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ABSTRACT BOOK

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Opening Session of IITM Hub of ICRC-CORDEX2023

Opening Session: Keynote Talk

CORDEX over Asia for advancing climate science on decision making scales

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This presentation provides an overview of the activities of the Coordinated Regional Climate Downscaling Experiment (CORDEX) domains over Asia. CORDEX is a WCRP framework to evaluate regional climate model performance through a set of experiments aiming at producing regional climate projections. The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships. In addition to the coordinated standard downscaling of CMIP models, CORDEX communities also carry out the so-called "Flagship Pilot Studies". CORDEX communities organize their activities through fourteen different CORDEX domains. In the greater Asia region, there are four CORDEX domains namely: South Asia, Central Asia, East Asia and Southeast Asia. This presentation summarises the activities carried out over these four domains. These include standard regional climate downscaling simulations, FPS projects and capacity development activities.

Opening Session: Keynote Talk

CORDEX South Asia: Linking science to society for enabling adaptation

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South Asia is a region highly sensitive to climate variability and change. Many communities in South Asia are exposed and vulnerable to weather and climate hazards such as floods, droughts, cyclones, landslides. Climate services play an important role in managing present and future climate risks. The knowledge and capabilities of at national and regional levels delivering climate services need to be strengthened to provide information needs to a diversity of stakeholders for informed climate change responses in South Asia. There is a need for tailoring climate services and co-design with the users to ensure that the modeling tools and products are fit for answering societally relevant questions. The end goal is to have a robust chain from production of climate data, analysis, development of products through to use. Identification of gaps and needs, understanding and mapping the user landscape, stakeholder consultations, developing of modeling tools for monitoring and modelling are needed to link science to society. There are opportunities to include tools and technology for capacity building, frameworks for reducing risks (hazard, exposure, vulnerability). An institutional capacity building approach was followed to build the capacity of various stakeholders in access and use of CORDEX South Asia climate projections and developing climate indices to support adaptation.

Keywords: CORDEX data, projections, climate modelling, tools, society

Opening Session: Keynote Talk

Regional climate information for water-energy-health integrated study

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To develop reliable regional climate information for climate change adaptation measures, we assess added values of regional multi-ensemble downscaling in collaboration with researchers of geoscience, social science, and humanities, and officials of local governments in Japan and CORDEX Asia.

To investigate uncertainty caused by the structural differences in climate models, multi-model ensemble regional climate scenarios over Japan and CORDEX Asia are developed and investigated for several impact assessments. Development of regional climate scenarios with statistical downscaling, and investigation of the added value of regional climate information for heat stress assessment and renewable energy (solar, wind, hydroelectric) assessment are presented. Attempts at downscaling land use and land cover change scenarios and flood assessment with urban greening for climate change adaptation will also be presented.

We discuss the current issues of developing policy-relevant regional climate scenarios in collaboration with local stakeholders.

Sessions A4 and A5:

Regional climate modelling/downscaling for South Asia Monsoon region

ORAL PRESENTATIONS

A4: Regional climate downscaling using high resolution climate models

A Regional Earth System Modelling framework over the CORDEX-SA domain

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A fully coupled high-resolution regional earth system model (RESM), namely ROM, is implemented over the CORDEX-South Asia domain to assess various aspects of the Indian summer monsoon rainfall (ISMR) covering the 1980-2017 period. Added values of ROM over its standalone version, named REMO, have been computed for mean precipitation, variability (intra-seasonal to interannual), extremes, and associated processes. Moreover, to investigate whether it is inevitably necessary to increase the horizontal resolution for better simulation of ISMR, we compared the simulated fields with two different horizontal resolutions (0.22°x0.22° and 0.11°x0.11°) and also the underlying spatiotemporal variability. ROM at both resolutions bears a close resemblance to observations in simulating the mean precipitation climatology and outperformed other regional climate models (RCMs) that participated in CORDEX- South Asia, however, with some systematic wet and dry bias over Central India and Northern Western Ghats. The improved representation of intraseasonal variability (active-break spell's duration and intensity) and interannual variability are attributed to the improved mean seasonal precipitation.

Additionally, the correct representation of sea surface temperature, Indian Ocean Dipole, and its underlying dynamics also contribute to improving the mean precipitation. Increasing horizontal resolution from 0.22°x0.22° to 0.11°x0.11° leads to a noticeable improvement in the simulation of JJAS mean precipitation by reducing the wet bias over western central India and southern peninsular India and dry bias over eastern central India. Overall, ROM showed higher skill than its forcing ERA-Interim reanalysis.

Overall, RESMs like ROM in studying climate variability and change is positive. As computational power continues to improve, these models can simulate the Earth's complex climate system (e.g. monsoon) with increasing accuracy and detail. They can provide valuable insights into the behavior of regional climate systems and help us to better understand and anticipate the impacts of climate change on different regions. In addition, the use of RESMs can inform decision-making at local and regional levels by providing more accurate and detailed climate information to planners and policymakers. However, more research is needed to improve the models' representation of certain climate processes, especially in our regions with complex terrain and coastline. The development of better observational datasets and advances in computing power will also be crucial for further improving the accuracy and reliability of RESMs.

Keywords: Regional Earth System Modelling, Monsoons, Precipitation, Extremes, CORDEX-SA

A4: Regional climate downscaling using high resolution climate models

Traditional MLR and advanced ML based statistical downscaling: a reliable tool for providing accurate inputs for crop simulation model.

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Adetailed study has been undertaken to investigate the homogeneous zone and various locationwise past climate change informations as well as its future projection over seven homogeneous zones of India from the latest simulationsof CMIP5/CMIP6 GCMs using several traditional multiple linear regression-based (MLR) approaches as well as advanced machine learning (ML) based approaches. The input required for hydrological and agricultural models are small scale in nature more preciously point location but available information from GCMs outputs are large scale in nature indicating a gap in terms of model's horizantal resolution. To bridge the gap between large to local scales, different downscaling techniques have been emerged to reliably provide local scale climatic information from GCMs simulations. This study aims to construct climate change scenario at regional and local scale over several homogeneous zones of India using the simulations from CMIP5/CMIP6 through conventional model output statistics (MOS) and perfect prognosis (PP) in addition to use several advanced machine learning (ML) techniques. It was alsoinvestigatedto see whether the ML based approach produce relative improvements in downscaling results compared to traditional multiple linear regression-based (MLR) approaches. The downscaled GCMs have been able to simulate the patterns and magnitudes of spatial variability of rainfall and temperature over different zones much better compared to raw GCMs. Future projections of downscaled GCMs have indicated increasing precipitation in varying percentage over majority portions of the country. Significant warming has been also found over all seven homogeneous temperature zones.Location specific downscaled precipitation and temperature developed over different homogeneous zones have been used as the inputs for crop simulation model (ORYZA2000) to see the changes of producitivity under changed scenarios.In general, the net cereal production is projected to decline at least between 4% and 10% by the end of this century under the most conservative climate change scenario. The Gangetic West Bengal (GWB) and its neighbourhood is expected to experience nominal change in the either sides as rice production increases by about 10% with 1^{o}C rise in temperature and falls by 30% with a rise of temperature by 2^{o}C.

Keywords: Machine Learning, Statistical downscaling, CMIP5/6, RCPs, SSPs, crop simulation model.

A4: Regional climate downscaling using high resolution climate models

High-resolution global modelling for regional climate studies

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The Coordinated Regional Climate Downscaling Experiment (CORDEX) aims to create a framework for evaluating and comparing the range of dynamical downscaling through spatially refining the climate information from the coarse resolution coupled models, which is usually achieved through Regional Climate Models. Here, instead of the conventional method, we are employing a different approach to acquire regional information using a Global Atmosphere General Circulation model with very high resolution (27km). We utilized the atmospheric version of the IITM Earth system model for this research.

The study briefly presents simulated mean features of the South Asian climate and compares them with their AMIP counterparts and existing CORDEX simulations. Notably, there are significant improvements, particularly over the Indian land region during the monsoon season, in simulating the mean climate and its variability. Furthermore, the study investigates the model's ability to simulate various weather phenomena, including tropical cyclones in the Indian region and wintertime weather features across the Himalayan and central Indian regions. Overall, the study showcases notable improvement in simulating weather and climate features when compared to its AMIP or CORDEX counterparts. These findings underscore the significance of employing high-resolution global modelling to elevate regional climate investigations and deepen our comprehension of local climate dynamics.

A4: Regional climate downscaling using high resolution climate models

Exploring the precipitation extremes over Hindu Kush Himalayas in CORDEX simulations

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The Hindu-Kush Himalayan (HKH) region is an area of utmost significance within the global climate system that exhibits a high sensitivity to climate variability. The complex mountainous terrains hold tremendous socio-economic, aesthetic, and ecological value, offering a habitat for a diverse range of flora and fauna and functioning as a watershed for a vast community. Nonetheless, the region is vulnerable to extreme precipitation events, such as heavy rainfall, that can lead to catastrophic consequences such as flooding, landslides, and damage to infrastructure, with potential ramifications on the livelihoods of local communities.

It is important to accurately represent the characteristics of extreme precipitation events over the HKH region in various datasets in order to improve our understanding of these events and their potential impacts. In this study, we evaluate the ability of Coordinated Regional Climate Downscaling Experiment (CORDEX) simulations to capture the trend and spatial variability of extreme precipitation events over the HKH region for different seasons using extreme precipitation indices prescribed by Expert Team on Climate Change Detection and Indices. We analyse how well the spatial precipitation variability and trends are captured by various CORDEX model simulations over HKH region using the CORDEX South Asia RCMs. Various stastical skill scores have used to evaluate the CORDEX simulations. From the preliminary analysis, the CORDEX models exhibit good skill in capturing the spatial and temporal patterns of extreme indices. The analysis results will be discussed. The findings from this work will help us to better understand the regional climate change and adapt to climate change impacts over the Himalayn region.

A4: Regional climate downscaling using high resolution climate models

Analysis of CORDEX evaluation Experiment over South Asia using RegCM5 based Dynamical Downscaling of ERA5

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This study used the latest version of RegCM regional climate modeling system (RegCM5) as configured in the framework of Coordinated Regional climate Downscaling Experiment (CORDEX) under the aegis of World Climate Research Program on regional downscaling efforts. Compared to the previous version of the model, the latest version includes the implementation of new RegCM5 non-hydrostatic core, with upgraded physics schemes and coupled model components. The study used evaluation runs at a spatial resolution of 25 km following the CORDEX protocol, using 42-year long simulations covering the period 1979–2020 with initial and lateral meteorological boundary conditions provided by the ECMWF-ERA5 reanalysis. We tried to assess the performance of RegCM5 in simulating seasonal climatology of the near-surface air temperature and precipitation over the Indian landmass. The results are compared against a multitude of observed datasets. Overall, the RegCM5 produces a good representation of Indian climate characteristics with a set of optimized parameters within the Tiedtke cumulus convection scheme. We further conclude that the simulated climatology of rainfall and temperature over South Asia is sensitive to the representation of the physical process in the model, particularly to the deep cumulus parameterization schemes used. Our results hope to provide a foundation enabling future studies of regional climate changes, climate change impacts, and adaptation options for India.

Keywords: regional climate modelling, regional downscaling, RegCM5, CORDEX, Dynamical Downscaling of ERA5

A4: Regional climate downscaling using high resolution climate models

Evaluating CMIP6 models for downscaling on the South East Asia CORDEX domain

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Based on the best-practice framework for sub-selection of CMIP6 model for Euro-CORDEX, we have evaluated 24 CMIP6 models for the South East Asia CORDEX region. These models were chosen based on the availability of lateral boundary conditions and the SSP3-7.0 scenario. They are evaluated by their performance of the northeast and southwest monsoons and annual cycle of temperature. SST is also considered in the tropical cyclone genesis region and as a driver of variability. In each of these categories we rate the models as being satisfactory, biased, significantly biased or implausible (not able to represent a key process). Implausible models are discarded but models with biases or significant biases are still considered for downscaling. High sensitivity models are considered as an optional component.

The southwest summer monsoon is assessed using JJA 850hPa flow. All the CMIP6 models we consider are somewhat able to reproduce key characteristics of this flow, none are considered implausible, and about a third are considered satisfactory. The northeast winter monsoon is assessed using DJF 850hPa flow. About a third of the models are able to reproduce this monsoon flow satisfactorily. The other models tend to have too strong an easterly component to the flow. The evaluation of near-surface temperature annual cycles found that the majority of models tend to under-estimate winter (NDJF) temperature. The main region for tropical cyclone activity is located in the Southern West Pacific. Half of the assessed models do not have any widespread SST bias in this region and can be classified as satisfactory, some have a small areas of bias, while four models have widespread and significant biases over this region. Overall changes in magnitude of temperature and precipitation across the SEA domain were also assessed for all CMIP6 models.

Following on from this evaluation exercise, we plan to run CMIP6-driven regional climate model experiments according to CORDEX SEA standards, and contribute the output to CORDEX SEA, making it available to the wider Southeast Asian climate community and contribute to national climate scenarios. We wish for our downscaling work to complement other work in the region and the amount of computational resource which will be available is currently unknown, therefore we do not make choices of which specific CMIP6 models to downscale. Instead we aim to prioritise: MIROC6 or MPI-ESM1-2-HR, NorESM2-LM, EC-Earth3-Veg or IPSL-CM6A-LR, and CNRM-ESM2-1. CanESM5 or UKESM1-0-LL could also be included as low likelihood/high impact models.

A5: Statistical Methods/ML techniques for regional climate downscaling

Bringing deep learning to the plate of climate scientists for downscaling

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To improve the resolution and accuracy of global climate model (GCM) outputs and hence better comprehend local and regional weather patterns, climate downscaling is an essential undertaking. Models that can reliably execute super-resolution in computer vision have been developed thanks to the progress in deep learning. However, due to the complicated nature of their architecture and implementation, these models have remained elusive to the weather and climate research community. Additionally, it is difficult for researchers who lack access to high-end GPU compute to use the deep learning models. To downscale gridded weather and climate research datasets, we introduce ClimateDownscaleSuite, a unified solution combining many deep learning models of computer vision. By allowing users to select the model that best suits their needs in addition to the practical constraints, this framework aims to give a trustworthy and accurate solution for climate downscaling. From models like SRCNN to complex ones like attention based transformers, we make them all easily accessible under one roof. As a use case example, we employ the nighttime lights data from DMSP OLS and VIIRS and then test the suite's various models on a nighttime lights dataset in a straightforward image-to-image regression job. ClimateDownscaleSuite allows for real-time adjustments to the upscale factor. The users may quickly and easily deploy deep learning based computer vision algorithms to large-scale climate downscaling with this tool.

A5: Statistical Methods/ML techniques for regional climate downscaling

Investigating the impact of custom loss functions to train a deep neural network for downscaling gridded precipitation data

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Understanding the trends and variations in precipitation patterns under changing climate scenarios is essential for better preparation, adaptation, and mitigation. Usually, the global climate model simulations are available at coarse resolution, which is unsuitable for regional applications. Further downscaling using dynamical/statistical methods and bias correction are required for generating high-resolution datasets at the regional scale. Recent progress in data-driven techniques like artificial intelligence/machine learning/deep learning (AI/ML/DL) offers a parallel route to generating high-resolution gridded datasets at cheaper computation costs and potentially improved accuracy. They are also capable to learn intricate patterns and highly non-linear relationships from the data and use that information to make decisions. However, training a DL-based deep neural network (DNN) to its full potential is challenging, especially for sparse and unbalanced data like precipitation. Loss functions are one major component of DNN training based on which the parameters of the DNN are updated during each training iteration. This study assesses the choice of loss functions to train a DNN for griddes precipitation downscaling, through a series of synthetic downscaling experiments using Integrated Multi-satellite Retrievals for global precipitation measurement data. A DNNbased downscaling architecture called super-resolution deep residual neural network (SRDRN) is chosen for experiments. The flexibility of AI/ML/DL techniques enables the incorporation of custom loss functions tailored to the specific downscaling objectives and domain knowledge, enhancing the SRDRN training process. In our experiments, we evaluated regular loss functions such as mean-squared error (MSE) and mean absolute error (MAE), as well as custom-weighted MAE and physics-constrained weighted MAE with mass conservation. The results show that the custom weighted-MAE and physics-constrained loss perform better than regular losses in reconstructing the mean climate and extreme events during the test period. Interestingly, all the trained models achieved a Pearson's correlation coefficient value above ~0.9 and a Kling-Gupta efficiency score above ~0.8 on the test set, which signifies the applicability of AI/ML/DL techniques for the highly challenging problem of precipitation downscaling.

Keywords: Precipitation, Downscaling, AI/ML/DL techniques, Neural networks, Superresolution

A5: Statistical Methods/ML techniques for regional climate downscaling

Future Changes in Precipitation Extremes over base Himalayan Uttarakhand region during Southwest Monsoon

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Uttarakhand is a Himalayan state of India and is highly vulnerable to extreme precipitation events and subsequent floods and landslides. The present study evaluated the state-of-the-art, high-resolution (0.25° × 0.25°) statistically downscaled NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) against the Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE) observational data for the baseline period of 1976 to 2005. This study also examined the projected changes in precipitation extremes during southwest monsoon season (June to September) over Uttarakhand under RCP 4.5 and RCP 8.5 scenarios for near future (2021-2050) and far future (2070-2099). In the near future, the monsoon precipitation over Uttarakhand may increase approximately by 13% and 16% under RCP 4.5 and RCP 8.5 scenarios respectively, and in the far future, it may increase by 23% and 36%. The different extreme precipitation indices show an increase in intensity and frequency, both in the near future and far future, under both scenarios, with the exception of consecutive dry days (CDDs). The projections suggest an increase in the highest 1-day rainfall (by 1.4 mm/decade and 3.3 mm/decade), the highest 5-day rainfall (by 2.7 mm/decade and 7 mm/decade) and extreme R95P precipitation days under RCP 4.5 and RCP 8.5 scenarios. Consecutive wet days may also become more frequent during monsoon season over Uttarakhand region. The study findings highlight the need for taking account of extreme precipitation events during climate resilience planning over Uttarakhand.

A5: Statistical Methods/ML techniques for regional climate downscaling

Identification of suitable predictors for statistical downscaling of rainfall over Indo-Gangetic Plains

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The Indo-Gangetic Plains (IGP) is located between 22°-32° N and 74°-90° E, and is one of several fertile areas within India known for its high agricultural productivity. Therefore, it is important to gain a better understanding of the predictors that influence the patterns of rainfall in this region. To downscale local precipitation in this region, one must choose suitable predictors from a broad pool of large-scale predictors accessible in the NCAR/NCEP reanalysis. This is due to the intricate connections that exist between the large-scale predictor fields and the local-scale predictands. Through statistical downscaling, the study sought to ascertain how effectively certain large-scale predictors might reproduce local-scale precipitation in homogeneous rainfall zones over IGP across four seasons namely, pre-monsoon (March, April, May), monsoon (June, July, August, September), post-monsoon (October, November) and winter (December, January, February). The downscaling models were calibrated using the principal component-based multiple linear regression technique, and each raw grid-point predictor field was transformed into Principal Components (PCs) using empirical orthogonal function (EOF) analysis. The study identified best performing predictors that consistently provided better downscaled results. The indices used for assessing the performance of predictors are R-squared value, adjusted R-squared value, and Akaike Information Criterion (AIC). It was found that these best performing predictors included commonly used predictors such as precipitable water, precipitation rate, relative humidity, and u-wind at different levels. Overall, the best performing predictors have been found to be not very sensitive to minor alterations in the size of the domain under consideration.

Keywords: Indo-Gangetic Plains, downscaling, predictors, EOF analysis, homogeneous rainfall zones

A5: Statistical Methods/ML techniques for regional climate downscaling

Probabilistic Projections of Future Temperature and Precipitation for Climate Risk Assessment in Vietnam

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Extreme climate events are rare but can have serious consequences. Assessing the quantitative likelihood of such events is crucial, but it is challenging due to the inaccuracy of commonly used GCM models in representing them, as well as their high uncertainty. In this study, a probabilistic model for extreme climate events in Vietnam called SMME-VN was developed using the Surrogate Mixed Model Ensemble method to predict temperature and rainfall under the SSP2-4.5 and SSP5-8.5 scenarios. SMME-VN is a joint probabilistic model derived from the weighted patterns of 35 GCM models and surrogate models taken from the CMIP6-VN dataset. Independent testing of the probabilistic model showed that it is highly accurate. Consistent with previous research, the SMME model predicts that higher latitudes will experience more warming than lower latitudes, with the northern mountainous provinces seeing the highest temperature increases and the South Central region experiencing the lowest. Under the RCP8.5 scenario, there is a 5% chance that the national average temperature will exceed 6.29°C. At the 95% probability level, the minimum temperature increase is 2.21°C. Rainfall is expected to slightly increase at the end of the century, with an average increase of 6.12% at the 5% probability level. The study also found that natural climate variability contributes significantly to the uncertainty in prediction results. However, as the century progresses, the uncertainty of extreme climate event predictions depends on the uncertainty of future greenhouse gas emission scenarios.

Keywords: probabilistic projection, climate risk, SMME, Vietnam, CMIP6-VN

Sessions A4 / A5
POSTER PRESENTATIONS

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Winter Precipitation Characteristics in an Ultra-scale Convection Permitting Model

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The Hindu-Kush Himalayan (HKH) region, characterized by steep orographic gradients, hosts a large range of topographic and climatic regimes which strongly influence global weather patterns and exhibit high sensitivity to climate change. Winter (NDJF) precipitation through extratropical, synoptic cyclonic storms over HKH gets stored primarily as glacial snowpack and holds socio-economic and agricultural significance. However, large spatiotemporal precipitation heterogeneity associated with complex terrain, and topographical effects, combined with a poor gauge network emphasizes the necessity of high-quality precipitation records with adequate spatiotemporal coverage. Moreover, a dearth of high- resolution data, applicable at global and regional scales, makes adequately resolving precipitation characteristics and associated driving mechanisms a challenging task. The present study aims to evaluate and compare 1-km resolution (k-scale) simulations in a WRF based convection permitting model over the HKH region using multi-source precipitation datasets including satellite (GPM-IMERG and GSMaP) observations and reanalysis datasets (IMDAA and ERA5) during November 2018-February 2019. Winter precipitation characteristics including extreme events and synoptic scale as well as small-scale processes at seasonal, sub-seasonal, daily, and sub-daily time scales have been studied. The findings revealed that the WRF k-scale simulations allowed for a more detailed analysis of localized patterns, and error and bias analysis demonstrated the reliability of the simulations. Further, different precipitation skill scores (CSI, ETS, BSS, HSS, POD and FAR) provided insight into how well the model simulations resolved extreme precipitation instances. The study underlines the necessity of k-scale simulations for accurately characterizing winter atmospheric dynamics for conducting monitoring and climate change impact assessment studies over the fragile HKH ecosystem. Detailed results will be discussed.

Keywords: Winter Precipitation; k-scale simulations; convection permitting model; Hindu-Kush Himalayas

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Analysis of shift in LPS trajectory over India during monsoons, its dynamics, and effects on spatiotemporal distribution of precipitation

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This study explores the causes and impacts of potential changes in the trajectories of low pressure systems (LPS) over the Bay of Bengal on the intensity and the spatiotemporal distribution of the Indian summer monsoon rainfall (ISMR).

LPS are responsible for nearly 60% of the precipitation received by the Indo-Gangetic belt during the monsoon season and also play a crucial role in extreme precipitation events. Previous findings suggest that changes in the trajectory of LPS may be causing differences in the spatiotemporal reach of moisture, resulting in wetter monsoons in the western parts of India and drier eastern regions like Odisha and Bihar. The present study analyses data obtained from a regional earth system model (RESM) called ROM and investigates the variability in the paths of the LPS using decadal analysis. ROM was simulated at a horizontal resolution of ~27 km over the CORDEX-SA region for 1980-2017 using forcing from ERA-Interim reanalysis. Additionally, the study rationalises these trends in terms of the underlying atmospheric dynamics, considering both adiabatic dynamics and the potential impact of future global warming on LPS activity.

Keywords: Low pressure systems (LPS), Indian summer monsoon rainfall (ISMR), RESM, ROM, CORDEX-SA, adiabatic atmospheric dynamics

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Investigation of Atmospheric Clouds over the western-Indian Region

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Clouds play a crucial role in the Earth's hydrological cycle and radiative budget and are integral to regional and global weather conditions. The cloud height, different layers, and vertical structure in the atmosphere significantly affect the weather/climate system, and changes in these properties manifest as climate change. The inadequate representation of these cloud parameters due to lack of observations causes uncertainty in models to determine the effect of clouds on future climate. To face future challenges and find solutions for climate change problems, monitoring and investigating the changes in cloud properties on both regional and global scales became essential. This study uses ground-based instruments, satellites, and reanalysis datasets to investigate clouds over a western-Indian region, Ahmedabad (23.02°N, 72.57°E) during 2019-2022. Ahmedabad is a highly polluted urban city in Gujarat, India, having a hot, semi-arid climate. Continuous observation of clouds is taken using a Ceilometer lidar stationed at the Physical Research Laboratory main campus. Ceilometer is a low-power, eye-safe, portable lidar which can measure cloud base heights and vertical visibility up to about 7.6 km with a vertical resolution of ~10 meters every 2 seconds. Investigations using lidar shows that the cloud occurrence over Ahmedabad doesn't show a distinct monthly pattern but is found maximum during the monsoon (June, July, August, and September). The total cloud occurrence over Ahmedabad in 2019, 2020, 2021, and 2022 is about 16%, 22%, 20%, and 15%, respectively. Single-layer clouds are found throughout the year, with average cloud base height lower during monsoon and higher during pre- and post-monsoon. The average CBH during April is ~ 6.6km, 7.4km, 6.6km, and 7.1km in 2019, 2020, 2021, and 2022, respectively. On the other hand, the average CBH in August is ~ 1.3km, 1.1km, 2.2km, and 1.3km from 2019-22. Muti-layer clouds are mostly found during the monsoon in all years of observation. These ground-based lidar observations substantiated by satellite and reanalysis datasets will be used to evaluate the radiation budget over the western-Indian region.

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Evaluation of CMIP6 GCMs performance during the Rabi and Kharif seasons over the New Alluvial zones of West Bengal

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In spite of gradual improvement of climate model starting from first assessment report to latest assessment report of IPCC, it is still necessary to test the model performance on a local domain or point locations the latest generation CMIP6, model still have shown inherent bias and uncertainty. Present study examined the overall performance of 13 CMIP6 GCMs over New Alluvial Zone (NAZ)of Gangetic West Bengal using different conventional statistical measures in addition to usual visual comparison of model outputs with observed maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation (PR) recorded at the Meteorological Observatory of Bidhan Chandra Krishi Viswavidaylaya. As different statistical indices are sensitive to different meteorological parameters, a wide range of indices like, index of agreement, some error indices and bias estimators are used to put more confidence on the results. The main focus is to provide a proper guidance to the model users for selection of suitable models on two major crop-growing seasons i.e., for Boro season (January to May) and Kharif season (June to October) for the target domain. In general, it is noted that model performance vary significantly based on the values of different statistical indices and crop growing seasons. CMIP6 models are able to reproduce observed mean climatology and inter annual variability of temperature ($T_{max}$and T_{min}) adequately for both the kharif and boro season while less number of model have shown such better performance in case of rainfall. Based on the values of different indices, an overall rank was assigned to each model and it was revealed that CNRM–ESM2–1 model from France was found to be the best performing model for kharif season and MRI-ESM2-0 model from Japan showed highest skill for boro season. On the other hand, the Australian model ACCESS-CM2 showed lowest skill for khariff season and the model MPI-ESM1-2-LR from Germany performed worse for boro season. So, any type of impact assessment study based on past and future projection of CMIP6 GCMs simulation, it is advisable to consider the group of better performs models in the ranking list and worst performing model should be avoided.

Keywords: CMIP6-GCMs, model evaluation, best performing model, model rankings.

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Increase in water vapour over India and Indian Ocean during the period 2003–2020: Implications for amplified regional warming

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The rise in greenhouse gases (GHGs) induced by human activities causes temperatures to rise both at regional and global scales. The most important GHG, water vapour, has a large positive feedback effect on the Earth's climate system and global warming. It increases the magnitude of climate change in response to natural and human-caused climate variability and its change through a powerful feedback. Here, we investigate the impact of rising surface temperature, sea surface temperature, evaporation (ocean), and evapotranspiration (land) on changes in water vapour over India and the Indian Ocean as assessed using reanalysis and satellite data for the period 2003–2020. It is observed that the column water vapour is very high over the Bay of Bengal, Northern Indian Ocean and Peninsular India, which varies from 30 to 60 kg/m2. Furthermore, a clear seasonal cycle is observed in water vapour over India, where the highest value is found in summer (June-August) and smallest in winter (December-February). The higher value observed during summer can be ascribed to the increased evapotranspiration as well as the transport of moisture from the adjacent ocean by the Indian Summer Monsoon winds. Most Indian regions show significant positive trends in the annual mean water vapour, about 0.1–0.2 kg/m2/yr during the period 2003–2020, consistent with the rise in evapotranspiration and surface temperature. On the other hand, negative trends are found in some areas in Bay of Bengal during spring (March-May), about -0.1 kg/m2/yr. There is a significant positive trend in water vapour in the entire troposphere (except 200 hPa) over the India land regions, with the highest values are estimated at 1000 hPa (0.034 g/kg/yr). The corresponding water vapour radiative effect (WVRE) is about 20–80 W/m2, depending on seasons and regions. The positive and high values of WVRE could also amplify the warming caused by the other GHGs. Henceforth, this study indicates that the water vapour is increasing over India and Indian ocean and it could affect the hydrological cycle, temperature and regional climate.

Keywords: Water Vapour, Evapotranspiration, Regional Climate, Indian Ocean

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Historical and future projections for variability in west Pacific subtropical high and its association with Indian summer monsoon by using CIMP6 simulations

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This study aims to analyse the historical and future projections of variability in zonal shift in west Pacific subtropical high and intensity of WPSH by using simulations of CIMP6 models. Based on the comparison of variability in WPSH which is analysed by using NCEP reanalysis data, total 8 models, AWI_CM1, AWI_ESM, BCC_CSM2, BCC_ESM, CAMS_CSM, MPI_ESM, NESM3 and IITM_ESM are selected from out 25 models of CIMP6 over the period1950-2014. The model AWI_CM1 is well estimate the climatological location of WPSH around 20°N (location index) and intensity of WPSH over the historical period which is approximately similar with NCEP reanalysis. The AWI_ESM, BCC_CSM2 and BCC_ESM1 are under estimating and remaining models over estimating the location of WPSH. The structure of WPSH during historical period is well simulated by the models are AWI_CM1, BCC_CSM2, and IITM_ESM as compared to NCEP. All most all the models are simulating the pattern of interannual variability in zonal displacement of WPSH during peak monsoon season (July-August mean). None of the models are not estimate the trend in eastward shift of WPSH expect the BCC_CMS2 which is also under estimate trend in eastward shift of WPSH (0.05 degree/year) as compare to the NCEP (0.16 degree/year). The interannual trend in intensity also under estimate by the model BCC_CSM2 (-0.04 gpm/year) as compared to NCEP (-0.2 gpm/year) and remaining models are simulating increasing trend in intensity which is opposite to NCEP (weakening trend in intensity). The rainfall over ISM region during JA season is well estimate by the models are AWI_CM1 and IITM_ESM as compared to the observation (Aphrodite). In addition, there is a positive correlation between and westward shift of WPSH and AISMR during JA season over the historical period observed by using Aphrodite data and all the models estimate positive correlation expect that the NESM3 model. The pattern of spatial correlation between location index and rainfall over ISM region is well estimated by all models. At end of the 21st century, all models are predicting the westward shift in western plank of WPSH along with intensification expect CAMS_CSM2 model projects is opposing with eastward shift and weakening of WPSH at end of the century. Future projections of All India summer monsoon rainfall from all the models are showing the increasing in amount of precipitation at end of the century. All 8 models are projecting that, there may be a strong positive relation between the westward shift of WPSH and precipitation over the AISMR.

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Processes associated with extremely heavy precipitation in the Meghalaya Plateau region: A case modelling study

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The Meghalaya Plateau (MP) located in northeast India is one of the rainiest regions in the world. On 18–19 August 2015, Mawsynram on the southern slope of MP received 745 mm of precipitation in 24 hr. This study investigates the dynamical, thermodynamical and cloud microphysical processes associated with this event through numerical simulations with fine horizontal resolutions (1 and 1/3 km). The control (CNTL) simulation with 1 km grid spacing suc cessfully reproduces the observed spatial pattern of accumulated precipitation. A simulation without MP (noMP) is carried out to examine the role of MP in this precipitation. From 1500 LST 18 to 0000 LST 19 (P1) when the low-level jet carrying warm and moist air towards MP is relatively weak, the upslope region receives a moderate amount of precipitation which is initiated over this region due to the orographic lifting, while almost no precipitation is received there in the noMP simulation. Warm microphysical processes play dominant roles in the precipitation in P1. From 0000 to 0900 LST 19 (P2) when the low-level jet is enhanced, the CNTL simulation shows very heavy precipitation in the upslope region, much heavier than that in the noMP simulation. Deep convective systems developed upwind of MP move towards MP. These convective systems merge together and strengthen over the upslope region. The accretion process is substantially enhanced by the vigorous updraughts at low levels over the steep slope of MP, resulting in heavy precipitation. The 1/3 km resolution simulation shows much heavier precipitation in the upslope region than the CNTL simulation. The increased horizontal resolution makes the slopes steeper, resulting in further intensification of the updraughts over this region. This increase in simulated precipitation reduces the deviation from the rain-gauge observation, implying the importance of very high horizontal resolutions in simulating extremely heavy precipitation in MP.

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Evaluating the Accuracy of Reanalysis Products for Wind Energy Development: A Comparison with In-Situ Observations

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This study investigates the role of reanalysis products in analyzing historical weather patterns, focusing on wind energy resource evaluations. The analysis reveals a decline in land surface wind speed from the 1970s, known as global terrestrial stilling, followed by a reversal around 2010. The representation of this trend and turning point in reanalysis products is uncertain. To address this knowledge gap, a comprehensive analysis is conducted, comparing three reanalysis products (ERA5, JRA-55, and NCEP/NCAR) with observational data from 32 meteorological stations for the period 1973-2005. Statistical metrics, including standard deviation, Root Mean Square Error, Mean Absolute Error, Mean Bias, correlation coefficient, and coefficient of determination, are used to assess the accuracy of the reanalysis products. JRA55 is found to closely match the observations, but significant differences exist between actual and simulated wind speeds. JRA55 exhibits exceptional agreement with observations, while NCEP/NCAR displays lower standard deviation. Considering the growth of the wind energy sector in the Subcontinent, this study emphasizes the importance of caution when using reanalysis products for wind assessment and forecasting in the region.

Keywords: Reanalysis products, Wind energy resource evaluations, Terrestrial stilling, Climatic wind patterns Accuracy of reanalysis datasets

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Hybrid Statistical Downscaling in Reducing Bias in drivers of Compound wet-warm event during the West African Summer Monsoon

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The study presents a preliminary baseline on the added value of adopting a physics mechanism-driven complex hybrid networks of neural layers in downscaling the drivers (temperature and precipitation) of compound warm-wet events during the West Africa summer monsoon season. The study reveals that when compared to the GCM, the hybrid deep statistical model reduces the historical biases significantly across the West Africa domain. We hope to improve the reliability of climate data that will guide adaptation planning and mitigation strategies for stakeholders in the region by doing so, and we encourage these models to improve their performance in order to better simulate current and future compound wet-warm events (CWWEs) for population risk assessment.

Keywords: Population exposure, neural networks, Summer Monsoon and downscaling

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

A Combined Approach For Runoff Estimation of Jhelum River Using Satellite and In-situ Gauge Data

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The accurate estimation of river runoff is crucial for water resource management and flood control. Satellite-based estimates of rainfall have the potential to improve runoff modeling in data-sparse regions such as the Jhelum river basin. This study assesses the accuracy of satellite-derived runoff estimates using four satellite products, including CHIRPS, PERSIANN-CDR, SM2Rain-ASCAT, and TRMM. The study area covers the Jhelum river basin in Pakistan, where gauge data is scarce. The study employs the Thiessen polygon method to calculate the area of the basin, and the rational formula and geo-environment is used for runoff modeling based on in-situ gauging stations. The results reveal that the TRMM and CHIRPS satellite products perform better than PERSIANN-CDR and SM2Rain-ASCAT in rainfall-runoff modeling of the Jhelum River. The correlation coefficient (R) for TRMM and CHIRPS are found to be 0.75 and 0.71, respectively, indicating a good correlation between the estimated and observed runoff values.

In contrast, PERSIANN-CDR and SM2Rain-ASCAT have lower R values of 0.54 and 0.58, respectively. Further analysis reveals that the performance of the satellite products varies spatially across the basin. The TRMM and CHIRPS products perform well in the upper and middle reaches of the basin, where rainfall is more frequent and intense, while PERSIANN-CDR and SM2Rain-ASCAT perform better in the lower reaches, where the rainfall is less intense. Overall, the results suggest that the TRMM and CHIRPS satellite products are suitable for estimating river runoff in the Jhelum River Basin. However, the performance of the satellite products is influenced by the spatial and temporal variability of rainfall, as well as the topography and land use of the basin. Therefore, caution should be exercised when using satellite-based estimates of runoff in data-sparse regions and calibration with ground-based data is essential. The findings of this study can provide valuable information for water resource management and flood control in the Jhelum River Basin and can be applied to other basins with similar characteristics.

Keywords: Runoff estimations, Rainfall-runoff modelling, SM2Rain-ASCAT, TRMM, Jhelum River, South Asia

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Comparative Analysis of Thunderstorms and Hailstorms Events in Jharkhand, India: Integrating Ground Observations with WRF Simulations

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Extreme thunder and hailstorm events in Eastern India, present complex challenges, and a wide range of societal implications. These severe weather occurrences not only disrupt daily life but also have significant consequences for infrastructure, agriculture, and public safety in the region. Jharkhand is one of the states in Eastern India that faces the wrath of these summer extreme events. In this study, two pre-monsoon storm events a thunderstorm event and a hailstorm event in the same season were simulated using the regional WRF-ARW model and ground observations, yielding diverse outcomes based on the examined parameters. The ground-based observations were obtained from micrometeorological tower at BIT Mesra location at Ranchi and WRF-ARW version 3.0 was used to simulate the same events. Local weather reports corroborated the accurate representation of temperature and wind components in both events. While the first event successfully simulated cloud and rainwater mixing ratios, the second event displayed significantly lower values in the WRF simulation in comparison to the ground observations. TKE values in the second case deviated from observed values, potentially due to height discrepancies. The model effectively represented planetary boundary layer and geopotential height values during both events. Sensitivity analysis-driven scheme selection, such as reanalysis, may enhance storm representation accuracy. As the peak event time neared, geopotential height decreased, indicating the model's potential for capturing event timing. Despite minor inaccuracies in certain parameters, the overall simulation of the short-lived storm events was satisfactory. In the study ground observations were comparatively accurate than the model simulated version. The user-friendly interface and comprehensive manual facilitated the model's use by researchers in numerical climate prediction of mesoscale events. The WRF ARW model demonstrates potential for in-depth analysis of short-lived extreme events. The study aims to advance the understanding of the physics and dynamics associated with extreme events on a regional level advancing the aims of CORDEX. The findings contribute to the broader discussion of mesoscale observational and numerical modeling studies on extreme events over tropical regions, with the goal of furthering our knowledge of these events and their impacts on society.

Keywords: extreme events, thunderstorms, hailstorms, WRF, mesoscale modelling

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

CMIP5 based past and future rainfall change over coastal saline zone of West Bengal

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Present study has been carried out to investigate the past and future rainfall change scenarios over the coastal saline agro-climatic zone of West Bengal using the observational rainfall data from the India Meteorological Department (IMD) and the 20 numbers of Global Climate Models (GCMs) simulations from the Coupled Model Intercomparison Project Phase 5(CMIP5). Multi-models ensemble of 20 GCMs known as "MME20", produce more realistic climate information at smaller domain like coastal and saline zone with a wide range of uncertainty along with ensemble prediction. CMIP5 models exhibit either dry or wet bias in case of historical rainfall and they are unable to reproduce the mean observed climate adequately. To reduce the uncertainty and inherent biases exhibits in the current generation CMIP5 GCMs, downscaling the GCMs simulation using observed climate data is recommended. The model evaluation study using multiple statistical measures revealed that the models CCSM4, CESM1_CAM5, and GFDL_CM3 performed well in the target agro-climatic zone among 20 considered CMIP5 GCMs. Future projection of rainfall using four RCPs of CMIP5 GCMs indicated an increase of annual and monsoon rainfall by 1-11% and 1-13% respectively by 2050s whereas pre-monsoon rainfall indicated 1-5% deficient in 2050s but 3-9% surplus in 2080s.

Keywords: Coastal saline agro-climatic zone, West Bengal, GCMs, CMIP5, rainfall change, MME20.

A4 and A5: Regional climate modelling/downscaling for South Asia Monsoon region

Assessing the role of Ocean Heat Content in modulating Indian Summer Monsoon Onset

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The onset of Indian Summer Monsoon (ISM) and its withdrawal exhibit significant variations from year to year. The climatological onset date for ISM is 1st June, with a standard deviation of eight days. The tropical oceans, particularly the Indo-Pacific, play a significant role in the circulation of ISM. Large-scale phenomena such as El-Niño and Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) can disrupt oceanic conditions, consequently modulates the ISM circulation. Sea surface temperature (SST) and Ocean Heat Content (OHC) are among the perturbed Ocean parameters associated with these phenomena. SST is significantly regulated by strong winds, evaporation, or dense clouds and does not accurately reflect the thermal energy present in the upper ocean. In contrast, OHC, that is measured as an integral from ocean surface to various depth, is more stable, shows very less spatial spread and has a stronger impact on monsoon than SST. Many studies have used SST over the Indo-Pacific Oceans for predicting ISM onset and Rainfall, but recent studies have suggested (OHC) can be a better predictor for ISM onset. The goal of current work is to provide a concise review of mean trends, ENSO-related variability in OHC anomalies, and their relationship to the onset of ISM. Analysis of the Indo-Pacific OHC are conducted over the entire tropical region for a sufficient amount of time to take ENSO fluctuation into account to validate the role of large-scale processes like El-Niño, Modoki and IOD as dominant mode of variability of OHC Anomaly. The central-eastern Pacific region, where the magnitude of OHC anomalies was found to be the largest, exhibits strongest signals at the ENSO time scale. Using EOF method for HC anomaly in the Indo-Pacific Ocean the spatial pattern of dominant mode causing the change in HC anomalies are investigated. Statistical technique of correlation and regression of different atmospheric circulation parameters on the dominant EOF mode and Principal Component has been used to understand the mechanism of onset with atmospheric circulation. Results show that, ISM onset is influenced by both atmospheric and oceanic variability. With this study new prediction skill can be proposed for the prediction of ISM onset using modified oceanic precursory signal that is not only limited to sea surface.

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Winter Fog Simulation Using WRF Model: A Case Study of Delhi

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Fog is hazardous to public health, aviation, road/railway transportation, economy. The substantial amount of fog causes the lower visibility mainly affect the boundary layer where the most of human resides. Hence, it is necessary to conduct research to forecast the intensity and duration of fog using numerical weather prediction models. This study employs a research and forecasting model for simulating fog weather with the aim of achieving precise fog prediction. The accuracy of prediction is widely dependent on appropriate parameterization scheme, horizontal & vertical resolution, grid dimensions, initial and boundary conditions should be used. We have investigated the characteristics of fog and its impact on human and other systems, highlighting the need for research in this area. Using the WRF model, the study simulates a dense fog event with visibility less than 200m that occurred in December 2019 over Delhi, which is part of the Indo Gangetic Plains. The region's silt and loamy soil has a high tendency to hold moisture, making it more prone to fog. The India Meteorological Department reported that Delhi recorded its minimum temperature in December since 1997 due to active western disturbances triggering fog formation. The study analysed two dense fog events that occurred in December 2019 using the best model configuration, reanalysis data of ERA-5, and land use data from the Indian Space Research Organization. The parameters influencing the fog, such as surface temperature, dew point temperature, wind speed, relative and specific humidity, Kinetic energy, downwelling longwave radiation were also considered. The study contributes to our understanding of the effects of climate and environmental conditions on fog and can inform future research and policy decisions.

A4/A5: Regional climate modelling/downscaling for South Asia Monsoon region

Future Changes in Mean and Extreme Precipitation over Peninsular Malaysia using CORDEX-SEA 5 km Simulations

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The Coordinated Regional Climate Downscaling Experiment (CORDEX) Southeast Asia further downscaled three of its 25 km product, i.e. EC-Earth, HadGEM2-ES and MPI-ESM-MR forced regional climate simulations to a higher resolution of 5 km. Newer RegCM4.7 model was used for this exercise. For the simulations over Peninsular Malaysia, analysis shows that these simulations have much smaller precipitation biases, and they are able to correctly predict the precipitation annual cycle over the east coast of Peninsular Malaysia compared to the 25 km simulations. The ensemble of these 5 km simulations indicates that the Peninsular Malaysia is expected to experience a decrease in its seasonal mean precipitation, regardless of RCP4.5 or RCP8.5 scenario. Aside from the decrease in seasonal mean precipitation, consecutive dry and wet days are expected to increase and decrease, respectively. This indicates that Peninsular Malaysia is to experience a longer dry spell in the future. At the same time, it

is being suggested that Peninsular Malaysia will be having fewer days with very heavy precipitation. Overall, the findings from this study suggest that the 5 km downscaled climate simulations improve greatly over that of 25 km, and that the Peninsular Malaysia region can expect a drier future climate and extremes.

Session B:

CORDEX Interaction with Society

ORAL PRESENTATIONS

B2: Integration of available climate information in support of decision making

Downscaling of Climate Data for Local Governments in Kerala

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Climate change is a pressing issue worldwide, with global average temperatures having risen up to 1.1°C since 1850 due to human-induced activities emitting carbon dioxide and other greenhouse gases. The consequences of climate change in Kerala include an increased occurrence of droughts, floods, landslides, and heatwaves, with extreme events expected to accelerate in severity in the future. To prepare for this future, it is crucial to understand how the climate will change.

In this study, data from atmosphere-ocean coupled general circulation model runs conducted under the CMIP5 for the representative concentration pathway (RCP) scenarios were used. This data was dynamically downscaled to a 0.5°×0.5° resolution using RegCM4 and RCA4 regional climate models (RCM) under the Coordinated Regional Climate Downscaling Experiment (CORDEX) South Asia programme. The monthly precipitation, maximum temperature, and minimum temperature for the historical run and climate scenarios RCP 4.5 and RCP 8.5 were analyzed for the period of 1976-2005, and projected for the near term (2021-2040), medium term (2041-2060), and long term (2061-2099). The downscaled data was then provided to the 1034 local self-governments (LSGs) in Kerala, enabling the generation of climate impact and adaptation assessments at the local level.

It is worth noting that under both the RCP 4.5 and RCP 8.5 scenarios, precipitation, maximum temperature, and minimum temperature are projected to increase in the future. Particularly significant is the faster rate of increase in minimum temperature compared to maximum temperature across all seasons. These changes in precipitation and temperature pose considerable challenges to the natural environment, human health, and the global economy. To mitigate these impacts, it is crucial for each LSG to adopt tailored measures, taking into account the specific agro-ecological characteristics of their region. Solutions need to be identified and implemented in various sectors such as agriculture, biodiversity, health, forestry, tourism, and the economy, enabling local governments to effectively adapt to climate change. Integrating these solutions into both short-term and long-term plans will be instrumental in building resilience and ensuring sustainable development.

This study represents a pioneering initiative in India, as it provides climate change information to local governments, empowering them to engage in adaptation planning and resilience building. By bridging the gap between climate research and local action, this approach sets a precedent for effective climate change governance and supports the sustainable development goals of the region.

B2: Integration of available climate information in support of decision making

Evaluation of extreme precipitation climate indices over Hindu-Kush Himalayan in CMIP5 to CMIP6

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The Hindu-Kush Himalayan (HKH) region is a crucial area in the world's climate system, highly sensitive to climate variability. The region is renowned for its unique topography and diverse vegetation and climate, which range from snow-capped high elevations to tropical and subtropical climates at lower altitudes. These mountainous terrains are of significant socio-economic, aesthetic, and ecological importance, providing a habitat for a range of plant and animal species and acting as a watershed for a large community. However, extreme precipitation events, such as heavy rainfall, can have severe impacts on the region, leading to flooding, landslides, and damage to infrastructure, which can affect the livelihoods of local communities. To assess the ability of climate models to predict extreme precipitation events in the HKH region, we conducted a study evaluating how well the extreme precipitation characteristics are represented in CMIP5 and CMIP6 simulations. We used extreme precipitation indices prescribed by the Expert Team on Climate Change Detection and Indices to evaluate the trend and spatial variability of extreme precipitation events over the HKH region for different seasons. Our aim was to determine whether there has been any generational improvement in newer models and to provide information useful to various stakeholders and policymakers. We found that while most of the model simulations from CMIP6 have marginally improved in capturing the precipitation extremes over the HKH region compared to CMIP5. This might be due to the complexity of terrain and the comparatively coarser representation of topography in global climate models. However, our analysis of the best models in each index showed considerable improvements in spatial bias and trend in CMIP6 compared to CMIP5. The robust global climate models identified in our study could be used to make future projections and help stakeholders and policymakers make informed decisions. The insights as gained from this study may provide a valuable guidance in downscaling Himalyan Cimate under the ongoing CORDEX downscaling initiatives using CMIP6 data products.

B2: Integration of available climate information in support of decision making

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

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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

B2: Integration of available climate information in support of decision making

Long-term forecasting of tropical cyclones over Bay of Bengal using linear and non-linear statistical models

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Forecasting tropical cyclones with climate and physical variability and observed cyclonic disturbances has been developed over the years for all the ocean basins successfully and is still one of the priorities for disaster risk reduction policymaking. This study attempts to forecast seasonal cyclonic disturbances and severe cyclonic storms over the Bay of Bengal, where about 80% of the tropical cyclones of the North Indian Ocean are formed. We have used three time-series models, namely, the seasonal autoregressive integrated moving average with exogenous variables (SARIMAX) model, artificial neural network-nonlinear autoregressive with exogenous variables (ANN-NARX) model, and the hybrid model. The basic purpose of considering three different models is to improve the forecasting accuracy of tropical cyclones. We have shown that the intensification rate of the severe cyclonic storms over the Bay of Bengal has been significant and increasing over the years. Results show that the ANN-NARX model with sea surface temperature and near-surface wind speed as predictors is the best performance model for long-term forecasting of cyclonic disturbances. Hence, the distribution of cyclonic disturbances is non-linear. The correlations between observed and predicted occurrences are 0.80 and 0.85 for cyclonic disturbances and severe cyclonic storms, respectively, corroborating, by and large, the forecasting accuracies of some previous studies. The forecasting of cyclonic disturbances indicates that they will vary from 5 to 13 annually and there will be, on average, one severe cyclonic storm per year. The likelihood of occurrence of severe cyclonic storms is most significant in the post-monsoon season. This forecast till 2050 would help the scientific community and policymakers significantly for applications and good disaster risk governance.

Keywords: Tropical cyclones; Seasonal forecasting; SARIMAX; Artificial Neural Network; Hybrid model; Predictors; Bay of Bengal

B3: Providing timely and relevant climate information for societal needs

Capacity Building of Rural Women in Accessing Climate Information in Himalaya: An Illustration of Bridging the Gap between Climate Science and Community Adaptation Needs at the Local Level

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In Himalaya, subsistence agriculture compels a large proportion of male-population to out-migrate, leading to feminization of farming system. Hence, women become primary resource developers and backbone of mountain economy. Climate change has stressed Himalayan agriculture through higher temperatures, altered precipitation patterns, and increasing frequency of climatic extremes. Women experience these changes acutely and disproportionately due to prevailing gender-differentiating norms. Moreover, due to diversity and complexity of terrain, climatic phenomena exhibit sharp variations at short spatial distances in Himalaya which is one of the most hydro-meteorological information deficit regions. The inadequacy of hydro-meteorological monitoring network, non-availability of early warning system, poverty, poor accessibility and gender inequalities have increased vulnerability of rural women to climate change. This poses severe challenges in reducing community vulnerability to climate change, as marginality, social inequalities and economic disparities are often amplified during risks at local level.

Study aims to build adaptive capacity of women by improving their access to climate information at local level with an illustration of Ramgad Watershed (65 km2), Kumaon Himalaya, India. This was attained by: (i) installing women-managed low-cost weather stations in 25 villages; (ii) educating rural women in observing climatic data; (ii) imparting training to women in generating meaningful and timely climatic information; (iv) educating women to share and discuss observed climatic information in village meetings; and (v) developing flash-flood early warning system for downstream communities. It was observed that women's access to climatic information not only improved their adaptive capacity to climate change, strengthening food and livelihood security but also helped to bridge the gap between climate science and local adaptation in underdeveloped mountains.

Keywords: Feminization of Agriculture, climatic extremes, inadequacy of hydro-meteorological information, women-managed low-cost weather stations, adaptive capacity to climate change

B3: Providing timely and relevant climate information for societal needs

Symbolic representation of district wise climate change scenarios of West Bengal state, India, using Thornthwaite classification scheme

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Now-a-days, multi-level stakeholders starting from grass-root level farming community to Government level policy makers need to have adequate climate change information before hand to implement appropriate adaptation and mitigation strategies towards combating climate change at local scale. However, availability of climate change data is not adequate at district and block level. The present study has attempted to reveal how the district level climate has changed in last 120 years over 23 districts of West Bengal in India using Thornthwaite classification scheme (TCS). The change of climate from moist to dry or vice-versa from mean climatological period of 1901-1930 to 1991-2020 has been assessed and represented through four different English letters based on the calculated values of TCS. The study of many indicators showed that symbolic representations remain same in some districts but in several districts these vary according to changes of time period. The $B_1A'a'w_2$ symbol was used to express climatic type of Purba Bardhaman during the first three climatological eras, but it was altered to $C_2A'a'w_2$ for the last period, showing a shift in moisture index (I_m) value. This reveals how the climatic type is continuously changing in North Bengal and South Bengal districts of West Bengal through the passage of time. Furthermore, it has been noted that while the majority of North Bengal districts have changed to drier conditions as their I_m value has decreased recently, several South Bengal districts indicate moist conditions compared to the previous climatological periods with increases in moisture index (I_m) value.

Key words: Climate change, Rainfall, PET, Index, Thornthwaite classification.

B3: Providing timely and relevant climate information for societal needs

Cause-and-effect relationships between urbanization and meteorology under climate change

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Populations around the world are increasingly moving towards urban areas, leading to increased urbanization, and the creation of megacities. Precipitation, temperature, and other meteorological patterns are significantly altered as a result of urbanization's influence on the local climate. Cities are more susceptible to and more severely affected by extreme precipitation events like heavy rain and flash floods than rural regions. Using a variety of remote sensing data and rainfall measurements, this study determines the cause-and-effect linkages between urbanisation and different meteorological phenomena. The level of urbanisation was measured using the normalised difference urban index (NDUI) developed over 136 megacities around the world. We use state of the art causal discovery algorithms to establish the relationships between urbanization and climate, further performing causal inference to answer questions related to the role of urbanization in modulating the meteorology. These results will enable the advancement of the science of urban climate and help in the design of adaptation strategies to increase the ability of urban areas to withstand natural disasters.

B3: Providing timely and relevant climate information for societal needs

Investigating the seasonal variation of simulated carbonaceous fine particulate matter over six homogeneous regions of India with focus on IGP region

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This study was aimed to assess Black Carbon (BC) concentrations in India, focusing specifically on the Indo-Gangetic Plain (IGP) region and utilizing the Weather Research and Forecasting model coupled with chemistry (WRF-Chem) v3.9.1.1. In this study we developed an air quality emission inventory called SAFAR-2018, and used the global EDGAR-HTAP inventory, to simulate BC concentrations for the year 2018 over the Indian region. This simulation provided insights into the seasonal and regional variations of BC concentrations. Surface meteorological parameters and BC concentrations were also compared to the MERRA reanalysis for the Indian region to confirm the accuracy of the results. The study observed that the simulation of surface C-PM concentration using the SAFAR-2018 emission inventory in the model was slightly overestimated, while the simulation with the EDGAR emission inventory was underestimated compared to the MERRA. On the other hand, the study found that the model-simulated meteorological parameters, such as wind speed at 2 m, surface temperature at 2 m, and Planetary Boundary Layer height, showed better agreement with observations. Furthermore, the study noted that the simulated geographic patterns of seasonal mean BC using the SAFAR-2018 emission inventory exhibited good agreement with the MERRA, unlike the simulation with the EDGAR emission inventory. The study found that in the Indo Gangetic Plain (IGP) region, the concentration of BC showed the highest peak during the winter season, followed by the post-monsoon season, as compared to the other six homogeneous regions of India. The annual hourly time series of surface BC_sf (using the SAFAR-2018 emission inventory) concentrations exhibited higher correlation coefficients with MERRA over the IGP, Northwest, Central Northeast, West Central, Peninsula, and Northeast regions (correlation coefficients of 0.84, 0.90, 0.85, 0.40, 0.84, 0.75, and 0.75, respectively) with RMSE values of 1.38, 1.44, 2.34, 0.44, 1.72, 1.35, and 2.00, respectively. These correlations were higher than those observed for the surface BC_ed (using the EDGAR emission inventory) concentrations, which exhibited lower correlation coefficients (R = 0.72, 0.84, 0.84, 0.37, 0.83, 0.74) and higher RMSE values (1.59, 1.48, 2.59, 0.77, 2.43, 2.01, and 2.17, respectively), except for the hilly regions. The study suggests that the model simulation using the SAFAR-2018 emission inventory was able to capture the pattern and magnitude of BC concentrations over the Indian region. This could help to better understand the impact of BC on climate and atmospheric conditions in India.

Keywords: Black Carbon (BC), Indo Gangetic Plain (IGP), Weather Research and Forecasting model, Emission inventory, SAFAR-2018, EDGAR-HTAP, MERRA reanalysis

B3: Providing timely and relevant climate information for societal needs

Climate Change Impact Assessment on The Khowai River Flow Using HBV Model

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Bangladesh is the most downstream country in the Ganges-Brahmaputra-Meghna basin and has at least 57 major transboundary rivers that enter Bangladesh from India and Myanmar. These transboundary rivers affect Bangladesh largely as a huge amount of water and sediments that flow through Bangladesh are carried by these transboundary rivers. Khowai River is one of the trans-boundary rivers which originates in the eastern part of the Atharamura Hills of Tripura in India. It plays an important role in the fields of irrigation, transportation and flood events of the north-eastern region of Bangladesh. It also contributes to the flash flood hazard in this region damaging agricultural products of large areas. Anticipated climate change may exacerbate the current situation as climate change will have a profound impact on the availability and variability of fresh water throughout the world. This study shows climate change impact assessment on the Khowai river flow using a semi-distributed, conceptual hydrological HBV model. The model was calibrated for 1980-2010 and validated for 2011-2019. The climate data have been collected from ECMWF (ERA5 data) and NOAA Climate Prediction Centre. To find out which gridded data set (ERA5 vs NOAA) works well against this Khowai basin, a few trial calibrations have been made. In terms of model efficiency and coefficient of determination, ERA5 shows better result than NOAA in both calibration and validation. But in the validation period, both ERA5 and NOAA show worse results than the calibration results. For this reason, another trial has been done using average rainfall (average of NOAA, ERA5 & Habiganj BMD station) which shows better results for all three periods (calibration, validation & whole period). Future precipitation, temperature and evaporation have been downloaded from CORDEX and the datasets have been bias corrected using quantile-based mapping method. Regional climate model - RegCM4-4 model, driving model – RCP 8.5 (considering worst case scenario) and CCCma-CanESM2 experiment (wet and warm scenario) have been considered while downloading future datasets from CORDEX for the climate change impact assessment. Hydrographs, average flow analysis, flow duration curve and frequency analysis have been made from the model driven future runoff data for climate change impact assessment on the Khowai river flow. Chakmaghat barrage which impacts over almost one third of the basin at upstream portion, has been taken into consideration. This study may play a vital role in the flood frequency analysis for the proper planning and water resources management of Khowai river basin.

Sessions B2 / B3

POSTER PRESENTAIONS

B2/B3: CORDEX Interaction with Society

Metric performance between CMIP model and historical IMD data

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The metric performance between a CMIP (Coupled Model Intercomparison Project) model and IMD (India Meteorological Department) data refers to comparing the accuracy of predictions made by a model with the actual outcomes observed in past data. The evaluation of a model's performance is critical in determining the usefulness of the model and improving its predictions.

To assess the model's performance, various metrics like Tylor skill score, correlation coefficient, index of agreement, Nash Sutcliffe efficiency and percentage bias have been used. These metrics provide insights into different aspects of the model's performance, such as its ability to correctly classify data points, detect anomalies, or predict values accurately. Comparing a model's performance with historical data provides a baseline for evaluating its effectiveness. If the model outperforms the historical data, it indicates that the model is capable of making more accurate predictions than previous methods. On the other hand, if the model's performance is worse than the historical data, it suggests that the model needs further refinement or that the historical data is not representative of the current situation. Overall, measuring the metric performance between a model and historical data is an essential step in the process. The findings of such a study would be relevant to the field of climate science and could inform future climate projections and policy decisions related to climate change mitigation and adaptation.

B2/B3: CORDEX Interaction with Society

Assessment of Wind Power Potential in Selected Locations of Pakistan: Analysis of Wind Speed Characteristics and Power Density Estimation

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This paper investigates the wind power potential at seven selected locations in Pakistan, including Gujranwala, Islamabad Capital Territory, Jhimpir, Kati Bandar, Khanewal, Multan, and Sialkot. Wind speed data collected from 2005 to 2016 at a height of 10 meters were analysed using ten distribution functions to characterize the wind speed characteristics and estimate the wind power density. The results indicate that Kati Bandar has the highest annual wind speed of 4.04 m/s, while Islamabad Capital Territory has the lowest at 1.33 m/s. The maximum power density of 258.75 W/m2 occurs in July at Kati Bandar, and the minimum wind power density of 1.68 W/m2 occurs in September at Islamabad at a height of 10 meters. Analyzing the wind power and energy density as functions of tower height reveals that higher tower heights result in higher wind power and energy density. Thus, the wind power density values in locations such as Gujranwala, Islamabad Capital Territory, Khanewal, Multan, and Sialkot are significant and can be harnessed using small-scale wind turbines for electricity generation. Furthermore, the performance of four small-scale wind turbines was evaluated, with the Pitch wind/30 kW Grid turbine achieving the highest annual capacity factor of 56.366% and the WS-12/8 kW turbine having the lowest at 15.416%. The minimum and maximum annual electricity costs in the studied locations were found to be 0.005 $/kWh and 0.032 $/kWh, respectively, using the Pitch wind/30 kW Grid and WS-12/8 kW turbines. These findings provide valuable insights into the wind power potential and economic feasibility of utilizing small-scale wind turbines for electricity generation in the selected locations.

Keywords: Wind power potential, Wind speed characteristics, Wind power density, Small-scale wind turbines, Annual electricity cost

B2/B3: CORDEX Interaction with Society

The effects of dust and anthropogenic aerosol on ozone in a semi-arid region in the Middle East

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The Scattering and absorption of solar radiation due to the direct effect of aerosols can change solar radiation reaching the earth's surface. Consequently, aerosols change the photolysis rate and cause changes in ozone production. Moreover, aerosols affect the temperature structure of the atmosphere semi-directly and thus modify ozone production. In this study, the effects of aerosol on ozone were analyzed over Zanjan, Iran, a semi-arid region in the Middle East during the period (2008-2018).

The results revealed a negative relationship between tropospheric ozone and Aerosol Optical Depth (AOD) both in the spring and summer. In particular, on dusty days, the aerosol has a negative influence on the concentration of ozone in the lower atmosphere. The correlation coefficients between particulate matter (PM_{10}) and ozone were negative on dusty months and dusty days. The small and negative values of Aerosol Index (AI), which were observed in late spring, summer, and fall, are due to the dominance of scattering aerosol (dust particles) in the atmosphere of Zanjan in these seasons. The higher values of AI in the winters are due to the increase in the local absorbing fine mode particles like urban/industrial.

A comprehensive study of the effects of the types of aerosols on ozone shows that coarse mode aerosols such as dust reduce the ozone concentration. On the other hand, anthropogenic fine mode aerosols such as urban/industrial have a positive effect on ozone production. Examining the relationship between AOD, Aerosols Radiative Forcing (ARF) and ozone, reveals that coarse mode aerosols such as dust with higher AOD, reduce the sunlight reaching the surface more than fine mode particles. As a result, ARF values become more negative at the surface, so the photolysis rate decrease considerably and the concentration of surface ozone is reduced.

B2/B3: CORDEX Interaction with Society

County-scale Climate Projections over Minnesota for the 21st Century

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Global warming has its largest amplitude in the higher latitude regions of the Northern Hemisphere. This is especially the case during winter months when reduced reflectivity from diminished snow cover leads to higher average temperatures. This process has led to warming at twice the rate as the rest of the planet. In addition to accelerated warming from local snow melt, this Arctic warming is contributing to strong warming over Minnesota, especially during winter, when Minnesota is one of the states that is warming the strongest within the contiguous United States. We have previously emphasized this strong warming in our study on high-resolution climate projections over Minnesota, and we are now producing an updated dataset with higher spatial resolution.

Here, we use ensemble climate simulations over Minnesota with the Weather Research and Forecasting (WRF) model coupled to input from six CMIP6 global climate models (GCMs). With WRF, we compute downscaled versions of the comprehensive global climate projections for the 20-year periods 2040-2059, 2060-2079, and 2080-2099. We also perform model integrations over the historical period of 1995-2014 in order to assess any systematic model uncertainties.

These projections build on our previous results at 10-km resolution, but now we use a higher 4-km horizontal resolution over Minnesota nested in a 20-km grid over the contiguous USA and southern Canada with 38 vertical levels in the atmosphere and a sophisticated representation of the many lakes that exist in Minnesota.

Our final results will show a more detailed representation of the ongoing warming for individual counties in Minnesota in all seasons, especially in winter. We expect conditions near the end of the 21st century that are significantly different from current climate. Our results will influence regional decision-making related to agriculture, infrastructure, water resources, and other sectors.

B2/B3: CORDEX Interaction with Society

Evolution of Ozone above Togo during the 1979–2020 Period

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The objective of this paper is to estimate the trend of the Total Ozone Column (TOC) over Togo. A Multi-Sensor Reanalysis-2 (MSR-2) of the TOC over the entire territory of Togo was used. A Multiple Linear Regression (MLR) method has been applied to retrieve the interannual contributions of different forcings and the long-term variability. It was found that the Annual Oscillation (AnO), the Quasi Biennial Oscillation at 30 mb (QBO30), the Solar Flux (SF), and the El Niño–Southern Oscillation (ENSO) has a statistically significant influence on the interannual variability of the TOC. The strongest contribution (22 ± 1.4 DU) is allocated to the AnO while the weakest (<1 DU) is attributed to the Semi-Annual Oscillations (SAnO). Before the peak year of the Equivalent Effective Stratospheric Chlorine (EESC) in the tropics in 1997, the trend is negative (−0.3% ± 0.9% per decade) and is not statistically significant. After the peak year, a statistically significant positive trend is observed. The trend of the TOC is 0.6% ± 0.2% per decade. The monthly TOC trend over Togo is positive and statistically significant during the rainy season (particularly during the monsoon period) except in April, unlike during the harmattan period (DJF), where the trend is not significant.

Session C:

CORDEX for impacts

ORAL PRESENTATIONS

C1: Societal Impacts

Performance of CORDEX models in reproducing block-level meteorological droughts characteristics

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Monsoon rains in India are highly unpredictable and unevenly distributed both in space and time. This results in serious hydrological imbalances, leading to droughts. One-third of India's districts have experienced more than four droughts in the last decade, affecting 5 crore people each year. The gross domestic product was reduced by 2%–5% between 1998 and 2017 due to severe droughts in the country. Framing adaptation strategies for effective drought management requires timely determination of drought levels through systematic analysis under future climate scenarios. This study aimed to address the decadal changes in meteorological droughts during 2030–2080. Regional climate model outputs from the CORDEX domain were evaluated for their ability to reproduce drought indices—standardized precipitation index and standardized precipitation evapotranspiration index. A comparative analysis between the above two indices was performed for all 36 meteorological subdivisions across the Indian subcontinent. For future scenarios (Representative Concentration Pathway [RCP] 4.5 and RCP 8.5), six global climate models and two regional downscaling models were selected from the Coupled Model Intercomparison Project Phase 5 and CORDEX, respectively. Their bias correction was performed using gridded rainfall and temperature datasets from the India Meteorological Department using the quantile mapping technique. Finally, geospatial mapping was performed using ArcGIS for all blocks within the meteorological subdivisions. These block-level drought data will be useful to drought managers and policymakers for framing suitable adaptation and mitigation strategies and contingency planning.

C2: Natural Ecosystem Impacts

Climatic and Anthropogenic Vulnerabilities of the Himalayan Ecosystem

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Climate change is a reality which is influencing the different ecosystems globally. The Himalayan ecosystem is a biodiversity hotspot hosting nearly 3160 endemic plant species, many of which are medicinally important, along with 300 mammals, 980 bird species and numerous other insects and amphibians. Thus, it is essential to quantify the impacts of climate change in the biodiverse region to reduce and manage the expected losses under the projected climate change. This study aims to provide a detailed account of the recent (1980-2019) and projected (2025-2099) climatic vulnerability under the RCP 8.5 scenario, based on the novel metric Velocity of Climate Change (VoCC), for the biogeographic regions of the Himalayas and Trans-Himalayas. The study will utilize bioclimatic variables from the best available reanalysis datasets and a high-resolution regional earth system model, ROM, to enumerate the changes in the velocities of the multivariate climate space and their subsequent climatic vulnerabilities. ROM was simulated at a horizontal resolution of 0.22° over the CORDEX-South Asia region. Additionally, the study will present an account of the anthropogenic vulnerability for the study regions based on the human footprint index.

Keywords: Vulnerability, climate change, Himalayas, projection, RESM

Sessions C1/C2

POSTER PRESENTATIONS

C1/C2: CORDEX for impacts

Investigation of Uncertainties in Added values and Multi-variable Bias Adjustment of Drivers of Heat Stress

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Regional climate models are widely used to dynamically downscale the general circulation models output. Downscaled products, to some extent, provide a clearer understanding of surface-induced processes compared to the parent model. However, there are several uncertainties associated with downscaling. Some uncertainties are related to the structural differences in climate models, while some are related to the biases in global- and regional-climate models. Post-processing methods such as univariate bias correction are commonly used to reduce the bias in the simulated data. However, to obtain information on compound events, where multiple drivers play crucial roles in regulating the intensity of that event, a multi-variable bias adjustment is necessary to retain the intervariable dependence between the drivers. The present study focuses on one such Multi-variable Bias Adjustment method adopted from topography adjustment of surface-dependent surface air temperature and relative humidity, which are the drivers of heat stress. Multi-model ensemble of global- and regional-climate models for the present climate are used. The efficiency of the bias adjustment is evaluated by comparing before and after adjustment biases with high-resolution observed data. The topic of added value is a key aspect of the discussion surrounding downscaling. Added values of the regional climate model are also examined before and after bias adjustment using a quantitative metric. Added values show improvement in model simulations, especially in low-altitude regions. Overall, the bias adjustment shows improvement in the climate drivers over low-altitude urban regions, encouraging its application for risk assessment of heat stress.

C1/C2: CORDEX for impacts

Long-term Seasonal Characteristics of Particulate Matter Using CMIP6 Models under various SSP Scenarios Over the Indian Region

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Climate change negatively affects air quality, which can have a negative impact on health. Weather patterns aid in both increasing and disseminating air pollutants like ground-level ozone, fine particles, wildfire smoke, and dust. The presence of particulate matter (PM) in the atmosphere causes substantial dangers to human health and the environment. India confronts unique problems in understanding and managing air pollution due to its diversified topography, population density, and industrial activities. Surface particulate matter (PM2.5 and PM10) concentration distribution was analysed at annual and seasonal scales over the Indian region from 1980 to 2021 using Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) reanalysis.

To estimate PM concentrations over India, this work employs a multi-model ensemble from Couple Model Intercomparison Project Phase 6 (CMIP6), which includes state-of-the-art global climate models. The accuracy and dependability of CMIP6 models in capturing PM distribution patterns throughout different regions of India are examined by a systematic comparison against ground-based observations from multiple CPCB stations across India. Future projections using different socio-economic pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) were also studied to understand particulate matter concentrations in terms of magnitude and seasonal scale will play a critical role in air quality and human health conditions by the end of 2100.

Furthermore, the study investigates the fundamental mechanisms and drivers of PM generation and transport within the Indian subcontinent. It explores the impact of many factors on the geographical and temporal variability of PM concentrations, such as anthropogenic emissions, natural sources, meteorological conditions, and regional topography. The study also examines the effect of local emissions versus long-distance transportation in contributing to PM pollution in various locations of India. The study's findings have important implications for India's air quality management, public health, and policy development. The integration of CMIP6 models with observations provides a comprehensive framework for assessing current PM pollution levels, identifying hotspots, and assessing the efficiency of mitigation initiatives.

Keywords: Particulate matter, CMIP6, Socio-economic pathways, seasonal scale.

C1/C2: CORDEX for impacts

CORDEX RCMs, CMIP5 GCMs and CMIP6 GCMs: Reliable climate models for assessing the impact of climate change on wind-driven processes

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In climate change impact assessment studies, the adaption and mitigation strategies over a vulnerable region requires reliable climate model projections. Even though many climate model's projections are available, the degree of usefulness of this information is limited until the information on performance of climate models is available. Intuitively the RCMs are presumed to perform better than GCMs and widely used without proper evaluation of RCMs added value. The current study evaluated and ranked the 77 climate models (16 CORDEX RCMs, 28 CMIP5 GCMs and 33 CMIP6 GCMs) along with their respective mean ensemble models as per their skill in representing near-surface wind speed over South-Asian (SA, 11°S to 30°N and 26°E to 107°E) domain using devised relative score based approach. The climate model performance is assessed relative to fifth-generation European Research Agency data over daily, monthly, seasonal and annual scales using suitable statistical techniques for the historical period (1979-2005). It was noticed that the most of CORDEX RCMs' performance is subpar compared to GCMs and this poor skill is higher over the ocean than the land region of the SA domain. The majority of the top ten performing climate models in SA's ocean regions come from CMIP6 rather than CMIP5 GCMs, however the situation is reversed in the SA's land regions. The spatial bias-maps of poor and best performing climate models over diverse climate variable scales were analysed to identify the statistically significant bias regions. This rigours intercomparison of climate models will aid in the selection of an appropriate climate model for reliable estimation of the impact of climate change on wind-driven processes/sectors (offshore-onshore wind energy sector, ocean-wave climate, ocean renewable energy sector and evapotranspiration) and which implicitly reduces the model-based uncertainty.

C1/C2: CORDEX for impacts

Long-term Effects of Human Activities on Aquatic Ecosystems: Insights from Paleolimnological Reconstructions of Dal Lake, India

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Excess sediment inputs and increased primary production in aquatic environments are often linked to human activities and can have far-reaching consequences for water quality and ecosystem health. The intensification of agriculture and urbanization in recent decades has led to elevated nutrient and sediment inputs to water bodies, contributing to eutrophication and degradation of aquatic habitats. Lakes sediments have been used as a record of terrestrial environmental changes since they hold a diverse range of isotopic, chemical, and biological indicators that reflect alterations in past climates and environments. Our study examined changes in the accumulation rates and sources of organic matter in Dal Lake, Srinagar, J&K, India, over the past 134 years using paleo-production proxies, including TOC, OM, TN, C/N ratio, and $\delta^{13}C$, measured in an 86 cm sediment core dated with fallout ^{210}Pb and ^{137}Cs activities. The average TOC value was found to be between 23.9 to 4.8% with an average of 14.6%; OM was found to be between 41.2 to 8.3% with an average of 25.1%; TN was found to be between 2.4 to 0.3% with an average of 1.3%; C/N ratio ranged between 13.29 to 6.53% with an average of 10.82% and $\delta^{13}C$ values ranged from -18.7 to -26 ‰ with an average of -22.6‰. The results reveal that the organic material in Dal Lake sediment has various sources including agricultural runoff and sewage. The input of these sources has increased over the years, leading to the accumulation of sediment and intensified eutrophication. These findings have important implications for the management of urban environments and the mitigation of pollution and climate change impacts. To maintain the health of aquatic ecosystems and safeguard human health, it is critical to develop effective strategies for reducing nutrient and sediment inputs, such as improved land use practices, waste management, and pollution control measures. Overall, the study emphasizes the importance of using paleolimnological reconstructions to better understand the long-term effects of human activities on aquatic ecosystems.

Keywords: Lake sediments, Paleolimnology, Isotopic proxies, Pb^{210} dating, Organic matter

C1/C2: CORDEX for impacts

Monsoon Mayhem: Unraveling the modulating Impacts of Indian Summer Monsoon on Climate Change

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Climate Change: The Countdown to Catastrophe, is one of the most significant challenges faced by our planet today, with devastating impacts on our environment, economy, and society. This study aims to investigate the impact of the Indian Summer Monsoon (ISM) on the socio-economic conditions of the Indian subcontinent. The study employs the datasets provided by 11 models from the Sixth Phase of Coupled Model Intercomparison Project (CMIP6), to analyze the behaviour of the ISM and predict its future trends. Specifically, the study estimates alterations in precipitation, temperature, surface pressure, moisture flux, wind, and latent heat flux for both land and oceanic areas throughout the summer monsoon season under the high-emission scenarios (SSP2-4.5, SSP5-8.5) and three different time frames: historical (1981-2010), near future (2031-2060), and far future (2071-2100). The research concludes that the models have proved to be highly efficient in predicting future scenarios and that the ISM has a crucial impact on the socio-economic conditions of the Indian subcontinent. In addition, the study highlights that the changing pattern of latent heat flux (LHF) during the ISM season is strongly influenced by the greenhouse gas concentration scenarios, with higher emissions leading to increased LHF. The increase in LHF is associated with a rise in atmospheric moisture content and evaporation from the land surface. The near- future scenario (2031-2060) shows a smaller increase (5-15 W/m2) in LHF, while the far- future scenario (2071-2100) demonstrates a higher increment (20-35 W/m2) over the oceanic region, indicating that the impact of climate change will intensify over time. These findings suggest that appropriate adaptation measures need to be implemented to mitigate the potential impacts of climate change. The use of CMIP6 data can support the development of these strategies by providing reliable projections of future climate scenarios and enabling further research on the drivers of climate change and their interactions with the Earth system.

Keywords: Climate Change, Indian Summer Monsoon, CMIP6, High-emission scenarios, Latent Heat Flux.

C1/C2: CORDEX for impacts

Rice (Oryza sativa) yield response to changing weather conditions using CERES-Rice Model

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The sensitivity analysis of the CERES Rice model v4.7.5 of the DSSAT modeling system was used to analyze the effect of changes in meteorological conditions on the yield of Basmati 385 and Pusa-44 farmed under the system of rice intensification (SRI) in Prayagraj, irrigation projects of India. The genetic coefficients were calculated using experimental data from 2019. The model was tested using rice growth and development data from the crop years 2020, 2021, and 2022. Daily maximum and minimum temperatures, precipitation, and weather station data were collected from each irrigation scheme's weather station, and daily solar radiation was generated using a weatherman in the DSSAT shell on the farms of two SRI farmers who were chosen at random from each irrigation scheme. According to the findings, increasing both maximum and minimum temperatures has an effect on Basmati 385 and Pusa-44 grain production under SRI. The rise in ambient CO_2 concentration resulted in an increase in grain yield for both Basmati and Pusa-44. The increase in solar radiation also had an increasing influence on the grain yields of Basmati 385 and Pusa-44. The study's findings indicate that weather factors in India's Prayagraj area impact rice output under SRI and should be taken into account to promote food security.

C1/C2: CORDEX for impacts

Heatwave analysis using CORDEX models in selected districts of India

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In a recent study, the Intergovernmental Panel on Climate Change reported an increase in the global temperature by 1.1°C above pre-industrial levels, with human activities being the main cause of this temperature increase. Rising temperatures can cause heatwaves to become more frequent and severe, leading to an increased risk of heat-related illnesses and deaths, particularly among vulnerable populations. Because several Indian regions witnessed summer temperatures over 45°C in recent years, it is crucial to understand the expected heatwave patterns. This study analysed historical and projected heatwave scenarios under Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 in the near term (2021–2050). Daily gridded data for the study period by the India Meteorological Department were used, and 10 global climate model ensembles from the CORDEX domain were used to determine projected changes. Overall, 42 districts in India that are more prone to heatwaves were considered to evaluate heatwave patterns and severe heatwave events, as well as their related changes during March and July.

The analysis indicated an increase in severe heatwave events in the future. Further, in the future scenarios, under both RCPs, maximum severe heatwave occurrences were expected to rise by 26% in northern districts such as Ludhiana and Hisar, which has already been observed. Similar increases under RCP 4.5 and RCP 8.5 were observed in southern districts such as Kumuram Bheem Asifabad and Suryapet. These study findings will aid in determining factors affecting sensitivity and resilience and help build strategies to lessen or adapt to the effects of heatwaves.

C1/C2: CORDEX for impacts

Long term regional changes in land surface temperature over an urban city, Uttarakhand

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The present study aims to estimate long term regional changes for the Dehradun district of Uttarakhand from 1995 to 2020. The five-year interval 1995, 2000, 2005, 2010, 2015, and 2020 were considered in regional analysis. Land dynamics and metrological parameters are analysed using remote sensing and GIS tools. The multi temporal images were taken from Land Remote Sensing Satellite System (LANDSAT) satellite (5,7 and 8). The categorization of images is done using supervised classification and LULC maps are formed the extraction of Land surface Temperature (LST) is also carried out using different mathematical calculations. Relative humidity, rainfall, wind speed was assessed for the same period. The results depict a 9.00% loss in thick vegetation and a 2.32% gain in built-up area for recent Landsat data, which may be related to the growth of urbanisation and industrialisation over the course of 25 years. A significant gain in built up, huge loss in vegetation is found with change in different meteorological parameters. Future development initiatives in the studied area may benefit greatly from this study's recommendations.

Keywords: Land use, Land cover, LANDSAT Satellite, Land surface temperature Remote sensing, Supervised classification.

C1/C2: CORDEX for impacts

Utilizing Coal Combustion Bottom Ash Residues for Eco-Friendly Production of Iron Oxide Nanoparticles and Their Prospective Application in “Sustainable Agriculture"

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Green nanotechnology has emerged as a crucial tool in addressing climate change challenges. It has been instrumental in the development of green energy sources, such as solar cells, fuel cells, and energy storage devices, which can lead to a significant reduction in carbon emissions. Iron oxide nanoparticles synthesized through the green synthesis method using bottom ash waste have been found to be effective catalysts for the production of hydrogen gas from water, mineral carbonation, and photocatalysis of greenhouse gases. This study aims to explore the potential of utilizing bottom ash residues generated from coal combustion as a sustainable source for the green synthesis of iron oxide nanoparticles. The synthesized nanoparticles were characterized using various analytical techniques, and the results indicated that they were successfully synthesized with a narrow size distribution and good crystallinity.
Furthermore, this study investigated the potential application of these nanoparticles in sustainable agriculture by assessing their effects on seed germination, plant growth, and soil quality parameters. The results showed that the application of iron oxide nanoparticles enhanced seed germination, plant growth, and soil quality parameters. This research presents a sustainable and eco-friendly approach for the production of iron oxide nanoparticles using coal combustion bottom ash residues, with promising applications in sustainable agriculture. By utilizing these applications, iron oxide nanoparticles can contribute to reducing the carbon footprint and overall impact of human activities on the environment, thus playing an important role in addressing climate change.

Keywords: Nanotechnology, Bottom ash, Green Synthesis, iron oxide particles, climate change.

C1/C2: CORDEX for impacts

Impacts of LULC and climate variability on Evapotranspiration, an important agricultural aspect

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Land use and land cover changes (LULC) are one of the important hydrologically significant modifications of the Earth's land surface. Due to climate change land surface-ecological interaction becomes critical environmental factor, so its strategies provide scenario at regionally and globally to understand this interaction. Evapotranspiration (ET) becomes important for different agro-meteorological studies. This study examined estimated ET changes by combining LUCC and climate data in cropping and non-cropping seasons. Study region lies over the Ranchi, Jharkhand India. The study region lies entirely in humid subtropical monsoon area, with hot summers and cold winters, and climate ranges from dry semi humid to humid semi-arid types (Lat. 23°26', long. 85°19', Elev. 609 MSL). It is in the eastern part of India where 'Monsoon Trough' is more dynamic and this is due to local and synoptic variations like heating effect of Plateau and the moisture incursion from the Bay of Bengal. Cropping season starts with sowing in mid-November and harvesting in March. LULC prepared from 2007 to 2020 for each year shows croplands, built-up & water bodies in the region. Results shows that agriculture land decreases from 196.20 to 163.95sq km, built-up land increased from 13.32 to 22.85sq km and water bodies decreased from 4.20 to 2.65sq km from 2007 to 2020. MODIS data products (MOD16A2) are taken for cropping and non-cropping season. The meteorological parameters wind speed (V), temperature (T), bright sunshine hour (BSS), rainfall (R) taken from IMD. The trends of climatic factors including T, V, BSS, and relative humidity (RH) were determined, among these climatic factors, BSS and V had the greatest influence on ET. There is 1% decrease in ET over the years. The reduction in agriculture has much greater effects on ET than change by other land cover types, as cropland decreases over the years ET also decreases in some years but in some year, area is less but ET is more as seasonal rainfall is more than normal. At cropping period there is very less impact due to T, but rainfall, BSS, V from month November to March. In non-cropping season ET is less affected by decreased agriculture area but affected by BSS, T in April, and May. Hence this study checks the LULC and ET have significant or insignificant correlation depending on geomorphological and climatic characteristic of a research area.

C1/C2: CORDEX for impacts

Quantifying the Impact of Climate Change Scenarios from CMIP5 Downscaled Models on Future Summer Rice Production in the New Alluvial Zones of West Bengal: An Assessment using ORYZA 2000

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Rice being the most significant cereal crop grown and produce in the state of West Bengal, India may face serious threat due to increased warming and elevated greenhouse gas concentration. So there are great challenges for the agro meteorologists to estimate future potential yield and future yield gap scenarios of rice at local scale under different RCPs scenarios of CMIP5. ORYZA 2000 was calibrated and validated over New Alluvial zone of West Bengal to predict future potential yield and quantify the future yield-gap variability of *Boro*-rice for three period i.e 2021–2040, 2041–60 and 2061–2080 with respect to baseline period of 1971-2000 over New Alluvial Zone (NAZ). The model showed adequate skill to reproduce observed yield variability with a high R^2 value (85.6) and comparatively less errors by 498.4, 52.8 and 0.716 estimated by the three error indices of RMSE, NRMSE, and NSE respectively. It is interesting to note that the future crop growth period would be reduced by 2-8 days for RCP4.5 and 2-11 days for RCP 8.5 compared to its normal growing period of 116-121 days. Under future elevated CO_2 level future biomass and potential yield showed a noticeable positive effect across all districts. Future potential yield is projected to be declined by 7.5-35.2%, 14.5-42.3% and 19.2-40.6% during early, mid and late 21st century as per RCP 4.5 scenarios. However the reduction is more in case of RCP 8.5 scenarios (9.7–57.7%) compared to RCP 4.5 (15.8–42.3%). Combined impact of elevated CO_2 and increased temperature indicates a slower rate decrease of yield loss for both the RCPs (1.1 to 26.6% under RCP 4.5 and from 3.6 to 26.9% under RCP 8.5) because CO_2 fertilization is somewhat offset the yield drop compared only temperature effect irrespective all six the districts of NAZ of West Bengal state.

Session D:

CORDEX in Practice

ORAL PRESENTATIONS

D8: Extreme Events: Observations and Modeling

A Retrospective Analysis of Tropical Cyclones Approaching CORDEX East Asia over the Past 75 Years

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This study investigated the characteristics of tropical cyclones (TCs) approaching CORDEX East Asian countries over a span of 75 years. By dividing the time period into two distinct periods—earlier years (prior to 1975) and recent years (after 1990)—the analysis revealed intriguing insights. Notably, the annual frequency of TCs was found to be higher in the recent years compared to the earlier years. Preliminary findings provided valuable observations on the behavior of TCs in recent years. It was noticed that TCs took relatively less time to reach land and had shorter durations over land when compared to those in the earlier years. Additionally, TCs in recent years exhibited stronger wind intensities and considerably lower pressures at the time of landfall, distinguishing them from the patterns observed in the earlier years. The analysis suggested that various factors contributed to the increased strength of recent TCs. Specifically, higher sea surface temperatures, weaker vertical wind shears, and a greater concentration of moisture around the centers of these TCs were identified as influential factors. These findings contribute to an improved understanding of the changing characteristics of TCs approaching East Asian countries. They emphasize the significance of climate variations, which have influenced the behavior and intensity of these tropical cyclones over the examined time frame.

Keywords: Tropical Cyclone, Extreme Event, CORDEX East Asia

D8: Extreme Events: Observations and Modeling

CO_2 surface flux estimation using ensemble based Kalman Filter approach (LETKF)

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CO_2 is a major greenhouse gas which contributes a significant fraction of the global temperature rise. Therefore estimation of CO_2 flux is extremely crucial to understand the global carbon cycle and its impact on climate change. CO_2 emission by source and removal by sink using top-down and bottom-up approach is highly uncertain due to quality observations and model transport bias. In recent years, Local Ensemble Transform Kalman Filter (LETKF) has emerged as a promising data assimilation technique for accurately estimating CO_2 fluxes from atmospheric observations. In this study, we used LETKF to estimate surface CO_2 flux. An atmospheric general circulation based chemistry transport model (MIROC4-ACTM) is used as a forward transport model. We conducted various observation system simulation experiments (OSSEs) to check the skill of the setup. Impacts of various control parameters towards convergence of the filter such as no. of ensembles, initial perturbation, observation uncertainty, correlation length, assimilation window, inflation method etc. are studied in detail.
Results obtained from these experiments have significant implications towards our next step of assimilating actual in-situ CO_2 and columnar CO_2 from satellite (XCO_2) measurement to produce more realistic CO_2 flux.

D8: Extreme Events: Observations and Modeling

Cyclone Mocha: Analyzing Impacts and Advancing Predictive Capabilities for Coastal Resilience

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Cyclone Mocha, an extremely severe cyclonic storm, struck the Bay of Bengal, causing significant devastation along the Myanmar coast and parts of Bangladesh. However, there were discrepancies in reported wind speeds, with IMD and NOAA SAR. The instrument of satellite synthetic aperture radar (SAR) measured a peak wind of 280 km/h at 23:57 UTC, May 13, which was the basis for the 281 km/h peak winds assigned by JTWC in their 0000 UTC May 14 advisory. According to IMD, Mocha achieved higher intensity at 2100 UTC May 13, with 225 km/h winds (3-minute average) and a central pressure of 931 hPa. Additionally, the prediction of storm surge heights varied widely, with JTWC forecasting over 20 m while no surge was reported in the Bangladesh region. The study focuses on addressing the challenges faced in predicting cyclones in this vulnerable region. The occurrence of Cyclone Mocha revealed several issues in cyclone prediction, including wind speed discrepancies, uncertainties in numerical models regarding landfall time and location, and inconsistent storm surge projections. The presence of open-source model outputs exacerbates panic within communities. It is crucial to minimize such panic and enhance prediction accuracy to improve coastal resilience. This study aims to analyze the impacts of Cyclone Mocha and advance the predictive capabilities for future cyclones in the Bay of Bengal. The objectives include assessing the accuracy of wind speed measurements, reducing uncertainties in numerical models, refining storm surge projections, and fostering consensus and collaboration among relevant organizations. The study utilizes numerical models and conducts sensitivity tests to simulate Cyclone Mocha. Large-scale synoptic analyses are performed to diagnose the cyclone from its inception to the landfall stage. These approaches provide insights into the event and its characteristics. The discrepancies in reported wind speeds highlight the need for standardized measurement techniques in cyclone monitoring. The uncertainties in numerical models emphasize the necessity of improving forecasting techniques for landfall time, location, and intensity. The varying storm surge projections underscore the importance of enhanced storm surge modeling and validation methods. Notably, the absence of a reported storm surge in the Bangladesh region necessitates a better understanding of local coastal dynamics. The study of Cyclone Mocha reveals both challenges and opportunities in improving cyclone predictions in the Bay of Bengal. Achieving consensus among National Meteorological Centres, allied organizations, academia, research institutes, and public and private industries nationally and internationally is vital for enhancing predictive capabilities. Standardizing measurement techniques, improving numerical modeling, refining storm surge projections, and considering local coastal dynamics are essential steps toward minimizing panic in communities and ensuring accurate predictions for future cyclonic events.

Keywords: Bay of Bengal, wind speed discrepancies, numerical models, synoptic analyses, collaboration

D8: Extreme Events: Observations and Modeling

Adequacy of ROM, a RESM, in capturing the precipitation extremes in Himachal Pradesh, India

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This study aimed to evaluate the Regional Earth System Model ROM's ability to capture extreme precipitation events in Himachal Pradesh, India, given the region's susceptibility to such events due to its complex topography and altitude-dependent climate. For the extreme study, total precipitation data of ROM at two horizontal resolutions of 0.22°x0.22° and 0.11°x0.11° for the period 1980-2017 was used. The model was simulated over the CORDEX-SA domain using forcing from ERA-Interim reanalysis. Indices considered in this study are consecutive dry days (CDD), consecutive wet days (CWD), and 95^{th} percentile and 99^{th} percentile precipitation for all four seasons. The results were compared with observations i.e., IMD and MSWEP precipitation data. ROM showed a good correlation (0.6) with IMD, highlighting its adequacy. ROM showed high skills in capturing the CDD and CWD indices however, precipitation extremes (95^{th} and 99^{th} percentile) showed noticeable differences. A more detailed analysis is going on and will be presented during the conference to highlight the robustness of the model. This study will assist in projecting the precipitation's extreme intensity and frequency in future under warming scenarios. Extreme precipitation projection will also aid the stakeholders in planning agriculture and water resource management in advance and in a sustainable manner.

D8: Extreme Events: Observations and Modeling

Machine learning based lightning prediction over Eastern India

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Lightning is one of the severe atmospheric phenomena posing serious threats to human life and property. However, the limited availability of lightning data especially over the Indian Sub-continent is a major constraint for lightning study. Hence, the development of proxy lightning data from other atmospheric variables is very important for both analysis and prediction purposes. The present study has been undertaken to assess the relative importance of various dynamic–thermodynamic factors in controlling lightning variability over Eastern India, one of the lightning-prone zones of India. Combined (LIS+ OTD) flash rate density (FRD) data obtained from Tropical Rainfall Measuring Mission (TRMM) available during 1995-2014 has been used in this study. Dynamic–thermodynamic variables have been procured from ERA5 re-analysis data. TRMM flash rate data has indicated east-west gradient lightning activity with maximum FRD taking place over eastern parts. Monthly variations have revealed peak lightning occurring mainly during pre-monsoon and monsoon seasons over the study area. Four machine learning (ML) models namely support vector machine (SVM), random forest (RF), gradient boosting machine (GBM), and artificial neural network (ANN) have been utilized for lightning prediction from ERA5 reanalysis predictors. Both calibration and validation results based on ML models have shown high agreement with the observed lightning variability over this region. A comparative analysis has been performed between results from ERA5 and CMIP6 predictors before the projection of future lightning scenarios.

Keywords: Lightning, Machine Learning, TRMM, ERA5, CMIP6, Eastern India

D8: Extreme Events: Observations and Modeling

A study of soil water dynamics in extremely dry and wet rainfall conditions over the core monsoon zone of India.

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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

D8: Extreme Events: Observations and Modeling

Assessment of extreme rainfall events over the Indian subcontinent during the historical and future projection periods based on CMIP6 simulations

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The impact of climatic change on Summer Monsoon Rainfall is studied to understand the Rainfall pattern towards the end of the century utilising Coupled Model Intercomparison Project, Phase 6 (CMIP6) released by the World Climate Research Programme (WCRP). The analysis of model simulations from CMIP6 was carried out using 64 years of the historical period (1951-2014) and future projections till the end of the century (2015-2100). The models are compared with observational data from the APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation) daily rainfall data. The analysis revealed that most of the models show an overestimation of rainfall in the annual cycle of rainfall in the historical period; however, a few of them underestimate the rainfall. The majority of them capture the onset signal of the summer monsoon in early June, along with a good seasonality in the daily rainfall climatology. The simulations that are coherent with the observational data sets are selected on the basis of the Taylor diagram for future projections in the four scenarios, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. They are available from the model outputs of EC-Earth3- Veg-LR, INM-CM4-8, INM-CM5-0, MIROC-ES2L and MPI-ESM1-2-HR. The selected models exhibit far greater agreement among the 30 models when it comes to the features of rainfall during the summer monsoon. We have given more emphasis on summer monsoon rainfall in the historical and future projection periods since the trends of rainfall are becoming more chaotic reported in observational studies. Over the Indian subcontinent, all of the chosen scenarios show an increased frequency of intense rainfall events with varying decadal and multidecadal features. Central India and west coastal belts are showing positive trends in extreme rainfall events towards the end of the century.

D8: Extreme Events: Observations and Modeling

Frequency of extremes precipitation is projected to increase during the 21st century over Indian River Basins (IRBs)

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Indian River Basins (IRBs) contribute to the large hydrology of South Asia. The risk of Hydro climate extremes such as floods and drought increases globally due to climate change, which amounts to economic losses in IRBs. This study projected the changes in hydroclimate extremes over the IRBs. To this end, the research is based on the observed data from India Meteorological Department (IMD) and the 13 bias-corrected models from Coupled Model Intercomparison Project Phase 6 (CMIP6) based on new Shared Socioeconomic Pathways (SSPs) scenarios. The study applied the Multi-Model Ensemble (MME) approach for the near (2015-2040), mid (2041-2070), and far (2071-2099) future to examine the changes in hydroclimate extremes over the IRBs. The study finds that the mean annual precipitation in the IRBs increases during mid of the 21st century. Under the low emission scenarios SSP1-2.6, the frequency of extremity will increase significantly in the western ghats and northeast Indian river basins, that indicate the lower emission of aerosols and greenhouse gases may increase the risk of flood disaster in the future over the IRBs. However, the Indus River basin shows a declining trend in precipitation. In low to high-emission scenarios, the projected 5-day precipitation extremes are intensive over the western river basins and upper Ganga basin. In contrast, to mean precipitation, there is a consistent increase in precipitation intensity on wet days over the central and western river basins of India. The results reveal that India's northern central and western river basins may experience heavy rainfall in the near future due to future warming climate. This study provides a timely updated finding about future floods and droughts in the IRBs based on more accurate climate projections and ground-based observations.

Keywords: Hydro climate extremes, Flood, Drought, Indian River Basins (IRBs), CMIP6

Session D8

POSTER PRESENTATIONS

D8: Extreme Events: Observations and Modeling

Quantifying current and extreme precipitation events in Nepal to inform hydropower stakeholders

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Bridging the gap between climate model datasets and their application for guiding climate change adaptation decisions remains challenging, particularly in high mountain regions with complex topography and limited observations for robust model validation. To overcome these challenges and meet the decision needs of hydropower stakeholders in Nepal, the Climate Analysis for Risk Information and Services in South Asia (CARISSA) project under the Asia Regional Resilience to a Changing Climate (ARRCC) programme, supported a collaborative project that promoted dialogue and innovation in the use of multi-model datasets, including from CORDEX South Asia.

Initial consultations with key hydropower stakeholders identified a need to better understand the risk of current and future extreme precipitation events during the monsoon season. Here we present new analysis of a best-estimate of present day precipitation extremes during the monsoon season in Nepal through combining multiple observational datasets. A set of representative scenarios of projected changes in precipitation extremes were created from a process-based evaluation of available climate model simulations from CMIP5 and CORDEX South Asia. These were used to communicate plausible futures with key stakeholders through workshops, interactive dialogue, participatory games and co-developed climate risk narratives. This range of methods helped scientists to communicate key messages, discuss the benefits and limitations of climate data, and inform tailored outputs that can support policy and planning at national and basin levels.

D8: Extreme Events: Observations and Modeling

Greenhouse forcing and its amplification mechanisms on Africa's hot days and nights

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The contributions of greenhouse forcing to amplified hot days and nights when temperatures exceed the 90th percentile (TX90p and TN90p) across Africa were accessed. TX90p and TN90p have significantly increased during the historical period (1960 and 2014), with an increase of 0.3% and 0.4%, respectively. Our result shows that the observed increasing trend in TX90p and TN90p across Africa is due to GHG forcing, mainly carbon dioxide (CO_2) forcing, which has led to an increase of about 0.2%/year and 0.3%/year, respectively. The shared socioeconomic pathways (SSP) emission scenarios demonstrate a projected increase of approximately 22%, 45%, 65%, and 70% in TX90p. In comparison, TN90p indicates a projected increase of 27%, 55%, 75%, and 80% under the low, intermediate, high, and very high GHG emissions scenarios, respectively. The observed increase in TX90p and TN90p is controlled by the decrease in total cloud cover and surface warming caused by GHG. A strong increasing trend of about 0.4 w/m2 in surface downwelling longwave radiation is detected over SAH higher than in other regions. Increasing warming leads to significantly enhanced longwave radiative forcing and reduced total cloud cover across Africa. An increasing trend in latent heat flux is seen across Africa since latent heating cools the surface by eliminating heat as water evaporates, which helps to limit the rise in surface temperature mainly during the day. The cooling effect of latent heating may be overpowered by heat buildup during the night, increasing TN90p. A decrease in sensible heat flux across Africa leads to less heat being transported between the surface and the atmosphere, which enables the surface to warm up more during the day.

D8: Extreme Events: Observations and Modeling

Optimization and evaluation of the Weather Research and Forecasting (WRF) model for wind energy resource assessment and mapping in Iran

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The main purpose of this study is to optimize the Weather Research and Forecasting (WRF) model regarding the choice of the best planetary boundary layer (PBL) physical schemes and to evaluate its performance for wind energy assessment and mapping in Iran. For this purpose, five PBL and surface layer parameterization schemes were tested and their performance was evaluated via comparison with observational wind data. Then the model was run for seventeen years (2004-2020) in order to assess the model's ability to estimate the wind energy production in Iran. Although WRF model is a regional and short-term model, it was run for 3 tears by supercomputers in ASMERC. It was also found that the WRF model errors depend on the horizontal resolution of the terrain data used and that WRF performance is weaker in simulating wind speeds below 3 ms^{-1} and above 10 ms^{-1}. Overall, by comparing WRF simulations with wind observations in Iranian areas where wind farms are currently in operation, it is concluded that WRF enables to provide accurate and reliable wind speed and direction data for realistic wind energy assessment studies in Iran.

Keywords WRF Model; Planetary boundary layer; Wind resource assessment; Iran

D8: Extreme Events: Observations and Modeling

Impact of North Tropical Atlantic on South Asian Summer Monsoon Variability

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The North Tropical Atlantic Sea Surface Temperature (NTA SST) anomalies, a key contributor to El Niño Southern Oscillation (ENSO) variability, have gathered 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 boreal spring NTA SST variability on the large-scale circulation and precipitation patterns over the Indian Summer Monsoon (ISM) region. The suite of observational and coupled model-based analysis provide a hypothesis for the association between NTA and ISM as intervened by ENSO variability. These process-based studies can be applied to the latest CMIP6 historical simulations so as to identify the best performing global coupled models to make future projections. The insights as gained from this study may also provide an important direction in downscaling CMIP6 data products over South Asian domain following the CORDEX protocol.

D8: Extreme Events: Observations and Modeling

Exploring the Vertical Moist Thermodynamic Characteristics of the Extreme Rainfall Events over Monsoon Core Region

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India receives the maximum rainfall (>80%) during the Indian Summer Monsoon (ISM) which arrives in June and withdraws in September. Central Indian Region (CIR), which lies in the core monsoon zone, is susceptible to the Extreme rainfall events (EREs), which significantly affects the rainfed agriculture and ultimately the economy of the region. On the other hand, EREs are one of the major consequences of the warming climatic conditions because it alters the hydrological cycle due to the moistening of the atmospheric column. Increased water holding capacity of the atmosphere and the greater instability leads to the advent of EREs, which are becoming more frequent and intense over CIR. A little attention has been paid to addressing the vertical moist thermodynamics of EREs. Apart from the moisture transport, the vertical atmospheric profile is also essential for understanding the development and occurrence of EREs. Therefore this study seeks to investigate the evolution of dynamic and moist thermodynamic characteristics of the vertical atmosphere, preceding the EREs over CIR, using ECMWF global reanalysis (ERA5) and INSAT-3D atmospheric sounding datasets. From the study, it is noticed that a strong warming in the middle troposphere and cooling in the lower troposphere is associated with the extreme days. At the same time, prior to EREs, higher water vapor accumulation is seen from the surface to the middle troposphere. In addition, the major ingredients of EREs including deep moist convection and higher buoyant instability, which occur when the moisture content is substantially higher, thus enabling dynamic lifting leading to extreme rainfall are observed over the CIR. Detailed results will be presented in the conference.

Keywords: Moist Thermodynamics, Indian Summer Monsoon Extremes

D8: Extreme Events: Observations and Modeling

Future changes in the potential intensity of tropical cyclone over the North Indian Ocean in response to the thermal structure of the atmosphere and the Ocean in CMIP6 models

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It is well established that the intensity of Severe Cyclonic Storms over the North Indian Ocean has increased in recent decades in response to the changes in the thermal structure of the atmosphere as well as Ocean. Due to rapid urbanisation of the coastal cities, more and more people are getting exposed to these changes. Life and livelihood of indigenous people living along India's vast coastal regions are more vulnerable to these changes. It is imperative to understand how tropical cyclone activity is affected by the changing climate so that policy-makers are able to develop appropriate strategies for mitigation. CMIP6 dataset offers a unique opportunity in assessing the projected tropical-cyclone activity in the North Indian Ocean by analysing various dynamical and thermodynamic factors to understand the projected variability in the thermal structure of atmosphere and Ocean in contributing to the changes in the cyclogenesis over NIO. Different variants of genesis potential index and storm identification and tracking schemes will be applied on historical simulations and then compared with re-analysis and actual storms track to identify the best models. Then the ensemble mean prepared using the best participating models will be examined to detect the future changes in comparison to the historical reference period.

D8: Extreme Events: Observations and Modeling

Evaluation of Monsoon Precipitation Extremes in WRF-based Dynamically Downscaled Reanalysis over the Indian Himalayas

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The Himalayan region is characterized by its prominent topographic diversity and substantial variation in regional climate patterns, rendering it particularly vulnerable to the ramifications of extreme precipitation events (EPEs), such as flash floods, river flooding, cloudbursts and infrastructural damages during the Indian summer monsoon (ISM). An accurate understanding of these extremes is crucial for effective climate adaptation and water resource management strategies. However, due to the complex topography and limited observational data, investigating precipitation extremes in the Himalayas remains challenging. Hence, high-resolution data is necessary to better represent EPE characteristics over the Himalayas and comprehend the mechanisms triggering localized natural disasters. This study investigates precipitation extremes using WRF-based dynamically downscaled reanalysis data, which provides high-resolution information over the Himalayan region. It is generated by dynamically downscaling global ERA5 reanalysis data using the WRF model. Here, we focus on examining the spatiotemporal patterns, frequency, and intensity of EPEs and their associated atmospheric dynamics. Preliminary results indicate that EPEs exhibit significant spatial heterogeneity across the Himalayas, with higher frequencies and intensities observed in certain subregions. The analysis also reveals the importance of both local-scale convective processes and large-scale synoptic systems, such as monsoon dynamics and orographic effects, in driving precipitation extremes. Furthermore, this study aims to explore the dynamic and thermodynamic processes associated with EPEs in the study region. Finally, our research seeks to provide scientific insights into the potential impacts of climate change on extreme events, thus contributing to effective disaster mitigation strategies in the Himalayan region. Detailed results of precipitation extremes over the Himalayas, and mechanisms altering the atmospheric conditions attributed to the EPEs will be discussed.

Keywords: Himalayas, HAR-V2 reanalysis, Extreme Precipitation Events

D8: Extreme Events: Observations and Modeling

Unveiling the Distinguishing Features of Normal and Extreme Cold Wave Events in North India

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Cold waves, characterized by extreme winter weather, are prevalent during the boreal winter season (November to February). The north Indian region experiences recurrent cold wave events, some of which exhibit high intensity, resulting in significant implications such as adverse effects on human health and increased mortality rates. This study aims to discern the distinguishing features of both normal and extreme cold wave events in north India and elucidate their interrelationships on a larger scale. Our analysis reveals that normal cold wave events are primarily driven by the Siberian high-pressure system, whereas extreme cold wave events are influenced by both the Siberian high-pressure system and the Arctic. Notably, the escalating Arctic warming has the potential to induce blocking conditions over the Urals through the meandering of the jet stream, consequently generating extreme cold conditions in north India. Collectively, these findings provide valuable insights into the intricate connections between climatic factors, shedding light on the dynamics underlying normal and extreme cold wave events in the north Indian region.

Keywords: normal and intense cold wave, Siberian High, Arctic warming, Ural blocking

D8: Extreme Events: Observations and Modeling

Sensitivity analysis of physics parameterization schemes for Western Disturbances over the Indian region: A high-resolution WRF model study

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The northwestern region of India experiences heavy precipitation, primarily during the winter season due to low-pressure synoptic weather systems known as Western Disturbances (WDs). These WDs cause heavy rain, cold waves, and fog in northern India, which disrupt daily life. This study aims to set up a numerical mesoscale model, i.e., the Weather Research and Forecasting (WRF) over the Himalayan region and investigating the dynamics and thermodynamics of WDs. Sensitivity experiments were performed using available physics options in the WRF model to find the best setup for precipitation related to observation. Three WD cases, 21–23 January 2019, 7–10 February 2019, and 27–29 January 2020, which affected northwest India, have been simulated with the WRF model. The National Centers for Environmental Prediction FNL (Final) Operational Global Analysis 1-degree by 1-degree gridded data was used to prepare the model's initial and boundary conditions every six hours. The results obtained show that the performance of the combination of the Thompson microphysics scheme, Kain–Fritsch cumulus scheme, Yonsei University planetary boundary layer, rapid radiative transfer model longwave radiation, and Dudhia shortwave radiation schemes gave a better simulation of the precipitation for the sensitivity experiments performed in the study. Also, the model was good enough to capture large-scale systems like the Subtropical Westerly Jet Streams, which transport moisture from the Mediterranean, Caspian, and Black Sea to the northern parts of the Indian subcontinent. Detailed results will be discussed further during the poster presentation.

Keywords: Western Disturbance, WRF, sensitivity analysis, parametrization schemes

D8: Extreme Events: Observations and Modeling

Evaluating complexity of the soil moisture - rainfall relation over core monsoon zone of India

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Over the last few decades hydro-meteorological extremes have increased in frequency, intensity and duration. 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 (SM) response to persistence and intensity of rain spells. We implement information-theoretic approach along with the conventional statistical analysis to explore the general association between SM and rainfall variability. We specifically consider the two recent cases of contrasting monsoon seasons, i.e. the year 2015 (deficit) and 2019 (excess) for the analysis. Chaotic degree, that characterizes uncertainty / irregularity of the underlying time series, clearly show increasing (decreasing) trend in the rainfall anomalies during 2015 (2019). SM anomalies on the other hand exhibit decreasing trend during excess (2019) year, consistent with the rainfall anomalies. It however shows no average trend during the deficit (2015) year – a typical characteristic of complexity. This hints towards the important role of SM memory during deficit (2015) year and also indicate the increasing interactivity of the SM with land surface processes. Since atmospheric forcing is the primary driver of SM variability, the outcomes suggest that distinct regional atmospheric forcing may be responsible for these two contrasting years.

Keywords: rainfall extremes, soil moisture, chaotic degree, soil moisture memory.

D8: Extreme Events: Observations and Modeling

Assessment of WRF Model in Simulating Heat Wave Events over India

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There has been great challenge to better understand how severe heat waves in the Indian continents are growing and are affecting the global climate. The North West (NW) and South East (SE) parts of India experiences high temperature and extreme Heat Wave (HW) during summer. In present study, the episodic HW events of 2015 and 2016 over Indian regions have been simulated using Weather Research and Forecasting (WRF) model. Simulations are carried out over three sub-domains of Indian region with varied horizontal resolutions of 27km (d01), 9km (d02) and 9km (d03). Six experiments (Exp1- Exp6) with different combination of physical parameterization schemes were performed using WRF model. The modelled Tmax obtained using different combination of parameterization schemes in WRF is compared with observations from India Meteorological Department (IMD) datasets across the entire India (d01), NW (d02) and SE (d03) domains during HW period of 2015. The model results indicate an overestimation of Tmax by +1°C to +2°C. This suggests that the regional temperature is influenced by the location and the complex orography. Overall, the statistical analysis (correlation, RMSE, FB) results reveal that best performance is achieved with Exp2 which is the combination of WSM6 microphysics (MP) together with radiation parameterization CAM, Yonsei (PBL), NOAH land surface and Grell-3D convective schemes. Moreover, to understand the dynamics of rising HW intensity, two case studies of HW days i.e. (22^{nd}-30^{th} May, 2015) and (14^{th}-23^{rd} May 2016) along with influencing parameters like Tmax, RH and prevailing wind distribution have been analysed over India. Model simulated multiday Tmax during 2015 HW event reaches up to 44°C in NW and SE part of India which reveal that it is the combination of the both temperature and RH that created a rare and deadly event during 2015. Strong El Nino effects, anthropogenic climate change, etc. might be possible causes of the temperature rise on those days. In 2016, HW is more prevailing towards NW while in SE region temperature range around 34-38°C but high RH (60%-85%) is likely one of the dominating factors giving rise to HW phenomena. The comparative research made it abundantly evident that these episodic events were unique in terms of duration, intensity and geographical spread which can be used to assess WRF performance and extreme HW events for future projections and to comprehend the scenario of extreme weather occurrences.

Keywords: WRF, Extreme temperature, Heat Wave, Relative Humidity, regional model