany**, 03-07 July, 2023

Dr. Pramit Kumar Deb Barman, Mr. Avishek Ray, Mr. Aswin Sagar, Mr. Rrakesh Ghosh, Mr. Parveen Kumar and **Mr. Kiran V.G.**

- Participation, General Assembly 2023 of the European Geosciences Union (EGU), Vienna, **Austria**, 23-28 April 2023.

Dr. Gaurav Govardhan

- Invited talk, Fifth Workshop on Atmospheric Composition and the Asian Monsoon (ACAM), Dhaka, **Bangladesh**, 08-10 June 2023

Mr. Ajit Prasad P., Mr. Yogesh Belgude, Mrs. Bhavana Naik and **Ms. C.P. Vijaya Kumari**

- Participation, Training programme on Administrative Vigilance and Prevention of Corruption handling/ Scrutiny/Investigation of complaints/ Grievance having vigilance angle, Kathmandu, **Nepal**, 28-30 September 2023

Dr. E.N. Rajagopal, Executive Head, IMPO

- Participation, 44th session of the WCRP Joint Scientific Committee, Brussels, **Belgium**, 08-12 May 2023.
- Participation, WCRP Open Science Conference 2023, Kigali, **Rwanda**, 23-27 October 2023.

Dr. Atul Kumar Sahai, Consultant

- Participation, WMO Sub-seasonal to Seasonal (S2S) Summit, and S2S Project Steering and Liaison Groups meeting, University of Reading, Reading, **UK**, 03-08 July 2023.
- Participation, WWRP Scientific Steering Committee Meeting, Geneva, **Switzerland**, 29 August - 01 September 2023

Dr. S.S.V.S. Ramakrishna, Project Manager

- Participation, Research Meeting on lightning strikes, Tokyo, **Japan**, 17-21 July 2023.

Dr. Rajmal Jat, Project Scientisit III and **Mr. Prafull Prakash Yadav, Project Associate I**

- To conduct a meeting aimed at developing "The Dust Early Warning System for Qatar" and to provide training on the Air Quality Model to the QMD Scientists and to explore future research collaboration between IITM & QMD, Doha, **Qatar**, 03-14 September 2023

Dr. Atar Singh Pipal, Project Scientist II

- Participation and Poster Presentation, European Aerosol Conference (EAC-2023), Malaga, **Spain**, 03-08 September 2023

Dr. Abhishek Gupta, Project Scientist II

- Participation and Oral presentation, 76th Annual Meeting of the Fluid Dynamics, Washington, DC, **USA**, 19-21 November 2023.

Mr. Abhijeet Kumar, Project Scientist II

- Participation, EUMETSAT Meteorological Satellite Conference 2023, Malmo, **Sweden**, 11-15 September 2023

Mr. Vikas Kumar Kushwaha, Mr. Abhijeet Murlidhar Gangane, Project Scientist I, Mr. Amol Suresh Vibhute and **Mr. Sumit Kumar, MRFP Sr. Research Fellow**

- Participation and Poster presentation, 28th General Assembly of the International Union of Geodesy and Geophysics (IUGG) 2023, Berlin, **Germany**, 11-20 July, 2023

Mrs. Pooja Pawar, Project Scientist I

- Participation, Fifth Workshop on Atmospheric Composition and the Asian Monsoon (ACAM), Dhaka, **Bangladesh**, 06-10 June, 2023
- Participation, UKRI GCRF South Asian Nitrogen Hub (SANH) Annual meeting, Peradeniya, **Sri Lanka**, 02-06 October 2023
- Participation, Global Major Groups and Stakeholders Forum and the main UNEA-6 Event, UNEP, Nairobi, **Keny**a, 24 February - 01 March 2024.

Mr. Narendra Gokul Dhangar, Project Scientist I

- Participation, UKRI GCRF South Asian Nitrogen Hub (SANH) Annual meeting, Peradeniya, **Sri Lanka**, 02-06 October 2023

Mr. Sanket Kalgutkar, Project Scientist I

- Participation, short term workshop including training on Prion Mk3 Unmanned System in Wales, **UK**, 17 July to 04 August 2023.

Mr. Surendra Singh, Senior Project Associate

- Participation, the First Indian Winter Expedition, Himadri, Ny-Alesund, **Svalbard (Arctic)**, 21 December 2023 to 15 January 2024.

Ms. Rupal Ambulkar, Project Associate-I

- Participation, Workshop and Conference on Modelling, Data Assimilation, Inverse Modelling and Model evaluation and discussion on the impacts of changing emission on air quality & climate, Brussels, **Belgium,** 19-23 June, 2023

Mr. Shivam Tiwari, DESK-MRFP

- Participation, 10th International Crustacean Congress, 22-26 May, 2023 and the combined Amphipod and Bioinformatics/Phylogenetics of Peracarids Workshop, Wellington, **New Zealand**, 29 May - 01 June, 2023

Ms. Tanisha Nag, MRFP- Senior Research Fellow

- Poster presentation, ASLO Aquatic Sciences Meeting 2023, **Spain**, 04-09 June 2023

Ms. Anila Sebastian, Senior Research Fellow

- Participation, General Assembly 2023 of European Geosciences Union (EGU), Vienna, **Austria**, 23-28 April, 2023

Ms. Sophia Yacob, Senior Research Fellow

- Participation, General Assembly 2023 of the European Geosciences Union (EGU), Vienna, **Austria**, 23-28 April 2023.
- Participation, WCRP Open Science Conference 2023 as a representative of the IITM Hub of the WCRP My Climate Risk, Kigali, **Rwanda**, 23-27 October 2023.

Ms. Manisha Tupsoundar, Senior Research Fellow

- Oral Presentation, 11th European Conference on Severe Storms (ECSS2023), Bucharest, **Romania**, 08-12 May 2023.

Ms. Pratibha Gautam, Ms. Rituparna Sarkar and Mr. Abhijith Raj, Senior Research Fellow

- Participation, American Geophysical Union Annual Meeting (AGU23), San Francisco, California, **USA**, 11-15 December 2023

Mr. Sandeep J., Senior Research Fellow

- Oral presentation, 3rd Workshop on Cloud Organisation and Precipitation Extremes, **Italy**, 04-08 September 2023.

Mr. Avinash Parde, Senior Research Fellow

- Participation, 9th International Symposium on Data Assimilation conference, **Italy**, 16-20 October 2023

Ms. Ganadhi Mano Kranthi, Senior Research Fellow

- Participation and Paper presentation, International Workshop of Typhoon Science and Technology Research Center (IWTRC), Yokohama, **Japan**, 08-09 November 2023.

Ms. Shruti Saini, Junior Research Fellow

- Participation, URSI General Assembly and Scientific Symposium (URSI GASS 2023) as Young Scientist Awardee, Sapporo, **Japan**, 19-26 August, 2023

Mr. Sankirna Joge, Junior Research Fellow

- Participation, Supper School at Ocean Science Centre Mindelo (OSCM), Mindelo, Sao Vicente, **Cado Varde**, 05-16 June 2023

Ms. Shibani Bhatt, Research Associate

- Participation, 76th Annual Meeting of the Fluid Dynamics, Washington, DC, USA and visit to the Aerospace Engineering Department, Embry-Riddle Aeronautical University, Florida, **USA** for scientific discussion and to explore collaboration possibilities, 19-29 November 2023.

Dr. Ipsita Roy, Research Associate

- Participation, XXI International Union for Quaternary Science (INQUA) Congress 2023, Rome, **Italy**, 13-20 July 2023

Dr. Uttam Pandey, Research Associate

- Participation, Scientific workshop "Novel Approaches in Tree-Ring Research", Freising, **Germany**, 04-06 October 2023

9. Regular Staff (as on 01.04.2024)

RESEARCH CATEGORY
DIRECTOR
DR. R. KRISHNAN
SCIENTIST - H
-
SCIENTIST - G
DR. A. SURYACHANDRA RAO
DR. C. GNANASEELAN
DR. S. D. PAWAR
DR. (SMT) THARA PRABHAKARAN
DR. G. PANDITHURAI
SCIENTIST - F
DR. ANUPAM HAZRA
DR. SANJAY J.
SHRI V. GOPALKRISHNAN
DR. (SMT) SUVARNA S. FADNAVIS
DR. P. MUKHOPADHYAY
DR. VINU VALSALA
DR. RAMESH VELLORE
DR. SUBODH KUMAR SAHA
DR. (SMT) PADMA KUMARI
SHRI P. MURUGAVEL
DR. H.S. CHAUDHARI
DR. DEVENDRAA SIINGH
DR. ANOOP MAHAJAN
DR. SACHIN D. GHUDE
SHRI S. MAHAPATRA
DR. SHIVSAI DIXIT
DR. M.N. PATIL
DR. MILIND MUJUMDAR
DR. (SMT). SUSMITHA JOSEPH
DR. K.M.C. REDDY
DR. (SMT.) SWAPNA P.
DR. ROXY MATHEW KOLL
DR. A. B. PAREKH
DR. G. S. MEENA
SMT SHOMPA DAS
DR. HAMZA VARIKODEN
DR. S.M. DESHPANDE
DR. (SMT.) PREETHI BHASKAR
DR. RAMESH K. YADAV
SCIENTIST - E
SHRI S.M.D. JEELANI (Comp. Engg.)
DR. SREENIVAS PENTAKOTA
DR. SAMIR POKHREL
DR. BIPIN KUMAR
DR. K. CHAKRAVARTY
DR. Y.K. TIWARI
DR. SAIKAT SENGUPTA
DR. SUBRATA KUMAR DAS
DR. JASTI SRIRANGA CHOWDHARY
DR. PRASANTH A. PILLAI
DR. NAVEEN GANDHI
DR. RAJIB CHATTOPADHYAY
DR. ABHILASH S. PANICKER
SHRI MAHESH DHARUA (Mech. Engg.)
DR. PHANI MURALI KRISHNA
DR. SABIN T.P.
DR. (SMT.) AMITA AJAY PRABHU
SHRI PREM SINGH

DR. (SMT.) LATHA R.
DR. DEEN MANI LAL
SHRI R.M. BANKAR (Mech. Engg.)
SHRI A.K. SAXENA (Civil Engg.)
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SHRI JAMIR HIRALAL NINDHANE
SMT. ARTI ISHWAR DULGACH

10. Publications

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18. सिंह विवेक, संभलकर चलाएं चैट-जीपीटी, अविष्कार, मई २०२३, २८-३१

Summary of Publications during the year 2023-24

Total No. of papers published in Journals	184
Papers with Impact Factor	169
Papers without Impact Factor	15
Cumulative Impact Factor	908
Average Impact Factor	4.935
Other Publications	18

A. R. Sulakhe & Co.

H.O. Anand Apartment, 1180/2, Shivajinagar, Pune - 411005.
Tele : +91-020-25535600, 25535221, Mobile : 9822012023
E-mail: anand@arsulakhe.com, admin@arsulakhe.com
www.arsandco.com
Branches : Mumbai | Solapur | Ahmedabad | Kolhapur | Ahmednagar | Hyderabad | Nagpur | Goa

Independent Auditors' Report

TO
THE DIRECTOR
INDIAN INSTITUTE OF TROPICAL METEOROLOGY

Opinion

We have audited the financial statements of the Indian Institute of Tropical Meteorology ("the Institute"), which comprise the balance sheet as at March 31, 2024, and the statement of Income and Expenditure for the year then ended, and notes to the financial statements, including a summary of significant accounting policies and other explanatory information.

In our opinion and to the best of our information and according to the explanations given to us, the aforesaid financial statements give a true and fair view in conformity with the accounting principles generally accepted in India, of the state of affairs of the Institute as at March 31, 2024 and the Statement of Income and Expenditure for the year then ended on that date.

Basis for Opinion

We conducted our audit in accordance with Standards on Auditing (SAs) specified by the ICAI. Our responsibilities under those Standards are further described in the Auditor's Responsibilities for the Audit of the Financial Statements section of our report. We are independent of "the Institute" in accordance with the Code of Ethics issued by the Institute of Chartered Accountants of India (ICAI) and we have fulfilled our other ethical responsibilities in accordance with these requirements and the ICAI's Code of Ethics. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our opinion.

Responsibilities of Management and Those Charged with the Governance for the Financial Statements

The Institute's Management is responsible for the preparation of these financial statements that give a true and fair view of the financial position and financial performance of the Institute in accordance with the accounting principles generally accepted in India. This responsibility includes the design, implementation and maintenance of internal control relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatement, whether due to fraud or error.

Those charged with the governance are responsible for overseeing the Institute's financial reporting process.

Auditor's Responsibility for the Audit of the Financial Statements

Our objectives are to obtain reasonable assurance about whether the financial statements as a whole are free from material misstatement, whether due to fraud or error, and to issue an auditor's report that includes our opinion. Reasonable assurance is a high level of assurance, but is not a guarantee that an audit conducted in accordance with SAs will always detect a material misstatement when it exists. Misstatements can arise from fraud or error and are considered material if, individually or in the aggregate, they could reasonably be expected to influence the economic decisions of users taken on the basis of these financial statements.

As a part of an audit in accordance with SAs, we exercise professional judgment and maintain professional skepticism throughout the audit. We also:

- Identify and assess the risks of material misstatement of the financial statements, whether due to fraud or error, design and perform audit procedures responsive to those risks, and obtain audit evidence that is sufficient and appropriate to provide a basis for our opinion. The risk of not detecting a material misstatement resulting from fraud is higher than for one resulting from error, as fraud may involve collusion, forgery, intentional omissions, misrepresentations, or the override of internal control.
- Obtain an understanding of internal control relevant to the audit in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the Institute's internal control.
- Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by management.

We communicate with those charged with governance regarding, among other matters, the planned scope and timing of the audit and significant audit findings, including any significant deficiencies in internal control that we identify during our audit.

We also provide those charged with governance with a statement that we have complied with relevant ethical requirements regarding independence, and to communicate with them all relationships and other matters that may reasonably be thought to bear on our independence, and where applicable, related safeguards.

For A R Sulakhe & Co
Chartered Accountants
Firm Reg. No.110540W

Kaustubh Deo
PARTNER
Membership No: 134892
Date: July 24, 2024
Place: Pune
UDIN: 24134892BKFAGR3409

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

(Ministry of Earth Sciences, Government of India)
Dr. Homi Bhabha Road, Pashan, Pune - 411 008.

BALANCE SHEET AS AT 31st MARCH 2024

1. CORPUS/ CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
CORPUS / CAPITAL FUND	1	271,66,41,453	818,52,35,417
RESERVES AND SURPLUS	2	3,52,51,532	3,38,68,106
EARMARKED/ ENDOWMENT FUNDS	3	1,08,08,989	85,63,981
SECURED LOANS AND BORROWINGS	4		
UNSECURED LOANS AND BORROWINGS	5		
DEFERRED CREDIT LIABILITIES	6		
CURRENT LIABILITIES AND PROVISIONS	7	32,66,65,277	33,37,81,500
INTEREST (TO BE SURRENDERED TO MOES)	7	2,47,57,909	1,98,88,226
TOTAL		**311,41,25,160**	**858,13,37,230**
ASSETS			
FIXED ASSETS	8	181,73,45,746	764,72,46,206
INVESTMENTS - FROM EARMARKED/ENDOWMENT FUNDS	9		
INVESTMENTS - OTHERS	10		
CURRENT ASSETS, LOANS, ADVANCES ETC.	11	129,67,79,414	93,40,91,024
MISCELLANEOUS EXPENDITURE (to the extent not written off or adjusted)			
TOTAL		**311,41,25,160**	**858,13,37,230**
SIGNIFICANT ACCOUNTING POLICIES	24		
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25		

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

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INCOME & EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH 2024

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services	12		
Grants/Subsidies (Received from Ministry of Earth Sciences, New Delhi)	13	136,16,75,973	135,99,57,152
Fees/Subscriptions	14		
Income from Investments (Income on Invest from earmarked/endow. Funds transferred to Funds)	15		
Income from Royalty Publication etc.	16		
Interest Earned	17		
Other Income	18	81,63,549	64,58,730
Increase/(decrease) in stock of Finished goods and works-in-progress	19		
TOTAL (A)		**136,98,39,522**	**136,64,15,882**
EXPENDITURE			
Establishment Expenses	20	49,59,86,108	46,22,19,698
Other Administrative Expenses etc.	21	38,00,59,131	36,28,86,248
Expenditure on Grants, Subsidies etc.	22	50,43,73,634	36,84,56,224
Interest	23		
Depreciation (Net Total at the year-end-Corresponding to Schedule 8) This includes the prior period depreciation as referred in notes on accounts. (Prior period depreciation Rs. 574,33,88,509/- & current period depreciation Rs. 38,39,84,609/-)		612,73,73,118	51,84,61,266
TOTAL (B)		**750,77,91,991**	**171,20,23,436**
Balance being excess of Income over Expenditure (A-B)			
Transfer to Special Reserve (Specify each)			
Transfer to / from General Reserve			
BALANCE BEING SURPLUS/(DEFICIT) CARRIED TO CORPUS/ CAPITAL FUND		**-613,79,52,469**	**-34,56,07,554**
SIGNIFICANT ACCOUNTING POLICIES	24		
CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS	25		

FORM OF FINANCIAL STATEMENTS (NON-PROFIT ORGANISATIONS)

RECEIPTS AND PAYMENTS FOR THE PERIOD / YEAR ENDED 31ST MARCH 2024

	RECEIPTS	AMOUNT			PAYMENTS	AMOUNT	
I	**Opening Balances**			**I**	**Establishment expenses**		**49,59,86,108.00**
a	Cash in hand		**10,000.00**	**II**	**Payment made against various project funds**		**1,11,60,084.00**
b	Bank Balances			**III**	**Advances to Others than schemes**		**8,62,300.00**
1	State Bank of India- Current Account -11099449733		**16,70,81,127.00**	**IV**	**Advance to Staff**		**23,18,392.00**
2	State Bank of India- VyaparAccount -38222234583		**3,49,53,022.00**	**V**	**Deposits with**		**39,790.00**
3	Pujnab National Bank- 0495000100169650 - Saving Account		**17,21,667.00**	**VI**	**Overheads**		**-**
4	State Bank of India - Project Current Account - 30128441802		**29,16,024.00**	**VII**	**Funds Retained from suppliers**		**2,08,08,502.00**
5	State Bank of India - 41123459119		**16,33,364.00**	**VIII**	**Statutory Liability**		**58,86,44,347.00**
6	State Bank of India - ENVIS - 40280284775		**2,623.00**				
7	Bank of Maharashtra - 60415673208		**10,52,51,592.00**	**IX**	**DESK**		**3,48,63,090.00**
8	Bank of Maharashtra - 60417381032		**29,28,839.00**		Recurring	3,49,46,271.00	
9	Canara Bank - IITM EIACP ENVIS - 110064181770		**-**		Non-Recurring	-	
10	Canara Bank - 110053624879 DESK		**-**		Advance	12,62,447.00	
11	State Bank of India- 41586057192 CAQM		**15,84,901.00**		Total	3,62,08,718.00	
12	State Bank of India NSM 41191367293		**30,03,959.00**		Less: Advance adjusted	13,45,628.00	
13	CNA Account (IMD & INCOIS Balance)		**3,80,73,184.00**				
II	**Grants Received**		**204,87,45,973.00**	**X**	**IITM Operations & Maintenance**		**38,80,82,450.00**
1	High Performance Computing (HPC)	21,60,00,000.00			Recurring	38,81,98,861.00	
2	Monsoon Convection Clouds & Climate Change (MC4)	90,25,70,000.00			Non-Recurring	6,306.00	
3	IITM - Operations & Maintenance	86,17,00,000.00			Advance	62,52,980.00	
4	Monsoon Mission	3,36,00,000.00			Total	39,44,58,147.00	
5	DESK	3,48,75,973.00			Less: Advance adjusted	63,75,697.00	

	RECEIPTS	AMOUNT			PAYMENTS	AMOUNT	
III	**Interest Received**			**XI**	**Monsoon Mission**		**6,71,48,867.00**
	Core Grant Interest		**72,72,105.00**		Recurring	6,71,48,867.00	
1	CLTD	62,19,212.00			Non-Recurring	-	
2	Penal Interest	22,401.00			Advance	9,61,000.00	
3	Cycle / Scooter Interest	863.00			Total	6,81,09,867.00	
4	HBA Interest	20,115.00			Less: Advance adjusted	9,61,000.00	
5	Interest (Principle Arrears) Recd. From MSEDCL	10,09,514.00					
6	Computer Interest	-					
b	**Interest - On Schemes**		**1,60,85,462.00**	**XII**	**HPC**		**16,17,80,632.00**
1	High Performance Computer System (HPC)	-			Recurring	15,06,30,209.00	
2	Monsoon Convection Clouds & Climate Change (MC4)	1,40,26,927.00			Non-Recurring	1,12,60,438.00	
3	NFAR	14,93,587.00			Advance	85,13,640.00	
4	Monsoon Mission - Extra Mural Funds	5,64,948.00			Total	17,04,04,287.00	
					Less: Advance adjusted	86,23,655.00	
IV	**Other Income**		**81,63,549.00**	**XIII**	**National Facility for Airborne Research**		**7,34,797.00**
1	Contribution to Pensioners Medical Sch.	8,72,400.00			Recurring	-	
2	Community Hall - Licence Fee & Welfare Charges	5,175.00			Non-Recurring	47,54,394.00	
3	Guest House charges	36,22,818.00			Advance	15,82,303.00	
4	Licence Fees	30,26,152.00			Total	63,36,697.00	
5	Maint of Colony Welfare	46,946.00			Less: Advance adjusted	56,01,900.00	
6	Sale of Scrap (Auction)	4,78,531.00					
7	Misc.Receipts	4,469.00		**XIV**	**Monsoon Convection Clouds & Climate Change (MC4)**		**96,50,59,206.00**
8	Water charges	74,736.00			Recurring	25,28,83,190.00	
9	Misc. Receipts From Salary	5,322.00			Non-Recurring	27,20,76,887.00	
10	Rent for Meghdoot Hall	27,000.00			Advance	70,94,09,024.00	
					Total	123,43,69,101.00	
V	**Any other receipts**		**62,49,77,514.00**		Less: Advance adjusted	26,93,09,895.00	
1	Receipts from various project	1,34,05,092.00					
2	Funds Retained from suppliers	38,63,706.00		**XV**	**Claims Receivable**		**25,49,480.00**
3	Claims Receivable	18,30,920.00					
4	Statutory liabilities	58,75,65,319.00		**XVI**	**Deposits From Creditors**		**22,72,117.00**
5	Deposits with	3,50,000.00					
6	Advance to others than schemes	9,88,300.00		**XVII**	**Interest surrendered to MoES**		**1,82,47,740.00**
7	Reserve & Surplus (Corpus Fund)	13,83,426.00					
8	Deposits from creditors	1,31,79,718.00		**XVIII**	**CNA ACROSS Expenditure**		**42,83,09,487.00**
9	Advance to Staff	24,11,033.00			IMD	41,33,50,252.00	
					INCOIS	1,49,59,235.00	

	RECEIPTS	AMOUNT			PAYMENTS	AMOUNT	
VI	**CNA ACROSS Grant**		**41,58,71,935.00**				
1	IMD	40,47,06,894.00		**XIX**	**DESK balance surrendered to INCOIS CNA**		**10,06,915.00**
2	INCOIS	1,11,65,041.00					
				XX	**CNA ACROSS Interest surrendered to MoES**		**64,53,330.00**
				XXI	**Provision for Employee Benefit (Gratuity & Leave Encashment)**		**26,64,929.00**
VII	**CNA ACROSS (Surrendered by IMD)**		**2,48,87,396.00**	**XXII**	**Closing Balance**		
VIII	**CNA ACROSS Interest Amount**		**62,13,186.00**	a	Cash in hand		**10,000.00**
IX	**Provision for Employee Benefit (Gratuity & Leave Encashment)**		**31,91,349.00**	b	Bank Balances		
				1	State Bank of India - Current Account -11099449733		**16,53,78,853.00**
				2	State Bank of India - VyaparAccount -38222234583		**2,50,19,075.00**
				3	Pujnab National Bank - 0495000100169650 (Saving)		**-**
				4	State Bank of India - Project Current Account - 30128441802		**28,47,563.00**
				5	State Bank of India 41123459119		**13,16,454.00**
				6	State Bank of India - ENVIS - 40280284775		**-**
				7	Bank of Maharashtra 60415673208 Balance in CNA Account (IMD & INCOIS)		**6,09,72,238.00** **5,05,23,028.00**
				8	Bank of Maharashtra 60417381032		**16,02,203.00**
				9	Canara Bank - IITM EIACP ENVIS -110064181770		**-**
				10	Canara Bank 110053624879 DESK		**-**
				11	State Bank of India 41586057192 CAQM		**25,31,291.00**
				12	State Bank of India NSM 41191367293		**10,93,850.00**
				13	Bank of Maharashtra 60437677172 DST INSPIRE		**33,968.00**
				14	Bank of Maharashtra 60443764895 DST-3237 (AD)		**13,33,169.00**
				15	Canara Bank 110114702643 (NCAP)		**29,14,516.00**
		TOTAL	**351,45,68,771.00**			**TOTAL**	**351,45,68,771.00**

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

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SCHEDULE - 24: SIGNIFICANT ACCOUNTING POLICIES FOR THE YEAR ENDED 31st MARCH 2024

The Indian Institute of Tropical Meteorology, Pune is an autonomous institute registered as a society under the Maharashtra Societies Registration Act, 1860 vide registration number MAH.688-PN dated 01.04.1971.

1. Basis of Accounting:

The financial statements are prepared based on historical cost convention unless otherwise stated and on the basis of the accrual system of accounting except in the case of Government Grants (Recurring & Non- recurring) which are accounted on actual receipt. The Recurring Grants are recognized in the Income & Expenditure Account and Non-Recurring Grants are treated as Capital fund. The accounts are prepared on the basis of going concern.

2. Fixed assets and Depreciation

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.

Depreciation on Fixed Assets is provided on Written Down Value Method as per The Income Tax Act 1961.

The depreciation on freehold land is not charged however on leasehold land the depreciation is charged over the period of lease.

3. Sponsored Projects

In respect of sponsored projects, the amounts received from sponsors are not capitalized under Fixed Assets and is considered as a revenue expenditure. The amount on receipt is shown under Current Liabilities – Earmarked / Endowment Funds - Schedule 3" and as and when the expenditure is incurred this head is debited.

4. Foreign Currency Transactions:

Transactions denominated in foreign currency are accounted based on the exchange rate prevailing on the date of transaction.

5. Employee benefits

The provision for gratuity and leave encashment payable on retirement is made on accrual basis.

6. Taxation

The income of the institute is exempt from Income Tax Act 1961. Therefore, no provision for income tax is made in the Annual Accounts.

For Indian Institute of Tropical Meteorology	**As per our Report on even date** **For & on behalf of** **A R Sulakhe & Co.** **Chartered Accountants** **(Firm Reg. No.110540W)**
(Dr. R. Krishnan) **(Director)** **Pune**	**(Kaustubh Deo)** **(Partner, Membership No.134892)** **UDIN: 24134892BKFAGR3409**

INDIAN INSTITUTE OF TROPICAL METEOROLOGY

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SCHEDULE - 25: NOTES ON ACCOUNTS FOR THE YEAR ENDED

31st MARCH 2024

1. Depreciation

The institute was following the Straight-Line Method of depreciation as per Income Tax Act 1961 / Companies Act 2013. The method of the depreciation has been changed retrospectively to Written Down Value (WDV) method as per Income Tax Act, 1961 in line with the practice followed in the other autonomous institutes under the ministry. Depreciation of Leasehold land is charged over the period of lease.

Sr. No.	Particulars	% Rate of depreciation
1	Machinery & Equipment	15%
2	Furniture	10%
3	Office Equipment	15%
4	Computers / Servers / Storage	40%
5	Electric Installation	10%
6	Library Books	100%
7	Other Fixed Assets	15%
8	Vehicle	15%
9	Building	10%

Due to the change of depreciation method retrospectively, there is prior period and current period depreciation amounting to Rs. 574,33,88,509/- & Rs. 38,39,84,609/- respectively. This has caused the deficit amounting to Rs. 613,79,52,469/- under Income & Expenditure Account. Accordingly, the overstated value of fixed assets reduced as per WDV as stated above comes to Rs. 181,73,45,746/- as on 31st March 2024.

2. Employee benefits

The provision for gratuity and leave encashment payable on retirement has been provided in the accounts on accrual basis. The liability as on 31st March 2024 towards gratuity and leave encashment is Rs. 15,77,97,533/- and Rs. 14,40,06,629/- respectively.

3. Previous figures have been re-grouped, reclassified wherever found necessary inconformity with the current year's presentation.

4. Paise had been rounded off to the nearest rupee.

Institute's Building: Foundation Day Celebration

Indian Institute of Tropical Meteorology

(An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India)
Dr. Homi Bhabha Road, Pashan, Pune - 411 008, Maharashtra, India

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