National Symposium on

# Challenges in climate services for health sector in the warming environment

# ABSTRACTS

March 2023

**ORGANIZED BY:**

**Indian Meteorological Society, Pune Chapter (IMSP)**

**In association with IITM & IMD Pune**

**Supported by Ministry of Earth Sciences (MoES)**

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# *MESSAGE*

*I heartily congratulate and compliment the Indian Meteorological Society Pune chapter (IMSP), for sustaining the Annual Monsoon Workshop (AMW) series as its flagship activity for more than two decades in collaboration with the India Meteorological Department (IMD) and the Indian Institute of Tropical Meteorology (IITM). IMSP has also made concerted efforts to constantly improve the AMW in form as well as content, along with an associated symposium in recent years. On behalf of the National Council of IMS, I express my deep appreciation of the tremendous efforts put in by the Executive Council of the IMSP to convene AMW-2022 on 28 March 2023 followed by a National Symposium on "Challenges in climate services for health sector in the warming environment" during 29-30 March 2023 at IITM, Pune. I am grateful to the Ministry of Earth Sciences (MoES), Govt. of India and other sponsoring agencies and partners for their support to this important activity of the IMS. It is a delightful coincidence that these events are taking place closely following the World Meteorological Day on 23 March 2023, on which the IMD is releasing a Special Issue of the journal Mausam featuring research papers based on the presentations made at the recent Seventh WMO International Workshop on the Monsoons (IWM-7).*

*The socio-economic fabric of India is closely intertwined with the monsoons, affecting every aspect of the lives of its people. From ancient history to modern times, the monsoons have therefore attracted the attention of experts as well as the laymen to develop and apply monsoon knowledge to manage the associated risks and exploit the opportunities provided by the monsoons. Every monsoon is different, with its own individual flavour, testing our current knowledge and offering windows to new insights. I am sure the AMW-2022 too will help us to diagnose the most recent monsoon, evaluate our current scientific tools and find new ways to improve our capabilities to understand and predict the monsoons.*

*The recent COVID-19 pandemic has demonstrated globally the vulnerability of public health to large-scale disruptions with devastating consequences. It is well-known that climate variability and change have both direct and indirect impacts on human health, which need to be adequately understood to help us develop early warning and response systems. India has world-class meteorological and health sectors, but there is an urgent need for these two sectors to come together to jointly address the challenges of climate and health exacerbated by the realities of a warming world. I look forward to the National Symposium this year to take stock of the challenges and pave the way forward for stronger collaborative efforts between the climate and health sectors.*

*On behalf of the National Council of the IMS, I convey our warm greetings to all the participants of AMW-2022 and National Symposium as well as all the members of the IMSP and wish the two events a grand success.*

***Rupa Kumar Kolli***

*President, IMS*

# *MESSAGE*

*It gives me immense pleasure to convey my warm greetings to the members of Indian Meteorological Society (IMS) and its patrons and partners organizing Annual Monsoon Workshop on 28th March 2023 & National Symposium on "Challenges in climate services for health sector in the warming environment" on 29th & 30th March 2023 at Meghdoot Auditorium, Indian Institute of Tropical Meteorology (IITM), Pashan, Pune.*

*It is a very well-known fact that Global Warning and Climate Change is a reality and its possible consequences are spreading to all walks of life. Climate change is the single biggest health threat facing humanity, and health professionals worldwide are already responding to the health harms caused by this unfolding crisis. Climate change is already impacting health in a myriad of ways, including by leading to death and illness from increasingly frequent extreme weather events, the disruption of food systems, increases in zoonoses and food-, water- and vector-borne diseases, and mental health issues. Accordingly, there is need of enhanced technology to explicitly account for weather/climate-based vulnerabilities, IMD in collaboration with other institutes of MoES and R&D institutes in the country and outside is continuously upgrading and enhancing the capabilities by augmenting modelling and observational network. The services to different sectors including health sector are being enhanced to safeguard the lives & economy of the country.*

*Recently, India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) has taken major steps in improving the weather, climate and hazards warning services in the country with the support of sister organizations of MoES like Indian Institute of Tropical Meteorology, National Centre for Medium Range Weather Forecasting, Indian National Centre for Ocean Information Services etc. With the improvement in observational and forecasting tools including augmentation of NWP models, radar network and satellite products, forecasting/warning services in respect of tropical cyclones, severe thunderstorms, nowcasting, flash/urban floods, urban climate, heavy rainfall, heat waves/cold wave advisories to farmers, fishermen, pilgrims and many others has been further strengthened.*

*I am overwhelmed by the response of students and young researchers who have submitted scientific abstracts for the National symposium from all across the country. Most of them are very interesting and provide new scientific knowledge to the society about the linkage between climate and health. I hope that the students will be highly benefitted from the interactions with the experts in the field and this would be the real success of the symposium. Further, I am very optimistic that the National Symposium will provide an excellent opportunity for interaction among scientists, experts, academician, stakeholders and industrialists to discuss the challenges in health sector in this warming scenario and bring out actionable recommendations for betterment of the society.*

*I wish the event a grand success.*

***K. S. Hosalikar***

*Chairman, IMS, Pune Chapter*

# ABSTRACTS

# Heat Stress and Health Warning System in Semi-Arid Region of Maharashtra, India

**Premsagar Prakash Tasgaonkar [1-2] and Priyanka Arun [3]**

*1 Researcher at WOTR Centre for Resilience Studies (W-CReS), Watershed Organisation Trust (WOTR), Pune, India.*

*2 PhD. Student at School of Social Work, Tata Institute of Social Sciences (TISS), Mumbai, India*

*3 MSc- Student at Environment Climate Change and Sustainability Studies- School of Habitat Studies, Tata Institute of Social Sciences (TISS), Mumbai, India*

## ABSTRACT

Climate change projections indicate that the world's most populated regions will experience more frequent, intense and longer-lasting heat-wave periods over the coming decades. Such events are likely to result in widespread overheating in the built environment, with an increase in heat-related morbidity and mortality. Although the relationship between weather and human health has been widely defined by outdoor temperature, corresponding increases in indoor temperature during heat events can also be harmful to health, especially in vulnerable populations. As World Health Organisation noted many systems have been based on heat–health responses that focus on urban areas, and many mitigation plans focus predominately on urban residents, but rural areas are still a blind spot. In connection to this, our pilot study was conducted in which heat-health advisory (through SMS) was disseminated to reduce the health impact and to manage the indoor and outdoor temperature. Our study aimed to understand the heat stress vulnerability in the rural area of (Yavatmal, Vidarbha region) and Jalna district (from Marathwada region) of Maharashtra, India. In total 80 data loggers were installed, 43 loggers measure temperature (T), and another 37 measure temperature and relative humidity (RH). Outdoor air temperature data were obtained from three installed automated weather stations (AWS) in study locations. In total 355 individuals are residing (49% male and 51% female) in the sample houses. The average temperature inside tin roof houses was the hottest (45.8°C) as compared to an outdoor temperature of 42.5°C between 12pm and 6pm. The self-reported Heat-Related Symptoms (HRS) reported are headache, heavy sweating, fatigue, intense thirst, vomiting etc. Common strategies to manage extreme temperatures are - the use of a cooler, fan, drinking penalty of water, changing in work schedule, taking more showers etc. Women, the elderly, people staying in tin-roof houses, labourers working in outdoor environments and people having pre-existing health conditions are most susceptible to extreme temperatures. The heat and health advisory were disseminated (SMS) to 2100 farmers, of which 93% reported that the advisories were useful, advisories helped them in rescheduling the outdoor activities (60%), helped in rescheduling the field activities (77%) and useful from a health perspective (87%).

# An empirical system for the prediction of heatwaves and operational monitoring of human heat discomfort

**Lekshmi S and Rajib Chattopadhyay**

*India Meteorological Department, Pune 411005*

## ABSTRACT

Heatwaves are periods of abnormally high temperatures more than the normal maximum temperatures. Several studies have identified the drivers of heatwaves based on different aspects, such as the synoptic scale systems, regional factors, and large-scale teleconnection patterns. Intraseasonal oscillations (ISO) are one of the dominant sources of ordinary and extreme weather conditions over the Indian region. However, in the Indian region, studies do not explicitly point out the existence of temperature ISO during the dry summer season. It is not clear whether the extreme temperature events over India can be explained as an amplification of such subseasonal modes, such as the mid-latitudinal heatwaves, which are identified as the extreme phase of Rossby wave mode amplification. In the current study, the dominant pair of intrinsic temperature ISO modes are identified using the empirical orthogonal function analysis of detrended surface temperature. Mode 1 and 2 are found to be driven by the mid-latitudinal Rossby waves, in which mode 1 follows the *subtropical westerly Jet waveguide* pathway and mode 2 follows the *European-Middle East-Indian Ocean pathway*, to propagate towards the Indian region.

Studies have shown that almost all the heatwave-related characteristics, such as frequency, duration, maximum duration, etc., are showing an increasing trend over different parts of the world as well as over the Indian region also. While northwestern India is impacted dominantly due to the dry heat conditions, the coastal states are also impacted by the humid heat discomfort. This poses an operational demand for the prediction and monitoring of heatwave type of situations and discomfort. The study proposes an operational framework for the short-range prediction of Excess Heat Factor Index (EHF) using the AI/ML-based method of Long Short-Term Memory (LSTM) network. Along with that, an operational framework for the real-time monitoring of the discomfort associated with the dominant modes of temperature ISO is also developed. This method is useful to identify the dry/humid heat discomfort conditions, mainly over the coastal states and southern peninsular India.

# Analysing the dynamics of malaria transmission through modelling in the Chhattisgarh state of India

**Shambhavi Krishna[1*] and Shailendra Rai[1, 2]**

*[1]K Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, Prayagraj-211002*

*[2] M. N. Saha Centre of Space Studies, University of Allahabad, Prayagraj-211002*

**Corresponding Author*

*Shambhavi Krishna*

*K Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, Prayagraj-211002*

*Email: shambhavi.krishna2908@gmail.com*

## ABSTRACT

India represents 3% of the global malaria burden, therefore malaria is a major cause of health concern in India especially in the remote forested areas of the country. India with diverse climatic conditions provide sustainable and ideal environment to malaria parasites and their vectors to cause transmission. India being the only high endemic country which has reported a decline of 17.6% in 2019 over 2018 and has sustained Annual Parasitic Incidence (API) of less than one since 2012.

The study includes the use of VECTRI (VECToR borne disease community model of International Centre for Theoretical Physics, TRIeste) model whose physics and associated parameters are based on the life cycles of the key vector, namely, Anopheles gambiae and parasite Plasmodium falciparum, is a mathematic dynamical model that accounts for the influence of population and climatic conditions, malaria transmission dynamics is investigated for a second most highly endemic region in India which is state of Chhattisgarh.

The model is calibrated over the region of Chhattisgarh for the time period of 20 years from 2000- 2019. The results shows the transmission along with malaria incidence are seen more in the months from July to September i.e., in the summer monsoon season. However, the activity declines rapidly around November. On linking temperature and rainfall to malaria vector abundance and disease incidence have yielded varied results in different districts in Chhattisgarh. The study shows that malaria transmission in Chhattisgarh shows strong spatial and seasonal variations across the state. Specifically, based on the EIR estimates, malaria transmissions are found to be more endemic in few of the southern, central and northern districts such as Baster, Dantewada, Sukma, Bijapur, Narayanpur, Kondagaon, Raigarh, Jashpur, Balrampur, Bemetara and Baloda- Bazar.

**Keywords:** EIR, Rainfall, Temperature, Anopheles gambiae and Plasmodium falciparum

# Indian Extreme Rainfall Events frequency in different climatological epochs

**Ananya Karmakar[1,*], Rajib Chattopadhyay[1]**

[1]*India Meteorological Department, Pune, Shivajinagar, Pune-411005, India.*

[*]*E-Mail: akananya1@gmail.com*

## ABSTRACT

In recent years, heavy precipitation events have resulted in several damaging floods in India. According to IPCC 2022, few Indian states are the most vulnerable to climate hazards such as floods, droughts and cyclones. India is one of the global hotspots identified in the IPCC report as well as domestic reports. The immediate health impacts of floods include drowning, injuries, hypothermia, and animal bites. Floods can potentially increase the transmission of the following communicable diseases: Water-borne diseases, such as typhoid fever, cholera, leptospirosis and hepatitis A and E. Vector-borne diseases, such as malaria. A detailed study on extreme rainfall events covering the entire region and using the latest data is urgently needed.

to obtain a clear idea about the impact of climate change on the extreme weather events of the country. The frequency of extreme rainfall events (heavy and very heavy rainfall) is analysed in four different climatological epochs of 30 years from in a 120 years of time span. The trend and intrinsic variability frequency of extreme rainfall events very diverges in epochs. The present study used 120 years of 1901 to 2020 of 0.25x0.25$^{o}$ IMD gridded rainfall data over the period of to analyse the occurrences of extreme rainfall events in the Indian region. A linear rise of trend has been noticed in heavy (100 to 150) and very heavy (>150mm) categories between the years 1901 and 2020. The core Indian monsoon region showed a high frequency of extreme rainfall events (above 100) in the inter-decadal time frames. A sharp rise in the number of events was observed in the post-industrial period (post-1980). It is noted that the Sea Surface Temperature over Equatorial Indian Ocean influence frequency of extreme rainfall events in the core monsoon zone. The strong correlation between Equatorial Indian Ocean Sea Surface Temperature and extreme rainfall events frequency (>0.6) suggesting the increased frequency of extreme rainfall events may increase the flood risk in the areas with high correlation for the upcoming years.

**Keywords:** Extreme rainfall, Climatological epoch, Sea Surface Temperature.

# The effect of terminal heat stress on wheat production in Haryana's eastern zone

**Yogesh Kumar[1]*, Shivinder Singh[2]**

*[1]*Krishi Vigyan Kendra, ICAR-National Dairy Research Institutes, Karnal, Haryana*

*[2]India Meteorological Department, Chandigarh*

*Corresponding author mail: yogeshgujjar62@gmail.com*

## ABSTRACT

Wheat (*Triticum aestivum* L) is one of the most important cereal crops of the world. Heat stress is one of the main abiotic stresses that globally lowers wheat grain yield, especially in semi-arid and sub-tropical regions. Heat stress is very damaging to wheat. Wheat yield can be reduced by 6% for every degree that the temperature rises. When the mean temperature during the grain filling stage exceeds 31 °C, terminal heat stress in wheat occurs. The main reason for the low productivity is the rise in temperature during grain filling. The range of normal maximum and minimum temperature prevailed during February was 21-24 °C and 5.5-9.3 °C, March 26.0-38.8 °C and 9.1-22.7 °C due to which the wheat crop ripened before its time. During 2020-21 & 2021-22, the average temperature in March and April was 2-3 28.4 °C higher and this increased the effect of terminal heat stress. As a result, the yield of the wheat was reduced by 2-3 quintals per acre. An abrupt rise in the maximum and minimum temperatures over Karnal results in a loss of 8–10% in the final crop yields of wheat in 2020–2021 and 2021–2022. The results indicated that wheat matured earlier than normal due to elevated temperatures. Maximum temperatures reached 40 ºC on March 15 during both consecutives years and remained at or above this level throughout the wheat harvesting period. Crop varieties that are resistant to heat stress were bred, climate change cropping practices were implemented, conservation agriculture was embraced, and planting window adjustments were some mitigation strategies to combat the effects of heat stress.

**Keywords:** Terminal heat stress, Temperature, Wheat, Yield loss

# A spatio-temporal study of Urbanisation impact on Land surface temperature, Soil salinity and Extreme drought events in Hyderabad

**Fawaz Parapurath*, Santanu Kumar Bal, A.V.M. Subba Rao and M.A. Sarath Chandran**

*ICAR-Central Research Institute for Dryland Agriculture, Hyderabad*
**Corresponding Author Email: faazzz96here@gmail.com*

## ABSTRACT

Urbanization has a substantial influence on the climate, and the land surface temperature is a key variable for understanding urban thermal patterns. The negative impacts of climate change also have a considerable effect on soil salinity. One of the frequent environmental issues that affect agricultural output and land resources is salinity, where less rainfall and high temperature are the significant determinants of the dynamics of soil salinity (semi-arid and arid regions). This study is aimed to calculate the change in NDSI (Normalized Difference Salinity Index), and LST (Land Surface Temperature) in accordance with the LULC (Land Use Land Cover) change over 2010-2020 in Hyderabad. Three main categories of LULC types were classified, namely Built-up areas/Urban settlements, Vegetation land, and Water bodies. A comparative analysis was also executed with the rainfall data of 2000-2010, and 2010-2020 for the identification of extreme drought events contributing to aridity and salinity. The change detection study revealed that Built-up areas/Urban settlements increased from 188 sq.km to 192 sq.km (4 sq.km). Consequently, the areas under salinity also increased from 5.45 sq.km to 8.28 sq.km (2.83 sq.km), and the average land surface temperature hiked from $27.8^0$C to $31^0$C ($3.2^0$C). This implies that urbanization has a substantial influence on salinity and land surface temperature. The comparative analysis of rainfall data depicts that, there was no single meteorological drought year occurred from 2000 to 2010, whereas from 2010 to 2020 two meteorological drought years happened with a percentage deviation of -26% to -50% (moderate drought) in 2015 and 2018 respectively. It is inferred that long-term continuous monitoring of land use change is a necessary first step in comprehending soil salinity change, and its consequences on other land use types. Reduced dilution capacity during drought times, and an increase in the percentage of streamflow originating from polluting point sources contribute to the hike in saline levels due to urbanization. To develop successful strategies to reduce the amplitude of Urban Heat Island (UHI) effect, it is critical to study the relationship between LST and urban surface features.

# Assessing Features-Based Verification for Indian Monsoon Extreme Rainfall

**Harvir Singh[1,2]*, Anumeha Dube[1], Raghavendra Ashrit[1] and Prashant Kumar Srivastava[2]**

[1]*National Centre for Medium-Range Weather Forecasting, Ministry of Earth Sciences, India*
[2]*Institute of Environmental and Sustainable Development, Banaras Hindu University, India*

## ABSTRACT

Numerical weather prediction (NWP) models are widely used for forecasting heavy rainfall events in the Indian region. However, the accuracy of these models can vary depending on various factors such as model configurations, data assimilation techniques, and physical parameterizations. Traditional verification metrics like the probability of detection (POD) and false alarm ratio (FAR) may not provide sufficient information to evaluate the performance of NWP models accurately. To address this issue, the study proposes a features-based verification approach to evaluate the performance of four NWP multi-models (NCUM, GFS, NCEP, and UKMO) in predicting heavy rain events in the Indian region from 2020 to 2022.

The study plans to use high-resolution observed gridded precipitation data from the Global Precipitation Measurement (GPM) mission and NWP multi-models to evaluate the shape, size, position, structure, and orientation of forecasted precipitation features and compare them with observed precipitation data. The study aims to identify the strengths and weaknesses of each NWP model in predicting heavy rainfall events and provide recommendations for improving the accuracy of heavy rain forecasting in the Indian region. The findings will be useful for disaster management and policy-making to mitigate the impact of extreme weather events on life and property.

This study highlights the importance of using a features-based verification approach that goes beyond traditional metrics to evaluate the performance of NWP models for heavy rain forecasting. The proposed approach will provide a more comprehensive understanding of the spatial and temporal characteristics of forecasted precipitation and will help improve the accuracy of heavy rain forecasting in the Indian region. The study will contribute to the existing knowledge of heavy rain forecasting and provide insights for future research.

**Keywords:** Features-based, Verification, Multi-models, NWP

# Role of agromet advisory services in healthy crop growth and increasing farmer's income

**R.S. Sayyad[1], V. M. Jadhav[2]**

*[1] Subject Matter Specialist-Agrometeorology, Krishi Vigyan Kendra, Palghar, 401703, (M.S)*
*[2]Senior Scientist & Head, Krishi Vigyan Kendra, Palghar- 401703, (M.S)*
*E-mail: rizwanasayyad94@gmail.com*

## ABSTRACT

India Meteorological Department (IMD) and Indian Council of Agricultural Research (ICAR) collectively started District Agromet Unit (DAMU) under Gramin Krishi Mausam Seva (GKMS) project at Krishi Vigyan Kendras (KVKs) to minimize the farm losses. DAMU, KVK, Palghar has received forecast from RMC, Mumbai bi-weekly (every Tuesday and Friday). District & Block wise Agromet Agromet Advisory Bulletin (AAB) were prepared & disseminated through different social media like What's app, Newspapers, AIR Channel, Television. 13295 tribal farmers getting benefits through what's app groups. The impact of AAS of DAMU was analyzed in end of the kharif season 2022 by conducting a feedback survey through google form shared in block level what's app groups created by DAMU. 300 farmers have given response though google form. It results that 63% of the farmers said that these weather-based agro advisories were useful in all practices of crop cultivation, followed by 14.7% of the farmers said that the advisories were play major role while taking decision at harvesting stage of crop, 11.3% of the farmers used forecast and advisory during sowing and transplanting stage.majority of the farmers responded belonged to age group of 41-60 years (38.6%) followed by 21-40 years (16.2%). 95% of farmers continuously carried out timely farm management according to given forecast and Agromet Advisory Bulletins (AAB), only 5 % of farmers did not. 40.7% farmers under rainfed farming system and 39.7% farmers under both rainfed & irrigated farming system following AAS. 51% of the farmers said that they were highly satisfied with these Agromet Advisory Services (AAS), followed by 36.7% of farmers satisfied with the Agromet Advisory Services. And 70% of them responded that they saved Rs.0-10,000 of their production cost because of timely getting weather forecast by DAMU. It is concluded from the study that weather forecast, agro advisories, extreme event alerts play major role in healthy growth of crop to reduce emergence of pest and diseases, decrease cost of cultivation, crop damage and enhanced yield of crops and farmers income too.

**Keywords:** weather, agro-met advisory services, farmers feedback

# Rainfall variability and probability analysis for crop planning in Narkhed tehsil of Nagpur

**Wankhede SY[1], Rokde SN[2]**

[1] *Subject Matter Specialist, Agrometeorology, KVK, GKMS ACROSS, District Agromet Unit, Krishi Vigyan Kendra, ICAR- Central Institute for Cotton Research, Nagpur*
[2] *Principle Scientist (LPM) and Head, Krishi Vigyan Kendra, ICAR- Central Institute for Cotton Research, Nagpur*
*Email id: wankhedesachin04@gmail.com*

## ABSTRACT

The economy of farmers mainly depends on agriculture. Narkhed tehsil is a major producer of oranges. Cotton, Soybeans, Wheat, Arhar, Green gram, Chickpea etc. cultivate in the Tehsil. Farmers often grow vegetables throughout the year in the Narkhed tehsil. Agriculture in the tehsil mostly depends on rainfall. Farmers supplement with wells, river water, irrigation dams and canals. Pimpalgoan Wakhaji is the biggest irrigation dam. Other irrigation dams include Kar dam, Paradsinga dam, Ambada dam. Rivers including Wardha, Jam, Mandakini, Wandali and Kolar are used for irrigation of the Rabi crop. The long-term rainfall data of 33 years of Narkhed tehsil were taken for analysis of rainfall variability and probability of dry and west spell with the help of incomplete Gamma Distribution and Markov chain models. The greatest risk to crop yields in Indian agriculture is attributed to the variability of seasonal rainfall and the uncertainty in the amount and distribution of rainfall for a given season (Virmani et al., 1980). The knowledge of rainfall variability and weekly probability helped in better agriculture planning and by taking decision of farm operations. Different characteristics of rainfall were carried out for the annual, seasonal, monthly and weekly basis. The percentage contribution of the mean seasonal rainy days to the seasonal mean rainy days (53.81) of Narkhed tehsil, contribute 2.19 %, 3.88 %, 86.32 % and 7.60 % for the Winter, Summer, South West Monsoon and North East Monsoon respectively. The seasonal co-efficient of variation (CV) was observed 104.61, 120.97, 31.35 and 84.32 during Winter, Summer, South West Monsoon and North East Monsoon respectively. It was observed that rainfall variability varies from (-) 38.0 to 83.7 per cent. Out of the 33 years of data studied, 19 years (1990, 1991, 1993, 1995, 1996, 1998, 1999, 2000, 2002, 2003, 2005, 2006, 2009, 2011, 2012, 2015, 2019, 2020 and 2021) was observed Normal (-19 to 19 per cent), 8 years (1992, 2001, 2004, 2008, 2014, 2016, 2017 and 2018) was observed deficient (-59 to -20 per cent) rainfall year, 5 years (1994, 1997, 2007, 2010 and 2013) was observed Excess (20 to 59 per cent) rainfall years, whereas only one year (2022) was observed Large excess (more than 60 per cent) rainfall year. Weekly rainfall of 10, 20 and 30 mm was considered as thresholds, as they have some relevance for carrying out agricultural farm operations like sowing, intercultural operation, agrochemicals application, fertilizer application, harvesting and threshing etc. under rainfed condition.

**Keywords:** Rainfed agriculture, Rainfall, Probability, Variability, Dry and Wet week, Weather based crop planning.

# Impact of climate change and variability on farm production through modelling under Sustainable Agricultural Pathway

**Dr. N. Subash**

*Principal Scientist, ICAR-Indian Institute of Farming Systems Research*
*Modipuram-250 110, Meerut, Uttar Pradesh, India*
*Cell No - +91-9457248070; +91-8272045060*
*Email: n.subash@icar.gov.in; nsubashpdfsr@gmail.com*

## ABSTRACT

Around 85% of the Indian farming community belongs to marginal and small farmer categories that are resource poor. Indian farmers are heterogeneous and unorganized in nature. Climate change and variability are likely to aggravate future food security by putting pressure on agriculture affecting its sustainability. Excess use of inorganic fertilizer along with frequent use of pesticides adversely affected the soil health. In addition to this, climate change and climate variability threatens productivity, livelihoods and nutritional security of small and marginal farmers. Under this situation, there is a need to study the vulnerability of these small and marginal farms under projected climate change. Under ICAR-AgMIP Collaborative Project, we have studied the impact as well as vulnerability of agricultural farms in two districts (Meerut in Uttar Pradesh and Karnal in Haryana) using Climate-Crop-Economic modelling approach. Current farms exposed to climate changes could experience a decline in net farm returns of 4% to 14% and a decline in per capita income by 3.0% to 8.6%. Though the magnitude of decline in net farm returns and per capita income may seem small, these will adversely affect a large proportion of farms – nearly 49% to 74% of the population. Future rice-wheat production systems in 2050s are also vulnerable to climate change. Up to 51% of rice-wheat farm households could be vulnerable to climate change impacts under a sustainable pathway. In the future production system the adaptation strategy would result in 9% to 12% increase in net farm returns, about 6% to 9% increase in per capita income and 3% to 4% decline in poverty. Under sustainable pathways, about 53% to 60% of the farm population would adopt the adaptation. There is a lot of diversity in soil characteristics; hence, at least three to four major soil types and their characteristics should be included for simulation, so that more accurate and realistic assessment results can be drawn.

# Impact Based Forecast (IBF) for Agriculture for minimizing the production losses in agriculture

**A. K. Misra*, M. R. Deo, J. P. Sable, Ravindra G. Patil, Asha Latwal, Kripan Ghosh**

*Agricultural Meteorology Division, India Meteorological Department Pune- 411005*
**Corresponding Author : ashutosh.imd@yahoo.com*

## ABSTRACT

Weather plays a crucial role for taking various types of decisions in agriculture to ensure optimal crop growth and yields. To fulfil the needs of weather information for effective farm operations, necessity of the Agromet Advisory Services (AAS) was felt long back to cater to the specific requirements of farmers in the country. Thus, providing information on selection of crops and varieties, crop management practices like sowing and harvesting of crops, pest and disease management, irrigation scheduling etc. based on realized and forecast weather was started by India Meteorological Department (IMD) in 1976 at State level. With the improvement in the accuracy and lead time of forecasts due to introduction of advanced numerical weather prediction models, improved data (both conventional and non-conventional) & its assimilation and introduction of high speed computers, AAS are being rendered by IMD at District level for all the agriculturally major districts (700) from 2018 and for selected blocks (~3100) from 2019 under Gramin Krishi Mausam Sewa (GKMS) scheme aiming towards enhanced crop production and food security.

District and Block level AAS bulletins, under GKMS scheme, are being prepared by various Agromet Field Units (AMFUs) and District Agromet Units (DAMUs) on every Tuesday and Friday which help the farming community to take appropriate decisions to achieve the optimal yield potentials of various crops. Recently, IMD started issuing 'Impact Based Forecast (IBF) for Agriculture' during the extreme weather conditions such as heavy rainfall, hail storm, cold wave, frost, heat wave, strong surface winds etc. These are particularly of exceptional importance when there are sudden changes in the prevailing weather conditions which may adversely affect the crops. For example, **heat wave conditions and significantly high temperatures in North Western Parts of the country during March and April 2022 resulted in decline of yield of wheat and other *rabi* crops as well as reduction of grain quality. In the current year (2023) also, during the later part of February, the sudden rise in temperatures, especially in Himachal Pradesh, is expected to have sterility in apples due to early flowering.** On the other hand, hailstorm is also noticed to cause considerable damage to winter and summer crops in many states of India. Adverse impacts of heavy rainfall on crops are also reported during various periods of the year. Timely issued IBF and appropriate agromet advisories are highly useful for the farmers to make necessary arrangements to save their crops; e.g. IBF **for Agriculture were issued for various districts of Mizoram on 22nd October 2022 in view of forecast of heavy rainfall due to Cyclonic Storm 'Sitrang' and accordingly farmers were advised to harvest the rice crop in next 1-2 days and move the harvested produce at safer places. Where immediate harvest was not feasible, farmers were suggested to postpone the harvest till the cessation of rains which helped them to reduce the crop losses. In present study, performance of IBFs issued for agriculture during various extreme weather conditions have been presented.**

**Keywords:** Impact based forecast, extreme weather events, heat wave, heavy rainfall.

# Impact of high temperatures on wheat growth and yield over north-west India

**Asha Latwal, Bhairavi Kurtkoti, Jacob Thampan, A. K. Misra and Kripan Ghosh**

*Agricultural Meteorology Division, India Meteorological Department Pune- 411005*
*Corresponding author mail: asha.latwal@imd.gov.in*

## ABSTRACT

In India wheat is the second important cereal crop after rice. The crop is primarily grown in the states of Central and North India during Rabi season which is usually sown during November-December and harvested in March-April. The crop productivity is influenced by a variety of biotic and abiotic factors, and among the abiotic stresses, the high temperature has significant impacts on growth and development of wheat. Rise in maximum temperature during December and January adversely affects the active tillering phase of the crop while the reproductive phase is affected if maximum temperature rises during February and March. Due to aberrations in temperature in last few years, wheat production across the northern belt of the country could not achieve the targeted estimates. The mean temperature requirement of wheat varies under different growth stages, such as 15-20°C, 18-24°C and 23-25°C for growth and development, flowering and grain development, respectively (Reddy and Reddy, 2007). However, it may differ among the varieties also. In current scenario high temperature from anthesis to maturity (specially during grain filling stage) is being observed as one of the major constraints limiting the wheat yield. Studies revealed that every 1oC rise in temperature may decrease the wheat production by 4-6 million tonnes (Aggarwal, 2008).

In view of above, response of wheat against high temperature during recent years over north-west India has been studied integrating climate information with Crop simulation model to combat adverse impacts and to suggest suitable strategies for improving the productivity. Two stations viz. Hisar in plains and Palampur in hills have been selected to assess the impacts under irrigated and rainfed conditions, respectively. Historical weather data of more than 35 years have been used to study the temporal variability and occurrence of high temperature events. At Hisar, during the whole study period, it has been observed that the number of days having maximum temperature departure exceeding 1oC ranged between 5-17, 3-22, 6-28 and 3-28 during January, February, March and April respectively; whereas, for Palampur, it ranged from 5-29, 6-24, 3-28 and 5-27 during above-mentioned months across the years. It is evident from the statistics of past few years that wheat yield has been fluctuating in these two districts, which may be due to the rising temperatures during February and March. Thus, there is need to follow appropriate measures such as adjustment in sowing time, selection of heat tolerant varieties, irrigation management, water harvesting in the areas of rainfed agriculture etc. to manage the crop heat stress for sustainable crop productivity and to ensure food security in future.

**Keywords:** High Temperature, Heat Stress, Wheat yield, Food Security.

# Climate Change: A predictor of tick seasonality and Kyasanur Forest Disease in Southern Western Ghats region of India

**R. Balasubramanian**

*Scientist E, National Institute of Virology, Kerala unit, Alappuzha*

## ABSTRACT

**Background Information:** Ixodid ticks (Acarina, Ixodidae) are the major vectors for infectious bacterial, viral, and protozoan pathogens affecting humans and animals. Kyasanur Forest Disease (KFD) is a viral zoonotic disease that has become endemic in many areas of the Western Ghats of India. The objective of this study is to determine the effect of climatic changes on tick abundance and KFD prevalence in the Western Ghats. **Methods**: The present study was conducted in the Western Ghats forest areas of the Wayanad district. The study was conducted from December 2017 to May 2019. Questing ticks were collected by dragging a flannel cloth. The collected tick species were identified. Air temperature and relative humidity were measured 5 cm above the soil surface using a temperature-humidity probe, and detailed climate data were obtained from the nearest meteorological station of the two study sites. **Result:** A total of 9,595 ticks were collected from December to May during the period of 2017–2018, and 4,512 ticks were collected during the 2018–2019 period. In the 2017-2018 study periods, the number of collected ticks increased from December to February and then decreased until May. Temperatures ranged from 28°C to 30°C, and a relative humidity of 60 to 80 percent was more favourable to support high questing nymph tick density (4.23 ticks per m of sampling) during December to February. From the onset of summer rain in April, the tick density was reduced to <1 ticks per minute of sampling. *H. spinigera* and *H. turturis* were predominant in all months and reached a peak in January. The KFD viral RNA was detected in 21 (3.67%) pools out of the 572 pools tested. In the year 2018–2019, the study area recorded three times more rainfall, and the total number of ticks collected decreased by 55.5% when compared to the previous year. The occurrence of *H. spinigera* and *H. turturis* dropped to 50.7% and 24.7%, respectively. **Conclusion**: Changes in climatic factors alter tick biology. In this study, tick infection was reported from December to February. This period was characterised by moderate temperatures (28°C–30°C) and relative humidity (60–80%), which favour the high questing nymphal activity. In addition, the results of this study on the flood event reported that the activity of ticks massively decreased after the flood. Hence, the extreme climatic conditions change the tick's seasonality and, therefore, the nature of tick-borne diseases.

# Climate effects on mosquito demographics in urban and coastal areas

**Pratip Shil**

*Scientist E, ICMR National Institute of Virology, Pune, India*
*Email: shilpratip@gmail.com*

## ABSTRACT

Climate change has brought new challenges in human health including the increased spread of vector-borne diseases like Dengue, Chikungunya, Zika, West Nile, Crimean Congo Hemorrhagic and other viruses worldwide. Gradual warming has resulted in tropical mosquitoes expanding their domain and spreading to new areas in temperate latitudes or moving up the altitude along the Himalayas. The Indian sub-continent with its unique monsoon system is prone to climate change effects. While the pattern and amount of monsoon rainfall has changed over the last decade especially along the west coast of India, extreme weather events like floods and draughts have increased in northern plains and central India. With this came the increasing burden of Dengue and Chikungunya in India over the last 10 years. This necessitated studies to understand the climate effects on mosquito demographics as well as on mosquito-borne diseases.

We have carried out first ever systematic year-round survey of mosquito demographics in India in both Urban and coastal settings. We determined the mosquito species diversity, seasonal variability in abundance and relationship of mosquito abundance with meteorological parameters in the Pune Urban Zone (18.52 N/73.85 E), Maharashtra in 2017-18 and also in the coastal villages in Alappuzha, Kerala in 2018-19.

In the Pune Urban Zone, which is located on the eastern slope of the Western Ghats mountains, thirteen species of mosquitoes were found covering 4 genera, ie, *Aedes, Anopheles, Armigeres* and *Culex. Culex* spp. was abundant throughout the year, while spurt in Aedes population was seen only during South West Monsoon (SW). Overall, mosquito abundance increased during the SW Monsoon due to low diurnal temperature range (DTR) along with increased rainfall and humidity, but decreased during winter followed by a slight increase during the Pre-Monsoon season.

In Kerala, the study provided valuable information about the mosquito demographics and seasonal variability of abundance in human settlements along the Arabian Sea shoreline in Alappuzha, India. A total of 20 species were identified across five genera: *Aedes, Anopheles, Armigeres, Culex* and *Mansonia*. *Culex tritaeniorhynchus* is the eudominant species followed by *Culex quinquefasciatus* and *Culex gelidus*. The seasonal variability of *Cx. tritaeniorhynchus* and *Cx. gelidus*, the two principal vectors for West Nile and Japanese Encephalitis viruses, were studied.

Also, the talk will include some highlights of work on climate and viral disease conducted by ICMR NIV Pune.

# Seasonality of TB in India

**Hardik Batra**

*Indian Institute of Technology, Bombay*

## ABSTRACT

India is home to 1/3rd of worlds TB cases, but we have not been successful in eradicating this 'perpetual epidemic' in-spite of significant efforts. The seasonality in occurrences of smear positive Tuberculosis cases in India is known for a couple of decades but the origins of such seasonality are not clear. In this work we explore the hypothesis that the seasonality in climate variables, especially temperature, humidity and dew point temperature, are associated with the seasonal incidences of Tuberculosis cases. We use the Daily-District wise data from the Revised National TB Control Programme (RMTCP), across the years 2017 to 2021, to empirically test the seasonality in TB cases in India. This dataset has significantly higher spatial (district-wise) and temporal (daily) resolution as compared to all past datasets presenting a unique opportunity to study TB and Climate links.

Consistent with past studies, we find that a north-south contrast exists in India. This contrast exists in the total number of infected cases per 100,000 people as well as in the amplitude of seasonality (difference between the peak and trough in TB cases during the year). This result is by and large valid across different districts in India and throughout the study period. We propose to further identify and quantify the time-lag between TB incidences and their climate precursors. Such information can help improve the distributive and allocative efficiency of supplies of tests for TB detection in advance.

# Prevalence of malaria cases over India: Prediction using NCMRWF weather forecasting model at Seasonal scale

**Priya Singh[1], Sushant Kumar[1], Raghavendra Ashrit[1], Akhilesh Kumar Mishra[1], Mahendra Benke[2], K C Gouda[2]**

*[1]National Centre for Medium Range Weather Forecasting, Ministry of Earth Sciences, A-50, Institutional Area Phase-2, Sec-62, Noida*
*[2]CSIR Fourth Paradigm Institute, NAL Wind Tunnel Road, Bengaluru – 560037, India*
*Correspondence: priyasingh@ncmrwf.gov.in*

## ABSTRACT

Malaria is a disease that is transmitted through the bites of Anopheles mosquitoes and is considered a vector-borne illness. In India, it has a significant impact on public health, with a large portion of the population experiencing malaria infections annually, which can result in fatalities. The prevalence of malaria varies considerably depending on the geographic location and climate, with meteorological parameters such as temperature, relative humidity, and rainfall having an impact on the breeding, growth, and transmission of the Plasmodium species of protozoan parasite responsible for causing malaria. There are certain regions in India which are very prone to malaria outbreaks. Based on the data from 2013 to 2018, the highest number of malaria cases in India was recorded in the central region, with the states of Chhattisgarh and Orissa reporting over 100,000 cases annually during this period. The weather dependence of number of malaria cases demonstrated a significant negative correlation with all India maximum temperature (-0.44), minimum temperature (-0.05), and relative humidity (-0.28), while displaying a positive correlation with all India rainfall (0.28). To minimize the fatalities and reduce the number of cases the concerned authorities should have a well-planned strategy in advance.

The **N**CMRWF **S**easonal **P**rediction **S**ystem (NSPS) is a coupled Numerical Weather Prediction model which provides the weather forecast guidance for the next 6 months. These forecasts have been utilized for Heat wave and Monsoon prediction over India. In this study we have evaluated the capability of NSPS using a mathematical malaria model for providing the guidance on the prevalence of malaria cases in India a few months in advance. The results based on the hindcast data for 23 years (1993-2015) suggest that NSPS represents the spatial and temporal variability at a reasonable skill up to 3 months with model initialized in May and Aug for the months of JJA and SON respectively.

**Keywords:** Malaria, Weather, Prediction, Seasonal, NWP model

# A curious case of the Indian Summer Monsoon 2020: The influence of Barotropic Rossby Waves and the monsoon depressions

**Nagaraju Chilukoti**

[1]*Department of Earth and Atmospheric Sciences, National Institute of Technology, Rourkela – 769008, India.*

**Email: chilukotin@nitrkl.ac.in/chilukotinagaraju@gmail.com*

## ABSTRACT

India has received above-average rainfall during the 2020 summer monsoon season. Total 12 Low Pressure Areas (LPAs) formed in the north Indian Ocean during summer 2020 (in JJAS season). The significance of this monsoon season is that August 2020 received the highest all-India rainfall in the past 44 years since 1976. This is accompanied by around 50% of the total seasonal LPAs formed in August 2020, none of which intensified into a monsoon depression (MDs). This study attempts to understand the characteristic features of monsoon rainfall during August 2020 and explore the plausible mechanisms behind the LPAs not intensifying/concentrating as MDs. It is noted that the anomalous warming over the Northern Parts of the Arabian Sea (NPAS) resulted in increased convection over this region in August 2020, as a result, strong low-level convergence is observed. In addition to this convergence, strong northwesterly winds emanating from central Asia merged with the enhanced cross-equatorial monsoon flow. However, this strong flow over the Arabian Sea sheared/dissociated into two branches: one extending up to northwest (NW) India along the monsoon trough, another one diverging into an anticyclone over the south Bay of Bengal (SBOB), which reduced the horizontal shear there (Barotropic Instability). This anticyclone strength over the SBOB and its westward shift is determined by the western north Pacific (WNP) anticyclone. Our analysis suggests that due to the poor barotropic instability over the head BOB, LPAs could not develop into MDs. Additionally, upper level (200 hPa) barotropic Rossby wave in August 2020 remains stationary over South Central Asia and retrogressed with a northeast to southwest orientation. It determined the path of movement of the low-level disturbance beneath and affected the all-India rainfall by virtue of enhanced rainfall over NW & Western Ghats (WG) regions. The interplay of the barotropic Rossby wave alongside low-level anticyclone over the WNP accompanied by local conditions caused the above normal rainfall over India in August 2020, even though there are adverse dynamical conditions.

**Keywords**: summer monsoon rainfall; low-pressure area; Rossby wave; barotropic instability; stationary; retrogress

# Chemical Characterization of Atmospheric Particles and their Microbial Activities at Urban Region of North India

**Shailendra Pratap Singh* and Ajay Taneja**

*Department of Chemistry, Institute of Basic Science, Khandari Campus, Agra*
*Dr. Bhimrao Aambedkar University, Agra*
*Email id: shailendrabhaskar047@gmail.com*

## ABSTRACT

The World Health Organization estimates that particulate matter (PM) air pollution contributes to approximately 800,000 premature deaths each year, ranking it the 13$^{th}$ leading cause of mortality worldwide. PM is a portion of air pollution comprising extremely small particles and liquid droplets containing acids, organic chemicals, metals, and soil or dust particles. PM is categorized by size and continues to be the fraction of air pollution that is most reliably associated with human disease. In the present investigation particulate matter ($PM_{2.5}$ and $PM_{10}$), microbial concentration, and metal concentration in the ambient environment of the city of Taj, i.e., Agra (India) were assessed.

The average mass concentration of $PM_{10}$ at Khandari and Trans Yamuna was found232.81µg/m$^3$ and 231.085µg/m$^3$ respectively and the concentration of $PM_{2.5}$ was found 147.24µg/m$^3$ and 121.915µg/m$^3$ respectively during the study period.

The composition of bacteria and fungi using a culture technique was also examined, which indicates that bacterial concentration was higher as compared to fungi. The levels of $PM_{2.5}$ and $PM_{10}$ are much higher than the recommended value set by NAAQS in India. Bacteria and fungi count numbers and nomenclatures were also reported in the study. Instead of the traditional culture method, BOD incubation techniques had been adopted in this study. Culture techniques had been used for microbial growth and biological characterization using different media, pH, temperature, and incubation periods. This study may help in developing a standard method for bacterial and fungal characterization.

# Analysis and assessment of ambient air quality at Tiruppur taluk

**Sharan Karthik**

*Kumaraguru college of technology*

## ABSTRACT

Air pollutants slowly deposit in the lungs and affect the respiratory system of human beings. Air exceptional in towns is getting worse due to the traffic, industrialization and urbanization. Major Pollutants inflicting air pollutants is particulate matter (PM10, PM2.5), Oxides of Nitrogen (NO2), Oxides of Sulphur (SO2), Carbon monoxide (CO) and Lead. Air samples are collected and determined by using Respirable Dust Sampler and Fine Particulate sampler and Gas analyser. Artificial Neural Network (ANN), Linear and Logistic Regression are used to predict the Air Quality Index and it will create air pollution awareness to the society. The calculated AQI values for 8 hours average PM10, PM2.5, SOX and NOX concentrations are categorized as good during the study period at all the sites. The AQI values calculated for ambient air quality parameters and its maximum concentration were obtained in the year 2015 was about 25.05 under good category. Data Mining tool WEKA 3.8.1 is chosen for the analysis. Different analyses are done on air pollution data of tiruppur taluk zone for six years (2015-2021) and regression algorithms are used to understand the data behavior patterns. Predictive analysis is used to evaluate the future trend of data using Linear Regression, and Random Forest, non linear regression SMOReg, Additive Regression and REPtree. Various errors are calculated to check accuracy of algorithms. As a result, the generalisation error in the following combination, which is utilised to estimate future AQI for Tirupur taluk using derived equation AQI = (0.58 x PM 10 ) + 0.2.

# Green conservation of hazardous red mud in fiber reinforced concrete

**Remisha S.R, Dr.A.Gandhimathi**

*Kumaraguru College Of Technology, Coimbatore, Tamilnadu*

## ABSTRACT

Red mud is a strongly alkaline leaching solid hazardous waste material generated in the Bayer process of alumina production. India ranks 4$^{th}$ place in alumina production. According to the Ministry of Mines (Oct 2022), India produces 9 million tonnes of red mud annually. The high alkalinity and caustic content of red mud will contaminate the groundwater and fertile soil, and also there is a limitation on the utilization of red mud. Due to its low utilization ratio, large amount of red mud is stacked in disposal areas, which may cause water pollution, soil salinization and heavy metal pollution. Red mud contains toxic metals such as arsenic, chromium, lead, nickel, zinc and radioactive elements such as thorium, potassium, and uranium, which cause severe effects on the environment and also on our health. And also, the concrete technologists are hardly working to reduce the environmental impacts produced by the construction. Cement is a significant binder material in concrete. But it emits $CO_2$ during manufacturing and during construction, 1 ton of cement produces 1 ton of $CO_2$, it widely impinges the environment. To surmount this effect experimental work is executed in Glass Fiber Reinforced Concrete (GFRC) with red mud added as a replacement for cement in the proportion of 5%,10%,15%,20% and 25% and 1% of glass fiber is added by volume for all the mixes. This study is executing in M20 grade of concrete. The mechanical behavior of GFRC such as compressive strength, flexural strength and split tensile strength is studied and it is found that 10% replacement of cement by red mud with 1% glass fiber gives optimum strength. The addition of glass fiber enhances the tensile and flexural strength of the GFRC.

**Keywords**: Red mud, Bayer process, toxic metals, radioactive materials, Glass fiber.

# Evaluation of spatial and Decadal Variability of PM2.5 on Human Health over the IGB regions of India

**Mohd Akbar Ali, Vijay Kumar, Sudhir Kumar Singh**

*K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, Prayagraj-211002, India*
*E-mail ID: maakbar@allduniv.ac.in*

## ABSTRACT

The Indo-Gangetic Basin (IGB) is one of the most polluted regions in the world, with high levels of particulate matter with aerodynamic diameter less than or equal to 2.5 microns (PM2.5). This study aimed to investigate the spatial distribution of PM2.5 concentrations in the IGB region and its impact on human health. We performed a spatial analysis of PM2.5 concentrations in the IGB using satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) for the period of 2011 to 2021. We used spatial interpolation techniques to generate high-resolution maps of PM2.5 concentrations in the region. Our results showed that PM2.5 concentrations were consistently high throughout the IGB region, with the highest concentrations observed in the central parts of the basin. The annual average PM2.5 concentration in the region was between 150 to 200 $\mu g/m^3$, which is more than ten times higher than the World Health Organization (WHO) annual average guideline of 10 $\mu g/m^3$. We found a significant positive correlation between PM2.5 concentrations and human diseases. Our findings highlight the urgent need for effective policies and interventions to reduce PM2.5 pollution in the IGB. Overall, this study provides valuable insights into the spatial distribution of PM2.5 concentrations in the IGB and its impact on human health. Our findings underscore the importance of reducing PM2.5 pollution to protect public health, particularly for vulnerable populations in highly polluted regions such as the IGB.

# Building Barriers, Building Health: The Benefits of Noise Reduction on Public Well-Being

**Mohammed Azarudeen AR**

*Kumaraguru College Of Technology, Coimbatore, Tamilnadu*

## ABSTRACT

Noise pollution is a growing concern for public health, with increasing levels of exposure in urban and industrial areas. It is caused by a range of sources, including traffic, construction, and industrial activities, and can have severe impacts on human health. Exposure to high levels of noise pollution can cause hearing loss, cardiovascular disease, sleep disturbance, and psychological distress. The use of noise barriers is an effective solution to reduce the negative impact of noise pollution on human health. Noise barriers are physical structures designed to block or absorb sound waves, reducing the level of noise exposure in the surrounding area. They can be made from a variety of materials, such as concrete, steel, and vegetation. Studies have shown that the installation of noise barriers in urban and industrial areas can have a significant positive impact on human health. By reducing noise exposure, noise barriers can prevent hearing loss, improve cardiovascular health, and promote better sleep quality. The installation of noise barriers along highways and railway lines has been shown to reduce noise levels by up to 10 decibels, leading to a 50% reduction in perceived noise. This reduction in noise exposure can have a significant impact on cardiovascular health, with a potential risk reduction of up to 40%. The use of noise barriers has also been shown to improve sleep quality and reduce the risk of sleep disturbance-related health problems such as obesity, diabetes, and depression. Furthermore, noise barriers can also have a positive impact on the environment by reducing noise pollution in surrounding areas, making them more liveable for people and wildlife. In conclusion, noise pollution is a serious public health issue, with significant negative impacts on human health. The installation of noise barriers is an effective and cost-efficient solution to reduce noise pollution and improve human health. Governments and policymakers should prioritize the installation of noise barriers in urban and industrial areas to reduce noise pollution and promote a healthier environment for everyone.

**Keywords**: Pollution, Human Health, Noise Barriers.

# Weather impacts and future projections of dengue mortality in Pune district under a changing climate: An AI/ML-based study

**Sophia Yacob**

*Indian Institute of Tropical Meteorology*

## ABSTRACT

Dengue is a major public health concern globally, and its incidence has increased significantly in recent years. Climate change has been linked to the incidence of dengue, but regional variations in weather conditions and the non-linear relationship between climate and dengue require further investigation. This study utilizes machine learning algorithm to evaluate the impacts of weather on dengue mortality in Pune district, India, over a 15-year period (2001-2015). A new dengue metric is defined that considers temperature, relative humidity, and rainfall-dependent variables to capture the complexity of the weather-dengue association. Results indicate that moderate rains spread in time favour increased vector abundance and, as a result, an increase in dengue mortality. In contrast, intermittent heavy rains with long dry periods can reduce dengue mortality. The current study finds that high dengue mortality years in Pune are comparatively dry, with fewer monsoon rains and flush events (weekly rainfall > 150 mm), but they have more wet weeks and optimal humid days than low dengue mortality years. Furthermore, they are devoid of heavy rains in the initial monsoon days of June and have favourable temperatures during the summer monsoon season. Based on these findings, a machine learning-based early warning prediction model is developed that provides a reasonable forecast accuracy (RMSE=1.01). Furthermore, projections based on the Coupled Model Intercomparison Project phase 6 (CMIP6) indicate that dengue mortality in Pune will increase by up to 102% by the end of the 21st century under the high emission scenario SSP5-8.5 in response to an increase in temperature, relative humidity, and changes in rainfall patterns. The study highlights the serious concern posed by climate change on the incidence of dengue, calling for effective prevention strategies and policy-making to control the spread of the disease.

# New nomenclature for clouds

**Pradip Kumar Pal**

*Outstanding Scientist (Retd.), Space Applications Centre, ISRO*
*pradippal@rediffmail.com*

## ABSTRACT

If one looks at the history or evolution of cloud nomenclature, the names were mostly derived from Latin words and they are a bit difficult to remember by ordinary people in India. Here is an attempt to rename the clouds which may be more acceptable to ordinary people in India.
First, let us look at the familiar names which are described in any meteorology text book. Luke Howard, an English pharmacist has first given the names for different cloud types in the beginning of the 19th century. Howard is mainly remembered now as the father of modern meteorology.

**Four basic types of Clouds**

Howard initially described three types of clouds, naming them Cirrus, Cumulus and Stratus. Here we propose equivalent new names for these three types of clouds.

मेघकेशा (Meghkesha - Cirro-form**)**

The meaning of Latin word 'cirro' is curl of hair. Meghkesha clouds are whitish and hair-like and, they are mainly composed of ice crystals.

मेघमाला (Meghmala - Cumulo-form)

Meghmala clouds generally look like white fluffy cotton balls and they are detached clouds.

मेघदूत (Meghdut - Strato-form)

Meghdut clouds are usually broad and wide spread appearing like a blanket.
To these three types, Howard subsequently added a fourth type.
He named this cloud, 'Nimbus', which is the Latin word for rain. Let us call it Meghraj.

मेघराज ( Meghraj - Nimbo-form**)**

**Ten Basic Types of Clouds**

From the World Meteorological Organization's (WMO) *International Cloud Atlas*, the official worldwide standard for clouds, the following are names of the ten basic cloud types. New names for these basic clouds are proposed here as follows.

1. मेघमाला ( Meghmala - Cumulus)
2. मेघदूत ( Meghdut - Stratus)
3. मेघमधु ( Meghmadhu - Stratocumulus)
4. मेाघद्रि ( Meghadri - Altocumulus)
5. मेघराजदूत ( Meghrajdut - Nimbostratus)
6. मेघनील ( Meghneel - Altostratus)
7. मेघकेशा ( Meghkesha - Cirrus)
8. मेघमणि ( Meghmoni - Cirrocumulus)
9. मेघनाथ ( Meghnath - Cumulonimbus)
10. मेघदूतकेशा ( Meghdutkesha - Cirrostratus)

# Relationship between Azores High and Indian summer monsoon

**Ramesh Kumar Yadav** [1]

[1]*Indian Institute of Tropical Meteorology, Pashan, Pune-411008, India*
*E-mail: yadav@tropmet.res.in ; Phone No. +91-020-25904361*
*https://orcid.org/0000-0001-8003-4558*

## ABSTRACT

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

**Keywords**: Indian summer monsoon; India Landmass; Asian jet-stream; vorticity; Rossby wave activity flux; Empirical Orthogonal Function; Principal Component

# Potential evapotranspiration inferred from tree-ring records during the last two centuries for western Himalaya in India

**Somaru Ram[1], Uttam pandey[1]**

*Indian Institute of Tropical Meteorology, Pune-411008, India*
*Email*: somaru@tropmet.res.in*
*Phone: 020 25904357; Fax: +91 020 25865142*

## ABSTRACT

Tree-ring width records from distinct locations have been carried out in relation to climate variations over the region. The 1st principal component prepared from multi-species tree ring chronologies is negatively correlated with temperature, potential evapotranspiration, and heat index but positively with the moisture index of the region during (March to May). However, HT and PET had a strong influence on tree growth as compared to temperature, has been reconstructed back to A.D. 1779. The reconstructed PET indicated extensive periods (1827-1845) of low PET at the ending phase of the Little Ice Age. It showed that the glaciers advance might have an influence on the reduction of downward shortwave radiation on the earth's surface over the western Himalayas; which causes low temperature and PET across the region. The results show longer tree ring chronologies have good potential to extend the climatic records and get valuable information regarding PET fluctuation during the past few centuries over the Himalayas.

# Recent calamitous climate change in India (1990-2019)

**V.S.L. Bhargavi[1], V. Brahmananda Rao[1,2], C.V. Naidu[1], D. Govardhan[3], P. Vinay Kumar[1]**

*[1]Department of Meteorology and Oceanography, College of Science and Technology, Andhra University, Visakhapatnam – 530 003, India*
*[2] Emeritus scientist, Instituto Nacional de Pesquisas Espaciais, Brasil*
*[3]Centre for Earth, Ocean and Atmospheric Sciences, University of Hyderabad, Hyderabad – 500 046, India*

## ABSTRACT

In the present study, we investigated the recent climate change in India. Our examination of changes for the recent past three decades (1990-2019) in the relevant meteorological parameters in a space and time frame revealed rise in droughts in the recent years, mainly due to substantial decrease in rainfall and increase in surface temperature over Central Northeast Indian and Northeast Indian regions (which includes fertile region). There is a significant rise in rainfall over the North western regions that includes desert regions. The scenario represents a dipole type pattern with drying over the Eastern fertile region and Moistening over Western desert regions. The reduction in rainfall and rise in surface temperatures is due to the rise in static stability. Static stability (SS) exhibited a significant positive trend over most of Indian region, which is a robust feature of climate change. This increment in static stability contributed to the weakening of rising limb of Hadley cell, provoking sinking motion, which in turn led to decrease of monsoon rainfall over parts of Northeast India (NEI), Central Northeast India (spanning Indo Gangetic Plain) (CNEI) and adjoining northern Indian regions. SS over ($35.75^0$ N- $36^0$N, $65^0$E-$98^0$E) (**SS***) exhibited a significant positive trend and is very significantly correlated with surface temperature changes over Northern parts of India, (especially over CNEI). **SS*** resulted in a sinking response at lower levels over CNEI and adjoining regions. The rise in sinking motion due to the increment in static stability, resulted in increase of temperatures near the surface over CNEI (spanning Indo Gangetic Plain) and adjoining regions. In the recent years, the observed decrease of rainfall associated with increase of surface temperature (especially over IGP) is calamitous, as this led to a significant evaporation and drying of soil, leading to severe droughts over these regions.

# Variability of Low-Level Jet over the Arabian Sea and its association with Indian Summer Monsoon Rainfall

**Archana Sagalgile[1], P.V.S. Raju[1], Akshay Kulkarni[1], Jagdish Prasad[2], VB Rao[3], Suvarna Fadnavis[4]**

*[1]Centre for Ocean Atmospheric Science and Technology, Amity University Rajasthan, Kant Kalwar, Jaipur, India*
*[2]Amity School of Applied Sciences, Amity University Rajasthan, Kant Kalwar, Jaipur, India*
*[3] National Institute for Space Research, São Paulo, Brazil*
*[4]Indian Institute of Tropical Meteorology (IITM), Pune, India*
*Email: archu09090@gmail.com*

## ABSTRACT

Monsoon rainfall is the most important water source for the livelihoods of more than one billion people in South Asia. The low-level jet (LLJ) is one of the important factors impacting Indian summer monsoon (ISM) rainfall. In this paper, we report the influence of LLJ on the ISMR using multiple data sets during the period 1981-2020: 1) ERA5 reanalysis and 2) Indian Monsoon Data Assimilation and Analysis (IMDAA) along with (3) Indian Meteorology Department (IMD) rainfall. The analysis is conducted over all India as a whole region along with Central India (68°E–87°E, 15°N–26°N), Northeast India (83°E–98.5°E, 21°N–30°N), Northwest India (69°E–84°E, 22°N–37°N), and Southern Peninsula (74°E–85°E, 7°N–19°N). Our analysis shows that the magnitude of LLJ is correlated significantly with ISMR over these regions except North–East India in both the data sets (0.5-0.8) (at 0.01 significance level).
Both data sets well reflect the spatial climatological aspects of LLJ at seasonal and sub-seasonal scales. However, compared to the ERA5 data sets, the amplitude of LLJ wind is lower in the IMDAA data set. The decadal analysis during 1981-1990 (Decade -1), 1991-2000 (Decade -2), 2001-2010 (Decade -3), and 2011-2020 (Decade -4) shows the increasing trend in seasonal mean wind speed $s^{-1}$ (0.5 to 2 m/s per year) and rainfall (20 to 100 mm/day per year) during all except decade 2. Further, the statistical analysis shows that the seasonal mean biases in ERA5 (0.233) are less than IMDAA (0.918), indicating the reliability of ERA5 data.

**Keywords:** LLJ, Indian summer monsoon, ERA5, IMDA, decadal trends.

# Modelling Impact of LULC and Climate Change on Flooding in the Brahmani River Basin by Coupling HEC-HMS and HEC-RAS Model under GIS Environment

**Dharmaveer Singh**[1]

[1] *Assistant Professor, Symbiosis Institute of Geoinformatics, Symbiosis International (Deemed University) Pune-411016 (India), E-mail: veermnnit@gmail.com*

## ABSTRACT

Controlling floods in a basin requires a thorough knowledge of how human-induced landscape and climatic changes affect the river's hydrologic response. By integrating data from LULC and climate change scenario (CMIP6) on HEC HMS and HEC-RAS platforms, the current study suggests a novel method for modelling and mapping river flooding in the Brahmani River Basin (BRB). The multi-spectral satellite data from Landsat-4 and Sentinel-2A was used to examine changes in LULC patterns brought on by human intervention (deforestation, increase in agricultural and built-up lands) between 1985 and 2018. The runoff peak flows and inundated areas for floods of various return periods were found to have increased significantly and in varied ways in accordance with model results obtained in land use circumstances of 2018 compared to 1985. This is due to a decrease in the amount of forest cover and an increase in the proportions of built-up and agricultural lands in the BRB. The flood peak discharge calculated using the outputs of the EC-Earth3 and MRI-ESM2 models under the SSP245 and SSP585 scenarios was also analysed for the upcoming (2071-2100) floods of varied return periods. Results show that under all scenarios, the volume of peak discharge and inundated areas would rise with time for all return times. For all return periods, SSP585 would result in a substantially larger rise than SSP245 in both models. In comparison to the high return term of 100 years, the rise is significantly bigger for the low return period of 2 years. Thus, the study has successfully explained the hydrological effects of human-induced LULC changes and delineated flood-inundated sites that the local authority may use to reduce fluvial hazard in the BRB. In addition, it offers promising fresh perspectives into river flooding, and this methodology might be used in other global basins.

**Keywords**: Climate change, LULC, flooding, HEC-HMS and HEC-RAS software

# Historical and future projections of droughts and floods in Indian summer monsoon rainfall based on CMIP6 simulations

**Catherine George[1,2], Hamza Varikoden[1] and Roja Chaluvadi[1]**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune*
*[2] Cochin University of Science and Technology, Kerala*

## ABSTRACT

Indian Summer Monsoon Rainfall (ISMR) is the most dominant monsoon system which occurs every year during the period of June-September (JJAS). The 21st century has observed regional changes in monsoon rainfall, which can be attributed to climate change. Several studies have pointed out that Global warming is the trigger for these changes and extreme events like floods and droughts. Thus, it is highly relevant to study the flood and drought events over India in this century as this plays a huge role in the country's agriculture and development. Coupled Model Intercomparison Project phase 6 (CMIP6) is used in the study for assessing the intensity and frequency of droughts and floods in historical and future periods. In the present study, we utilised 53 CMIP6 models to screen better simulating models of ISMR. Most models were found to be capturing the annual precipitation pattern of ISMR but there is a strong underestimation of rainfall. 8 models were selected based on the Taylor diagram which compared the normalised standard deviation and pattern correlation values of the models and observation data. These selected models show the closest relation to that of ISMR and further analysis was carried out based on the selected models. From the composite anomaly of rainfall in drought and flood years during the historical time frame, it was observed that the selected models portray an overestimation of drought conditions over India whereas a better, nearly closer simulation is seen in flood events. For the future projections, the major Shared socioeconomic pathways (SSP1-2.6, SSP2-4.5, SSP3- 7.0 and SSP5-8.5) were analysed for near (2015-2035), mid (2047-2067) and far (2079-2099) future time periods. It was found that droughts are increasing in the near future whereas floods are increasing in the far future. This is because, in the warming climate, precipitation is likely to increase in the far future. But it was also observed that the intensity of droughts is seen to be increasing in the far future whereas that of floods is found to be decreasing.

**Keywords:** CMIP6, Indian summer monsoon rainfall; SSP; future projections; variability and trends; floods and droughts.

# Understanding the dynamics of Arabian sea monsoon eddy system and its regional impact

**Devyani Kamble[*a], Aditi Deshpande [a], Anandakumar Karipot [a]**

*[a] Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune - 411017, India*

*Email: devyani.kamble2591@gmail.com*

## ABSTRACT

There are three anticyclonic circulation systems in the Arabian Sea along the Somalian coast: the Socotra Eddy (SE), the Great Whirl (GW), and the Southern Gyre (SG). During Indian summer monsoon season composite analysis was performed for weak and strong monsoon years for both pre-monsoon (MAM) and monsoon (JJAS) seasons using reanalysis data over the period of 1959 to 2021 to determine eddy structures. From the composite analysis it is seen that, during strong pre-monsoon years small eddies develops between the 12N to 16N, above the Socotra land and during weak pre-monsoon years eddies form between 4N to 10N. There is no formation of Socotra eddies during weak monsoon years and GW occurs much closer to Socotra land between 10N and 12N. GW occurs between 4N and 10N during strong monsoon years, and SE begins northeast of GW. Freshening is stronger during the strong monsoon years over the eddies compared to the weak monsoon years. Ocean heat content (OHC) is calculated up to a depth of 700 m to understand the warming over the eddies. OHC is more during weak monsoon years around the Socotra land compared to strong monsoon years. During weak monsoon years around Socotra land, cooling is observed. Warming is observed during strong monsoon years, where the GW and SE have developed. Based on the composite analysis, it appears that only GW is very significant during the weak monsoon season, while both GW and SE are significant during the strong monsoon season.

# Precipitation Forecasting by Deep Learning based Model using Bhopal Radar Data

**Hrishikesh Haral[1,2], Bipin Kumar[2], MCR Kalpureddy[2], Sanjay Yadav[2,3]**

*[1]IISER Pune, Homi Bhabha Road, Pashan, Pune, 411008, India*
*[2]Indian Institute of Tropical Meteorology, Homi Bhabha Road, Pashan, Pune, 411008, India*
*[3]Defence Institute of Advanced Technology, Girinagar, Pune, 411025, India*
*Haral H K*
*Email: hrishikesh.haral@students.iiserpune.ac.in*

## ABSTRACT

Precipitation forecasting is essential because heavy and irregular rainfall can have many impacts, like the destruction of crops and farms and damage to property, so a better forecasting model is essential for an early warning that can minimize risks to life and property and also manage the agricultural farms in a better way. In this study, we use Bhopal Radar Precipitation Data for 2021 JJAS duration with twenty minutes resolution to develop the Deep Learning-based Conv LSTM model. Data was first converted from polar to cartesian coordinates to make as input for the model and Data Capping was employed to remove the outliers using winsorization method. Further, to deal with NaN values, data was transformed from real space to exponential space, making the data range in [1, ∞], and the NaN values were replaced by '0'. This approach has been earlier performed in the literature and works well for CNN based models. The model performed well for five days lead time forecast. Its performance was evaluated using the Pearson Correlation Coefficient with a max value of 0.62 as seen in the below figure.

**Keywords**: Deep Learning, ConvLSTM, Radar Data, Precipitation, Exponential Space

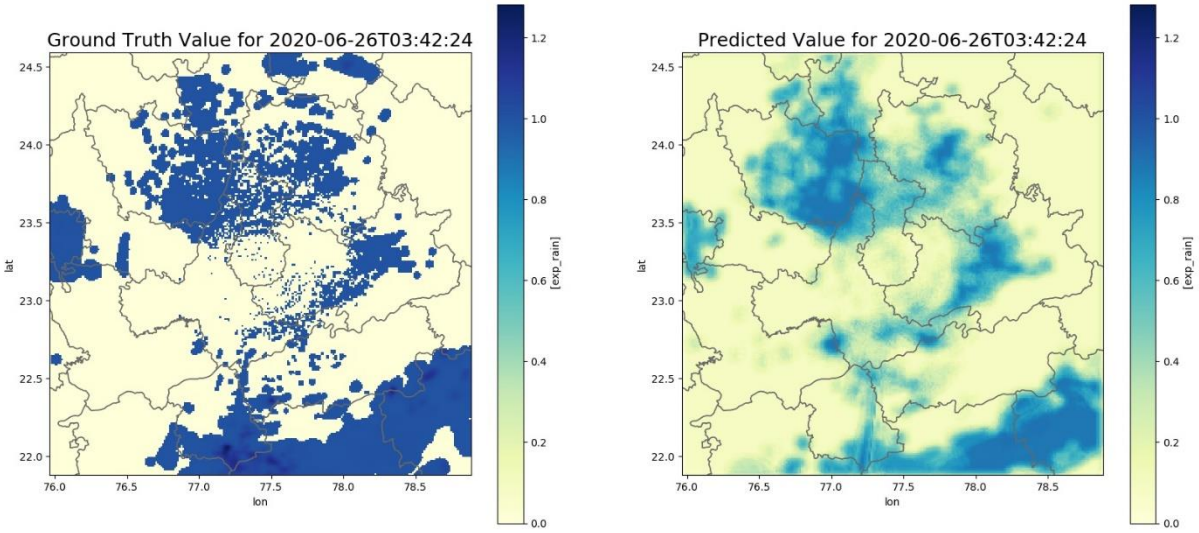


*Figure 1:The first day lead time forecast using 5 previous day input. The correlation is 0.6219.*

# Characteristics of global precipitation extremes in CMIP6 models

**Nishant Uchale [1,2], Bhupendra Bahadur Singh [2], Pradeep Kumar Pallath [1]**

*[1]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India 411007*

*[2]Indian Institute of Tropical Meteorology, Pune, India, 411008*

## ABSTRACT

Climate models are indispensable tools for simulating the climate variability, climate change and future projections. Studies have reported significant increase in precipitation extremes across the globe in association with anthropogenic warming. However, the majority of such research is constrained by spatial domain (e.g Global Land or region specific) and done on an annual basis. Seasonal changes in available solar insolation and resulting general circulation, strongly affects the distribution of precipitation across the globe which governs where actually the maximum precipitation falls. Particularly, monthly changes can be large during the transition seasons. In this study we assess the performance of Coupled Model Intercomparison Project Phase 6 (CMIP6) models in reproducing the statistical characteristics of precipitation extremes by taking daily maximums on a monthly basis across the globe evaluated against the observations over the period 1980-2014. Our results show significant biases in frequency and intensity of extreme precipitation across CMIP6 models mostly over the tropical belt, Pacific and Indian Ocean. Most of the models underestimate the precipitation extremes and are unable to reproduce the spatial patterns. Analysis of probability density estimated based on daily maximum precipitation on a monthly basis, shows that the width of the curve increases during boreal summer in observations as well as the models. Density estimates also show that models have difficulty in capturing the extreme values above 150 mm, however this might be a result of coarser resolution of models. Noted bias in regional patterns of extreme precipitation may be linked to a variety of factors, including the convection parameterization, model physics, and circulation.

# Exploring the Dynamics of Tropical Cyclones through Deep Learning-Based Forecasting of Mixing Layer Depth

**Sourav Kumar Khan[1,2], Bipin Kumar[2], Bishakhdatta Gayen[3,4], Manmeet Singh[2] and Bajrang Chidhambaranathan[4], SVSSNVG Krishna Murthy[1]**

*[1]Defence Institute of Advanced Technology, Girinagar, Pune, 4110025, India*
*[2]Indian Institute of Tropical Meteorology, Pune, 411008, India*
*[3]Centre for Atmospheric & Oceanic Sciences, Indian Institute of Science, Bengaluru, 560012, India*
*[4]Mechanical Engineering Department, University of Melbourne*
*E-Mail: sourav_mam21@diat.ac.in, khansourav1999@gmail.com*

## ABSTRACT

The mixed layer is an important component of the ocean that connects with the atmosphere and is responsible for transferring heat, moisture, and CO2. The depth of the mixed layer is influenced by turbulent mixing and small-scale eddies, which are driven by atmospheric forces and ocean processes. Understanding and predicting the mixed layer depth (MLD) is crucial to investigate ocean dynamics and its impact on air-sea exchange, including the intensity of extreme events such as tropical cyclones. In this study, we use deep learning models (ConvLSTM and ConvGRU) for the forecasting. We utilized 26 years of daily reanalyzed data from three different repositories (ERA5, ORAS5, and Tropflux) for both the Bay of Bengal and Arabian Ocean. The model was trained separately for each season to capture seasonality.We evaluated the model's performance using the Pearson Correlation Coefficient, and found that the ConvLSTM model outperformed the ConvGRU model. Additionally, we found that a combination of three variables outperformed all six variables, suggesting that a simpler model may be more effective.The best-performing combination of variables was then tested on other seasons, and was found to perform better than the original six-variable model. This highlights the importance of selecting the appropriate variables for the model and considering seasonality when predicting MLD.Overall, our findings demonstrate the potential of deep learning models for forecasting MLD and understanding the dynamics of the ocean. By accurately predicting MLD, we can improve our understanding of air-sea exchange and the impact of extreme events such as tropical cyclones.

**Keywords:** Deep Learning, ConvLSTM, ConvGRU, MLD forecasting, Bay of Bengal, Arabian Ocean, Cyclone intensity

# Linking the subtropical jet and winter precipitation over North-west Himalaya under future warming scenarios

**Soumyadeep Roy**[1], **Dr. Charu Singh**[1]

1 *Indian Institute of Remote Sensing, Indian Space Research Organization (ISRO), Dehradun, India.*

## ABSTRACT

The impact of subtropical jet stream on western disturbance is well known. The strength and position of subtropical jet influences western disturbances which in turn controls the winter precipitation over the Himalayan region. In this study the Coupled Model Inter-comparison Project phase six (CMIP-6) model datasets will be used to look into the intensity and position of the subtropical jet stream at the end of this century (2066 to 2100) under different future warming scenarios. In this study, 5 models are taken to create a multi-model mean for both the historical and future projections (SSP 245 & SSP 585). The multi-model mean is used to investigate the changes in the winter precipitation over the North-west Himalayan region. Study shows significant inhomogeneity in the changing precipitation pattern under different SSPs. The zonal wind speed at 200 hPa level is used to study the subtropical jet stream. The intensity and position of subtropical jet stream at the end of the century is also analyzed to link the winter precipitation changes over NWH region with the varying signature of subtropical jet stream under different warming scenarios.

**Keywords:** CMIP6, North-west Himalaya (NWH), subtropical jet stream, SSP, multi-model mean.

# Spatiotemporal variations of the surface and Planetary Boundary Layer characteristics within the Indian monsoon core region

**Sumedha Lawande, Anandakumar Karipot, Rohini Bhawar**

*Department of Atmospheric and Space Sciences, SPPU*

## ABSTRACT

The planetary boundary layer (PBL) is defined as the lowest 100 to 3000 m of the troposphere that is formed as a result of turbulent exchange processes between the surface and atmosphere. The present study primarily explores the features of atmospheric boundary layer within the monsoon core zone over the Indian subcontinent. The monsoon core zone (MCZ) of India extends roughly from 18.0 °N to 28.0 ° N, and 65.0 °E to 88.0 °E. The MCZ consists of regions spanning Gujarat and Rajasthan in the west to Odisha and West Bengal in the east. Large parts of Uttar Pradesh, Madhya Pradesh and central Maharashtra also fall under this zone. Several studies have shown that the boundary layer over the Indian subcontinent exhibit large variations at differing spatio-temporal scales, in relation to the monsoon variations. The monsoon core zone with distinct rainfall and surface characteristics in the east-west direction, also undergoes large spatial variations in the surface fluxes and PBL characteristics, which are further amplified in relation to the active break phases of the monsoon, localized extreme precipitation events and inter-annual rainfall variability. The present study is carried out using IMD high resolution rainfall data, European Space Agency – Climate Change Initiative (ESA-CCI) soil moisture data and PBL height and surface fluxes from ECMWF Re-Analysis (ERA5) data over the Indian region. The core zone is divided into different Latitude-Longitude boxes of dimensions $6^o$ x $3^o$, in the west-east direction and the differences in the features in association with the monsoon variability are investigated. Data during 30 years period (1991-2020) are used to calculate anomalies and study the intra-seasonal and inter-annual variations in the spatiotemporal characteristics of surface fluxes and PBL characteristics within the MCZ. The mean behaviour as well as anomalies for selected case studies are presented in the results.

# On the teleconnection between Arctic Oscillation and winter precipitation extremes over the Indian region

**S. D. Sanap**

*Climate Research and Services, India Meteorological Department, Pune*
*sakha.sanap@gmail.com*

## ABSTRACT

The winter precipitation in the Northern and central Indian regions is beneficial for the growth of winter crops and the maintenance of the glaciers in a mountainous region. On the other hand, occurrences of hailstorms and thunderstorms over plains adversely affect the agriculture and allied sectors. Hence understanding the occurrence of these events and appropriate forecast and timely warning dissemination is indispensable. All India precipitation anomaly for January 2020 was 64% above long period average. Excess to large excess precipitation was received in most of the central and north Indian regions with various thunderstorms/hailstorm events. A strong positive phase of the Arctic Oscillation (AO) was perceived in January 2020. The AO-induced prolonged Euro-Atlantic blocking was identified and found in concurrence with precipitation departures over the Indian region. Large-scale analysis on different timescales (monthly, weekly and daily) reveals the detouring of the mid-latitudinal westerlies (southward intrusion) with induced cyclonic circulation over the North Indian region. The lowering of the $0^{o}$C isotherm and the development of atmospheric instability with moisture supply from the Arabian Sea and the Bay of Bengal resulted in occurrences of thunderstorms/hailstorms over the region. The excess to large excess precipitation during January 2020 over the Central and North Indian region is mainly attributed to the Euro-Atlantic Blocking-induced changes in regional dynamics and thermodynamics. The fidelity of the extended range prediction system (ERPS) in envisaging the week-wise precipitation forecast was also examined. Prediction skills of the ERPS for week 1 were found to be fairly good, however region of occurrence and magnitude was underestimated with the progression of the lead time. The variations in the week-wise precipitation prediction are mainly attributed to the underestimation of the phase of the AO and intensity of the Euro-Atlantic blocking by ERPS.

# Understanding the precipitating cloud systems that led to the devastating floods over Pakistan during 2022 summer monsoon

**Tiasha Dev*, D. C. Ayantika†, Divya V‡, K. M. Sumit† , Kalik, Vishisth†, Aditi Deshpande*, R. Krishnan†**

** Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India*

*† Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India*

*‡ Department of Atmospheric Sciences, Cochin University of Science and Technology, Kerala*

## ABSTRACT

During the summer monsoon season of 2022 unprecedented precipitation enhancements occurred over Pakistan leading to devastating flood situations over the country. In particular, during a 15-days heavy precipitation spell in August some areas experienced accumulated precipitation of more than 500 mm, which far exceeds climatological distribution. Using GPM retrievals, the present study investigates the storm structure and anomalous atmospheric conditions that supported the development of the observed flood producing cloud systems. We have chosen the extreme precipitation spell to study the precipitation and latent heating structure of the deep cloud cluster and their convective-stratiform separation. The radar reflectivity and latent heating profiles captured by GPM swath reveal the predominance of stratiform precipitation within the cloud system. Analysis of atmospheric variables from ERA5 reanalysis dataset showed enhanced transport of moisture from western Pacific across the Indian landmass towards Pakistan. We find that the large influx of moisture sets a favourable environment for the growth of deep cloud systems over the arid and semi-arid regions of Pakistan.

# A Seasonal and Decadal Scale Spatio-Temporal Analysis of Precipitation Distribution over Physiographic Region of Gujarat Using Precipitation Concentration Index (PCI)

**Lakhan Jain[1] and Bindu Bhatt[2]**

*The Maharaja Sayajirao University of Baroda, Vadodara*
*Email: igeographers@gmail.com[1], bindu.bhatt-geography@msubaroda.ac.in[2]*

## ABSTRACT

For a nation like India, whose economic growth relies primarily on agriculture and allied sectors and is further tied strongly to rainfall distribution, it is imperative to comprehend and quantify long-term rainfall variability at the regional scale. This study looks at the spatio-temporal distribution of precipitation in Gujarat's physiographic regions using the Precipitation Concentration Index (PCI) indicator on seasonal (SWM) and decadal scales based on daily rainfall data from 1961 to 2020 (60 years). The objectives have been accomplished by employing the newly developed daily gridded, high spatial resolution IMD4 rainfall dataset that interpolated at 0.25° x 0.25° resolution at fixed spatial grid points throughout the country. The results indicate a moderate (PCI>10 ≤ 15) to irregular (PCI>16 ≤ 20) trend in seasonal precipitation distribution in the Kutch region. Following 1990, Kutch has been experiencing an increase in irregularity in seasonal precipitation distribution trends, which increased the risk of flash floods and drought-like conditions. In contrast, South Gujarat has seen a uniform (PCI ≤ 10) to moderate seasonal precipitation distribution. The Saurashtra in Southwest and Central Gujarat experiences a moderate seasonal trend in precipitation distribution. North Gujarat has seen an increase in irregularity in the recent decade. The complex physiography of Gujarat has reflected in the varying seasonal trend of precipitation distribution. The findings show that the PCI is an essential indicator for predicting risk due to extreme events and helps in effective mitigation strategy at an early stage.

**Keywords:** IMD, Gujarat, Physiographic, Precipitation Concentration Index (PCI), Spatio-Temporal.

# Global monsoon system; Trends and variability in the summer and winter seasons

**A. M. Fazal [1,2] , Hamza Varikoden [1] , and M. J. K. Reji [1]**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India*
*[2] Kerala University of Fisheries and Ocean Studies, Department of Physical Oceanography, Kochi, Kerala*

## ABSTRACT

The current study examines the trends and variability of rainfall patterns in various monsoon systems around the world using Climate Research Unit monthly data from 1901 to 2020. The different monsoon systems were selected based on the rainfall difference between boreal summer(June–September: JJAS) and austral summer (January–February: JF), which is also known as theannual range (AR) of rainfall. The northern hemisphere (NH) monsoon regions receive the most rainfall during JJAS, while the southern hemisphere (SH) monsoon regions receive the most rainfall during JF. Among the NH domains, North America (NAM) has the highest value ofmean rainfall of 206.3 mm month$^{-1}$, followed by South Asia (SAS, 204.3 mm month$^{-1}$), and the least value of mean rainfall is observed in Southern Africa (SAF, 8.1 mm month-1) in JJAS; however, the highest mean rainfall value is observed over Australia (AUS) with a value of 241.7 mm month$^{-1}$ followed by South America (SAM, 213.1 mm month$^{-1}$) in JF.

The interannual rainfall pattern of JJAS shows significant increasing trend for the East Asia (EAS, 2 mm month$^{-1}$ century$^{-1}$), and a significant decreasing trend for West Africa (WAF) and SAS (-4 mm month$^{-1}$ century$^{-1}$), however, AUS and SAM (WAF and SAS) show significant increasing (decreasing) trends with slope values 19 and 5 (-2 and -1) mm month$^{-1}$ century$^{-1}$, respectively during the austral summer. A significant in-phase relation between summer and winter rainfall values at the 1% level is observed among the WAF, NAM, and SAF in the boreal summer, whereas the correlation coefficients are insignificant in the austral summer. The significant multi-decadal variability of WAF, SAS, SAF, and SAM and the interdecadal variability of EAS and NAM are clear in the power spectrum of boreal summer. The multi decadal variability is observed only for the SAF and SAM, and the inter-decadal variability is observed for the remaining domains during the austral summer.

# Nowcasting of Rainfall using Deep Learning based Model

**Abhijit Malkar[1,2], Rajib Chattopadhyay[2] , Bipin Kumar[2], D. Srikanth[2]**

[1]*Indian Institute of Tropical Meteorology, Homi Bhabha Road, Pashan, Pune, 411008, India*

[2]*Defence Institute of Advanced Technology, Girinagar, Pune, 411025, India*

*Email: abhijeetmalkar1997@gmail.com*

## ABSTRACT

Nowcasting of rainfall is an essential tool for public safety, transportation, urban planning, construction, infrastructure, and agriculture. It provides valuable short-term information that can help people and organizations make informed decisions and prepare for potential impacts of heavy rainfall.

Therefore, it is essential to provide advance forecasts to stockholders and policymakers in order to better manage potential risks to human life, livestock, and property, and to inform farmers so that they can better manage their agriculture farms. In this study, using reanalysis data with hourly time resolution from the ERA5 repository, we develop a deep learning-based precipitation nowcasting model. ConvLSTM, the model used in this study, has already been used in the literature for similar tasks. The model was assessed using the Pearson correlation coefficient (CC), and it performed very well, with CC values of 83.97, 75.77, 70.54, and 60.38 for forecasts of one to four hours, respectively.

**Keywords:** Deep Learning, ConvLSTM, Nowcasting, normalisation

# Surface Temperature Variation over urban city of India during a Decade

**Aditi Singh[1], Geeta Agnihotri[2] and R.S. Mahes kumar[1]**

*[1]Ministry of Earth Sciences, New Delhi, India*
*[2]India Meteorological Department, Bengaluru, India*

## ABSTRACT

This study focuses on analysis of temperature variations over a metropolitan city Bengaluru, the the capital and largest city of the southern Indian state of Karnataka. Due to its high elevation, Bangalore usually enjoys a more moderate climate throughout the year, although occasional heat waves can make summer somewhat uncomfortable. The coolest month is January with an average low temperature of 15.1 °C (59.2 °F) and the hottest month is April with an average high of 35 °C (95 °F).The present study aims to analyze the temperature variations over Bengaluru during the recent decade (0210-2022) using observations from the India Meteorological Department (IMD) observational network and ERA 5 reanalysis data. The number of heat waves and cold wave days are obtained in each year. The number of heat and cold waves and the variability depends on the location and may be linked to the changing climate patterns.

# mangeshMeteorological drought intensity analysis using drought indices for India

**Rajalakshmi S[1], Gandhimathi A[2]**

[1]*Assistant Professor, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore*
[2]*Assistant Professor, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore*

## ABSTRACT

Meteorological drought is defined as the deficiency of precipitation from expected or normal levels over an extended period of time. In India, the most drought-prone regions are the arid and semi-arid regions. Monthly data of temperature and precipitation for the states of India covering a period of 39 years from 1981 to 2019 was collected from power access climate data and used for the assessment of drought in all states of India. The standardized precipitation index (SPI) is a probability-based indicator has wide application because of its simplicity. Aridity index of De Martonne ($I_{DM}$) are quantitative indicators used to classify the climates of different regions and it provides the ratio of precipitation to temperature which is mainly used to determine the development of drought in an area. This study characterizes the meteorological drought using Standardized Precipitation Index (SPI) and Aridity index of De Martonne($I_{DM}$) for the states of India. Number of occurrences of dry & wet years is identified in the states of India. SPI and $I_{DM}$ are analyzed for Seasonal and Annual time scale basis. By using Gamma distribution, SPI values were calculated for the collected precipitation data. The Annual results of SPI indicated that almost all the states in India are falls under near normal condition; many states of India are recorded with 2 years of Extremely dryness condition and $I_{DM}$ indicates that Gujarat, Delhi, Haryana, Rajasthan, Uttar Pradesh are having high number of occurrences of arid condition, many states of India recorded with 2 years arid condition. By proactively planning for drought, the society will be better prepared to deal with the damaging effects of drought in the most efficient manner. Though the prediction of onset and termination of drought are difficult to determine, one can identify various indicators of drought and by tracking them the crucial means of monitoring drought can be provided.

**Keywords:** Drought analysis, Standardized Precipitation Index, Aridity index of De Martonne, Precipitation, Temperature, Dry/Wet condition.

# Understanding the trends in Indian Summer Monsoon Rainfall

**Neha Lakhan Hikare**

*Indian Institude of Tropical Meteorology*

## ABSTRACT

The variabilities in all-India summer monsoon rainfall (ISMR), the rainfall averaged over the Indian landmass during the summer monsoon season (JJAS), have been examined in this study. In recent decades, there has been large spatial variability in the summer monsoon rainfall over the Indian subcontinent. The period 1970 – 2020 witnessed significant trends in summer monsoon rainfall, with a declining trend over northeast India, whereas an increasing trend is observed over the northern parts of the west coast of India. These trends are examined post-1970s. The climatological features, trend analysis, mean and extremes in summer monsoon rainfall are examined, associated with large-scale monsoon circulation. Different indices have been used to explore the extreme rainfall over the Indian subcontinent during the summer monsoon season, namely Rx1day (one-day maximum rainfall), R50mm (frequency of heavy rainfall days as indicated by number of rainy days exceeding 50 mm of rainfall) and No Rain (frequency of no rain (dry) days depicting number of days with zero rainfall). The trend analysis reveals that region of declining trend in summer monsoon rainfall, eg. northeastern parts of India, experience a declining trend in one-day maximum rainfall and frequency of heavy rainfall (> 50 mm) days, and an increasing trend in no rain days. Whereas the regions of increasing trend in summer monsoon rainfall, eg. northern parts of Western Ghat region, experience an increasing trend in one-day maximum rainfall and frequency of heavy rainfall (> 50 mm) days, and a declining trend in no rain days.

# Drought monitoring and assessment with different indices in India

**Ajay Kumar[1], Namendra Kumar Shahi[3] and Shailendra Rai[1,2]**

*1 K. K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, Prayagraj, India*

*2 M. N. Saha Centre of Space Studies, University of Allahabad, Prayagraj, India*

*3 Institute of Environmental Geosciences (IGE) Grenoble Alpes University (UGA) 38400 Saint-Martin-d'Heres, Grenoble, France*

*Email: ajaymaurya.kumar0@gmailcom,raishail@gmailcom*

*Presenting author's name – Ajay Kumar*

*Email id ajaymaurya.kumar0@gmailcom*

## ABSTRACT

Monitoring drought and declaration is a crucial part of managing the risk associated with it. To achieve this, different drought indices are used that are continuous functions of various hydrometeorological variables. Many studies have introduced and implemented various drought indices which are majorly classified as meteorological, hydrological, agricultural drought index. In this study, the performance of seven drought indices is compared for monitoring drought in India. It should be noted that there is no perfect or universally applicable drought index. The selection of drought indices for monitoring in a specific area depends on the availability of climate data and the index's ability to effectively detect spatial and temporal variations during drought events. In a study conducted in India the performance and applicability of various drought indices (Standardized Precipitation Index (**SPI**), Standardized Runoff Index (**SRI**) and Standardized Soil Moisture Index (**SSI**)) were evaluated for both abnormally dry and wet conditions during **1979-2020**. In this study, comparison of indices is based on their ability to accurately simulate both the cycles for different regions of India. We found a shift in the drought prone area in all the three indies during the period 1979 to 2020.

# Mechanisms underlying the sub-seasonal variability of Indian Summer Monsoon 2021

**Amol Vibhute[1,2*] , Jasti S. Chowdary[1] , Darshana Patekar[1] , Hyo-Seok Park[3] , K. Koteswara Rao[4], Anant Parekh[1] , and C. Gnanaseelan[1]**

*1. Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, 411008, India*
*2. Savitribai Phule Pune University, Pune, 411007, India*
*3. Department of Ocean Science and Technology, Hanyang University, Ansan, South Korea*
*4. Centre for Climate Change and Sustainability, Azim Premji University, Bengaluru, India*

## ABSTRACT

Severe changes of rainfall within the season leads to extreme weather events such as floods and droughts. This can disrupt ecosystems, cause damage to human infrastructure, and displace human populations. Human caused global warming is not the sole cause of extreme weather events, increased average global temperatures have increased the intensity of these events through the subseasonal variability of rainfall. Understanding the subseasonal rainfall variability in the climate change era is of utmost importance. During the summer monsoon season of year 2021, India Meteorological Department (IMD) reported strong subseasonal rainfall variability in the Indian subcontinent. During the month of August 2021 rainfall recorded a 19% deficit, lowest since 2002 according to IMD. At the same time, abrupt changes in all India rainfall from the month of August to September is noticed with rainfall percentage departure changed from -19 to 35 i.e., total change of 54%. Such a huge increase of rainfall in September was not anticipated as the August rainfall was largely deficient. It is found that the tropical-midlatitude circulation interaction played an important role in altering the subseasonal rainfall over India in summer 2021. The Southward displacement of the Asian jet and Pacific Japan pattern caused moisture divergence over the monsoon region in August and caused deficit rainfall. On the other hand, changes in upper level mid-latitude wave propagation are associated with the Silk Road pattern responsible for high rainfall over northwest India in September 2021. Understanding the dynamics and physical mechanisms that are responsible for such unusual changes in monthly/subseasonal rainfall are useful for its skillful prediction. Mechanisms and dynamics underlying for deficient (positive) rainfall in August (September) 2021 is analysed further in detail in observations and CFSv2 hindcasts.

**Keywords:** Sub-seasonal rainfall variability, Displacement of Asian jet, Pacific Japan pattern.

# Aerosol-cloud interaction in post-monsoon as observed with in situ measurements and a numerical model

**Anjana J Vadhyar, Thara Prabhakaran and Manoj M G**

[1]*Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune – 411008*

[2] *Indian Institute of Science Education and Research, Bhopal -462066*

**anjanavad17@gmail.com*

## ABSTRACT

Aerosol–cloud interactions remain one of the main uncertainties in the numerical modeling of the weather and climate. The aerosols mainly impact the clouds via Cloud Condensation Nuclei (CCN) or Ice nuclei particles (INP). The study analyses the microscale characteristics of clouds during post-monsoon using aircraft observations conducted as a part of CAIPEEX over the southern peninsula along with simulations from the WRF to assess CCN sensitivity. Results show that a high concentration of CCN reduces the mean effective radius of particles for limited water content leading to reduced precipitation efficiency (depending on the humidity of the air) since tiny cloud drops are ineffective in a collision, partly due to lower fall speeds and partly due to lesser collision efficiencies. The simulation indicates that the mixed-phase cloud processes are found to be determining factors for heavy precipitation. Meanwhile, the prime impact of the CCN was to increase the graupel, snow, and rainfall, with an increase in the cloud top heights. In the recent view of anthropogenic pollution (aerosol loading), understanding the ways in which these particles affect the atmosphere is really necessary for future assessment and to reduce the uncertainty in the climate models.

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**Keywords:** Aerosol-Cloud Interaction, Cloud Condensation Nuclei, Precipitation efficiency

# Detection and Attribution of Indian Ocean Sea Level Rise

**Ardra D[1,2], Swapna Panickal[3], Sandeep Narayanasetti[3]**

*[1]Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, 110016, India.*
*[2]Department of Atmospheric Sciences, Cochin University of Science and Technology, Kochi, 682016, India.*
*[3]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, 411008, India.*

## ABSTRACT

The energy balance of the climate system is significantly regulated by the Oceans around the globe. Over the past 50 years, 93% of the stored heat over the Oceans led to thermal expansion and a rise in sea level. This study mainly focuses on the Indian Ocean Sea level change resulting from ocean temperature changes, termed Thermosteric Sea Level (TSL) change or Ocean thermal expansion. To quantify the amount of sea level variation over the Indian Ocean by each forcing (natural-only, aerosol-only, greenhouse gas-only (GHG-only) historical), an optimal fingerprinting method is used. To carry this out, we compare available observations to a set of single-forcing experiments (driven by external forcings, including historical, natural-only, GHG-only and aerosol-only) with climate models from the sixth phase of the Coupled Model Intercomparison Project, CMIP6 archive (Detection and Attribution Model Intercomparison Project, DAMIP) for the period 1950–2010. We also use preindustrial control runs to understand the internal climate variability. Our analysis shows that all-forcing ensemble approximately produces comparable values with the observations. However, the GHG-only ensemble shows an increasing trend in Thermosteric Sea Level with greater values than the observed values. In contrast, the aerosol-only ensemble shows smaller values compared to the observations due to its overall cooling effect on the climate system. Scaling factors obtained from Regularized Optimal fingerprinting method explain that the anthropogenic forcing contributes about 85% to the Thermosteric Sea Level change in the Global Ocean and more than 65% to the Thermosteric Sea level change in the Indian Ocean (Beta values 0.8666 for Global and 0.6838 for the Indian Ocean region). Note that the individual experiments such as GHG-only, aerosol-only, and natural-only experiments could not explain the observed Thermosteric Sea Level change.

**Keywords:** Indian Ocean, Thermosteric Sea Level change, Optimal fingerprinting method

# Diurnal variation of extreme rainfall events over Jammu & Kashmir using latest half hourly IMERG V6 dataset

**Arvind Pagire[1], and Charu Singh[1],**

*[1] Marine and Atmospheric science department, IIRS, Dehradun, India*
*Corresponding author – Dr. Charu Singh, Email id: charu@iirs.gov.in*

## ABSTRACT

The GPM satellite constellation data is combined using the Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm to estimate precipitation across global region which provides the data with a very high temporal (half hourly) and spatial 10 km resolution. The present research examined the characteristics of diurnal variation of extreme rainfall events over the Jammu & Kashmir (J&K) region using the most recent half-hourly IMERG V6 dataset. Three percentile distribution thresholds, such as 98, 99, and 99.99 have been estimated for the investigation of the 3-hourly and half-hourly variation of EREs frequency and intensity. Diurnal variation of 3-hourly accumulated rainfall threshold indicates that the early morning (05.00 IST) receives highest intensity following the morning hours (08.00 IST). Similarly, diurnal variation of half-hourly rainfall threshold indicates that midnight hours (02.00 to 05.00 IST) has highest intensity as compare to other IST. Maximum intensity for EREs across the Jammu & Kashmir has been found during the night time (02.00 AM, 05.00 AM) and in the early morning (08.00 AM and 11.00 AM). The spatial distribution of frequency of EREs indicate that the southern part of J&K (60-120 in last 22 years) are found to be highly vulnerable. In addition, the southern part of J&K found to be more frequent for EREs.

**Keywords:** IMERG, GPM, EREs, J&K

# Impact of North Tropical Atlantic on South Asian Summer monsoon variability

**Ajinkya M. Aswale[1,2,*], Sooraj K P[1], Swapna P[1], Pascal Terray[3], Sandeep N[1,2]**

*[1] Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune 411008, India*
*[2] Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune 411007, India*
*[3] LOCEAN/IPSL, Sorbonne Universités (UPMC, Univ Paris 06)-CNRS-IRD-MNHN (Campus Université Pierre et Marie Curie), 4 Place Jussieu, BP 100, 75252 Paris cedex 05, France*
** Corresponding author email id: ajinkya.aswale@tropmet.res.in*

## ABSTRACT

The North Tropical Atlantic Sea Surface Temperature (NTA SST) anomalies, a key contributor to El Niño Southern Oscillation (ENSO) variability, have garnered more attention in the recent years. Taking consideration of these renewed interest this study intends to conduct detailed analysis, using observations/reanalysis and long-term numerical simulations of a global coupled model (IITM Earth System Model, IITM-ESM), so as to bring out the role of the NTA SST variability on the large-scale circulation and precipitation patterns over the Indian Summer Monsoon (ISM) region. Monthly composite analysis of the atmospheric and oceanic variables, using NTA events, further suggest that the boreal spring NTA SSTs can modulate the ISM characteristics in the subsequent summer. So, we found a coherent association between ISM and spring NTA, with ISM strengthening (weakening) during the positive (negative) phase of NTA. The suite of observational and numerical model-based analysis provides a mechanistic hypothesis for the association between NTA and ISM as intervened by ENSO variability.

# Characterization of Rainfall Patterns in the Western Vidarbha Region

**Dr. Sapana Sasane**

*Department of Geography, Savitribai Phule Pune University,*

## ABSTRACT

Western Vidarbha Region, the daily rainfall data have been collected for five stations: Akola, Amravati, Buldhana, Washim, and Yavatmal districts from Indian Meteorological Department, Pune. Daily rainfall data for Akola, Amravati, Buldhana, Washim, and Yavatmal stations were available for 31 years from 1990 – 2020. To study the rainfall variability of the Western Vidarbha region. To understand the precipitation trends, Parametric linear regression, and Non-parametric test Mann Kendal test with student t-test to check the significance level at annual, and seasonal scales. To study the probabilities of dry and wet spells during the monsoon season used Markov chain method for the five districts of 18 stations of the Marathwada region of Maharashtra. According to the criterion given by India Meteorological Department (IMD), Vidarbha is among the six rainfall-deficient regions of the country. In addition, Vidarbha's annual potential evaporation values range between 162 and to180 cm. The combined effects of scarce rainfall and high evaporation rates produce disastrous effects on the overall agricultural productivity of this region, which has become one of the serious concerns leading to farmer suicide in the Vidarbha region, Maharashtra. Hence, the region needs the immediate and thoughtful intervention of scientists and the farming community.

# Risk assessment of extreme wind hazard over India

**Ravi Ranjan[1], Parmeshwar D. Udmale[2], Subhankar Karmakar[1,3,4]**

*[1]Environmental Science and Engineering Department, Indian Institute of Technology Bombay, Mumbai 400076, India*

*[2]Centre for Technology Alternatives for Rural Areas, Indian Institute of Technology Bombay, Mumbai 400076, India*

*[3]Interdisciplinary Programme in Climate Studies, Indian Institute of Technology Bombay, Mumbai 400076, India*

*[4]Centre for Urban Science and Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India*

## ABSTRACT

Severe wind is one of the major hazards facing India. Cyclonic winds are the major source of wind hazard in the eastern coastal states, including Gujrat and Maharashtra in western coast. The non-cyclonic winds driven by synoptic lows, thunderstorms and strong convective weather systems affect almost entire India. The study of risks from non-cyclonic wind is often ignored due to the fact that winds, with the exception of tornadoes, were considered less a life threat. Moreover, the study of risk to wind extremes has been explored only for few limited contexts or sectors viz., electrical transmission & distribution system, buildings/infrastructure damage, and wind energy potential. There is a crucial need to use holistic approach by considering lower threshold to include non-cyclonic windstorms such that it also includes damages which are not permanent but are of socioeconomic importance. For example, power outages, road accidents (low visibility), debris born injuries, risk to outdoor labors/workers and disturbance to all mode of transportations (roadways, waterways and airways). Current study attempts to make a novel contribution to the risk literature by following the IPCC AR6 (2021) definition of risk as a function of hazard, exposure and vulnerability. Indicators of hazard (extreme wind and associated rainfall), socio-economic contributors of vulnerability (such as infrastructure, technology, finance and social nets) and exposure (space), are combined to develop an overall risk index at district-level over entire India. 10m-gust windspeed (m/s) hourly data for last four decades at very high resolution (~12 km) is used for the assessment of hazard. Further, the study employs TOPSIS approach to combine the contributing indicators and generate indices on hazard, exposure and vulnerability. This risk assessment will facilitate in identifying optimal wind mitigation strategies for reducing economic losses. Study emphasizes on the importance of including non-cyclonic wind extremes for better understanding and more realistic representation of risk from extreme wind hazard.

**Keywords:** Extreme Wind, IPCC AR6, Risk Assessment, Vulnerability, India

# Understanding the structural changes and inner core processes of tropical cyclones during rapid intensification

**Ganadhi Mano Kranthi[1,2], Medha Deshpande[1], Emmanuel R[1,2], and S. T. Ingle[2]**

*[1]Indian Institute of Tropical Meteorology, Pune, Ministry of Earth Sciences, India*

*[2]School of Environmental and Earth Sciences, KBC North Maharashtra University, Jalgaon, Maharashtra, India*

*E-Mail: ganadhi.kranthi@tropmet.res.in*

## ABSTRACT

Rapid intensification is the key process for all intense tropical cyclones (TCs). Our aim is to understand the association of structural changes like secondary eyewall formation and eyewall replacement cycle with the intensification of the tropical cyclones occurring over the North Indian Ocean which a less explored topic. To investigate these, we utilized satellite data and the non-hydrostatic Weather Research and Forecasting (WRF) model at cloud permitting resolution (3 km) considering a case of a super cyclone storm Amphan. Compared with the best track data, the simulated tropical cyclone track is reasonably captured though deviates slightly at the time of landfall. The simulated tropical cyclone intensity is overestimated but the rate of intensification is captured well. We investigated the structural changes in the simulation and observed that the tropical cyclone rapidly intensified as an extremely severe cyclonic storm during the formation of eye and primary eyewall. Then the secondary eyewall or concentric eyewall formed and TC further intensified and reached the lifetime maximum intensity as a super cyclonic Storm. The primary eyewall started disappearing and secondary eyewall radius started decreasing to replace the primary eyewall. During this structural change the tropical cyclone started weakening. These structural changes qualitatively match with the features seen in microwave satellite images. Further we are planning to study the role of microphysical processes happening during these structural changes.

# Climate Response of *Abies pindrow* in adjacent valleys of the Pir Panjal Range of Himalaya

**Uttam Pandey[1], Naveen Gandhi[1], H. P. Borgaonkar[1]**

*[1]Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune*

*Emails: uttam.pandey@tropmet.res.in; naveen@tropmet.res.in; hemant@tropmet.res.in*

## ABSTRACT

The Kashmir valley is bowled shaped, extended in NW-SE direction, and bound by the Pir Panjal and Zanskar mountain ranges. The Pir Panjal ranges received precipitation in the form of rainfall during intense Indian Summer Monsoon (ISM) and snowfall in harsh winters due to the western disturbances. The region's vegetation is dominated by *Abies pindrow* in the intermixed conifer forest of the valley. However, the influence of the climate is different throughout the valley due to changes in microclimate. Therefore, we selected *Abies pindrow* to analyse the climatic responses to the growth of the trees in the region. More than 100 tree-ring samples of *Abies pindrow* were collected from the Gulmarg and Kupwara valleys of north-western Kashmir. Though both the valleys are affected by the western disturbances and ISM during its peak, the relationship between tree growth and climate indicates heterogeneity of climate response in the adjacent valleys. It may be due to changes in climatic conditions in both valleys owing to geomorphological features. Therefore, developing a tree-ring network for individual valleys is necessary to understand long-term climate variation beyond instrumental climate records. The analyses of change in climate response of *Abies pindrow* in the adjacent valleys will be presented at the conference.

# SST-Convection relationship during MJO and MISO

**B. Rhituja[1,2], M. K. Roxy[1], Aditi Deshpande[2]**

*[1]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India*
*[2]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India*

## ABSTRACT

In the tropics, the dominant presence of intraseasonal variabilities like Madden-Julian Oscillation (MJO) and Monsoon Intraseasonal Oscillation (MISO) highly influences the rainfall variability on a global scale. These intraseasonal variabilities also affect the frequency, strength, spatial and temporal distribution of severe weather events. In this study, we investigate the SST-convection (outgoing longwave radiation, OLR) relationship and the ocean-atmosphere processes involved, during MJO and MISO over the central equatorial Indian Ocean (MJO Phase 2 region), for the period 1982 to 2021. This is a region where both the MJO and the MISO are active during boreal winter (December-January) and boreal summer (June-August), respectively. The analysis is focused on the 20-100-day timescale when the SST and OLR anomalies are dominant over the Phase 2 region. Results from the observations show a lead-lag relationship between these two variables. The response is faster during MISO, where OLR lags the SST by ~12 days; whereas it is comparatively slow during MJO with a lag of ~13 days. The faster response time during MISO is linked to the summer months, which boosts moisture transport and SST, and the onset of the summer monsoon, which introduces dynamic instability, causing an uplift. The SST driven shift in OLR indicates that a degree change in SST, results in an OLR change of ~45 $Wm^{-2}$ and ~65 $Wm^{-2}$ during MJO and MISO respectively. A composite analysis of the SST maximum events during MJO and MISO is performed, revealing that in both cases, the increased SST anomalies are primarily influenced by surface latent heat flux (SLHF) anomalies, with suppressed downward shortwave radiation (DWSR) anomalies enhancing it. Furthermore, the SLHF anomalies and DWSR anomalies play a dominant role in contributing to effective positive SST anomalies during MISO than MJO. The findings additionally highlight that the change in SST per day during MJO (despite a relatively low OLR anomaly) is comparable to that during MISO due to the shallow mixed layer depth during the winter for the MJO. Overall, the results here provide a better understanding of the mechanisms involved in modulating intraseasonal SST variations, and provide insights for incorporating these feedbacks and variations for improving model forecasts of MJO and MISO.

# A comparative study on understanding the long-term variability in carbon sequestration of different biospheres over Indian Region

**Smrati Gupta [1,2], Yogesh K. Tiwari [1], and Pramit K. Deb Burman [1]**

*[1] Indian Institute of Tropical Meteorology, Pune, MoES, GOI*
*[2] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi*
*Presenting Author's Name: Smrati Gupta*
*E-Mail:smratigupta01@gmail.com, phone: +91-9420871503*

## ABSTRACT

A study on different biosphere sectors over Indian region was taken up. Four different biosphere regions, 0.5°*0.5° spatial region, have been selected considering the varied geospatial and climatic variability of these regions from Central India, Northeast region, the Western Ghats, and Western Himalayan region. The climatic conditions of these four regions are different so are the biosphere constituents of these regions. We expect the Gross Primary Productivity (GPP) to enhance during all India Summer Monsoon rainfall season but in varied magnitudes suggesting a role of climatic parameters and flora in these regions. The GPP from FLUXCOM for the duration of 2001 to 2019 (19 years) and satellite-derived vegetation indices like Normalized Vegetation Index NDVI, Enhanced Vegetation Index EVI and Leaf Area Index LAI are used in this study to understand the response of region vegetation to this variability. EVI seems to be better related to GPP in comparsion to NDVI the preliminary analysis. Further analysis suggests LAI be better correlated to GPP than EVI and NDVI in many seasons in these four regions. Also, the meteorological parameters like surface temperature, rainfall, soil water, and other derived parameters like Vapor Pressure Deficit are also studied. It is also observed that the year-to-year variability in the climatic conditions could also have a role to play in the observed features. Vegetation is one of the potent markers to observe the climate change; this long-term data and further analysis are taken up to understand if there is any significant impact of the changing climate scenario on the vegetation in these regions.

**Keywords:** Terrestrial biosphere, Gross Primary Productivity, Vegetation Indices, Climate change

# Interannual variability of summer Cross Equatorial Cell during the last century and its association with monsoon circulation

**Rahul U Pai[1, 2,*], Anant Parekh[1], Jasti S. Chowdary[1], and C. Gnanaseelan[1],**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune – 411008*
*[2]Savitribai Phule Pune University, Pune – 411007*
*rahul.pai@tropmet.res.in*

## ABSTRACT

The present study understands the interannual variability of the Cross Equatorial Cell (CEC), an integral part of the Shallow Meridional Overturning Circulation of the Indian Ocean during boreal summer (June to September) using century-long ocean reanalysis data. It is found that Simple Ocean Data Assimilation (SODA) represents the variability of the upper 30m averaged summer meridional currents near the equator than the 20th-century Ocean Re-Analaysis (ORA-20C). Strong and weak CEC years are identified based on the standard deviation threshold (2.56 Sv) of CEC transport. Strong (weak) CEC year composite displayed more (less) southward transport (~3 Sv). The interannual standard deviation of meridional heat transport associated with summer CEC is found to be 0.26 PW, which is 60% of its mean. The strong (weak) CEC years resulted in the increase (reduction) of southward meridional heat transport followed by a reduction (increase) in upper ocean heat content and sea level over NIO. Heat budget analysis is carried out to estimate the role of ocean circulation promoting variability in the upper ocean heat content of NIO. A detailed analysis reveals that the CEC variability displayed coherent relation with zonal wind variations at $10^{o}$N which displays a close association with monsoon circulation variability. The study concludes that the variability of summer CEC is forced by zonal wind variations associated with monsoon circulation and modulates the upper ocean heat content and sea level over NIO at the interannual time scale.

# Examination of soil water dynamics during in extremely dry and wet conditions inferred from COSMOS-IITM Pune site observation

**Mangesh M. Goswami[1,2], Milind Mujumdar[1], Naresh Ganeshi[1], Bhupendra Bahadur Singh[1], Madhusudan Ingale[1], R. Krishnan[1] and S. N. Patil[2]**

*[1]Indian Institute of Tropical Meteorology, Pune-411008.*
*[2]Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon*

## ABSTRACT

Soil Moisture (SM) is a key element of surface and subsurface hydro-meteorological processes. In this context, continuous high-resolution profile observations of soil moisture provide precise quantification to understand soil water dynamics under changing climate. In order to understand how soil water dynamics affect energy exchanges during extremely dry and wet climatic conditions, we use hydro-meteorological observations available at the COSMOS-IITM site (located in the core monsoon zone of India) for the period of 2019-2022. Significant differences in soil moisture profiles are evident on inter-seasonal and annual scales. Absence of convective activities and the persistence of higher daily mean temperatures (> 35 deg. C) during the pre-monsoon season of 2019 (and 2022) led to persistent dry conditions, while excess rainfall during the monsoon and post-monsoon season supported wetter conditions at the study site. Persistent dry SM conditions during 2019 (and 2022) pre-monsoon season is associated with weakening of evapotranspiration (ET) at the expense of stronger exchange of sensible heat flux from the land surface to the atmosphere. However, the excess latent heat flux during the monsoon and post-monsoon seasons of 2019 enabled substantial evapotranspiration. Interestingly, the net soil water storage at the surface is higher in 2020 due to frequent intense rain spells during two successive years.

**Keywords**: Soil moisture, dry and wet extremes, sensible/latent heat flux, evapotranspiration

# Role of Equatorial Central Pacific SST in Modulating Rainfall over North India during Indian Summer Monsoon

**Monalisa Sahoo[1,2] and Ramesh Kumar Yadav[1]**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India*
*[2]Savitribai Phule Pune University, Pune, India*
*monasahoo95@gmail.com*

## ABSTRACT

The summer monsoon season contributes about 80% of annual rainfall in the highly populated region of north India. The teleconnections moderating the variation of summer monsoon rainfall in this region are not satisfactorily understood. A pathway of the equatorial central Pacific sea surface temperature (PSST) influences the north India summer rainfall is revealed from the high-resolution, more reliable, and state-of-the-art 41-year (1979–2019) observational data analysis and numerical experiment. The rise in PSST intensifies convection over the equatorial central Pacific with compensatory subsidence over the western equatorial Pacific. Consequently, a much broader and intense anomalous convergence is developed at the upper-troposphere, which subsequently intensifies the Asian subtropical westerly jet-stream. The Asian jet intensification strengthens the tropospheric wind shear at north India, as the low-level monsoonal winds are easterlies over there. The strong wind shear restricts the convective activities in north India.

**Keywords:** Asian jet-stream, north India, sea surface temperature, subsidence, summer monsoon, tropospheric wind shear

# Soil moisture revamps the temperature extremes in a warming climate over India

**Naresh Ganeshi[1], Milind Mujumdar[1], Yuhei Takaya[2], Bhupendra Singh[1], Mangesh Goswami[1], R Krishnan[1], Toru Terao[3]**

*[1]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India.*
*[2]Meteorological Research Institute, Climate Research Department, Ibaraki, Japan.*
*[3]Faculty of Education, Kagawa University, Kagawa, Japan.*

## ABSTRACT

Soil moisture (SM) plays a crucial role in altering climate extremes through complex land-atmosphere feedback processes. In the present study, we investigated the impact of SM perturbations on temperature extremes (ExT) over India for the historical period (1951–2010) and future climate projection (2051–2100) under 4 K warming scenario. We note that more than 70% area of the Indian landmass has experienced significant changes in characteristics of ExT due to SM perturbations. In particular, we see larger impact of SM perturbations on ExT over the north-central India (NCI), which is a hotspot of strong SM-temperature coupling. Over NCI, a 20% departure in SM significantly revamps frequency, duration and intensity of ExT by 2–5 events/year, 1-2 days/event and 0.5–2.1 °C, respectively, through modulating surface energy partitioning, evapotranspiration and SM memory. Importantly, the impact of SM perturbations on frequency and duration of ExT events becomes less prominent with intensification of global warming.

**Keywords:** Soil moisture, temperature extremes, soil moisture-temperature coupling, soil moisture memory, model sensitivity experiments

# Decadal Prediction Skill of Indian Summer Monsoon in CMIP6 Models

**Subrota Halder[1,2,*], Anant Parekh[1], Jasti S. Chowdary[1], and C. Gnanaseelan[1]**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune – 411008*
*[2]Savitribai Phule Pune University, Pune-411007*
**subrotahalder.jrf@tropmet.res.in*

## ABSTRACT

Decadal climate prediction fills the gap between short-term and long-term climate projections and has important implications for decision-making. However, assessing decadal predictions using coupled models is challenging, particularly for Indian summer monsoon (ISM) variability. To address this, the skill of decadal prediction systems of CMIP6 is being assessed using 9 CMIP6 models. The 'dcppA-hindcast' monthly data from a set of 10-yr-long hindcast experiments initialized every years from 1960 to 2014/../2019 (57-60 experiments) available at ESGF nodes. The decadal prediction experiments are initialized in the September-December from the observed climate state, including atmosphere composition and ocean and sea ice conditions. The ensemble mean from 5 ensembles is produced for each model for each IC years. Multi-model ensemble (MME6) is calculated averaging outputs from all available models with equal weightage. The predictive skill is evaluated by computing the anomaly correlation coefficient (ACC) related to the forecasted and observed anomalies, in order to assess the capability of the models in reproducing the observed variability. Tropospheric Temperature (TT) is an important indicator for the monsoon evolution, with land-sea thermal contrast and diabatic heating playing important roles in establishing and maintaining the monsoon circulation. In the lead year (LY) 1, all the models show significant ACC with a confidence level of 95% throughout the region. Six models in LY 2-5 show significant ACC. As far as meridional gradient of TT is concerned, the models have better ACC for the southern region (40°E-100°E, 15°S-5°N) than the northern region (40°E-100°E, 5°N- 35°N) in all LYs. ACC analysis for vertical shear of zonal winds (200hPa -850hPa, which manifests baroclinic nature of monsoon circulation) for different leads are found to be lesser than TT. Models have better skill in predicting temporal evolution of thermodynamic based indices rather than circulation based indices.

**Key Words:** Decadal Prediction, Indian Monsoon, Dynamics, Thermodynamics

# Changes in the features of thunderstorm activity over Kerala, South India

**Nandhulal K., Hamza Varikoden & Vishnu R.**

## ABSTRACT

Kerala is one of the regions in India where lightning incidents are relatively more. Results of a study based on reported incidents of lightning show that, on an average, there are 118 reported lightning accidents per annum in Kerala (Murali Das et al., 2004). During the period, April 1995 to February 2003, in a year there are about 30 to 40 flashes recorded in a square kilo meter of area (GHCC NASA, 2005). Studies were conducted to understand the characteristics of thundercloud formation and spatial-temporal variations of lightning activity over Kerala (Murali Das et al., 2007, Vishnu et al., 2010, Vishnu, 2012). There are also some studies focusing on the lightning activity and its characteristics specifically over south India (Unnikrishnan et al., 2021). However no studies were conducted to figure out the variations in thunderstorm activity if any, due to the changes in prevailing climatic conditions. The present paper is an attempt to determine if the lightning activity over Kerala has changed, and to evaluate how much the change has been influenced by climate change.

# Characteristics of recent Cloudburst events based on INSAT data

**Manali Saha[1]and Charu Singh[2]**

*[1] Indian Institute of Technology, Bombay, [2] Indian Institute of Remote Sensing, Dehradun*

## ABSTRACT

Cloudburst or extreme rainfall events (ERE) are defined as the heavy intensity precipitation events in a short amount of time and are the most catastrophic weather events causing huge destruction of properties and life every year. It has been shown in previous studies that the North-West Himalayan region is highly prone to the cloud burst events during the pre-monsoon and monsoon seasons. In the present work, identification and analysis of all recently occurred cloud burst events for the year 2021 have been carried out over this region. High resolution satellite products of INSAT 3D (OLR, HE Rain, and Cloud Top Properties) and SRTM Dem are utilized here for comprehensive analysis of the spatial -temporal characteristics of the cloudburst events. The Cloud Top Temperature (CTT) and Cloud Top Height (CTH) have been estimated using the Stefan Boltzmann Law and Hypsometric equation respectively to get insight into cloud growth during the cloud burst events. Present analysis shows that on an average the OLR values drop considerably about 7 hours before the extreme rainfall episodes, thereafter a remarkable drop in the CTT about 4 hours before the event in association with the increase in the CTH from 2km to a maximum of 20 km are noted. The clouds during the events are found to be high level deep convective and Nimbostratus clouds. Further, OLR anomalies propagation is seen to be North Easterly for monsoon months with approximate speed of about 2.6 m/sec and South Westerly of about 3.9 m/sec speed for pre-monsoon months. Thus, capturing of the cloudburst events based on INSAT data shows promising results and can be therefore used for nowcasting for future events.

# Implications of initial conditions and role of Micro-physics in WRF Simulation: A case study of north east Thunderstorm

**Devanshu Kanaujia [1], Namendra Kumar Shahi [3] and Shailendra Rai [1,2]**

*[1] K. K. Banerjee Centre of Atmospheric and Ocean Studies, University of Allahabad, Prayagraj, India*

*[2] M. N. Saha Centre of Space Studies, University of Allahabad, Prayagraj, India*

*[3] Institute of Environmental Geosciences (IGE) Grenoble Alpes University (UGA) 38400 Saint-Martin-d'Heres, Grenoble, France*

*E-mail: devanshukanaujia@gmail.com, raishail77@gmail.com*

*Presenting Author's Name: D. Kanaujia*

*E Mail / Contact Details: devanshukanaujia@gmail.com*

## ABSTRACT

Thunderstorms (a typical mesoscale convective system) often cause severe and devastating flash floods and related disasters. Prediction (in lead time) of the thunderstorm in the scale of time and space yet remains a challenge. Most of the mesoscale models of recent decades still have difficulties capturing the synoptic conditions that lead to thunderstorm formation. Due to an inaccurate initial and boundary condition, weather phenomena are an initial value problem. So accurate initial condition plays an important role, while simulating mesoscale phenomena such as thunderstorm. The north-eastern part of India remains highly prone to thunderstorm activities during March-April-May (pre-monsoon period), and we need a high predictable model. This is well known in advance that convection plays a vital role in the formation of severe thunderstorms. Hence, the Advanced Research version of the Weather Research and Forecasting (WRF-ARW) model was used in this study to perform the numerical simulation. The different sensitivity experiments were performed with different microphysical schemes and different initial and boundary conditions. This study investigates the role of initial and boundary conditions in simulating thunderstorm events during the pre-monsoon period over Kolkata and its nearby region using a numerical model. The model simulation outputs were validated with the observations. Thermodynamic and dynamic indices like the Convective Available Potential Energy, Convective Inhibition Energy, Lifted index, K-index, Total Total Index, was also studied to quantify the convective instability of the atmosphere. It was found that the Fine resolution GFS (.25*.25) gives a better result in comparison to FNL(1*1) model performs well in simulating the severe weather events, associated thermodynamical, dynamical processes and associated land surface-atmosphere processes. However, the model shows a sensitivity that varies with the experiments in different microphysical schemes.

**Keywords:** WRF_ARW, thunderstorm, sensitivity experiments, Thunder squall, initial value problem

# El Niño Southern Oscillation variability in Observations and CMIP6 Models

**Tanu Sharma[1] and Satyaban B. Ratna[1]**

*[1] Climate Research and Services, India Meteorological Department, Pune, India*
*Presenting Author's Name: Sharma Tanu.*
*E-Mail: tanu35bhp@gmail.com*

## ABSTRACT

The El Niño-Southern Oscillation (ENSO) is a prominent ocean-atmosphere coupled phenomenon over the Pacific Ocean, which is known to strongly influence the various weather and climate phenomenon across the globe including the Indian Summer Monsoon Rainfall (ISMR). The sea surface temperature (SST) is an essential variable in understanding the changes in the various climate phenomenon on Earth including ENSO. This study comprises a preliminary analysis of the SST values and the Niño3.4 Index for the June to September (JJAS) season from 1901 to 2014, using 12 global climate models of the 6th generation of the Coupled Model Intercomparison Project (CMIP6). Based on the Niño3.4 Index, the El Niño and La Niña events are identified. The composite analysis of El Niño and La Niña is discussed and the results are compared with the observations. The results are helpful in improving our understanding of the ISMR–ENSO relationship in the climate models.

**Keywords:** ENSO, CMIP6, Monsoon teleconnections, Sea Surface Temperature.

# Long - term monsoon rainfall characteristics over different districts of Kerala

**Gopika Venugopal C[1,2], Hamza Varikoden[3] , C. A. Babu[2]**

*[1]Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi - 110 016, India*
*[2]Department of Atmospheric Sciences, Cochin University of Science and Technology, Kochi - 682 016, India*
*[3]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pashan, Pune - 411 008, India*
*[3]Email:hamzavarikoden@gmail.com , [2]Email: babuca@cusat.ac.in ,*
*[1]Email: gopikac1997@gmail.com , [1]Ph No: +91 9072217070*

## ABSTRACT

Kerala state located on the southwest peninsular region of India is a narrow strip of land with Western Ghats mountain range on the eastern side and Arabian Sea on the western side. The landforms of Kerala have three distinct physiographic zones namely, the low land, the midland and the high land from the west to east. Due to the complex topography of Kerala, the climate, especially the rainfall patterns, varies substantially within a short distance from the coastline to the Western Ghats. Hence the regional variability in rainfall characteristics over Kerala plays a crucial role in shaping the regional climate. There have been several studies on the long-term rainfall variability over Kerala, but relatively few have focused on rainfall variability on a smaller scale. Studies on long-term regional rainfall variability and trend over Kerala is important. In this study, we focused on the district-wise southwest monsoon rainfall variability and trend over Kerala in view of climate change aspects for the past 121 years and the long-term trends in extreme rainfall events during southwest monsoon season. IMD daily gridded rainfall dataset for a period, 1901 – 2021 is used for the analysis. We analysed long-term trends in seasonal rainfall, percentage of contribution and frequency of occurrence of extreme rainfall events during the monsoon season. A significant decreasing trend in monsoon rainfall is observed over the majority of the districts in Kerala. Idukki is the only district showing a significant increasing pattern. The influence of Western Ghats orography in shaping the rainfall patterns over different districts of Kerala can be well noticed in our analysis. The frequency of occurrence of extreme rainfall events during the monsoon season and their contribution to seasonal rainfall is exhibiting a decreasing trend. Wavelet analysis of seasonal and extreme rainfall events indicates that there is no homogeneity in the rainfall characteristics of extreme and seasonal rainfall in each and every district. They appeared to be heterogeneous in nature with one having a decadal variability while the other exhibiting a multi decadal variability.

# The effect of rapid urbanization on surface air temperature trends: Case study of Ambala district in Haryana

**Namita Yadav[1], Rishabh Singh[1,] Kushagra Rajendra[1], Amit Awasthi[2]and Charan Singh[3]**

[1]*Amity School of Earth and Environmental sciences, Amity Education Valley Gurugram, Manesar, Panchgaon, 122412, Haryana, India*

[2]*Department of Applied Science, University of Petroleum & Energy Studies, Dehradun, 248007, Uttarakhand, India*

[3] *India Meteorological Department. Ministry of Earth Sciences. Government of India.*

## ABSTRACT

Urbanization is a necessary component of social and economic development in the modern world. Nonetheless, the rate at which urbanisation is occurring results in significant environmental impacts, due to which different climatic effects is observed. Variations in rainfall, temperature, humidity, evaporation, wind velocity, and other meteorological parameters over the long-term are referred to as climatic variability for an area. To identify these types of variabilities, the monthly and seasonal trend analysis of surface air temperature for past three decades are is conducted for Ambala district of Haryana.

Standard Non-parametric Mann Kendall test and Sen's slope estimator is used to find out the trends along with its significance. According to the Haryana census report (2021), there is 55.81% hike in urban population, so monitoring of urban expansion in Ambala is studied using Google Earth Engine. It is observed that population is frequently converting larger areas of land into buildings and other infrastructure, which is one of the causes for the rise in temperature in the city.

Trend analysis of monthly and seasonal data for maximum temperature has shown increasing trend with positive z values varying between 1.67-8.96 (z value <1.65 shows increasing trend with <90% level of significance) for all months and seasons. For average and minimum temperature, results show both positive and negative behaviour. Hence, it is important to measure and understand the environmental changes that has already happened during recent year. These analysis and pattern will help planners to make more precise forecasts of the future. Strategies based on the predictions helps to promote international goals at the microplanning level to reduce its harmful local and global effect.

**Key words:** Urbanization, Trend Analysis, Climate Change, Mann Kendall, Sens slope estimator

# Role of soil moisture during the active phases of the Indian Summer Monsoon

**Pratibha Gautam[1, 2], Rajib Chattopadhyay[1, 3], Gill Martin[4], Susmitha Joseph[1], A.K. Sahai[1]**

*1. Indian Institute of Tropical Meteorology, Pune 2. Savitribai Phule Pune University*
*3. India Meteorological Department Pune, Maharashtra 411005 4. Met Office, Exeter, UK*
*E-mail: Pratibha.gautam@tropmet.res.in*

## ABSTRACT

What is the role of soil moisture in maintaining the land ITCZ during the active phase of the monsoon? This question has been addressed in this study first by using ERA5 reanalysis datasets, and then we evaluate the question in the CFS model-free run. Like rainfall, land surface parameters (soil moisture and evaporation) also show intraseasonal oscillation. Furthermore, the sub-seasonal and seasonal features of soil moisture are different from each other. During the summer monsoon season, the maximum soil moisture is found over western coastal regions, central parts of India, and the northeastern Indian subcontinent. However, during active phases of the monsoon (i.e., on sub-seasonal timescales), the maximum positive soil moisture anomaly was found in North West parts of India. Land surface characteristics (soil moisture) also play a pre-conditioning role during active phases of the monsoon over the monsoon core zone of India. When it is further divided into two boxes, the north monsoon core zone, and the south monsoon core zone, it is found that the preconditioning depends on that region's soil type and climate classification. Also, we calculate the moist static energy (MSE) budget during the monsoon phases to show how soil moisture feedback affects the boundary layer MSE and rainfall. A similar analysis is applied to the model run, but it cannot show the realistic preconditioning role of soil moisture and its feedback on the rainfall as in observations. We conclude that to get proper feedback between soil moisture and precipitation during the active phase of the monsoon in the model, the pre-conditioning of soil moisture should be realistic.

# Halogen chemistry over the Indian Antarctic station Bharati

**Shrutika P. Wagh[1], Anoop S. Mahajan[2], Rohini L. Bhawar[1]**

*[1]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India*
*[2]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India*
*Corresponding author: Dr. Anoop S. Mahajan (anoop@tropmet.res.in)*

## ABSTRACT

Ozone is naturally present in the atmosphere and is mostly (~90%) found in the stratosphere. Stratospheric ozone protects the Earth by absorbing harmful ultraviolet radiation. In addition to the stratosphere, ozone is also found in the troposphere. Ozone near the surface of the Earth is toxic to human health and vegetation production. It also acts as a greenhouse gas, although a small amount of tropospheric ozone is important since it is the main source of hydroxyl radicals. Over the last few decades, the ozone concentration in the troposphere has been increasing due to anthropogenic activities and understanding its budget is crucial for modelling atmospheric chemistry. Reactive halogen species like bromine oxide (BrO) and Iodine oxide (IO) play an important role in atmospheric chemistry because they act as catalysts in ozone depletion. In this study, we use the Multi-Axis Differential Absorption Spectroscopy (MAX-DOAS) instrument to measure BrO at the Indian Antarctic base, Bharati, for over one year (Dec 2018 to Feb 2020) period. The slant column densities of the oxygen dimer ($O_4$), BrO and IO are retrieved in the ultraviolet and visible spectral regions. Elevated concentration of BrO was observed at lower elevation angles during the spring season (September-October) and for IO elevated concentration was observed during the summer season. A Radiative Transfer Model is been used to get the mixing ratio of BrO and IO. The mixing ratio for BrO goes up to 20 pptv whereas the mixing ratio of IO is 2 pptv for the whole data period. The aim of this study is to quantify the impact of BrO and IO on surface ozone depletion at Bharati.

# Influence of the April southern annular mode index on the heavy rainfall event in the month of August over Kerala, India

**Sreevidya Ravi**

*Cochin University of science and Technology*

## ABSTRACT

In recent years heavy rainfall events (HRE) have increased over Kerala during the month of August. This study attempts to identify the global teleconnections of such HRE and understand the mechanisms. A high-resolution 0.25*0.25 gridded daily rainfall data set for 40 years (1981-2020) from IMD is used for the study. The rainfall above the $95^{th}$ percentile in a grid is considered a heavy rainfall event. During the study period, an increasing trend (significant at 5%) in the frequency of HRE over Kerala during August is observed. The correlation analysis used for identifying global teleconnections patterns, reveals that the HRE of August over Kerala shows a negative correlation (significant at 5%) with April southern annular mode index (ASAMI). The HRE has a simultaneous negative correlation with the MSLP of the western Indian Ocean, and a positive correlation with low-level cyclonic circulation in the mid-latitudes of the south Indian Ocean and the South Pacific Ocean. On the other hand, ASAMI has a positive correlation with August MSLP in the western Indian Ocean and a negative correlation with low-level cyclonic circulation in the mid-latitudes of the south Indian Ocean and the South Pacific Ocean. The correlation analysis of global SST with HRE and ASAMI shows that ASAMI influences HRE in August via the southwest Pacific Ocean. The ASAMI induces positive SST anomalies in the southwest Pacific Ocean ($177^0$W-$150^0$W, $20^0$S-$41^0$S) in April. These SST persist from April to August and shows a development toward the Equator from April to August. These SST anomalies in April influence the HRE. Moreover, HRE shows a simultaneous correlation with a weak La Nina phase in the Pacific Ocean and a positive IOD in the Indian Ocean. The southwest Pacific SST ($177^0$W-$150^0$W, $20^0$S-$41^0$S ) in April also show an almost similar relation with global SST in August. Hence ASAMI and southwest Pacific SST anomalies in April can be considered as a predictive signal for HRE. Further study is required to determine the underlying mechanism of these remote teleconnections

# Surface and Atmospheric Boundary Layer features over the Indian subcontinent during extreme temperature events

**Ketaki Belange, Anandakumar Karipot, Aditi Deshpande**

*Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India 411007*

## ABSTRACT

Extreme weather events such as heatwaves and associated extreme temperatures have been on the rise in the recent decades. Prevailing synoptic conditions together with the regional land surface and atmospheric boundary layer processes are mainly responsible for the occurrence of heatwaves over a region. In 2015, large parts of the Indian sub-continent experienced two severe heatwaves, in late May and early June. The late May heatwave is considered as the fifth deadliest in the world and the second deadliest in India. There was another severe heatwave in 2016 as well. A comprehensive study has been carried out to better understand the role of land surface and boundary layer processes in modulating the heatwave intensity. Reanalysis data products, IMD gridded surface air temperature data and ESA CCI soil moisture datasets of 30 years (1991-2020) have been used for the analyses. The mean and anomalies of various parameters such as air temperature, sea level pressure, geopotential height, soil moisture, PBL height, and surface fluxes during and preceding to the extreme temperature events have been studied in detail. The inter-relationship among the different parameters and their role in the generation and intensification of extreme air temperature events have been brought out in the study.

# Evaluation of global solar radiation reanalysis data for solar power applications

**Komal Vikas Navale, Anandakumar Karipot, Kishore Kumar Grandhi and Rohini L. Bhawar**

*Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India 411007*

## ABSTRACT

There are growing interests around the world to increase the use of non-conventional energy resources, in an effort to reduce the dependence on fossil fuels and thus lower greenhouse gas emissions. Solar energy resources, where solar radiation is directly converted to electricity with the use of solar panels, is one of the major renewable energy sources being extensively explored and extracted in India. Several aspects, including variations in the solar radiation and meteorological conditions influence the power production. Cloud cover is the most important factor that determines the intensity of solar radiation reaching the surface, which exhibit large spatial and temporal variations at differing scales. Identifying the suitability of a location for the installation of solar power farm and to estimate the expected energy output require accurate information about the solar radiation reaching the surface in cloudy conditions and its temporal variations. In situ observations of solar radiation are available only at selected locations and for limited periods. The use of validated solar radiation reanalysis data will help detailed analyses related to solar energy applications.

The analysis of solar radiation variations in cloudy conditions during different seasons of the year, related variations in the generated solar power and validation of the reanalysis solar radiation data in cloudy conditions are the main objectives of this study. The region selected for the study is Pune. Evaluation is performed using the global solar radiation ERA5 and IMDAA (NCMRWRF) reanalysis datasets, and the outcomes are contrasted with the in situ surface observation data for a two year period. In order to assess the reduction in power produced as a result of the change in the radiation pattern, the power output from solar panels is also compared with the radiation data. This study will help better understand the reduction in power produced by solar panels during cloudy and unfavourable weather conditions.

# Future Changes of Indian Summer Monsoon in CMIP6 Projections

**Lekshmi M. S.[1,2], Roxy Mathew Koll[1], Vineet Kumar Singh[1]**

*[1]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune, India, [2]College of Climate Change and Environmental Sciences, Kerala Agricultural University, Thrissur, India*

## ABSTRACT

Accurate future monsoon projections are important for climate policy choices. The current study evaluates future monsoon projections in the Coupled Model Intercomparison Project Phase 6 (CMIP6) by considering the combined impact of thermodynamic and dynamic responses of rainfall to global warming. The thermodynamic response refers to the rise in atmospheric moisture content due to warming caused by increased greenhouse gases, and the dynamic response relates to changes in atmospheric circulation patterns due to global warming. CMIP set of models, in general, reproduces the thermodynamic response of rainfall to an increase in temperature, but they have biases in representing the dynamic response of rainfall to these changes. However, previous studies use all models irrespective of this bias. Hence, here we selected the models based on their ability to reproduce the observed wind and rainfall pattern over the Indian monsoon region. Using these models, we understand and quantify the future changes of the monsoon under global warming and identify the dynamic and thermodynamic mechanisms driving these changes. The near-term (2021–2040), mid-term (2041–2060), and long-term (2081–2100) variations of the Indian summer monsoon (ISM) have been studied under SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios.

The present drying trend over the subcontinent is projected to continue in the near-term as a result of the weakening monsoon circulation. The low-level monsoon winds are projected to show distinct changes by 2040 with a strengthening over the north Arabian Sea and a weakening over the south Arabian Sea. This is found to have an impact on the mid-term and long-term ISM rainfall. In the long-term, there is a projected rise in wind speed over the north Arabian Sea by 21%. This, combined with an amplified moisture supply, is predicted to bring about an increase in precipitation over the north of west coast region and the central Indian region by 22%. A similar trend in rainfall is not found over the southern parts of the peninsula because of the weakening south Arabian Sea wind speed (-18%). These weak winds are insufficient to transport the increased moisture from the warming west Indian Ocean to the subcontinent. Instead, the warming will cause the moisture to rise above the ocean, leading to an increase in rainfall over the Arabian Sea. However, projections indicate that there will be a 13% increase in rainfall over the southern parts of the peninsula by 2100. Here, the dynamic response in weakening monsoon circulation is compensated by the thermodynamic response in increased moisture. Utilizing these projections from specific periods in the future, our research aims to facilitate the development of appropriate adaptation measures and enhance policymaking.

**Keywords:** CMIP6, Indian Summer Monsoon Rainfall, Monsoon Circulation, Climate Projections

# Relation between rainfall and soil moisture variability during dry and wet extremes over core monsoon zone of India

**Madhusudan Ingale[1], Milind Mujumdar[1], Bhupendra Bahadur Singh[1], Naresh Ganeshi[1,2], Mangesh M. Goswami[1,3], and R. Krishnan[1]**

*[1]Indian Institute of Tropical Meteorology, Pune-411008*
*[2]Savitribai Phule Pune university, Pune-411007*
*[3]Kavayitri Bahinabai Chaudhari North Maharashtra University, (KBC-NMU) Jalgaon - 425001*

## ABSTRACT

Monsoon variability plays a major role in soil moisture dynamics, distribution and variability over the Indian subcontinent. Though monsoon rainfall and soil moisture are tightly coupled, the patterns evolve distinctly each year. Using high resolution observational and reanalysis estimates of rainfall and soil moisture, we investigate how soil moisture responds to persistence and intensity of rain spells. For this purpose, we diagnose the general association between them and specifically analyse two recent cases of contrasting monsoon years, i.e. 2015 (deficit) and 2019 (excess) rainfall. Spectral analysis reveals that the modes of soil moisture variability are concurrent with rainfall variability. The monsoon of 2015 (2019) exhibits zonally (meridionally) propagating ISOs with major contributions from high (low) frequency components which modulates moisture content in the soil, and leads to shorter (longer) persistence over an extended period. The soil moisture memory time scales are found to be 40-50 days during 2015 (deficit year), while it exceeds 60 days during 2019 (excess year). Our study indicates the "orderliness" of soil moisture response to rainfall variability scales with deficit or excess conditions.

**Keywords:** rainfall extremes, soil moisture, Core Monsoon zone, spectral analysis, soil moisture memory.

# Characterizing soil moisture - rainfall variability during dry and wet extremes over core monsoon zone of India

**Madhusudan Ingale[1], Bhupendra Bahadur Singh[1], Milind Mujumdar[1], Naresh Ganeshi[1,2], Mangesh M. Goswami[1,3], and R. Krishnan[1]**

*[1]Indian Institute of Tropical Meteorology, Pune-411008*
*[2]Savitribai Phule Pune university, Pune-411007*
*[3]Kavayitri Bahinabai Chaudhari North Maharashtra University, (KBC-NMU) Jalgaon - 425001*

## ABSTRACT

In recent decades hydro-meteorological extremes have increased in frequency, intensity and duration, resulting in socio-ecological disruptions. A comprehensive understanding of spatiotemporal variability and trends in such extremes is therefore vital for evaluating their severity and impact. In this work, we analyse a few of these aspects by investigating soil moisture response to persistence and intensity of rain spells. We implement wavelet analysis with an information-theoretic approach to explore the general association between soil moisture and rainfall variability, specifically for the two recent cases of contrasting monsoon seasons, i.e. for the year 2015 (deficit) and 2019 (excess). Spectral analysis reveals that the monsoon season of 2015 (2019) exhibits major contributions from high (low) frequency components which modulates moisture content in the soil, and leads to shorter (longer) persistence over an extended period. The soil moisture memory time scales are found to be ~ 27 days during 2015 (deficit year) whereas it increases to ~ 34 days during 2019 (excess year). Furthermore, the higher chaotic degree of annual variability patterns in soil moisture and rainfall for 2015 (deficit) makes it strongly nonlinear as compared to 2019 (excess). Since atmospheric forcing is the primary driver of soil moisture variability, the outcomes suggest that distinct regional atmospheric forcing may be responsible for these two contrasting years.

**Keywords:** rainfall extremes, soil moisture, spectral analysis, nonlinear, soil moisture memory.

# Monitoring spatio-temporal day and night Land Surface Temperature from MODIS satellite images: A study on Vadodara district, Gujarat

**Sharmistha Bhowmik[1], Bindu Bhatt[2]**

*The Maharaja Sayajirao University of Baroda[1], The Maharaja Sayajirao University of Baroda[2]*

## ABSTRACT

An ample number of urban environmental concerns have emerged in cities all over the globe as a result of rapid urbanization and intense human involvement. Urbanization triggers an increase in the earth's heat flux. To evaluate the net radiation budget at the Earth's surface Land Surface Temperature (LST) is significant. The study focusses on the study of LST evaluating the 8-Day Land Surface Temperature/Emissivity Data from the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) (MOD11A2) in Vadodara district of Gujarat. Day and night temperature was analyzed for 2014, 2017 and 2020 for both pre-monsoon and post-monsoon season. For the pre-monsoon months of (March-April-May) were used and for post-monsoon (October-November-December) were used. The LULC changes were evaluated using the MODIS Land Cover Type Yearly L3 Global 500 m SIN Grid (MCD12Q1) satellite images, which was then rescaled to 1km to match the resolution with MOD11A2 images. To examine the impact of impervious area contributing to an increase in land surface temperature, the percentage of impervious area was also calculated.

**Keywords:** Land Surface Temperature, MODIS images, Day temperature, Night temperature, Impervious Area.

# Simulation of the Indian Summer monsoon 2021 and 2022 in SPEEDY-AGCM

**P. Singh, J.S. Chowdary, A. B. Parekh and C. Gnanaseelan**

*Indian Institute of Tropical Meteorology, Pune-411008*

## ABSTRACT

Present study made a use of the International Center for Theoretical Physics ICTP AGCM SPEEDY, (Simplified Parameterizations, privitivE-Equation DYnamics”) to carry out successful simulation of 2022 summer monsoon. In this study, the AGCM is configured with eight vertical (sigma) levels and with a spectral truncation at total wavenumber 30. The boundary conditions are derived from the ERA interim re-analysis. The standard horizontal resolution corresponds to a triangular spectral truncation at total wavenumber 30 (T30), with a standard Gaussian grid of 96 by 48 points. The model allows a time-varying SST anomaly to be superimposed to the climatological SST, hence the AGCM is forced by the observed SST anomalies. Various monsoon features, lower and upper level monsoon circulation, mean sea level pressure distribution, atmospheric convection spatial distribution as well as rainfall spatial and temporal evolution are studied in detail. Model could reproduce large scale features associated with the Tropical Indian and Pacific Ocean as well as Indian summer monsoon reasonably well, however regional features are simulated with some discrepancies. Recent three years starting from 2020 to 2023, anomalous La Nina conditions over equatorial Pacific, making it as one of unusual ‘Protracted’ La Nina event. In particular, La Nina related SST cooling is stronger in summer 2021 and 2023 compared to 2020. In this study, we have examined Indian Summer Monsoon rainfall variability in observations and AGCM simulations. Though, La Nina and negative IOD like conditions prevailed in both 2021 and 2022 summers, AGCM forced with observed SST could simulate 2022 ISM features well but not 2021. Factors that are responsible for model failure in 2021 case in AGCM simulations are discussed. Overall skill of the model in simulating ISM rainfall is also investigated.

# Quantifying the cloud base height over tropical region Pune, India

**Mrunal S. Naik, Rohini Bhawar , Pallath Pradeep Kumar**

[1]*Department of Atmospheric and Space Science, Savitribai Phule Pune University, Pune, India*

## ABSTRACT

Clouds prove an essential entity in forecasting of the weather. Low-altitude clouds tend to be relatively thick optically, and they reflect the incoming solar radiation thus, cool the atmosphere. High-altitude clouds are usually optically thin and their overall impact is to warm the atmosphere.

Here, we are using the cloud base data from the ceilometer instrument which is installed on the terrace of the department of Atmospheric and Space Sciences. The diurnal variability of cloud base height during different seasons, the variability of single and multilayer clouds has been studied over Pune. The average of 5 years data shows that the maximum occurrence of single layer cloud base is during winter (63.1%) and minimum during monsoon (24%) seasons whereas, maximum occurrence of double layer cloud base is during monsoon (76%) and minimum during winter (5.1%). It is observed that maximum occurrence of clear sky is during pre-monsoon and winter (31.9%), low level cloud base dominates during monsoon (62.2%), while mid-level and high-level cloud base is found to be maximum during pre-monsoon (53.3%; 12.3%) respectively. During monsoon period cloud base height 2 (CB2) is found to be ranging between 1700-3700 m height. Interestingly, the frequency of occurrence of CB1 and CB2 during winter shows that both the base height contributes almost equally. During pre-monsoon and post-monsoon the variation in CB1 is similar for all years except that the post-monsoon is characterized by higher heights. Higher CB2 heights dominate in pre-monsoon while high interannual variability in CB2 is observed in post-monsoon. Variation of CB1 and CB2 during monsoon does not show any significant diurnal variation.

# Convective and stratiform precipitation projections of Indian Summer Monsoon in warming world using CMIP6 models

**Praneta Khardekar[1], Hemantkumar S. Chaudhari[2], Rohini Bhawar[1], Anupam Hazra[2]**

*[1] Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune, India*
*[2] Indian Institute of Tropical Meteorology, Pune, India*

## ABSTRACT

Precipitation change along the South Asian region in response to global warming has a large impact on environment and is highly uncertain. As we know that clouds are the primary modulator of Earth's radiation budget they also play a key role in increase or decrease of precipitation. Thus, in order to know the impact of clouds and rainfall in this warming world a study is done using the CMIP6 Models. Best 10 models from CMIP6 historical simulations were selected on the basis of their ability to represent the annual cycle of precipitation, coefficient of variation along the ISM region. Pattern correlation determined was found to be in agreement with the observational dataset. The total precipitation which is a combination of convective and large scale rainfall is also studied using the CMIP6 models. Multi-model ensemble depicts better representation of convective precipitation and stratiform precipitation as compared to individual models, which over-estimates the convective precipitation and under-estimates the stratiform rainfall. Model simulated total cloud fraction depict pattern correlation of above 0.6 with respect to observation. In case of multi-model ensemble, pattern correlation of total cloud fraction reaches to 0.85. Further, selected CMIP6 models are used for the estimation of future projections of rainfall in the warming scenario (1 percent increase in $CO_2$ concentration: 1pctCO2). Models depict increased precipitation over Indian land region in future scenarios and variability is also supposed to be increased due to projected increase in standard deviation of precipitation.

**Keywords:** CMIP6, precipitation, 1pct$Co_2$, stratiform, convective, pattern correlation.

# Comparison of Multi-Satellite Rainfall Data with Observations from Gauging Station Network in Marathwada Region

**Kailas K Dakhore[1], Shantanu S Dhawase[2], Yadav E Kadam[1], Rahul Nigam[3], Kripan Ghosh[4], Amol N Jondhale[1] and Ramakrishna B Mane[1]**

*[1]AICRP on Agrometeorology, VNMKV, Parbhani*
*[2] Department of Agricultural Meteorology, VNMKV, Parbhani*
*[3]Space Application Center, ISRO, Ahmadabad*
*[4]Agromet Division, India Meteorological Department, Pune*

## ABSTRACT

Use of satellite precipitation data has been increased for the various purposes like as an input in modelling and other forecasting methods. But the satellite data cannot be used directly before its validation with the real-time ground-based data for further analysis. Hence it becomes an inevitable to compare the satellite-derived data with the rainfall data measured at different weather stations situated across the area.

The study was conducted to evaluate the accuracy of satellite-derived rainfall data over Marathwada region and tested against the data collected from automatic weather stations located across eight districts of Marathwada region. The rainfall data of four years, i.e., from 2018 to 2022, except 2020, was analysed and both were compared through simple statistical techniques such as mean absolute error (MAE) and root mean square error (RMSE) in Microsoft excel spreadsheets. The satellite data was obtained from three satellites, namely: INSAT (Indian Satellite), GPM (Global Precipitation Measurement Mission) and NOAA (National Oceanic and Atmospheric Administration).

The data was collected on daily basis and it was summarized as seasonal average for the ease of comparison. The comparison of INSAT satellite data with the rain gauge station data from 2018 to 2022 was shown better results the RMSE was less than 20 mm in 2019 and 2018 in few districts but rest of the year RMSE was more than 20 mm. Whereas the minimum mean absolute error (MAE) 2.1 mm/day for Beed district during 2019 while maximum MAE was observed 11.8 mm/day in Parbhani district during 2019. Overall the INSAT satellite was shown the better agreement with all districts and MAE was below 10 mm/day expect the Parbhani, Nanded and Hingoli during 2022. For the GPM satellite the MAE was less than 5 mm/day during all the years and the RMSE was below 20 mm/day in all districts expect Jalna during 2018 and 2022 it was 24.8 and 23.2 mm/day respectively. The NOAA satellite precipitation was shown the better results in terms of MAE was less than 5 mm/day for entire study period and RMSE was also found less than 20 mm/day during all the years except Parbhani during 2019 and 2021 it was above 20 mm/day.

**Key Words:** Accuracy assessment, satellite precipitation product, Rain gauge rainfall.

# Interaction between the dipole modes of the Indian Ocean

**Sebastian Anila [1,2] and C. Gnanaseelan [1]**

*[1]Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune-411008*
*[2]Savitribai Phule Pune University, Pune-411007*

## ABSTRACT

Indian Ocean Dipole (IOD) is an air-sea coupled variability in the Tropical Indian Ocean (TIO), which has strong impact on the climate variability over the Indian Ocean rim countries. Though many IODs co-occurred with El Niño/Southern Oscillation (ENSO) in the past, IODs do evolve independently suggesting the possible role of internal dynamics of the Indian Ocean. In this study, the Subtropical IOD (SIOD) is reported as a trigger or a link for the formation of such pure IODs. The study further highlights the existence of a cyclic feedback between IOD and SIOD through tropical subtropical interaction when ENSO forcing is absent/weak. Through this feedback cycle, the positive (negative) SIODs favour positive (negative) IODs and positive (negative) IODs favour negative (positive) SIODs. The internal feedback between IOD and SIOD is found to be responsible for the observed biennial tendency in IOD and SIOD. The mechanisms associated with the feedback cycle and the causative factors are demonstrated in detail. The positive SIOD induced warming over the southwest subtropical Indian Ocean supports a meridional cell favouring the equatorward expansion of the subtropical anticyclone thereby initiating the equatorial easterlies during the pure IOD years. On the other hand, the southeastward extension of western warming associated with the positive phase of IOD initiates warm anomalies in the northeastern subtropics. The upper level divergence, high absolute vorticity gradient and the associated barotropic Rossby wave source in the southern subtropics then generate an equivalent barotropic Rossby wave pattern in the midlatitudes. The cyclonic circulation associated with this Rossby wave train supports the generation of negative SIOD through wind evaporation SST feedback.

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

**Raju Mandal[1,2*], Susmitha Joseph[1], A. K. Sahai[1], Avijit Dey[1], R. Phani[1], D. R. Pattanaik[3], M. Kaur[1] and N. Karmakar[1,4]**

[1] *Indian Institute of Tropical Meteorology, Pune, India*
[2] *Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, India*
[3] *India Meteorological Department, New Delhi, India*
[4] *National Centre for Medium Range Weather Forecasting, Noida, India*
**E-mail: raju.cat@tropmet.res.in*

## ABSTRACT

Cold wave (CW) events over India are usually observed during the boreal winter months, November to February. This study proposes an objective criterion using the actual, departure from normal and the percentile values of the daily gridded minimum temperature (Tmin) data for the monitoring of the CW events over the Indian region and also checks its usefulness in a multi-model ensemble extended range prediction system. The large scale features associated with these CW events are also discussed.

Utilizing this proposed criterion and considering the number of average CW days/year for the entire study period and recent decades, the CW prone region has been identified. By calculating the standardized area-averaged (over the CW prone region) Tmin anomalies time series, the CW events are identified over the period 1951-2022. Analyzing the temporal variability of these events, it is seen that there is no compromise in the occurrences of the CW events even under the general warming scenarios. It is found that the long CW events (>7days) are favoured by the La-Nina condition and short CW events (≤7days) are favoured by the neutral condition in the Pacific. Also, the blocking high to the north-west of Indian longitude with very slow movement of westerly trough to the east is found to be associated with the long CW events, whereas in case of short events the blocking high is not so significant. The multi-model ensemble prediction system is found to be reasonably skilful in predicting the CW events over the CW prone region up to 2-3 weeks in advance with decreasing confidence in longer leads. Based on the forecast verifications it is noticed that this forecasting system has a remarkable strength to provide an overall indication about the forthcoming CW events with sufficient lead time in spite of its uncertainties in space and time.

**Keywords:** Cold waves, The Symmetric Extremal Dependence Index, La Niña, Multi-Model Ensemble, Extended Range Prediction

# Harmonics embedded in extreme rainfall over India during monsoon and its link with global SST

**Reshma T.[1], Hamza Varikoden[2] and C. A. Babu[1]**
[1]*Department of Atmospheric Sciences, Cochin University of Science and Technology, Kochi - 682 016.*
[2]*Indian Institute of Tropical Meteorology, Ministry of Earth Sciences Pashan, Pune - 411 008.*
Presenting Author's Name: *Reshma T.*
*E-Mail: reshma.krishn@gmail.com*

## ABSTRACT

For the Indian subcontinent the skillful prediction of the ISMR on interannual to multidecadal time scales, is very important owing to its profound impact on the agriculture, hydrology, and social well-being of the people over the region. In this study, harmonics embedded in extreme rainfall events during summer monsoon from 1901 to 2021 across the West Coast (WC), Central India (CI), and Northeast India (NEI) are investigated. The investigation also intends to identify potential SST zones that have a consistent link with extreme rainfall at the interdecadal (ID), decadal (D), and multidecadal (MD) time scales, as well as the change in their linkage due to climate change, which helps to improve rainfall prediction skills in different timescales. Extreme rainfall is defined as daily rainfall with a percentile value greater than 99; hence, yearly extreme rainfall is calculated using the aforementioned criteria and referred to as the Extreme Intensity Bin (EIB). EIB was further filtered out in the ID (3-9 years), D (10-15 years), and MD (35-60 years) timescales according to the significant periodicities obtained from spectral analysis. The study also used ID, D, and MD filtered SST in the Arabian Sea (AS), Bay of Bengal (BoB), Indian Ocean Dipole (IOD), North Central Pacific Ocean (NCPO), Nino3, Southwest Pacific Ocean (SWPO), and North Atlantic Ocean (NAO) domains, which revealed a substantial long-term connection with ISMR. In the ID, D, and MD timescales, a lead/lag correlation was performed between EIB and SST (SST lags behind EIB). For MD, in WC, and CI, EIB has the strongest correlation with AS and BoB at zeroth year, while IOD and Nino3 at 3 to 4 years, and SWPO and NAO at 5 to 10 years. Nonetheless, in NEI, IOD and Nino3 have the highest correlation on the zeroth period, while the SWPO and NAO's periods have also decreased compared to WC and CI. There is also a regional and temporal difference in the association between EIB and SST over the ID and D timescales and also over the recent years in ID, D and MD timescales data due to climate change.

**Keywords:** Summer monsoon rainfall, Extreme rainfall, Rainfall harmonics, Rainfall-SST relationship.

# Sensitivity of cyclone TAUKTAE to different microphysical and cumulus parameterization schemes using WRF

**Debasmita Chakraborty, Sougata Basak and Rohini L. Bhawar**

*Department of Atmospheric and Space Sciences, SPPU*
*Corresponding Authors:*
*chakrabortydebasmita1999@gmail.com & sougataslg16@gmail.com*

## ABSTRACT

This study investigates the sensitivity of the Weather Research and Forecasting (WRF) model to different microphysical and cumulus parameterization schemes on the tropical cyclone "TAUKTAE" which formed over Arabian sea during May 2021. “TAUKTAE” started as a low pressure system over southeast Arabian Sea & adjoining Lakshadweep area in the morning of 13th May 2021, turning into a depression then deep depression and finally a cyclonic storm in the evening of 15$^{th}$ May. The landfall occurred over Saurashtra on 17$^{th}$ May. The WRF model is widely used in atmospheric research and operational weather forecasting, and the choice of model physics can significantly impact the simulation of tropical cyclones. In this study, we use the NCEP GDAS/FNL 0.25° global tropospheric analyses and forecast grids dataset for the initial and boundary conditions needed for the input in WRF. We perform a series of simulations using different microphysical and cumulus parameterization schemes and compare the results to observations of "TAUKTAE". The sensitivity of the model to different parameterization schemes is evaluated based on several metrics, including track, intensity, and precipitation. Our results show that the choice of microphysical and cumulus parameterization schemes can have a significant impact on the simulated storm characteristics such as storm track, rainfall and wind patterns. This study provides valuable insights for improving the accuracy of numerical weather prediction models in simulating tropical cyclones.

# India-wide Extreme Rainfall Driven Flood Hazard Forecasting

**Ankan Chakraborty[a], Subhankar Karmakar[a,b,c], Subimal Ghosh[a,c,d]**

[a]*Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay, Mumbai 400076, India*

[b]*Environmental Science and Engineering Department, Indian Institute of Technology Bombay, Mumbai 400076, India*

[c]*Centre for Urban Science and Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India*

[d]*Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India*

## ABSTRACT

Extreme rainfall events are getting more frequent and intense globally with warming climate. Flood, driven by extreme rainfall events, require early warning system for preparing adequate disaster response. However, the existing state-of-art extreme rainfall forecast systems encounters many issues like low hit rate, high false alarm and spatiotemporal biasness etc. Moreover, previous literature has not considered the rainfall hazard forecasting at national scale for India. This study aims to forecast the extreme rainfall driven flood hazard as the probability of occurrence of an extreme rainfall event, for a given forecasted rainfall value with sufficient lead days. The hazard model is based on conditional probability of historical observed and forecasted rainfall data. In this study, the method is applied at national scale for India using reliable data source of observed rainfall from the India Meteorological Department (IMD) and forecasted rainfall from Global Ensemble Forecast System (GEFS) Reforecast Version 2 for year 1985 – 2018. Extreme rainfall days are defined as those days on which the observed rainfall has exceeded the 95$^{th}$ percentile value for that particular grid. The hazard values are evaluated at grid level for lead time of 1, 3, 5, 10 and 15 days. It was observed that the hazard maps are in accordance with the observed rainfall pattern and it is also validated by some recent rainfall driven flood events of India. This model will help the stakeholder to identify most hazard prone regions for the near future (weeks). Proper evacuation and mitigation planning can be executed for those particular regions before the upcoming extreme rainfall event hit the location.

**Keywords**: Extreme Rainfall, Flood, Forecasting, Hazard, India

# More rainfall in Northwest India caused by Northwestern Arabian sea warming in recent years

**Nimmakanti Mahendra[1,*], Nagaraju Chilukoti [1], Jasti S. Chowdary[2], Tamás Bódai [3,4]**

*[1]Department of Earth and Atmospheric Sciences, National Institute of Technology, Rourkela – 769008, India.*
*[2] Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune - 411 008, India.*
*[3] Pusan National University, Busan, South Korea.*
*[4] Center for Climate Physics, Institute for Basic Science, Busan, South Korea.*
**Email: mahendra9990met@gmail.com*

## ABSTRACT

In this study, we investigate how a warming in the Northwestern Arabian Sea (NWAS) causes an upheaval of low-level summer monsoon circulation and rainfall in the Indian subcontinent. We claim that in recent years anomalous strong cyclonic circulation that emerged over northwest India (NWI) to the NWAS affected local rainfall. This is coherent with warming over the NWAS originating from below and penetrating easterly anomalies along the monsoon trough. Furthermore, sheared moisture-laden monsoon flow heading for the NWAS through NWI intensifies rainfall in the area. The NWAS has warmed more rapidly in the last two decades than before. We have come to understand the cause of this accelerated warming as one of a changing ocean dynamics. The latter is mainly due to the weakening of the positive wind stress curl at the northern edge of the monsoon low-level jet (LLJ), resulting in weakened upwelling in the region. In addition, ocean heat convergence also contributes to the warming, even though the drivers of the wind and ocean circulation changes themselves may be forced remotely. Considering the gruelling floods over this part of the Indian subcontinent, our new insights presented here have broader implications for the prediction and projection of the monsoon variability, change, and extremes.

# Numerical modelling of the Bay of Bengal Tropical Cyclone Characteristics during 2001-20 and the impact of scatterometer winds

**[1]Ipshita Bhasi*, [1]Jagabandhu Panda*, [1]Debashis Paul, and [2]Subodh Kumar**

*[1]Department of Earth and Atmospheric Sciences, National Institute of Technology Rourkela, Odisha 769008, India*
*[2]Molecular and Atmospheric Spectrometry Group (GSMA), University of Reims Champagne-Ardenne, Reims, France*
**Email for correspondence: ipshitabhasi@gmail.com ; pandaj@nitrkl.ac.in*

## ABSTRACT

The paucity of observational data over the North Indian Ocean (NIO) region poses significant challenges in effectively monitoring and forecasting extreme weather events such as tropical cyclones (or TCs). Since direct observational measurements of dynamic and thermodynamic variables at different atmospheric levels are insufficient to provide a deeper understanding of the interacting forces, a numerical modelling-based approach is needed to address the synoptic scale convective processes. The present study aims to investigate the characteristic features of the Bay of Bengal (BOB) TCs through the Weather Research and Forecasting (WRF) modelling framework that includes three-dimensional variational data assimilation (3DVAR). And intends to focus on various ocean, atmosphere, dynamics, thermodynamic, or physical characteristics to understand the TC characteristic differences pertaining to the distinct intensification, genesis locations, and seasonality. In the process, the impact of the assimilation of scatterometer winds is discussed for 36 BOB TCs during 2010-2020. To conduct the assimilation experiment, the TCs are categorised into three classs, i.e., Cyclonic Storm (CS, 34-47 kts), Sever Cyclonic Storm (SCS, 48-63 kts) that includes both SCS and Very Sever Cyclonic Storms (VSCS, 64-119 kts), and Highly Intensified Cyclonic Strom (HICS) including Extremely Severe Cyclonic Storm (ESCS, 90-119 kts) and Super Cyclonic Storm (SuCS, > 120 kts). Two sets of numerical simulations are conducted for each cyclone, i.e., the control or CTRL experiment without the data assimilation and the second one, considering the 3DVAR (DA simulation). CTRL simulations are initialized with NCEP-FNL and NOAA Sea surface temperature (SST) data sets, and DA simulation considers modified initial conditions prepared through the 3DVAR technique, where scatterometer winds are assimilated into the WRF model. Both simulations utilized the same set of physical parametrizations. The results show improvement in case of DA simulations compared to CTRL for different classes of tropical cyclones during the pre-monsoon, post-monsoon seasons, and sectorial analysis ensured through the Root Mean Square Error (RMSE) of minimum sea level pressure (MSLP) and maximum sustained wind (MSW). It was observed that during the genesis and intensification period, the DA simulation results exhibited more accurate estimates compared to CTRL in predicting MSLP and MSW. The wind shear analysis is done to determine the model's performance during the developing and strengthening stages. RMSE of the predicted wind shear from DA and CTRL run is compared to Indian Monsoon Data Assimilation and Analysis reanalysis (IMDAA), and the results reveal that the DA reduces error in the SCS and HICS classes compared during pre-monsoon season. Overall, DA shows improvement in forecast for MSLP by 12%, 17% and 21% for 24, 36 and 48 h compared to CTRL simulation. Similar improvement in the prediction of MSW is also observed with 53%, 37% and 25% in 24, 36 and 48 h of simulation for DA compared to CTRL simulation for all TCs analysed in a composite mode. These results indicate the potential effectiveness of 3DVAR with scatterometer wind data assimilation in improving the prediction accuracy of TC-related parameters, which can enhance the monitoring and forecasting of extreme weather events in the BOB region.

**Keywords:** Tropical cyclones, Scatterometer wind, WRF, Data assimilation, IMDAA

# Weather-Climate-Water-Environmental Services Integration and generating Impact based Forecast and Warning

**RK Jenamani,**

*India Meteorological Department, Delhi*

## ABSTRACT

In prior to 2020, most of the weather and climate early warning system (EWS) service providers focused on monitoring and predicting mainly meteorological part of extreme weather and climate events over an areas such as periods/timings, intensity, spatial extent, and duration of the impending event. In those periods, hardy they were providing any advance information on hazard types, vulnerability of various exposures and population or communities, their coping capability, where these extreme weather events hit. No information was there also about overall likely risk/impact of the event over those areas. Study shows improvement in prediction capability alone of specific severe weather events (e.g. heavy rainfall) has many limitations in triggering effective early safety actions by disaster managers, user agencies and safety approach adopted by public at large, to reduce the damages and economic losses and human suffering. Analysis of past severe weather events, their impacts and time taken for restoration to normalcy shows often big gaps. The major reason has been major gaps in conveying what such severe weather event or climate extreme may cause to a particular area, population living there, etc, called exposure. Example-a heavy rainfall event may cause land slide, local flash flooding, dam outflow, riverine flooding or inundation for longer period further secondary and tertiary impact like drinking water issues and water borne diseases, ration and essential food availability and livestock management etc, in case event persist for longer period say 3-7 days like Kerala 2018.It is becoming urgent for more countries to make the transition from focusing only on the accuracy of event based forecasting of such extremes to Hazard-based forecasting to also outlining the potential impacts of a forecast – an evolution from "what the weather will be" to "what the weather will do". This has been a **"shifting of all components of EWS to develop and adopt an integrated system with all such informations for issuing Impact based weather forecast and Warning-IBFW".** By which, standalone weather and climate forecast systems have been extended by all, to further integrate into hazard forecast systems (hazard models) with impact estimate (risk based models), promise many benefits for the emergency phase, for instance, for organizing evacuations, thus trigger action and timely response from public.

Further, in recent years, another major shifting in the service field, has been seen among NHMS providers mainly by developed countries and **WMO, 2022, https://meetings.wmo.int/SERCOM-2/SitePages/Session%20Information.aspx** have been "to adopt all needful techniques, technology and IT based solutions in order to integrate all components of Weather-Climate, environmental and hydrological monitoring and prediction systems" into one system in order to link across the components for value chains and to all sectors like adopting S2S, Urban EWS, health EWS, Heat EWS and action plan and deliver truly people centric and sector-specific customized timely services and early warnings to minimize their impacts to various sectors. Built back to normally across all spectrum of disasters have been faster, due to prior hazard intensity estimate, areas likely to be impacted, advance preparation with timely financial allocation of need for emergency management and with timely mobilization of disaster response forces and shifting of their toolkits. **In the present talk, global and national progress in IBFW of integrating all these services into one, have been reviewed, along with case studies over India from recent past major severe weather and climate extremes of 2019-2022 by analyzing those sector-wise impacts. This covers major extreme temperatures and extreme heavy rainfall periods, Dense fog and Thunderstorm and Cyclone related hazards along with issues and challenges, related to sharing various Data, partnership with stake holders and performances of IMD newly IBF and risk based warnings systems for all these extreme weather and climate during 2020-2023.**

# Impact of Air-Sea Coupling and sensitivity of surface roughness parameterization on simulation of an extremely heavy rainfall event over Kerala

**Vimal Jose Vazhathara[1], Yesubabu Viswanadhapalli[2,*], C.V. Srinivas[3], Biyo Thomas[1], Ravi Kunchala[1]**

*[1]Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, 110016*
*[2]National Atmospheric Research Laboratory, Gadanki- 517 112, Andhra Pradesh, India.*
*[3]Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, Tamilnadu, India*

## ABSTRACT

Kerala, a state on the southwest coast of peninsular India, experiences disastrous flooding and landslides in the recent years. The complex orography accompanied by its geographic location close to ocean are key factors in enhancing the precipitation patterns over the state of Kerala. In this study, we analyzed the role of air-sea coupling and sensitivity of roughness parametrizations on simulation of an extremely heavy rainfall event over Kerala occurred between 14 and 17 August 2018 using the Weather Research and Forecasting (WRF) coupled with Price-Weller-Pinkel (PWP) model and varying the different surface rough parametrization schemes. The coupled model results are validated against the available observations such as AWS, radiosonde data from Wyoming and the multi-satellite merged rainfall product. The results clearly suggest that the air-sea coupling enhances the supply of air-sea fluxes, which in turn intensifies the thermodynamic conditions favorable for heavy rainfall over Kerala. Further analysis with the sensitivity of air-sea flux parameterization different schemes indicates that the surface roughness scheme with the dynamic variation of surface drag better predicts the mesoscale features and rainfall associated with the extreme rainfall event. Our analysis also suggests that the extreme rainfall over Kerala was triggered by high convective instability due to the strong westerly jet along with the formation of offshore vortex at lower levels and the transport of mid-tropospheric moisture from the Bay of Bengal. The experiment with enabling the air-sea coupling along with the dynamic variation of surface drag clearly enhances the supply of air-sea fluxes and leads to improved prediction of extreme heavy rainfall pattern and intensity over Kerala.

**Keywords**: Extremely heavy rainfall, Monsoon Depression, Kerala, Air-Sea coupling, Sea surface roughness

# Triple-dip La Niña (2020-2022) and associated Indian Summer Monsoon Rainfall

**Madhuri Musale[1], Satyaban B Ratna[1], C. T. Sabeerali[1], Tanu Sharma[1], P. Rohini[1], O.P. Sreejith[1]**

*[1] Climate Research and Services, India Meteorological Department, Pune, India*
*Presenting Author's Name: Madhuri Musale*
*E-Mail:mmusale774@gmail.com*

## ABSTRACT

El Niño-Southern Oscillation (ENSO) is the most important driver of the Indian summer monsoon rainfall (ISMR) interannual variability. In the recent period during 2020-2022, there was three consecutive La Niña in the equatorial Pacific which is widely known as ‘triple-dip’ La Niña. India received normal to above normal summer monsoon rainfall during these three-monsoon season. The present study investigates the "triple-dip" La Niña and associated variabilities in the ISMR by analyzing observation and Monsoon Mission Climate Forecasting System (MMCFS) forecasts. The spatial distribution of the sea surface temperature (SST) and ISM rainfall anomalies are analyzed and compared with the observation to verify model’s performance in forecasting the broadscale SST and rainfall patterns. We also analyzed the performance of the MMCFS model to forecast the Niño3.4 SST anomaly during the southwest monsoon season (June-September) with different lead times. It was seen that for all three years, the Niño3.4 SST anomaly was forecasted well by the model with four months of lead time. However, the forecasted monsoon rainfall was overestimated by the model.

# Robustness of Large scale extreme precipitation events in the CMIP6 downscaled decadal hindcast

**Gopinadh Konda[1], Jasti S Chowdary[1], Anant Parekh[1], Gnanaseelan C[1]**

[1]*Indian Institute of Tropical Meteorology Pune, India*

## ABSTRACT

In recent years, the subcontinent of India has been experiencing widespread floods induced by large-scale extreme rainfall events (EREs). These extreme rainfall events are mainly associated with monsoon low-pressure systems. The forecast of these high-flood-potential events remained challenging. In the present study, we assess the representation of the EREs by the Decadal Climate Prediction Project (DCCP) activity experiment dccpA-hindcast from CMIP6 group of models. Spatial resolution of the MPI-ESM1-2-HR (here after MPI model) is often too coarse to get reliable representation of the local or regional scale. To minimize the uncertainties/biases in the model, we used empirical quantile mapping (EQM) to develop bias-corrected data at daily temporal and 0.25° spatial resolution for the 4 models (Earth3, MIROC6, MPI-ESM1-2-HR, and NorCPM1) of subcontinent of India for the period (1961-2028; lead-1 to lead-10 year). It is identified that, after the bias correction, precipitation biases (JJAS mean) in the model significantly decreased. Before the bias correction the frequency of the EREs are high, while the frequency is decreased after bias correction (close to the observations). The threshold of extreme rainfall (R95) values are high over the Western Ghats, monsoon core, and eastern India regions, however MPI model (before bias correction) is able to capture the R95 peaks in the eastern India region with weak magnitudes compared with the observations. On the other-hand bias corrected models show the consistency in R95 peaks with the observations. The composite of extreme rainfall events (75$^{o}$E to 85$^{o}$E, 18$^{o}$N to 28$^{o}$N; LEREs area>=70,000 km$^{2}$) clearly suggest that, wide spread of the rainfall activity is situated over the monsoon core region and the Western Ghats with magnitudes >50mm/day. However, before bias correction hindcast models underestimates the rainfall over the Western Ghats and overestimates the eastern India rainfall, this clearly suggests that failure of the model in representing the convection over the orographic regions. After the bias correction, models well capture the rainfall over Western Ghats and significantly minimize the eastern Indian rainfall. In the over all, after the bias correction models well represents the mean features associated with the EREs over the Indian region.

# Prediction of Northeast Monsoon (NEM) Rainfall over Peninsular India by Genetic Programming Approach

**Hemchandra R. Pawar [1], Satishkumar. S. Kashid [2]**

*1 Research scholar, Walchand Institute of Technology, Solapur-413006, India.*
*2 Professor, Walchand Institute of Technology, Solapur-413006. India*
*Email: hemchandra.pawar@gmail.com,sskashid@gmail.com*
*Telephone/Mobile No.: +919975955411,+919011579656*

## ABSTRACT

The monsoon rainfall and the resulting streamflow in Indian rivers have a remarkable impact on the socio-economic aspects of India as the agricultural sector majorly depends upon monsoon rainfall. It is crucially important to understand the rainfall variability, its connection with other climatic parameters, and its prediction as the Indian economy is an agrarian economy. 'Northeast Monsoon' (NEM) is one more form of monsoon activity experienced by the Peninsular Indian region. The NEM contributes anywhere between 30% and 60% of the annual mean in meteorological sub-divisions of Tamil Nadu, Kerala, coastal Andhra Pradesh, and Rayalseema. NEM season is important from the point of Stream flow, reservoir yields, and water resources available for agricultural and other purposes. Despite having significant agricultural and economic importance, the NEM has been considerably understudied as compared to the summer monsoon. Therefore predicting NEM rainfall is quite important.

A wide range of rainfall forecast techniques is in use for weather forecasting at regional and national levels. The most widely used techniques for climate prediction are Regression, Multi-target Regression, Artificial Neural Network, Recurrent Neural Network, Genetic Programming, Fuzzy Logic, etc. Genetic Programming can be thought of as a Genetic Algorithm, applied to a population of computer programs. It creates a working computer program automatically, from the given problem statement. Genetic Programming works on the population of computer programs iteratively and breeds a new generation of programs by applying analogs of naturally happening genetic operations, to arrive at the best program giving the most accurate solution. Genetic programming is capable of solving much more complicated problems.

In this work, Genetic programming approach is adopted using Discipulus software for the prediction of NEM rainfall over Tamil Nadu, India. For the prediction of NEM rainfall global climate indices viz. ENSO, EQUINOO, and OLR were considered. It has been observed that Genetic programming has given satisfactory results. The value of Pearson's Correlation Coefficient (r) between observed and predicted rainfall was (r=0.92) for the training phase and (r=0.64) for the testing phase, NSE for the training phase (0.85), Testing phase (0.37), and RMSE for training phase (79.50), testing phase (132.80) are quite satisfactory.

**Keywords:** Northeast Monsoon, Rainfall Prediction, Genetic Programming, Peninsular Indian Region

# Assessing the performance of two high resolution ensemble prediction models in predicting monsoon rainfall over India

**Anumeha Dube and Raghavendra Ashrit**

*National Centre for Medium-Range Weather Forecasting, Ministry of Earth Sciences, India*

## ABSTRACT

Forecasting rainfall over India during the monsoon season is challenging and this is further hampered by the uncertainty in the deterministic numerical weather prediction (NWP) models. Ensemble prediction systems (EPS) provide an efficient way of sampling the inherent uncertainty present in these models. Verification of forecasts obtained from an EPS is a necessity, in order to increase confidence in using these forecasts. This study deals with the verification of the probabilistic rainfall forecast obtained from the National Centre for Medium Range Weather Forecasting (NCMRWF) Ensemble Prediction System (NEPS, 22 member + 1 control lagged EPS) and the Global Ensemble Forecast System (GEFS, 20 member + 1 control) which is run at IITM for the monsoon season i.e., JJAS 2022. Verification is done based on the Brier Score (BS) and its components (reliability, resolution and uncertainty), Brier Skill Score (BSS), Reliability Diagram, Relative Operating Characteristic (ROC) curve, Area under the ROC (AROC) curve and Continuous Ranked Probability Score (CRPS). The observation data set used in this study is the IMERG data which is a gridded dataset with a horizontal resolution of 10 km.

Verification is carried out using 5 different rainfall thresholds i.e., 5, 10, 20, 50 and 100 mm/d and the various metrics are calculated. It is seen from the analysis that both the models have a tendency to over-predict rainfall (shown by the reliability curve below the diagonal line). It is also seen that the ROC curve moves away from the top left corner (perfect ROC) towards the diagonal with the increase in rainfall threshold as well as the forecast lead time. Similarly, the CRPS shows an increase with the increase in lead time.

**Keywords:** Ensemble Prediction System, Forecast Verification, CRPS, Monsoon Rainfall

# Decadal changes in predictability of the IPOC-ISM relationship in coupled models seasonal hindcast

**Darshana Patekar[1,2], J. S. Chowdary[1], A. Parekh[1], C. Gnanaseelan[1]**

[1]*Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune 411008, India*
[2]*Savitribai Phule Pune University, Pune 411007, India*
*E-Mail: darshana.jrf@tropmet.re.in*

## ABSTRACT

The long-range prediction of the Indian summer monsoon (ISM) in coupled models is useful to make predictions of seasonal mean rainfall that contributes to socio-economic stability of country. However, understanding and assessing the coupled model hindcasts/ simulations in representing the monsoon teleconnections is equally crucial as ISM rainfall variability is highly tied to remote forcing. The newly found Indo-western Pacific Ocean capacitor (IPOC) mode has enormous impact on ISM on an interannual and interdecadal timescale in observation as well as in coupled climate models. As IPOC is a coupled mode due to coherent anomalies over Tropical Indian Ocean (TIO) and Western North Pacific (WNP) that form inter-basin interaction, evaluating the prediction skill of IPOC mode is essential. In the present study, retrospective forecasts from the ENSEMBLES multi-model project based on May and February initial conditions are considered over 1960-2005 and their skill is assessed in predicting the multi-timescale variability of summer IPOC mode and its relationship with ISM. On an interannual timescale, IPOC induces tripolar precipitation correlation with positive (negative) signal in the southern peninsular and northeast India (monsoon trough region) during summer. Based on regional correlation patterns, a precipitation tripole index (PTI) is prepared. It is noted that all five models and their Multi-Model Ensemble (MME) are able to predict the IPOC components reasonably well at 1 and 4-month lead; but failed to predict the IPOC-ISM/PTI relationship.

Further, models show enhanced skill in predicting the IPOC components in the recent decades (after the early 1980s) as revealed from the 21-year sliding correlation between the observation and models. The difference in IPOC-ISM teleconnection is noticeable in the Pre-83 (weak) and Post-83 (strong) periods in the observation. Interdecadal relationship between the IPOC and ISM is not well predicted by models.

Additionally, to evaluate whether the IPOC-related components during spring season could predict the summer PTI over India in observations, a multiple linear regression model is constructed. This model can reproduce the observed interannual variability and predict the summer PTI well in advance from spring season. More importantly, this regression model is capable of predicting regional rainfall peaks over northeast India, central India, and southern peninsular India reasonably well. These process-based observed lead-lag relationships represent an advancement in monsoon prediction.

**Keywords:** Indian Summer Monsoon, Tropical Indian Ocean warming, Western north Pacific anticyclone.

# PQPF for Monsoon 2022 using EnsembleBMA and EnsembleMOS Methods

**Abhijith V[1,2] Raghavendra Ashrit[1] Sunita Verma[2] and Snehalata Tirkey[3]**

*[1]National Centre for Medium Range Weather Forecasting, Ministry of Earth Sciences*
*A-50, Institutional Area Phase-2, Sec-62, Noida*
*[2]Institute of Environment and Sustainable Development, Banaras Hindu University*
*[3]Indian Institute of Tropical Meteorology, Pune*

## ABSTRACT

Ensemble prediction system (EPS) using perturbed initial conditions has proven successful over the deterministic forecasts to provide probabilistic forecasts and to support risk-based forecasts and warnings. But developing, operating and regularly improving modern EPSs capable of producing high-quality data is extremely expensive. Ensemble forecasts often suffer from under dispersion and systematic biases due to errors in initial conditions, model uncertainties, approximations, and data assimilation assumptions. Hence any ensemble prediction system that aims to produce reliable and accurate forecast must now include statistical post-processing to proper calibration of ensemble spread and removal of systematic biases. These calibration methods include parametric distributional regression models as well as nonparametric approaches and semi-parametric methods based on modern machine learning techniques.

The current study compares the performance of two parametric postprocessing techniques, EnsembleBMA and EnsembleMOS, in postprocessing high resolution 24 hour accumulated rainfall forecasts. The postprocessing was applied on 12km resolution rainfall forecasts from GEFS model for lead times 1-10 days for monsoon 2022. The Rainfall observations from GPM with the same resolution was used in bias correction. Post processing involves bias estimation using moving window training data and bias correction of the actual data. Both the methods yield bias corrected Probabilistic quantitative precipitation forecasts (PQPF). The results were verified with verification metrices viz. CRPS, Brier Score and Reliability diagrams. The CRPS have exhibited noticeable improvement for all lead times during the study period.

# Mechanism and prediction of summer season short drought over India using Monsoon Mission CFS hindcasts

**Gowri Vijaya Lekshmi[1,2], Prasanth A Pillai[2]**

[1] *Department of Atmospheric Sciences, CUSAT, Kochi*
[2] *Indian Institute of Tropical Meteorology, Pune*
*(gowrivijayalekshmi@gmail.com)*

## ABSTRACT

Southwest monsoon season (June–September) is the primary rainy season for India which contributes 70–90% of the annual mean rainfall. Monsoon seasonal rainfall exhibits large year to year variability which is around 10% of the long term mean. Monsoon droughts (below normal rainfall) had catastrophic effects on agriculture, water resources, food security, economy and social life in the country. Thus seasonal prediction of drought condition at a lead time of 2-3 months have vital role in planning the economic strategy of the country. To improve drought mitigation and preparedness, we need to improve our present knowledge about the spatial and temporal variability of droughts. Their main effects can be observed in agriculture, land cover, and soil moisture reduction; soil moisture (SM) is another crucial slowly varying component, which can influence the atmosphere through its impact on evaporation and surface energy fluxes. Present study using observations and hind casts from monsoon mission Climate Forecast System (MMCFS) analyses the monthly and seasonal drought over India and the major factors contributing it. Numerous indices have been proposed to quantify the different types of droughts, in which the Standardized Precipitation Index (SPI, McKee et al. 1993) is used in the present study. Our study shows that the short term drought indices (SPI3 and SPI6), its duration and intensity are mainly controlled by soil moisture, land surface temperature over India and SST anomalies in the tropical Pacific. Along with that, Atlantic SST also has a significant contribution in the recent decades. Boreal summer drought severity and duration has an increasing trend in the recent period. CFSv2 has a skill of around 0.5 for SPI3 and SPI6 at a lead of three month hindcasts (Feb IC) with an RMSE of less than 1. Skill is slightly lesser for monthly drought indices. Meanwhile, the model intensity and duration of model predicted drought conditions are mainly depend on the Sea surface anomalies of tropical Pacific Ocean, underestimating the observed role of soil moisture. Over all CFSv2 has moderate skill in predicting boreal summer drought, but need to have improvement in predicting the peak value of SPI index and its spatial distribution, which will improve the prediction skill further.

# Relationship of ENSO and Indian Summer Monsoon Rainfall (ISMR) in the coupled model

**Renu S. Das[1,2] , Suryachandra A. Rao[1], Prasanth A. Pillai[1], Ankur Srivastava[1], Maheswar Pradhan[1] and Dandi A. Ramu[1]**

*[1] Indian Institute of Tropical Meteorology, Ministry of Earth Science, Pashan, Pune 411008, India.*
*[2] Department of Atmospheric and Space Science, Savitribai Phule Pune University, Pune 411007, India*

## ABSTRACT

Indian Summer Monsoon Rainfall (ISMR) variability is often associated with the El Niño Southern Oscillation (ENSO). This work shows that state-of-the-art models with an improved skill for seasonal prediction of ISMR overestimate the ENSO-ISMR correlation. Our analysis indicates that in coupled models, all months of JJAS show a strong relation between ENSO and ISMR. However, observations show no significant correlation between Indo-Pacific SST anomalies during August. This weak association between ENSO and ISMR during August is due to increased synoptic variability. Thus, the effect of large-scale flow dominated by ENSO is suppressed by the formation of the synoptic system in the Bay of Bengal (BoB), making the ENSO-ISMR relation feeble in August. In models, the synoptic variance contribution is less than 20% in monsoon core regions, whereas this contribution is 40-70% in the observations. The analysis shows that the meridional gradient of potential vorticity, anti-cyclonic vorticity bias, and dry moisture bias leads to the underestimation of synoptic variability in the model. This study highlights that the reason for poor potential predictability in the present climate model is due to the underestimation of the synoptic variability due to the Low-Pressure System in the models.

Thus, this study highlights the following points:

- The coupled model overestimates the ENSO-ISMR relationship.
- The Synoptic-variance is underestimated in the present climate model.
- The underestimation of synoptic variability in the model limits the predictability of the ISMR.

# Deep Learning based Prediction of Extreme Precipitation considering the effect of Marine Heatwaves

**Matin Ahmed[1,2*], M. K. Roxy[1], Dr. Debasish Pradhan[2]**

*[1]Indian Institute of Tropical Meteorology (IITM), Pune, India*
*[2] Defence Institute of Advanced Technology*
**Corresponding author: matinahmed000@gmail.com*

## ABSTRACT

Precipitation forecasting is an important aspect of weather prediction, as it has significant impacts on various sectors, including agriculture, infrastructure, and human safety. Traditional statistical methods have shown limited accuracy in precipitation prediction, especially in the case of extreme precipitation events. In recent years, deep learning techniques, such as Convolutional LSTM (ConvLSTM) networks, have shown promising results in improving precipitation prediction. However, the impact of marine heatwaves on extreme precipitation events has not been fully explored.

This study aims to investigate the impact of marine heatwaves on extreme precipitation events and to improve extreme precipitation prediction using a ConvLSTM network. The ConvLSTM network is trained on historical data, including both precipitation and sea surface temperature (SST) data, to capture the spatial and temporal dependencies in the data and make predictions of extreme precipitation.

The results of this study show that marine heatwaves can have a significant impact on extreme precipitation events, and that the inclusion of SST data in the ConvLSTM network can improve the accuracy of extreme precipitation predictions.

In conclusion, this study demonstrates the importance of considering the effect of marine heatwaves on extreme precipitation events and the potential for deep learning techniques, such as ConvLSTM networks, to improve extreme precipitation prediction accuracy. The results of this study have important implications for decision making in various sectors that are impacted by extreme precipitation events.

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## Call for contributions & Submission of Abstracts for the National Symposium

**Theme-1:** Understanding Weather and Climate extremes in changing climate.
**Theme-2:** Improving the prediction skills of extremes in changing climate.
**Theme-3:** Impact of Extreme weather on Human & Animal health.
**Theme-4:** Extreme weather and crop health.
**Theme-5:** Climate change and communicable diseases.
**Theme-6:** Climate change and Pandemic risk.
**Theme-7:** Pollution and Human health.
**Theme-8:** Data driven health impact modelling using AI/ML.
**Theme-9:** Effective communication of climate services to general public.
**Theme-10:** Tailoring of climate information for decision making in the health sector.

## Important Dates

Abstract submission starts on: **30th January 2023**
Abstract submission ends on: **8th March 2023**
Communication of Acceptance of Abstract: **10th March 2023**

## Link for Abstract Submission

https://forms.gle/49oJUrngxwSmziRW8

*or scan here*

## Registration Fees

For IMS Members: **Rs. 400 /-**
For Non-IMS Members: **Rs. 600 /-**
(Payment to be done on-spot at the conference venue from 08.30 am of 28th March 2023)

## Contact Information


punechapterims@gmail.com
020 - 25572213 / 25904239
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**Dr. Divya Surendran, Secretary, IMSP**
divya.surendran@imd.gov.in


# Annual Monsoon Workshop (AMW-2022)

and National Symposium on

**"Challenges in climate services for health sector in the warming environment"**

**Organized by:**

Indian Meteorological Society, Pune Chapter (IMSP)
(In association with IITM & IMD Pune)

**Dates:**

*28th March 2023 (Tuesday)*: AMW-2022
*29th & 30th March 2023 (Wednesday & Thursday)*: National Symposium

**Venue:**

Meghdoot Auditorium
Indian Institute of Tropical Meteorology (IITM),
Pashan, Pune-411008, India

*How to reach* Google Map

**Supported by:**

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## About IMSP & Annual Monsoon Workshop (AMW-2022)

The Indian Meteorological Society, Pune Chapter (IMSP) is one of the largest and most active local chapters of the IMS. It has about 600 members actively associated with the Pune offices of the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM), various departments of Savitribai Phule Pune University, CDAC, IISER and other institutions. IMSP is also one of the most important platforms for many senior members of the IMS settled in Pune after retirement but still very active, for sharing their experience and knowledge with the next generation. In order to keep pace with the rapid developments in the field of Meteorology and allied sciences, the IMSP regularly organizes popular lectures by eminent meteorologists from India and abroad and also conducts thematic programs focusing on popularization of Meteorology among the general public and academic institutions like schools, colleges, etc. An annual flagship activity of the IMSP is the 'Annual Monsoon Workshop (AMW)', being conducted regularly every year since 1989. The behaviour and unique features of the latest monsoon season are presented and discussed during the Annual Monsoon workshop. The workshop provides meteorologists, engaged in the operational services as well as research, an opportunity to consider various features of the monsoon from their multiple points of view. In addition, the participating scientists share their views and knowledge on the perceptible trends in the monsoon activity and their implications in the context of global climate change and its impacts. The behaviour and unique features of the south-west & north-east monsoon seasons of 2022, along with Predictions on different time-scales (Long range, extended range, medium range & short range) and their validation will constitute the overarching theme for AMW-2022.

## About the National Symposium on "Challenges in climate services for health sector in the warming environment"

Global warming and climate change are directly and indirectly affecting the health of humans, animals as well as the plants. There are undeniable evidences that climate change and variability can act as an amplifier of threats to different aspects of global health system. Human health outcomes are largely affected by both extreme weather events and gradual changes in weather and climatic conditions. Every year, they are disrupting more and more lives and also exacerbating chronic health conditions like asthma, expanding the range of infectious diseases, and worsening mental illness. This threat is aggravated within vulnerable communities, including socioeconomically disadvantaged- and minority-communities.

The direct effects of climate change on the animal health are primarily due to increased temperatures and frequency and intensity of heat waves. Depending on its intensity and duration, heat stress affects livestock health by causing metabolic disruptions, oxidative stress, leading to different types of infections and death. Rising temperatures lower the survival rates of many species due to the changes that lead to less food, less successful reproduction, and interfering with the environment for native wildlife.

Changes in precipitation patterns and increase in temperatures are making it difficult for many plants to survive in their natural habitats. In some cases, the combination of these extreme climate variables is creating favourable conditions for the invasive pest outbreaks, leading to the loss of plant species. The nature and structure of soil is also getting altered with the abnormal changes in weather and climate. This can disrupt the plant growth and crop yields and can ultimately lead to reduced food availability and food quality.

Climate services for health is an emerging field of applied science and it is one of the priority areas of the Global Framework for Climate Services (GFCS), along with agriculture and food security. Factors leading to the effects of climate change on health are extremely complex, involving not only environmental drivers, but also ecological and social aspects, economic interests, and individual and community behaviour. Therefore, strengthened communication and collaborations among climate and health actors/people at all levels are very much essential for implementing effective climate-health services. This national symposium will provide an ideal platform to present and discuss recent findings on the linkage of climate and health sector and associated challenges.

## Invited talks during symposium by experts

- Health impacts of heat/cold extremes and mapping of temperature-related mortality/morbidity risks.
- Changing patterns of infectious diseases with changing climate
- Strengthening the national capacities on biodiversity, climate and health inter-linkages,
- The role of health professionals in Climate Action.
- Climate Resilient health care systems.
- Scope of Climate Services in controlling Vector Borne Diseases and Expectations from Climate Community
- Climate information needs of the health sector for early warning and risk management

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