ABSTRACTS

National Symposium on

Understanding the Science of Heatwaves under the Warming Scenario and Challenges Ahead

19th March 2024

Venue: IITM Pune

ORGANIZED BY

INDIAN METEOROLOGICAL SOCIETY, PUNE CHAPTER (IMSP)

IN ASSOCIATION WITH

INDIA METEOROLOGICAL DEPARTMENT (IMD)

INDIAN INSTITUTE OF TROPICAL METEOROLOGY (IITM)

OCEAN SOCIETY OF INDIA (OSI)

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FOREWORD

I convey my hearty compliments to the Indian Meteorological Society Pune chapter (IMSP) for living up to its reputation as one of the most dynamic chapters of the IMS, by organizing this symposium on the highly topical subject of heatwaves, in close collaboration with the India Meteorological Department (IMD) and the Indian Institute of Tropical Meteorology (IITM). IMSP has been making concerted efforts to highlight the socio-economic impacts of weather and climate, and the associated role of meteorology and allied sciences and services through such symposia in recent years. On behalf of the National Council of the IMS, I express my deep appreciation of the tremendous efforts put in by the Executive Council of the IMSP and the Office of Climate Research and Services (CRS) of IMD in this regard. I am grateful to the Ministry of Earth Sciences (MoES), Government of India and other sponsoring agencies and partners for their support to this important activity of the IMS. The topic of the symposium is also highly relevant to the upcoming World Meteorological Day on 23 March 2024, with the theme "At the Frontline of Climate Action". As we celebrate the 150th year of the establishment of the IMD, this symposium also showcases the increasingly critical role of meteorological services in contributing to societal well-being and progress.

I welcome the publication of this abstract volume, which encapsulates the collective efforts of researchers, practitioners, and experts dedicated to understanding and addressing the challenges posed by heatwaves. Heatwaves represent a pressing issue in today's world, with their frequency, intensity, and duration increasing due to the complex interplay of natural climate variability and human-induced climate change. In India, where extreme heat events are not uncommon, the impact of heatwaves on human health, agriculture, infrastructure, and ecosystems is profound and far-reaching. I am pleased to note that the abstract volume consists of a diverse array of contributions from leading experts in the field, spanning meteorology, climatology, public health, urban planning, policy, and more. Each abstract represents a unique perspective, insight, or research finding that adds to the collective body of knowledge on heatwaves.

The IMS recognizes the critical importance of advancing scientific knowledge, fostering interdisciplinary collaboration, and promoting evidence-based solutions to mitigate the impacts of heatwaves. We truly believe the widely recognized scientific insight that "every single death directly due to heatwave can be prevented". Through this symposium, we aim to provide a platform for meaningful dialogue, exchange of ideas, and dissemination of research findings that will contribute to enhancing our understanding of heatwaves and improving our capacity to manage their impacts.

I hope the discussions and collaborations fostered within this symposium lead us closer to effective solutions for managing heatwaves and enhancing societal resilience in the face of a changing climate.

Dr. Rupa Kumar Kolli
President, IMS

PREFACE

Welcome to the National Symposium on "Understanding the Science of Heatwaves under the Warming Scenario and Challenges Ahead" during 18-19 March at Pune, organized by Indian Meteorological Society Pune Chapter (IMSP) in association with India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and Ocean Society of India (OSI), with support from Ministry of Earth Sciences (MoES). In recent years, the frequency and intensity of heatwaves have intensified globally, presenting significant risks to human health, ecosystems, infrastructure, and economies. India, with its diverse climate and large population, stands particularly vulnerable to the impacts of rising temperatures. The scorching heatwaves that grip various parts of the country annually underscore the urgent need for proactive measures and collaborative efforts to mitigate and adapt to this weather phenomenon. Against this backdrop, the National Symposium provides a timely and much-needed forum for experts, researchers, practitioners, policymakers, and stakeholders to deepen our understanding of the underlying science behind heatwaves.

The Heatwave Symposium serves as a platform for knowledge exchange, innovation, and collective action. Through engaging discussions, presentations, and workshops, participants will have the opportunity to deepen their understanding of heatwave dynamics, share best practices, and forge partnerships to build resilience at local, regional, and national levels. From developing early warning systems and enhancing heat resilience in vulnerable communities to integrating climate adaptation strategies into urban planning and infrastructure development, the symposium will foster discussions on innovative approaches and actionable solutions.

We are overwhelmed by the response of students and young researchers who have submitted scientific abstracts for the National symposium from all across the country. We hope that the students will be highly benefitted from the interactions with the experts in the field and this would be the real success of the symposium. We extend our sincere gratitude to all participants, sponsors, and supporters who have contributed to making this Symposium possible. Your dedication and engagement underscore the importance of concerted action in addressing the urgent issue of heatwaves and advancing our understanding of the science behind them. Together, let us rise to the challenge of understanding heatwaves under the warming scenario and chart a path towards a more resilient, equitable, and sustainable future.

Dr. Satyaban B. Ratna
Secretary, IMS, Pune Chapter

Shri K. S. Hosalikar
Chairman, IMS, Pune Chapter

INVITED TALKS

Assessment of Heat-Health Risks and Economic Impacts

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ABSTRACT

This presentation is based on an ongoing study being conducted on heat-health risks in India. Heat Stress is a growing concern in India, although the magnitude and pattern of health risks and impacts is insufficiently understood. Effective interventions are needed in a context of rising heat waves to protect those most at risk. Heat stress is associated with health risks, including heat rash, cramps, exhaustion, heat stroke, hospitalisation, and deaths from respiratory, cardiovascular and renal diseases. Prioritising cost-effective interventions for these largely preventable impacts is an urgent imperative. The associated economic costs to households and society can be substantial. Some cities, districts and states in India, have formulated Heat Action Plans while others have made progress in implementation of these plans. In fact, unprecedented heatwaves, as experienced in May 2022, have led to a disaster management framing for heat wave management across India.

A transdisciplinary framing is adopted for the research and mixed methods are required, synthesising stakeholder perceptions, policy document analyses, bio-physical health parameters, economic costs and avoided damages, and weather/climate data. This presentation will highlight some of the key pathways of health risks from heat stress and the potential economic and social consequences of heat stress impacts, for vulnerable populations such as the elderly, children, and outdoor workers. It will subsequently discuss the range of adaptation interventions to manage health risks, impact evaluation of the economic costs of adverse consequences and economic valuation of the benefits from effective interventions to manage heat stress for communities.

Model Heat Action Plan for Indian Cities: A Way Ahead

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ABSTRACT

Currently Heat Action Plan (HAP) is a tool available for managing and planning extreme heat concerns at various scales, from regional to local. Most of the Heat Action plans today focus on public health and revolve around emergency response and preparedness. The model Heat Action Plan attempts to look at extreme heat concerns holistically. It is developed on the basic framework of eight core elements suggested by WHO guidelines. It also addresses three different temporal scales: long, medium, and short-term. Here, the four important domains critical for planning and managing extreme heat in urban areas are public health, epidemiology, meteorology, and urban planning. This model Heat Action Plan incorporates four domains and eight core elements and measures extreme heat management and planning at three different time scales: short, medium, and long-term. It also provides guidance for the background studies required for the heat action plan. This modeled framework also discusses the review and evaluation mechanisms of the heat action plans.

Marine Heatwaves, Tropical Cyclones, and Terrestrial Heat Waves Cascading in a Changing Climate

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ABSTRACT

Heatwaves are among the deadliest weather phenomena in northwest India and Pakistan, killing about 350 people annually. Terrestrial heatwaves are projected to increase by six-fold in this region if emissions are to continue—which raises concerns for the vulnerable population that is projected to reach 1 billion by 2050. While we know that the frequency and intensity of heatwaves have increased in the region, their driving mechanisms are largely unknown. Here we identify an intriguing interplay between extreme weather events in the marine, atmospheric, and land environments that lead to these deadly events during the pre-monsoon cyclone season (April–May). We find that an increasing number of marine heatwaves in the Bay of Bengal—riding on a rapid ocean warming—are energizing tropical cyclones and driving intense heat over the Indo-Pak region. About 90% of the cyclones during this season were preceded by marine heatwaves.

The duration of marine heatwaves in the basin has increased from about one day to six days per year, while the area covered has increased by 86%, during 1982–2019. These marine heatwaves intensify the local convection, enhancing the cyclone updraft by almost twofold over the Bay of Bengal. This anomalous atmospheric circulation leads to the subsidence of dry air over northwest India and Pakistan, heating the atmosphere and occasionally driving severe heatwaves. Considering that the rapid warming in the Bay of Bengal is projected to continue into the future, the cascading impacts and interplay between the marine heatwaves, tropical cyclones, and terrestrial heatwaves depicted here need to be closely monitored for early mitigation and adaptation.

Health-Based Thresholds for Heat Early Warning Systems

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ABSTRACT

Temperatures across the globe are rising as much faster pace in the recent years and breaking records of warming by each passing year. Last decade had been the warmest with 2023 being the warmest year in the history of humankind ever since the global record keeping of temperatures began in the year 1850. The rising heat is putting more and more people across the world at risk and underlying vulnerabilities among communities further exaggerates the risk posed by exposure to increasing temperature. While the vulnerability assessment is essential to know who are at higher risk of extreme heat, where are they located, and what factors are inflating their risk, the development of local extreme heat threshold is essential to know WHEN the risk of extreme heat is starts rising. Simply saying, what is the cut-off point of a thermal variable at which the risk of health impact starts increasing in each population. Heat-Stress is a common terminology used to indicate the impact of extreme heat on human health. Usually, it is understood as a situation where too much heat is absorbed by the body of a person which leads to situations like heat cramps, heat exhaustion, and if not treated then the dangerous situation of heatstroke. But the question that arises here is "how much heat is too much heat?" and for how long should it last to cause heat stress? Is that the criteria used by Indian Meteorological Department (IMD) for defining heatwave in India? We read in the earlier unit that during the 2003 European heatwave, around 15000 people died alone in France and that too at temperature hovering around ~37°C only for few days. Whereas, in India, IMD declares heatwave only if the temperature reaches 40°C in plains and remains above that for two consecutive days. This means that people living in different climates (hot/cold/humid) are acclimatized to local climate and weather conditions. A French resident will feel the temperature very hot in India during summer whereas for an Indian resident the summer temperatures of France will be quite comfortable and therefore, the extreme heat (heatwave) temperature cut-offs also known as Thresholds of one place should not be applied to another place in general. Why should heat action plans of different cities/districts in India have their local thresholds? This is because the criteria of the heatwave in plains, hills, and coastal areas defined by IMD is applied for all such places. Whereas people living in the plains of northern India may have different temperature level susceptibility than people living in the central or western plains of India. Also, IMD declares heatwave only when the temperatures cross the cut-off value for two consecutive days whereas there is ample evidence suggesting that the health impact such as increased morbidities and mortalities can be seen on the very first days of extreme temperature events itself...! And therefore, local thresholds are essential for an effective heat-health early warning system.

India's Heat Action Plan: A Successful Public Health Intervention for adaptation and mitigation against extreme heat

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ABSTRACT

Heat waves are becoming more frequent, intense, and longer-lasting as a result of climate change. They have a significant impact on both human health, productivity, and livelihood, as well as society. Heatwaves can have a substantial influence on population health, resulting in increased death and morbidity. Higher temperatures are directly linked to increased mortality and morbidity from heat stress.

In 2010, Ahmedabad was hit by a very hot wave that ran for almost a week during the height of summer, from May 19th to May 17th. The temperature went up to 47oC. There were 310 deaths on May 21, 2010, when the heat wave reached its peak at 47ºC. All-cause mortality rates for the heat wave week were higher than the average for the previous year. This meant that 800 more people died during the heat wave. An analysis of all the deaths that happened in the city in May 2010 showed that 1344 more deaths happened than were expected.

In partnership with the Indian Meteorological Department (IMD), the Ahmedabad city government, and other stakeholders, the IIPH-Gandhinagar has led the threshold-based heat action plans. The low-cost Ahmedabad Heat Action plan has shown to be very effective in reducing and preventing morbidity and mortality from heat-related disorders. The Ahmedabad Heat Action Plan was adopted as a template for similar plans in low-income areas by other cities. Therefore, there is an urgent need to implement such a life-saving plan in other settings to generate new shreds of evidence for scaling it up.

Heat Waves over India: Long Term Variability and Trends

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ABSTRACT

Using HW information of 103 stations from Indian main land during the hot weather season (March to July) for the last 62 years (1961-2022), various statistical aspects of heat waves (HWs) and severe heat waves (SHWs) such as long-term climatology, decadal variation, and long-term trends were examined. The link of HWs/SHWs with ENSO phenomena, which is known impact the weather world over was also examined. HWs are generally experienced over the north, north-west, central, east India and north-east Peninsula [together called core HW zone (CHZ)] with highest frequency during May. It was observed that many areas of the country (north, northwest, central and northeast Peninsula) have experienced HW days of ≥8 HW days on an average per season. The SHW were mainly experienced over north, northwest and central parts of the country. The study observed noticeable decadal variation in the frequency, spatial coverage and area of maximum frequency both in the HW/SHW days over the country. Compared to previous five decades, there was noticeable increase in the HW/SHW days over the country during the recent decade 2011-2020, which is also the warmest decade for the country as well as for the globe. It was also observed that there is an appreciable increase (decrease) in the number of HW days during El-Niño (La-Niña) events. Severe Heat waves were more prominent (longest and hottest) in El-Niño years. Significant increasing trends in the HW days were observed in many stations from CHZ (CCZ), which is in tune with similar trends observed over various other parts of the world. The possible physical mechanisms for the observed linkage of these temperature extreme events over the country with the El-Nino / La-Nina are also discussed here.

Keywords – Heat Waves, Decadal Variation, Climate Change, Long Term Trends, Climatology, ENSO.

Heat-Health Adaptation — A multi-disciplinary viewpoint

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Geophysical Fluid dynamics, Climate Modelling, Extremes in the Climate System

ABSTRACT

Even though extreme heat has been considered a serious health hazard for many decades, attempts at understanding the impacts of heat and building adaptation capacity to extreme heat have mostly been confined within disciplinary boundaries. This can lead to inefficient, and sometimes incorrect, ways of measuring and conceptualizing the relationship between heat and health.
Using the IPCC risk framework, I will try to outline a systems approach to heat-health adaptation which will try to address the following questions:

1. What are the different determinants of health risks due to heat?
2. What we (the weather/climate community) are good at, and can contribute productively?
3. Where we need inputs from other disciplines?
4. What inputs can we provide to other disciplines?

HPC-enabled Urban Integrated Modeling: Challenges and Solutions

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ABSTRACT

The rapid urban growth in Indian cities makes large urban populations vulnerable to environmental problems such as heat waves, pollution episodes, and urban floods. Forecasting such environmental scenarios at the meso- and micro-scale involves complex cross-sectorial highly coupled systems with two-way or multi-way linkages between Meteorology, air quality-CFD, and hydrology. To resolve this, a multi-scale integrated coupled urban 'meteorology and hydrology, CFD, and air quality' modeling system is necessary to capture the urban representation of micro-scale city environmental conditions and skilful forecasting.

C-DAC has extensively researched and developed a modeling framework for an improved urban scale weather, hydrology, and air quality prediction systems to depict the heterogeneous characteristics within the city. C-DAC developed an advanced modeling system that integrates various components such as high-performance computing, input data, observations, satellite data, validation and verification methods, multi-model interoperability, multi-scale ensemble modeling, and 2D/3D visualization into a single platform to assist researchers and stakeholders.

The advanced integrated modeling framework was run in quasi-operational mode, and the outputs were shared with stakeholders in near real-time. The products' skills have been statistically evaluated against readily available observations and confirmed to be highly reasonable and satisfactory in different cities of India.

The system employs a model resolution of 1.5 km for India and 0.5 km for city-scale weather modeling. Air quality modeling utilizes a model resolution of 10 km for India and 2 km for a city-specific domain. We utilize 1920 cores/processors of a High-Performance Computing (HPC) resource. It requires approximately 10 hours to process and produces 400 GB of data daily. Our study confirms that a highly sophisticated, high-resolution model, high-performance computers, and adequate storage facilities are also needed to effectively represent environmental phenomena at the city-scale (sub-kilometer) resolution.

An automated decision support system (DSS) is under development to translate and transfer research outputs to users and stakeholders and assist operational agencies in real-time. The system will provide ward/area-wise forecast data on rainfall, unusual heat waves, heat index, the intensity of Urban Heat Islands, warnings about urban flooding, air quality index and other pollutant concentrations, and interactive maps for planning and readiness.

Soil moisture induced land-atmosphere interactions in the evolution of extreme temperature over India

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ABSTRACT

Soil moisture plays a key role both for the water and energy cycles through regulating the partitioning of net surface radiation into sensible, latent, ground heat flux and layer heat/energy content, and by partitioning of precipitation into evapotranspiration, infiltration, changes in layer water content water content, and runoff. Therefore, soil moisture plays a crucial role in altering climate extremes through complex land–atmosphere feedback processes. We study the impact of soil moisture variability in governing such interactions and how it can alter the characteristics of temperature extremes over India. In particular, it is noted that soil moisture perturbations exert substantial control on the near-surface temperature variability over north-central India (NCI), a hotspot for soil moisture-temperature (SM-T) coupling. Our findings suggest that increase (decrease) in soil moisture tends to significantly decrease (increase) the frequency and duration of extreme temperature events over NCI.

ORAL & POSTER PRESENTATIONS

Heat-wave-Intensity-Duration-Frequency (HWIDF) curve and the impact of seven air quality parameters on heat waves in major climatic zones of India

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ABSTRACT

Heat-wave-Intensity-Duration-Frequency (HWIDF) curve is employed to establish the relationship between the intensity, duration, and frequency of heat wave incidents. This approach offers a more comprehensive understanding of heat waves by considering their intensity, duration, and frequency for India's six climate zones: The Arid zone, Semiarid zone, Montane, Humid subtropical zone, Tropical wet, and Tropical wet & dry zone. These curves are used to evaluate the probability of encountering heat waves with varying levels of intensity and duration. They also help to measure the changes in heat wave intensities for different return periods in relation to the evolving climate. Subsequently, the MRI-ESM2-0 model output were also used to assess the disparities in HWIDF (Heat Wave Intensity-Duration-Frequency) by comparing scenarios with and without human emissions. This analysis aimed to determine the specific impact of human activities on heat waves. Our findings indicate that heat wave intensity poses a greater danger under historical conditions when compared to natural conditions, particularly over a span of five and ten consecutive days. We also study a central pollution control board (CPCB) database of air quality parameters during a heat wave and non-heat wave period (summer season from April to July month) from 2010 to 2023 for seven parameters ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO, O_3) for six climatic zones of India. Our analysis determines that particulate matter ($PM_{2.5}$ and PM_{10}) has more influence on heat wave as compare to non-heat wave periods for all climatic zones of India. It is also seen that the Arid, Semi-arid, and Humid subtropical zones highly polluted air quality during heat periods. The chance of occurrence of NH_3 pollutants is approximately invariant or has lower variability, while the probability certainty of PM_{10} and $PM_{2.5}$ is lower and uncertainty is higher; hence, this suggests a greater degree of variation. we observed that the worst polluted climatic zone and city is semi-arid, and Delhi and the lowest polluted zone and city are Montane and Thiruvananthapuram – Kerala

Analysis of Heat Wave over different physiographical regions in India

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ABSTRACT

The heat waves (HW) in tropical and subtropical region are deadliest throughout the world. This study represents HW characteristics over the tropical country India mainly divided in three different landmasses i.e. hilly, plains and coastal. This work presents the HW characteristics quantification based on physiography of the regions in India assessed over a period of 70 years (1951-2020) using the Indian Meteorological Department (IMD) observed data. Mostly the earlier studies are more focused on HW in the plains and coastal regions. HW in hilly region has been excluded by using single threshold for whole Indian region so, based on the topographical features three thresholds of daily maximum temperature (DMT) i.e. DMT >40^{o}C(plains), DMT >37^{o}C (coastal), DMT > 30^{o}C (Hilly)) are being applied. The spatio-temporal analysis of HW shows its occurrence in hilly regions (J&K, Manipur, Mizoram and Tripura) since 1972 and maximum 10 days HW in Northern region. The coupled model intercomparison project phase (CMIP6) model output for 7 models have been assessed to quantify the performance in capturing the HW parameters compared to IMD observations. The ensemble mean of 2 CMIP6 models i.e. EC Earth3 and MPI LR has been used to project future changes in HW properties over India under different emission scenarios i.e. SSP126 and SSP 585. The key finding of this study shows year 2050 onwards, a sharp increase in HW days, HW events, HW duration (average & maximum) will increase in hilly, coastal and plains region. Under SSP 585 the southern part will likely get more new hotspots of HW in India and there will be significantly more longer, intense and frequent HW occurrence as compared to SSP 126. The results shows the need of improvement in understanding of HW at regional scale and specially in hilly region.

Keywords: Heat wave; CMIP6, HW Duration, Physiography region

Exploring the Synergy between MJO in Shaping Pre-Monsoon Heatwaves and Monsoon Onset

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ABSTRACT

The Indian summer monsoon (ISM) and pre-monsoon heat waves (PMHW) are critical phenomena that shape the climatic landscape of the Indian subcontinent. The variability of these events is influenced by both large-scale and local-scale sources of variability, with the Madden-Julian Oscillation (MJO) playing a pivotal role in shaping their interplay. The MJO, a tropical intraseasonal oscillation, affects pre-monsoon heat waves in India via its linkage with monsoon onset and the subsequent development of favorable atmospheric conditions. During the pre-monsoon period, the MJO's active phases bring enhanced convection and low-level moistening, increasing the likelihood of cyclone formation in the Bay of Bengal. These cyclones can either trigger early monsoon onset or cause prolonged heatwaves if they fail to initiate the monsoon. This research paper aims to investigate the dynamical relationship between MJO phases, as measured by Real-time Multivariate MJO (RMM) index, and occurrence of PMHW as well as the ISM onset and progress in continental India. The differential dynamics associated for about two-fold rise in the HW occurrence in the South East, Eastern and North West India is explored using the MJO Phase analysis in this work. A weak MJO acts as a conductor, amplifying the risk of PMHW in specific locations depending on the current MJO phase and continent's slow monsoon progression, which disrupts typical weather patterns. The wet (dry) phase leads to early (late) monsoon onset over Kerala (MOK) in India. To address the progress of monsoon the DOM in Rajasthan (MOR) is considered and the rainfall anomalies during MOK-MOR period are linked to the MJO phases. It is inferred that the wet MJO phase with negative OLR anomaly triggers the fast progress of monsoon over India. To explain the linkage of PMHW, DOM and its progress in continental India with MJO, geopotential height (GPH), wind circulation, velocity potential (VP), sea surface temperature (SST) and outgoing longwave radiation (OLR) anomalies have been computed and used in extensive analysis. These parameters directly influence the development, intensity, and spatial extent of PMHW and so the ISM onset in Indian subcontinent. The insights from this dynamical study can be incorporated into NWP models, improving predictions of extreme weather events and the accurate prediction of DOM.

Long- term trends of Heat Waves and El Niño-Southern Oscillation (ENSO) impacts in a semi arid basin of Tamil Nadu

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ABSTRACT

The study examined the existing trends of heatwaves during the hot weather season for the last 55 years in Vaippar basin. Various statistical aspects of heat waves such as heat wave frequency, heat wave duration and heat wave maximum duration is analysed. A climatic event that affects the global climate is El Niño–Southern Oscillation (ENSO). Since 1980, prolonged droughts and floods have been linked to ENSO's effects as a result of global climate change. Indirectly, the presence of ENSO affects economic activities like agriculture, fisheries, devastates the environment, and causes health issues. Numerous research have been conducted done on ENSO. Research on how ENSO affects local regional climate, particularly in arid and semiarid basin, is still lacking, nevertheless, Ocean-land interaction in coastal zones and effect of ocean-level change is studied. Furthermore, large-scale areas have been the focus of earlier research. In addition, there is still more to know and understand about how ENSO affects local temperatures, particularly in cities. The Oceanic Nino Index (ONI) and meteorological data from 1965 to 2020 are used in this study. This study found that although the value of the ONI index varies, the existence of ENSO has an impact on the daily temperature. Furthermore, the effect of ENSO on temperature is predicted in this study using linear regression. The results of this study are useful in understanding the impact of ENSO on heat waves temperature in a semi arid basin to provide mitigation strategies in reducing the impact of ENSO.

Keywords: Heatwaves, ONI index and ENSO

Trends of Temperature over Indian Districts in Winter Season

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ABSTRACT

In last few years, India has observed a milder winter than usual with lesser intensity and frequency of cold waves and higher maximum and minimum temperatures than normal. The milder winters have a significant effect on agriculture, especially Rabi crops like wheat and potato,and energy resources like water resources. As per the IPCC summary report, for a warming of 1.5 degrees C, there will be an increase in the frequency of heat waves associated with longer warm and shorter cold seasons. For warming of 2 degrees Celsius, heat extremes would often reach critical tolerance thresholds for agriculture and health. To understand and analyze the regions of milder winters, we have calculated the district-wise trend of temperature using the frequency of excellence method(normal + 1sd) from the last 30 years(1990-2020) data. It was found that the number of districts with milder winters has increased in the last few years due to factors like global warming, delayed onset and reduced frequency and intensity of western disturbances, persistent El Nino during winters, strong IOD(Indian Ocean Dipole) and higher Sea Surface Temperature(SST) of Indian Oceans. Some local factors like warm winds blowing in from the Arabian Sea, coupled with the absence of colder air from the northeast, contributed to elevated temperatures in peninsular India whereas Cyclone Vardah which brought a lot of moisture has impacted the temperature, especially in Central India this year. The policymakers and administration can use this data to mitigate the adverse effects of mild winter on agriculture and the economy.

Identification of Heat Island Hotspots in Pune City

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ABSTRACT

The urban heat island effect has been worsened by urbanization and the significant increase in urban populations that has occurred in recent decades. There has been much focus on understanding the causes and patterns of the urban heat island effect. However, there have been very few quantitative studies conducted on the impact of this effect specifically for Pune city. In this paper, we aim to address this gap by analysing the India Meteorological Department's surface observational data for maximum temperature (Tmax), minimum temperature (Tmin), and relative humidity (RH), as well as land use data from the European Space Agency (ESA) for a period of 10 years (2012-2022). Our study primarily investigates the variation pattern and spatial distribution characteristics of urban heat islands in Pune city. We use different time thresholds for day-time (13^{th}, 14^{th}, 15^{th}, and 16^{th} hours) and night-time (03^{rd}, 04^{th}, 05^{th}, and 06^{th} hours) to identify the trends and intensity of temperatures, RH, and heat islands in both urban and non-urban areas of Pune city. The study finds that the diurnal variation of daytime temperature is highest in the urban environment at 13^{th} hours, with a marginal temperature difference of approximately 2-3 °C. This difference decreases towards 14^{th}, 15^{th}, and 16^{th} hours at all of the stations. Additionally, it is observed that radiative cooling is highest (~4 °C) in non-urban areas and lowest in urban areas at 06^{th} hours, providing evidence of the presence of heat islands. Furthermore, analysis of monthly temperature variation reveals that urban areas experience the highest temperatures in April, while non-urban areas experience the highest temperatures in May. Two out of six stations in the urban environment have been identified with a significant increasing trend in Tmax, Tmin, and heat islands during April and May. Alarming trends of increasing Tmax and Tmin during day-time threshold hours are also observed in non-urban stations, indicating a concerning situation for the heat budget and serving as an indicator of climate change. Moreover, we find that three stations in the urban environment act as heat islands (with island temperatures ranging from 5 to 8 °C) during night-time (05^{th} -06^{th} hours) in the summer season from 2012 to 2020. However, further analysis is needed to investigate the dominant factors contributing to this phenomenon, such as scattering/absorbing aerosols, emissions of trace gases and greenhouse gases (GHGs), and the classification of land/building surfaces, among others.

Keywords: Climate Change, Heat Stress, Hotspots, Urban Heat Island

Marine Heat Waves – Reason for Cyclogenesis in the Arabian Sea (2013-2022)

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ABSTRACT

In recent years, it has been observed that the number of cyclones in the Arabian Sea have increased. Though there are many studies on the cyclogenesis of the Cyclones and the factors that lead to the formation of cyclone, one factor that is being studied in this project is of the Marine Heat Wave. The project aims to study the relation between the Marine heat wave events that occur in the Arabian sea and the duration at the time when cyclones have taken place in the Arabian sea in those coordinates and dates. Various studies have been taken on Marine heat waves and its effects on Marine Life, Bay of Bengal, Cyclogenesis of Amphan.

This project aims to compare the data taken from NOAA OI SST day mean data for the last ten years from 2013 to 2022 and calculate and filter out the marine heat wave events occurred in each coordinate of the Arabian Sea with the resolution of 1X1 deg in the latitude and longitude and compare the events with the date of occurrence of a particular cyclone in these last ten years along with its coordinates and also the date on which the lowest expected pressure was observed along with its coordinate.
Though there are various other scope related to this study, this project aims to find the relation and trend between Cyclogenesis in the Arabian Sea and Occurrence of Marine Heat Wave events in those coordinates. Python script has been used extensively for the generation of output, plots, graphs and desired result.

Heat Waves in India: Patterns, Associations, and Subseasonal Prediction Skill

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ABSTRACT

Heatwaves (HWs) in India during Mach-June and from 1951 to 2023 are thoroughly analysed in this work, emphasising trends, decadal variations, and related large-scale features. Average HW days per decade and anomalies are computed using HW criteria based on high-resolution maximum temperature data. The findings indicate a notable increase in HW occurrence in the central, southeast, and northwest regions after 2000. Month-wise analyses reveal detailed patterns, showcasing increased HW days in non-traditionally hot months, like March in southern regions. This indicates a temporal and spatial intensification of extreme summer. Examining the spatial HW trends exposes a notable increase in total HW days/year over northwest, central and south-eastern regions, while few others witness decreasing trends. The study reveals significant increasing trends in the total number of HW days in the two HW-prone regions (Northwest and Southeast) from 1951 to 2023. It is further noted that the HW spells have become persistent in recent years over these regions. The analysis of large-scale characteristics associated with three different types of HW spells emphasises the possible role of oceans and atmospheric variables in HW patterns. Introducing the extended range prediction system version 2 (ERPSv2), the study assesses its subseasonal prediction skill, demonstrating superior performance compared to ERPSv1, particularly with a three-week lead time. Validation through a case study on the June 2023 HW disaster showcases ERPSv2's efficacy in forecasting real-time events with a four-week lead time. Incorporating ERPSv2 adds a practical dimension, enhancing HW predictions and facilitating timely responses to extreme heat events, crucial for public health measures and climate resilience planning in the face of escalating HW occurrences.

Keywords: Heatwave; spatial and temporal intensification; large-scale features; SEDI scores; subseasonal prediction.

How heatwave condition varies in recent three years throughout the country in connection with orange and red alert ?

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ABSTRACT

Heat wave is a spell of above normal temperature typically characterised by significantly high temperature as framed by IMD. Heatwaves usually result in human discomfort, health risks for individuals, domestic animals, poultry etc. Simultaneously, it can create threat to standing crops due to evapotranspiration from soil as well as crop. Heatwaves are one of the deadliest hazard in the line with the IPCC prediction. Heatwave forecasting requires expertise in data collection, synoptic analysis, climatology and application in numerical weather modeling. Heatwave forecast is crucial in context of effective adaptation and planning. Threshold for heatwave warnings as adopted in India are based on i) **departure from normal** and ii) **actual maximum temperature**. Heatwave and severe heatwave criteria are: When maximum temperature of a station reaches ≥40° C for plains and ≥30° C for hilly regions; Heatwave: Maximum temperature departure from normal +4.5° C to +6.4° C; Severe heatwave**:** Maximum temperature departure from normal ≥+6.5° C; Based on actual maximum temperature Heatwave: When actual maximum temperature ≥45°C, Severe heatwave: When actual maximum temperature ≥47°C. Moreover, criteria for heatwave for coastal stations; When maximum temperature departure is >+4.5°C from normal, heatwave may be described, provided maximum temperature ≥37°C. To declare heatwaves the above mentioned criteria should be met for at least in two stations for a met sub-divisions for at least two consecutive days and it will be declared on the second day.

In India, heatwave occurs mainly during March to May which is considered, here, for this study. The peak month of heatwave over India is May. Heatwave develops over northwest, central India and even to eastern parts of India and peninsular India. The States where heatwaves are predominant, includes Madhya Pradesh, Chhattisgarh, Rajasthan, Gujarat, Maharashtra, Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Odisha, Andhra Pradesh and Telangana etc. In this paper all the technical-cum-operational aspects of heatwaves are discussed. It is observed that the favourable conditions which aggravate heatwave are: i) transportation / prevalence of hot, dry air over a region, ii) absence of moisture in the upper atmosphere, iii) the sky should be practically cloudless and iv) large amplitude anti-cyclonic flow over the area. Heatwave begins when high pressure in atmosphere moves in and pushed warm air towards a ground. Sometimes *EL-Nino* condition favours heatwave developments.

The study of heatwave is essentially important for governments, societies, stakeholders, for common people and even for farmers. Every year in some areas of country it occurs affecting human being, domestic animals, crops in a significant manner. Huge impact of heatwave throughout the major parts of country, prompted the authors to take up this study. In this connection, IMD issues different heatwave warnings with colour code, jointly with NDMA (National Disaster Management Authority). Colour codes are: Green (no action), Yellow (be updated), Orange (be prepared) and Red (take action). Heatwave observations during 2021 to 2023 where number of days in a month were 5 or more and orange or red alert / warnings were there from March to May are discussed. The study revealed that During 2021, only areas of heatwave / severe heatwave affected areas were Saurashtra and Kutch during March-April. During 2022 the duration of heatwave / severe heatwave were significantly higher over west Rajasthan, west Madhya Pradesh, Saurashtra-Kutch and even Himachal Pradesh during March. The extent (spread) and duration of heatwave / severe heatwave were significantly high over Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, Gujarat, Uttar Pradesh, Bihar, Jharkhand and Gangetic West Bengal during April, while during May only west Rajasthan and west Madhya Pradesh were affected. During 2023 heatwave / severe heatwave were the minimum in country, where only areas of Konkan Goa (during March), Gangetic West Bengal (during April, May) and Odisha (during April) were affected. Naturally, the study indicated year to year variation in extreme weather due to heatwave and severe heatwave.

The study of heatwave for areas of country in recent years is very important. The extent (area) and duration of heatwave / severe heatwave varies year wise during the study period. During 2022 the extent and period of heatwave was highly significant as compared to other study years. The extension of this study for more number of years can help planners, researchers in a better way to work for heatwave IBF (Impact based forecast) jointly with NDMA.

Keywords: Heatwave criteria, IPCC, Hazard, Impact, IMD warnings, Severe heat wave, IBF, NDMA.

Assessment of heatwaves and heat stress over Eastern India under changing climate

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ABSTRACT

The extreme events like heat waves are often referred to as the "silent atmospheric killer" because its effects on human health are not always immediately obvious. The impact of climate change has led to an increase in heat waves over the recent years. This study has been undertaken to analyse heat waves and heat stress patterns over Eastern India during the periods of 1961-2020 and 1981-2020 respectively, for the months of April, May, and June. To identify a heat wave episode, the 90th percentile of daily maximum temperature over a 5-day window has been considered as the threshold. Furthermore, three heat stress indices (HSIs) based on temperature and relative humidity, namely, Humidex, Simplified Wet-Bulb Globe Temperature, and Apparent Temperature have been used to estimate and categorize heat stress levels. In general, the majority of heat waves have occurred in the months of April and May while heat stress has been at its peak in June. There has been an increase in the number of days exceeding the 90th percentile of daily maximum temperature as well as the frequency and duration of heat waves in recent years, specifically, during 2011-2020 with respect to the earlier years. Considerable changes have also been found in heat stress levels during the recent decade- either the strength of heat stress has increased (i.e., from slight to moderate or moderate to strong) or an increase in area coverage by a specific heat stress level has been noticed, as compared to the preceding years. Additionally, noticeable decreasing trends in heat stress have been observed over certain areas during some sub-periods. These findings give an overview of the geographical variation in the enhancement of heat waves and heat stress under the influence of the changing climate over the study region.

Keywords: Extreme events, Heat waves Frequency, Heat waves duration, Heat Stress Indices, Climate Change, Eastern India.

Observed and projected changes in maximum temperature over Kottayam- A case study

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ABSTRACT

In recent times, the issue of global warming has garnered significant attention in newspaper headlines, reflecting a troubling trend of rising temperatures not only during the scorching summer months but also extending into other seasons. Kerala, a coastal state known for its abundant atmospheric humidity, is experiencing a notable increase in heat levels. This surge in temperature has far-reaching consequences, impacting not only the human population but also the environment. The abrupt changes in temperature pose challenges for humans, animals, and plants to adapt to, potentially leading to increased health problems, mental illnesses, crop damage, and more.

Kottayam, a district in Kerala, is situated between Alappuzha to its west, Idukki to its east, Ernakulam to its north, and Pathanamthitta to its west, and it does not have a coastal region. Temperature changes in the Kottayam district are considered in this study as it has witnessed abrupt variations in temperature from the norm during both winter and summer seasons in recent years. The study examines the variation of maximum temperature in the Kottayam district using in-situ data and CMIP6 model data. The analysis reveals a consistent rise in maximum temperature year by year, indicating that days are becoming progressively warmer compared to previous years, with an increase in the frequency of extreme temperatures. The projected changes in maximum temperature highlight spatial variations across the Kottayam district, with the most significant deviations occurring in the west and gradually diminishing towards the east. Importantly, this temperature increase is not confined to the summer season but extends into the winter months, indicating a trend towards warmer days in the future. Consequently, it is imperative to address the potential impacts of these projected temperature changes and implement appropriate mitigation measures.

Keywords: Temperature, Warm days, Mitigation

Shifting of the Zone of occurrence of extreme weather event – Heat waves

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ABSTRACT

In this study an attempt has been to examine whether there is any significant shift of the region of occurrence of extreme weather events in decadally during March to June months. Following the IMD guidelines we have identified heat wave location all over India for the period 1991-2020 (3 decades) using MAUSAM report and 1961-2020 (6 decades) using IMD gridded datasets at 1^o x 1^o resolution. In the first part extreme weather event caused by heat waves (HW) and severe heat waves (SHW) has been made. In each decade broad region covering the recurrence of has been identified using extreme weather events associated with HW/SHW. This process is repeated for decadal-wise. To analyses these data sources to identify patterns and trends in HW/SHW frequency, duration, intensity and geographic distribution over time. The study observed a spatial-temporal shift in the occurrence of HW/SHW events, with a significantly increasing and decreasing trend in Indian states with HW/SHW prone regions. The west coastal region has seen an increase in HW locations starting with Konkan Coast up to Kerala and also observed that North-east states are facing HW/SHW in last decade. In the last decade, SHW locations are marked from northwest to southeast India around the central region as if following a linear structure.

The occurrence of HW/SHW in the hilly states like Meghalaya, Assam, Himachal Pradesh and Uttarakhand is unprecedented and disastrous conditions that can be a dangerous trend for the future. This observational evidence provides valuable insights into the impact of climate change on extreme heat events and helps inform mitigation and adaptation strategies.

Keywords: Heatwaves, Severe heat waves, Zonal shifting, Extreme weather, Climate Change

Relation between Meridional Mass Transport and Temperature Patterns: Insights from Observations

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ABSTRACT

Earlier study shows the significant increasing temperature trend over the tropics in last three decades. The aim of this study is to see how the meridional mass transport is impacted by the tropical warming. This study investigates relation between the multi-level meridional mass transport (average over 45°E-120°E) dynamics with surface temperature (35°S -35°N, 45°E- 120°E) during the MAM season from 1990 to 2021.We know that mass stream function is associated with the meridional velocity, so there may be a change in the mass transport in the global warming scenarios. Observation, reveals a poleward meridional mass transport in both the hemispheres, with the maximum ascending branch witnessed off the equator, i.e. for northern hemispheric ascending branch observed over 5°N -20°N whereas for southern hemispheric ascending branch observed over 5°S -20°S. Additionally, employing an empirical orthogonal function (EOF) analysis of the meridional mass stream function and temperature over same region suggests a significant positive correlation of 0.41 for the first mode of principal component (PC) of the EOF. Furthermore, a correlation PC1 of surface temperature and multi-level mass stream function shows poleward tilted pattern, where maximum correlation is noted over 700hPa-200hPa region in the both hemisphere. Current study elucidates the intricate relationship between meridional mass transport and temperature patterns based on EOF patterns, offering valuable insights into large-scale atmospheric dynamics. But, further study is required to establish a detailed physical mechanism between the diverse surface temperature anomalies with mass stream function under recent warming scenario.

Keywords: Meridional mass transport, Mass stream function, Temperature.

Mapping Heat Stress: Understanding the impact on Maharashtra

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ABSTRACT

The present study investigates the pattern and trend of heat stress conditions across various regions of Maharashtra from 1970 to 2021 using Thom's Discomfort Index. The monthly change in discomfort level was assessed for 18 meteorological stations in Maharashtra. As the dataset spanned over 52 years, decadal analysis of comfort levels was also carried out for all the stations. Results revealed that the discomfort level in summer months has increased from decade 1971-80 to 2011-20. The study identifies a significant rise in discomfort levels, leading to states of medical emergency in April, May, and June in eastern Maharashtra during the period 2011-2021, which was not witnessed during the previous decades. Furthermore, it delineates regional disparities, indicating that western Maharashtra and Marathwada experience comparatively lower discomfort levels compared to Vidarbha and Konkan regions. Temporally, discomfort peaks from April to July, while spatially, coastal areas exhibit consistently high discomfort levels, with extreme conditions prevalent even in eastern and northern Maharashtra during summer and early monsoon months. These findings highlight the urgency for targeted interventions, both from the general public and government, to mitigate the adverse effects of heat stress, particularly in vulnerable regions.

Keywords: Heat Stress, Decadal change, Thom's Discomfort Index, Maharashtra

Heat Wave Dynamics and Regional Vulnerability: A Comprehensive Study over India

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ABSTRACT

This study examines the vulnerability and causes of heat waves across the Indian subcontinent amid on-going global warming. Using an updated, high-resolution surface air temperature dataset from the India Meteorological Department (IMD) covering 1951-2021, the research identifies regions with peak temperatures and heat wave susceptibility, especially during May. Results delineate three distinct maximum temperature zones: West Rajasthan, North Madhya Pradesh and Southwest Uttar Pradesh, and East Maharashtra. Conversely, localized heat wave vulnerability regions emerge in the north, northeast, and southeast, distinct from the maximum temperature zones. Soil temperature data validate these identifications, highlighting the impact of local radiative heating. Heat wave causation is attributed to anomalous southwest, west, and northwest wind flows from the identified maximum temperature zones. Notably, heat waves in southeast India since 1970 underscore recent global warming effects. Climate model simulations align with observed temperature zones, emphasizing radiative heating's role. The study underscores the importance of understanding regional temperature patterns and atmospheric circulations for heat wave prediction and vulnerability assessment, offering insights for climate modeling and adaptation strategies. Furthermore, the study analyzes heat wave spatial distribution, frequency, and trends in India from 1951 to 2021. Statistical analyses of monthly maximum temperatures reveal higher occurrences in May, especially in Andhra Pradesh and south Telangana. Moderate hot regions experience more heat wave days. Additionally, the study explores the El-Nino Southern Oscillation's (ENSO) influence on Indian heat waves, identifying distinct temperature zones during ENSO events and their associations with atmospheric and oceanic conditions. This research contributes valuable insights into heat wave dynamics and regional vulnerability, aiding climate research and adaptation planning.

Keywords: Heat waves, Maximum temperature, Climate Models, ENSO, temperature zones and Heat wave regions

Spatial and temporal variability of Heat Wave and extreme maximum temperature over Rajasthan, India

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ABSTRACT

This study is an initiative to figure out the spatial and temporal variability of mean temperature, extreme maximum temperature, frequency and intensity of heat wave (HW) events over Rajasthan. The daily maximum and minimum temperatures data of ten stations of Rajasthan have been used and analyzed for the period of 1969 to 2022. The study reveals that the May is the peak month of summer. More than five days mean frequency of HW is observed over northwestern parts of the state in May. The study reveals that the extreme maximum temperatures are showing increasing trend in March and April over many parts of the state except southern and central parts.

The recent past two decades 2001-2010 and 2011-2020 shows steep rise in frequency of heat wave events over many parts of the state. Out of the total ten stations, Jodhpur is least affected by this change and is showing almost constant trend for all summer months. Churu has shown significant rise in frequency of heat wave for all summer months. North-west and south-east Rajasthan has found two significant heat wave prone regions. A non-parametric Mann-Kendall test has been applied at 95% confidence level for the HW and extreme temperature for different stations. The rise in frequency and intensity of HW in the March is a signature of early onset of summer season in Rajasthan. The increase in extreme temperature and frequency of HW may be attributed to rapid urbanization, deforestation and industrial development leading to the climate change.

Keywords: Heat wave, extreme temperature, maximum temperature, Mann-Kendall test, climate change etc.

Understanding Climate Indices related to Maximum Temperatures over Madhya Pradesh

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ABSTRACT

In Madhya Pradesh, the summer season is characterized by high temperatures, making it essential to understand the patterns of extreme heat events due to their potential impacts on various sectors. The increasing global temperatures have led to a rise in the intensity and frequency of extreme weather events, including heatwaves, both globally and locally. This study aims to analyse climate indices related to extreme heat and temperature, as recommended by the World Meteorological Organization (WMO), across major stations in Madhya Pradesh. By examining these indices, the study tries to identify any trends or variabilities in extreme heat events over the region. Additionally, it seeks to assess the impacts associated with these extreme temperatures on sectors such as agriculture and health. One significant aspect of the research involves examining the maximum temperature records during summer to provide insights into the severity and duration of heatwaves experienced in the state.

Keywords: Extreme Temperature, Heatwave, Climate Indices

Assessment of Extreme Weather Events (heat and Cold wave) over different districts of West Bengal

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ABSTRACT

Extreme weather and climatic events have received increased attention in the last few years, due to the often large loss of human lives and exponentially increasing costs associated with them. According to IPCC's Assessment report, Climate change and Global warming are the main reason behind this extreme conditions. Within past few years, the world has experienced thousands of extreme weather events like flood, drought, heat wave, cold wave etc. which had the capability to destroy human lives, infrastructure, agriculture and economy as a whole. India even West Bengal is not exception of this condition. Heat wave and Cold wave are one of the most important extreme events in today's scenario. In this study, daily maximum temperature data for different districts of West Bengal for the period 1951-2013 was used to count how many days heat wave occurred in different threshold values and numbers of events were accumulated for the summer season extending March to May for each district and each year. The temporal variation of heat wave events for different threshold were estimated and displayed (Agro-climatic zone basis). Three types of threshold has been used for predicting the heat wave trend. They are Tmax+2ºC (mild heat wave events), Tmax+3ºC (moderate heat wave events), Tmax+4ºC (moderate heat wave events). In case of each threshold level, almost all the districts of each agro-climatic zones of WB showed decreasing trend of heat wave events. As for example it varied from -98 days/63 years in New alluvial zone to -8 days/63 years in hill zone districts. The results prove that though all over the world people are experiencing global warming but its influence on the summer months of WB is not so prominent. In the same way, daily minimum temperature data for different districts for the period 1951-2013 was used to count how many days cold wave occurred in different threshold values and numbers of events were accumulated for the winter season extending from December to February for each district and each year. Here also three types of threshold has been used for predicting the cold wave trend. They are Tmin-2ºC (mild cold wave events), Tmin-3ºC (moderate cold wave events), Tmax-4ºC (severe cold wave events). In all 3 types of cases, almost all the districts of WB showed decreasing trend of cold wave events for parametric and non-parametric trend analysis respectively. As for example, in case of moderate cold wave event(the 2nd threshold), the cumulative number of events varied as -4 days,-4days,-3days,-31days,-12days,-17 days /63 years in the districts of hill,Tarai,Old Alluvial, New Alluvial, Red and Laterite and Coastal and saline zone respectively. These results prove that all over the world people are experiencing global warming and the decrease of cold days is the result of winter warming in the winter months of WB.

Keywords: Heat wave, Cold wave, Agro-Climatic Zones of West Bengal, Parametric and Non-Parametric Trend.

Observational substantiation of heat wave inclination in India

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ABSTRACT

During the 50 years from 1961 to 2010, there has been a significant increase in the frequency of heat waves across India. Heat wave intensity is highest in years with El Nino. In 2015 heat wave was observed in 9 states of India but in 2020 heat wave was observed in 23 states of India. The methods of distribution of the nature of heat wave in two types, like observational method and the other is the statistical analysis of the change in maximum temperature. Through these two methods, it is seen that the level of heat wave has increased significantly in North West India, Central India and South India. The frequency of heat waves is comparatively less in North East India. The results obtained using the Mann-Kendall method and the Sen slope method implies in 1951 and 2010, the nature of 10-day heat waves has increased in the Western Ghats and several regions of adjacent western and southern India, while the number of 10-day heat waves has increased in Rajasthan. During the 50 years from 1970 to 2020, according to ground station observation reports, Rajasthan experienced 160 to 167 heat wave days. According to OLR, upper tropospheric humidity and 500 hPa wind share tendency, the heat wave hotspot is concentrated over West Central India, Rajasthan, Madhya Pradesh, Telangana and Peninsular India. According to the CIMP5 climate model data, heat wave intensity will increase 40 times across India by 2100.According to the Global Earth System Model, the average temperature will increase by 0.5 to 2.0°C (by 2049) in east central and northern India. According to the Indian Meteorological Department's temperature data, heat wave intensity will increase in South India. Generally, West, Central and South India are among the regions prone to increase in dry heat index, but wet heat index regions prevail in West Bengal, Odisha and adjoining areas. Even though the maximum temperature is comparatively low, than north west & central India all these regions have high water vapor content, so the discomfort is high. For this reason, public life is disrupted in humid & hot sultry summer.

Keywords: OBSERVATION, TRENDS, HEATWAVE, INDIA.

Validation of temperature predictions from IMD-GFS model across India for the year 2023

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ABSTRACT

Validation of temperature forecasts is paramount in the context of daily weather forecasting. Accurate temperature predictions are essential for a myriad of societal activities, from planning outdoor events to managing energy consumption and agricultural practices. Validation ensures that forecast models are reliable and trustworthy, bolstering public confidence in weather forecasting agencies. By analyzing the performance of forecast models through validation metrics, meteorologists can identify areas for improvement and refine their techniques, ultimately enhancing the quality of forecasts. Continuous validation fosters a cycle of improvement, allowing forecasters to learn from past errors and make adjustments to optimize future predictions. This study validates temperature forecasts from the India Meteorological Department's (IMD) Global Forecasting System (GFS) model against actual temperature measurements. Validation is conducted both at individual stations throughout the year and country as a whole, spanning up to 120 hours of forecast. Various statistical measures, including correlation coefficients, root mean square errors, and bias, are computed across different regions and temporal scales. Results indicate that the GFS model's temperature forecasts shows a consistent bias, which varies both spatially and temporally. Understanding this bias can aid forecasters in issuing more accurate operational forecasts.

Keywords: Temperature forecast, Verification, Global Forecasting System.

Combined influence of warming trend in temperatures, land use changes, anthropogenic activities, and persistent climate modes on the Sweltering heat conditions across South Western Peninsula India in February 2024

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ABSTRACT

This study examines the combined effects of land use changes, anthropogenic activities, persisting climate patterns, and warming temperatures on the extreme heat experienced in South Western Peninsula, India in February 2024. The month of February witnessed extreme heat worldwide and the winter in Northern Hemisphere has been scorching hot across southern peninsula India, which has been temperatures that are uncommonly elevated. Coastal and midland regions of Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh experienced unprecedented temperatures, either daily or for the entire month of February. The unusual warmth aligns with the ongoing trend of rising temperatures noted from June 2023, marked by seven successive new world monthly temperature records, including January 2024. Global sea surface temperatures are currently at their highest recorded levels. Although El Niño has increased temperatures in certain regions, human-caused climate change remains the primary long-term contributor. Conversely, certain regions in North India had unusually low temperatures from January to February of 2024. Additionally, the region's minimum nighttime temperatures were significantly higher than normal. As a result of a dry and warm air mass being pushed by a high-pressure system caused by changes in the location of the Zonal circulation brought about by El Nino, warm weather has dominated much of February on the South West Peninsula of India. The higher sea surface temperature anomaly that lasted from January to February 2024 in the Southeast Arabian Sea had an impact on the local land-sea thermal circulations. A number of mountainous regions of Kerala experienced an increase in fires that began as early as February due to the high temperatures and prolonged drought. Factors contributing to the hottest February on record in Kerala in recent history included high temperatures, dry soils, rapid urbanization, unscientific land use changes, and weak low-level winds.

The Role of Humidity in Rising Heat Stress in India

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ABSTRACT

Extreme weather events are being brought on by global warming and meteorological changes, with India being particularly affected by heat stress. Understanding and analyzing heat stress is essential to ensuring the health and productivity of people across a variety of industries given the size of the population and the variety of outdoor activities they engage in. In India, the highest temperatures occur before the monsoon begins, typically in May or by the beginning of June. A valid indicator of thermal stress experienced by people is the wet bulb temperature (WBT) and heat index which takes into account various meteorological factors like temperature and humidity. Despite the huge importance of WBT and Heat Index on the health of people, studies considering the WBT and heat index factors are limited in India. This study employed reanalysis data of ERA5 to assess the spatial distribution and trend of WBT and Heat Index along with factors like temperature, dew point temperature, relative humidity, and surface solar radiation over India during pre-monsoon (March-June) season for the period 1992-2022. The Heat Index values were categorized into various thresholds defined by the National Weather Service (NWS) to identify the percentage of days experiencing mild to extremely dangerous heat index. Maximum temperatures above 42 ^{O}C were reported over 30-years in the Indo-Gangetic plains, the state of Rajasthan, a few locations in central-eastern India, and the northwest plains of India close to the Pakistan border. The increasing temperature anomalies indicated a warming trend over the three-decade period from 1992-2022.A deadly maximum wet bulb temperature of 35 ^{O}C was detected in regions along the Pakistan -India border. The trend analysis revealed an increasing trend in WBT and Heat Index over the years from 1992-2022.

Keywords: Extreme weather events, Wet bulb temperature, Heat Index, Thermal stress.

Assessing the Impact of Subseasonal Tropical Oscillations on Heat Stress over the Indian Region

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ABSTRACT

Heat stress is one of the most catastrophic natural disaster in recent climate causing more deaths than any other natural disaster. Human bodies dissipate heat through evaporative cooling or sweating when ambient air temperatures exceed body temperature. However, high humidity can impair this crucial cooling process, especially when coupled with warm weather, posing a grave risk to outdoor workers. Hence, Understanding the underlying factors and processes of humid heat will enable policymakers to implement measures that safeguard workers from hazardous heat stress. Further, India is surrounded by the Sea from sides which leads to advection of warm and humid heat inland. Hence, defining heatwave or heat stress only with temperature may underestimate its impact. This study investigates the role of BSISO and convectively coupled equatorial waves (i.e., Equatorial Rossby wave (ER), Equatorial Kelvin wave (EK), and Mixed Rossby-Gravity and Tropical Depression (MT) wave) in modulating the heat index across the country. The frequency of extreme caution events is found to almost double over most of the region when the wet phase of ER, BSISO, and both phases (dry and wet) of MT prevails. While the frequency of danger and extreme danger events is enhanced (almost 100% increased from climatology) over northwest to southeast India. However during the dry phase of ER, the central and southern peninsular India shows a 30-70% increase in heat stress frequency while northwest India and IG plains show a decline in heat stress with frequency reduced to almost zero i.e complete suppression of humid heat waves. Further, the long term increase in frequency of danger and extreme danger and decrease of extreme caution category is observed over most of the region. Our results suggest that alongside global warming and other climate variability modes such as ENSO and AMO, tropical subseasonal oscillations exert a significant positive influence on heat stress. Moreover, recent advancements in subseasonal oscillation forecasting, with a predictive capability extending up to approximately four weeks, offer opportunities for improving extended-range predictions of heat stress events when combined with the insights derived from our analysis.

Characterization and Simulation of the 2022 Heatwave over Northwest India and Adjoining Countries

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ABSTRACT

The present study investigates the characteristics and potential mechanisms underlying the intense, prolonged heatwave that impacted the northwestern regions of India and Adjoining countries during the summer of 2022. Observational findings reveal maximum temperature anomalies exceeding 3.5°C in March and April 2022, marking the second-highest temperature recorded in northwestern India and adjoining regions over the last 122 years. The region experienced elevated temperatures; specifically, from March 10 to April 20, 2022, temperatures consistently rose to more than 6°C above daily climatology. We have analyzed atmospheric variables of the ERA5 reanalysis dataset during the prolonged spell. Positive Outgoing longwave radiation anomalies coincide with regions experiencing substantial temperature anomalies, while negative mean sea level pressure anomalies promote dry air convergence, inhibiting cloud formation. Increased geopotential height anomalies and boundary layer height suggest heatwave intensification and atmospheric mixing. Results also show that the strong subsidence and clear sky conditions over northern India and adjacent areas enhance land surface heating, intensifying the heatwave. In addition, we assess the prediction skills of the non-hydrostatic mesoscale model (WRF) in simulating prolonged and higher intensity heat waves, such as the 2022 cases, using operational availability of initial and boundary conditions (NCEP-GFS, IMD-GFS, and NCMRWF-GFS). In our assessment, using the contingency table, we observed that the WRF model with the initial, lateral boundary conditions of IMD-GFS has grid-wise Heidke skill scores of 0.36, 0.3, and 0.32 for 0-day, 1-day, and 2-day predictions, respectively, demonstrates superior predictive capabilities in comparison to the NCEP-GFS and NCMRWF-GFS data when integrated into the WRF model.

Keywords: heatwave, WRF model, Stationary wave, subsidence

Observed Intensification of Moist Heat Stress over the Indian Region

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ABSTRACT

The dynamical drivers associated with the dry and moist heat stress modes are dominantly the upper-level anticyclonic circulation. However, what differentiates dry and moist heat stress is the thermodynamic impacts caused by humidity. Over the Indian region, two dominant subseasonal temperature modes are found to drive the dry and moist heat stress conditions. While mode 1 causes the dry heat stress, mode 2 leads to the moist heat stress conditions, especially over the coastal regions. The large-scale circulation features associated with the subseasonal modes are driving the regional circulation, leading to the outflow of moisture away from the Indian landmass for mode 1. At the same time, for mode 2, the inflow of moisture from the Bay of Bengal drives the moist heat stress condition, especially on the East Coast to Central India. It was found that both modes drive similar heat stress conditions based on the NWS Heat Index over the Indian region, even though mode 1 is attributed to dry heat stress and mode 2 is attributed to moist heat stress conditions. A phase plot devised based on the principal components of these modes can be used to monitor the dry and moist heat stress modes over the Indian region. The risk associated with the heat stress is assessed based on the location of a point in the (PC 1, PC2) phase space. Warnings are devised for different phases, which gives information about the type of heat stress and the exposure to the hazard in terms of its spatial extent.

Mode 2 shows a long-term increasing trend over the Indian region. The intensification of mode 2 is analyzed based on the observational vorticity and temperature patterns. The intensification in mode 2 has its implications in both the intensity and the spatial extent of the high-temperature conditions. Also, the possible role of the warm SST of the southernmost Bay of Bengal near the coast of Indonesia is also noted, which can cause regional circulation features and moisture inflow towards the Indian region, leading to intensified moist heat stress conditions.

Keywords: Heat Stress, Extreme Temperature Events, Monitoring, Heat Discomfort, Intensification of heatwaves.

Heat budget analysis of 2015 Indian Heatwave

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ABSTRACT

Heatwaves are classified as one of the deadliest events that expose millions of humans to risk. The existing literature has identified three physical mechanisms that are involved in the development of atmospheric heatwaves: diabatic heating of air near the Earth's surface, adiabatic compression and resulting warming of the descending air, and warm temperature advection. These processes typically work together to produce heatwaves, with their relative importance varying between daytime and night-time heatwaves as well as between the regions under consideration. Understanding the dynamics of the heatwaves over South Asia is one of the key areas that need further exploration. The heat budget equation quantifies the change in the temperature anomaly for a region and the aforementioned processes. In the present work, the heat budget equation is analyzed to understand the 2015 Indian heatwave. The heatwave occurred during 4-12 June, 2015, and is concentrated in Central India region. ERA5 is employed to quantify the physical processes that caused the heatwave. The findings indicate that this heatwave event is caused by a significant contribution from quasi-locally produced diabatic heating in addition to adiabatic warming.

Keywords: Heatwave, Diabatic Heating, Adiabatic heating, Advection

Heat waves over Andhra Pradesh: A preliminary study

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ABSTRACT

Heat waves are the major extreme events noticed during the summer or pre-monsoon (March-May) period over the country. Among the many states in India, Andhra Pradesh is one which is vulnerable to the heatwaves during the above period. The number of heatwave days over Andhra Pradesh are noticed with inter and intra annual variability. The north-south trough over central Indian parts is mostly responsible for generating north-westerly or northerly winds. These winds leads to dry and stable atmosphere over the regions and enhances the heat wave conditions over many parts of Andhra Pradesh and the neighbouring states of Telangana, Tamilnadu and Odisha. The absence of maritime easterlies over south peninsula region right from lower tropospheric level to up to 500 hPa height can be seen during the heatwave period. In the present study the heat waves over Andhra Pradesh were analysed during the period 2019-2023. Among the period, 2019 and 2023 are witnessed with more number of heat wave days with a count of 35 and 22 respectively. While remaining years are witnessed with 7 (2020), 4 (2021) and 1 (2022) heat waves. The highest number of heat waves are noticed in the months of May and June in 2019 while only during June in 2023. The monthly and seasonal mean winds show the absence of maritime easterlies and presence of northerly or north-westerly winds at 850hPa and 500 hPa levels. The synoptic analysis also suggests that the presence of strong anomalous anti-cyclonic circulation in winds during the above mentioned months in 2019 and 2023 which indicates the weaker presence of moistened either easterly or westerly winds. However, during the years 2020, 2021 and 2022 it is clearly noticed the presence of westerlies with anomalous easterly winds at 850 hPa and 500 hPa height. The state of sea surface temperature also plays an important role in generating heatwaves. The weak and moderate ElNiNo condition in 2019 and 2023 enhanced the above normal condition of maximum temperatures while moderate and weak LaNiNa conditions supported the suppression of heatwave conditions over Andhra Pradesh.

Keywords: Heatwaves, ElNiNo, LaNiNa, Eastrly winds, anomalous winds.

Regional and Global impact of Heat Wave and Heat Stress

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ABSTRACT

The science of heat waves and heat stress is an important area of study delving into many aspects of extreme temperatures regionally and globally as heat waves increase in frequency and intensity, the scientific principles of understanding the underlying process is essential in order to develop effective mitigation and adaptation strategies.

Various factors such as geography, local climatic systems, etc. in urban areas, their conch shell meadows and green spaces are often due to interactions with water temperature. Heatwaves, characterised through prolonged intervals of extreme warmth, directly make a contribution to heat stress in people by means of overwhelming the frame's capacity to alter its internal temperature . This can result in quite a number health problem like lifestyles-threatening heatstroke, underscoring the vital relationship among those phenomena.

Globally, heat wave science reveals the complex interactions between atmosphere and ocean. Increasing global temperatures are associated with human activities, especially greenhouse gas emissions. A solid understanding of feedback data and meteorological data processing techniques and ground station observation is essential for accurate climate modelling and future heat wave model forecasting. This global approach is critical for international cooperation to address climate change.
The science of heat stress includes physiological responses, public health implications, and identification of populations most susceptible to its adverse effects like for heat stress your body starts to get warmer, it overheats and then as it tries to regulate itself, it can lead to different things — the first of which we're all familiar with: sweat. This includes early warning systems, heat management, and increasing medical preparedness to reduce the health effects of heat wave exposure.
In conclusion, the science of heat waves and heat stress is a complement to local complexity and comprehensive global climate policy. Advances in this field not only deepen our understanding of Earth's changing climate, but also guide policy makers, urban planners, and public health practitioners to develop migratory approaches effectiveness.

Heat Stress Hazard Mapping: Insight to a Novel Approach

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ABSTRACT

The recent Intergovernmental Panel on Climate Change (IPCC) AR6 report indicates a significant increase in observed hot extremes (including heatwaves) and confidence in human contribution to these changes, particularly in the South Asian (SAS) domain encompassing the Indian subcontinent. Global trends since the 1950s reveal a rise in both frequency and intensity of extreme heat events, with notable societal and economic repercussions. India, in particular, faces escalating heatwave challenges amid ongoing warming trends and projections, leading to heightened population exposure to heat-related risks. Rising temperatures, attributable to global warming, exacerbate heat stress, posing health risks such as heat stroke, exhaustion, and related ailments. Occupational illnesses and injuries are also prevalent consequences of extreme heat exposure, particularly in agrarian economies like India, where heat stress can intensify drought and worsen water scarcity for irrigation, resulting in substantial economic losses. Consequently, the impact of heatwave hazards is extensively discussed in academic and political arenas. This study employs a non-parametric multivariate approach to develop a Universal Thermal Climate Index (UTCI)-based hazard map for India. The map identifies and categorizes prominent heat hazard areas based on thermal stress levels, with the probability of occurrence mapped using exceedance probability relative to UTCI assessment scales. The resulting heat stress hazard map serves as a valuable tool for various applications, including public and individual precautionary planning, urban and regional development, the tourism industry, and climate research. Thus, the necessity for a country-level heatwave hazard map is evident. The vulnerable community including the farmers, who are attempting to combat with the extreme temperature issues will be benefited with the developed hazard map.

Keywords: Exceedance probability, hazard map, heat stress, India, multivariate approach, non-parametric method

Understanding the Science of Heatwaves through Land-Atmosphere Feedbacks

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ABSTRACT

Amidst climate change, the unprecedented increase in the frequency, intensity and duration of heatwaves globally and over India in recent decades has been a reason for serious concern for human health, agriculture and overall the ecosystem. An in-depth physical understanding of heatwaves is thus essential for the prediction of heatwaves in the short-range to extended range timescale. Apart from large-scale SST anomalies, changes in land surface state can also influence atmospheric circulation patterns, potentially leading to the persistence of anomalous high-pressure systems that favour the occurrence of heatwaves. Soil moisture anomalies can have a significant impact on local temperature and humidity leading to the initiation and/or intensification of heatwaves and even heat stress. The seminal role of land surface state i.e. soil moisture in the intensification of heatwaves is unravelled in this study. Observational in-situ, reanalysis and satellite data have been used to characterise and quantify the anomalous soil moisture conditions prior to the occurrence of heatwaves of different intensities and the associated atmospheric conditions. It is noted that the observed severe heatwave cases over India have been preceeded by deficit soil moisture anomalies. Results suggest that accurate land surface initialisation and representation of land-atmosphere feedbacks in operational models can significantly improve heatwave forecasts.The authors gratefully acknowledge the financial support given by the Science and Engineering Research Board, Department of Science and Technology, Government of India to conduct this research.

Keywords: Soil moisture, Land-atmosphere feedback, Heatwaves, Prediction

Evaluation of monitoring and forecasting heatwaves based on heat index in summer 2023

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ABSTRACT

The heatwave is a type of meteorological extreme event observed in tropical and sub-tropical countries. Heatwaves produce health hazards and discomforts to normal life. India Meteorological Department (IMD) declares a heatwave condition based on two criteria. First is the departure of maximum temperature measured on the day with normal values and second is if the maximum temperature of the station attains or crosses 45^{o}C or 47^{o}C ie. severe heatwave. Many operational meteorological agencies in the world use the index to monitor and forecast the heatwave. The current study reports an index based monitoring of heatwave during March to June 2023. The index-based method has an advantage over the traditional one is that the extent of the heatwave (geospatial aspect) effect can be seen on maps so that warnings can be issued to subsequent areas to be alerted one day before. We have used three indices for monitoring and forewarning of heatwaves i.e. Excess heat index, heat stress, and excess heat factor (EHF). In this way, daily monitoring is done for the heatwave season of 2023. The advantage of this method that it expresses excess heat felt by human beings during the change in climatic conditions over 30-33 days and not just meteorological conditions. Forewarning is also issued using EHF, which is computed with the LSTM Model (AI-based). In this study, we discuss the evaluation of the success of index-based heatwave monitoring and forewarning for the summer season of 2023 (March -June 2023).

Keywords: Heatwave, monitoring, forewarning.

Reveal of near-term multisectorial temperature extremes in India by using the CMIP6-DCPP models

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ABSTRACT

Prediction of near-future climate (next decade) variations, especially temperature and rainfall, is critical for water resource management, disaster mitigation, and agricultural development. Initialized General Circulation Models (GCMs) simulations from the CMIP6 decadal climate prediction project (DCPP) provide the status of future climate for a decade. These predictions have remained uncertain because many coarse resolution climate models do not accurately simulate the regional phenomenon. In this study, we have developed the downscaled and bias corrected (DBC) Tmax and Tmin for Indian region and examined the heat and cold waves characteristics. The area influenced by the extremely high and low temperatures associated with the large and small area heat waves and cold waves are well captured in the DBC product. The temperature extreme indices showed the increase of warm and cold extremes in the present decade over India. DBC product shows the increase (decrease) of mean maximum (minimum) temperatures by ~0.6^{o}C (0.3^{o}C) during AMJ (NDJF) season over India in the current decade (2017 to 2026). It is found that, the number of extreme heat wave and cold wave days are better represented in the DBC hindcast product. An increase in the number of heat and cold wave days over India is predicted for the coming decade with 90% confidence level, which provides useful and important information for the stakeholders. Over all, the DBC product produced in this study is found to capture the intensity, frequency, and spatial distribution of heat (cold) waves over India very well and so will serve as a potential tool for policy makers and disaster managers.

Heat stress analysis using RTMA over India

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ABSTRACT

The present work is aimed to analyze the Heat Wave (HW) conditions and heat stress by using the high-resolution Real-Time Meso-scale Analysis (RTMA) over India. The RTMA is a high-spatial and temporal resolution analysis/assimilation system for near-surface weather conditions. The objective of this study is to generate and verify the 2m temperature analysis from RTMA that available at a high spatial resolution of 2.5km over Indian domain during the heat wave period of April 2023. The characteristics of the large-scale atmospheric circulation related to the HW are also analyzed using the ERA5 reanalysis during the HW period. The surface temperature from RTMA is verified with IMD station observations as well as GLDAS data sets during the HW period. The comparison of 3 hourly temperatures shows reasonable improvement in the RTMA analysis by capturing the regional scale features compared to background fields. The spatial and temporal variation of temperature from RTMA is well compared with the IMD station observations. It is also observed that highest temperature is reasonably well brought by the RTMA and comparable with the temperature reported by the IMD at various locations. The absolute mean errors for RTMA in predicting the maximum temperatures over the HW affected regions of Bihar, Odisha, West Bengal and East Uttar Pradesh are found to be as lower as 0.02^{o}C. Further location specific HW analysis of RTMA shows very high skill i.e., the mean error is less than 2°C over most of the locations for all the HW days. The Heat Index (HI) which indicates the heat risk is found to be at extreme caution to danger level over most of the HW regions. Overall, the study indicates that RTMA final analysis fields are highly usable for now-casting and severe weather monitoring.

Keywords: RTMA, GLDAS, Heat waves, Maximum temperature, Heat Index

Atmospheric Blockings over North Atlantic Teleconnect to the Heatwaves over Northwest India: A Study of the Present, +1.5°C and +2.0°C Warming Worlds

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ABSTRACT

In the summer of 2015 a heat wave claimed more than 2500 lives in southeastern India. Wehner et al., (2016) showed that the risk of this heat wave has increased due to anthropogenic forcings. Using ERA5 reanalysis and IMD Observation, we found that the Geopotential-height at 500hPa over North Atlantic region Granger Cause Maximum Temperature (Heatwaves) over Northwest India at lag-3 day and the Rossby wave numbers 6, 7, 9 are having higher event coincident rate, higher probabilities, larger area coverage in both regions (MAMJ, 1979-2018). In light of the Paris accords, future stabilization of global mean temperature at the 1.5°C above pre-industrial aspirational target and the "not to be exceeded" 2°C target, the possibility of increases in extreme temperatures under these scenarios is very real. We make use of model output contributed under the Half a degree Additional warming, Prognosis and Projected Impacts project (HAPPI; Mitchell et al., 2017).

The HAPPI database contains output from many atmospheric GCMs with multiple simulations (~100 each) of historical (2005-2015), +1.5°C warmer decade, and +2°C warmer decade. We compare modelled data (and bias corrected model output where available) against observed daily temperatures from the IMD and reanalysis products to get circulation features. The total number of event days (MAMJ) Heatwaves over Northwest India preceded by the Geopotential height at 500hPa over North Atlantic (atmospheric-blockings) is doubling, and tripling in the +1.5ºC and +2.0ºC warmer world, respectively compare to the present world (2006-2015). Probability of the teleconnection between Geopotential Height at 500hPa over North Atlantic and daily maximum temperature TMAX (Heatwaves) over Northwest India at lags from 1 to 5 days will increase during +1.5ºC and +2.0ºC warmer worlds. The number of blocking event days over the North Atlantic as well as the TMAX anomaly event days over Northwest India during MAMJ season were found to be increasing in the +1.5°C and +2°C future simulations. Our findings confirm that Rossby wave numbers 7 and 9 trigger both anomalous blocking over North Atlantic and anomalous TMAX anomaly over Northwest India regions, which makes persistence of the teleconnection (statistically significant at the 95% level) in the warmer climates and will lead to higher TMAX anomalies over Northwest India with probabilities of 0.308, 0.324, 0.284 (statistically significant at 95% level) in the historical, +1.5°C, and +2°C future simulations respectively.

Improvement in heat wave extrapolation in the sub-regional scale.

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ABSTRACT

A heat wave situation is considered when the maximum temperature rises to 4.5°C and above normal . In the last 10 years, In 2015 Palodhi, Rajasthan recorded the highest temperature of 51°C. The spatiotemporal shift is increasing the intensity of heat waves over North West, Central and South Central India. Out of which the highest incidence is seen in West Madhya Pradesh (0.80 events/year). (IMD gridded MT data 0.5°*0.5° resolution). Geophysical weather satellite imagery & thermal scanner image such as OLR Image, solar radiation image, soil moisture product etc. has increased reliance on heat wave forecasting in the sub regional areas. Early warning of small to large area heat waves is becoming possible through the use of multi model analysis techniques. Numerical weather prediction models are being used to make reliable short and long term predictions of heat waves. By combining two or more weather models, special weather models are being developed through which heat wave forecasting can be done more accurately at sub-regional scales. The Indian Meteorological Department currently provides reliable combined model based T-max forecasts for the next 7 days to highlight the distribution of heat waves over sub-regional areas. In addition, the impact basis predicts the upcoming heat wave by looking at the location of the jet stream and the location of the high pressure system through synoptic scale analysis. A climate model is a computer simulation of the Earth's climate system. The use of this model provides an idea of past climate conditions as well as future climate conditions and heat wave trends from large to small areas . Climate forecasting models provide long-term understanding of temperature rise, temperature distribution and nature of heat waves over large regions. Climate models predict the distribution, nature, and intensity of heat waves at regional and larger scales by predicting El Nino, La Nina, and IOD scenarios. At the regional level the Indian Meteorological Department is maintaining micro-regional meteorological records through deployment of block-based AWSs, and through micro-regional maximum temperature distribution maps, an unbiased and dependent view of regional trends in heat flux emerges.

Keywords: HEATWAVE, FORECASTS, TRENDS, AREA.

Understanding Climate Variability in North India: A Machine Learning Perspective

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ABSTRACT

Rising temperatures driven by global warming exacerbate the frequency and severity of heatwaves, while also influencing precipitation patterns. Understanding these interconnections is essential for assessing climate change impacts and devising effective adaptation and mitigation strategies, especially in regions with diverse topographies like North India. Integrating cutting edge Machine learning techniques while combining data from satellite observations, ground-based measurements, and numerical models, the study aimed to unravel the intricacies between precipitation and various atmospheric variables while allowing the efficacy evaluation of ML algorithms across North Indian States. Correlation results between temperature and precipitation across Rajasthan and Uttarakhand displayed significant positive relations (0.343 and 0.399, respectively), indicating a strong relationship between the two. Himachal Pradesh and Uttar Pradesh exhibited weaker positive associations (0.156 and 0.375), suggesting a nuanced interplay. However, Jammu and Kashmir showed a slightly negative correlation (-0.084), hinting at complex dynamics in that region. Utilizing four supervised machine learning algorithms—Random Forest (RF), XGBoost (XGB), K-Nearest Neighbors (KNN), and Support Vector Machines (SVM)—the study uncovered compelling findings. Random Forest (RF) stood out for its efficacy, achieving impressive accuracy rates ranging from 83.6% to 84.7% for most states. SVM outperformed others in Jammu and Kashmir and Uttarakhand, with accuracies of 79% and 84.5%, respectively. Temporal analysis highlighted significant shifts in climate dynamics over time, with potential implications for future precipitation trends. Integration of emerging techniques like Automated Machine Learning holds promise in democratizing access to advanced data science tools, empowering stakeholders to navigate climate change challenges with precision and effectiveness.

Keywords: Climate Dynamics, Heatwaves, Machine Learning, North India, Precipitation Patterns

Review of Heat Stress over Indian Region

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ABSTRACT

The world is presently going through global warming, the intensity of this is observed much more in the 21st century. In India, heat waves typically occur during the summer season during March to June before the Monsoon period. It is a period of abnormally high temperatures, typically 45°C i.e. More than the normal maximum temperature, that occurs during the summer season in the plains and 40°C in the hilly regions, which are normally cooler.

Studies have found that increase in the frequency, intensity and duration of heatwaves are likely to occur due to global warming. Heat stress is related to heatwave due to overheating of the human body. Globally, 2015 was the hottest year recorded, during this period in India more than 2300 people died due to heat stress. As Heat stress corresponds to heat waves it can be measured by change in factors like Temperature, Surface Radiation, Relative Humidity and Wind Speed.

Heat stress impacts can be more severe in urban areas compared to rural areas due to a phenomenon called as the Urban Heat Island (UHI) effect, which is caused by the combination of more heat absorbing surfaces like rooftops, buildings, paved surfaces, trapping of hot air between buildings and limited tree cover. Higher urban temperatures can cause greater energy use during the summer, increased air pollution and greenhouse gas emissions.

In the present work, we reviewed some of the heatwaves indices over Indian region and found that Indian Heat Index-IHI, Excess Heat Factor-EHF and similar indices can be useful for heatwaves studies and analyzing this data over Indian region can provide overview of how Global Warming affects heat waves causing Heat stress.

Keywords: heatwaves, discomfort, urban and rural impact of heatwaves, heat stress indices.

Heat wave in Andhra Pradesh and Telangana states during 2023

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ABSTRACT

The heatwave conditions (days with abnormally warmer temperature i.e. > 5^0C above normal) results in adverse impacts on human health, water resources, power generation and on agriculture. Hot weather conditions (> 40^0C) were experienced in Rayalaseema districts from 28th March, 2023 and over coastal Andhra Pradesh and Telangana districts from 10th April 2023. The hot spell was suppressed due to advance of moist southwest monsoon current in Andhra Pradesh on 22nd and in Telangana on 24th June, 2023. In 2023, the frequency of occurrence of heatwave days' district wise in Coastal Andhra Pradesh were, 1 in Nellore, 6 each in Srikakulam and Prakasam, 8 in West Godavari, 12 each in East Godavari and Krishna and 16 each in Guntur and Visakhapatnam. East Godavari, Guntur and Visakhapatnam districts were worst affected with severe heatwave conditions as they recorded severe heatwaves for 7 days, 6 days and 5 days respectively. The frequency of occurrence of heatwave days in Telangana were, 16 days in Khammam, 9 each in Adilabad, Karimnagar, and Medak, 8 each in Warangal and Nalgonda, 2 in RangaReddy and one in Hyderabad districts. It was nil in Mahabubnagar district. Khammam district was worst affected with severe heatwave conditions for 7 days in Telangana. Rayalaseema experienced heatwaves for 3 days in Ananthapur, 2 days in Kurnool and 1 day in Chittoor and nil in Cuddapah districts respectively. Heatwaves were realized in Telangana and Rayalaseema sub-divisions in the month of June only and before the onset of monsoon on 24th June, 2023 with frequency of occurrence 20 days and 5 days respectively in the season. Impact based Forecast and Heat wave warnings saved many people from mortality.

Key words: Heat wave, Hot weather season, Monsoon, severe heat wave, Human health

Helping Communities Stay Cool: Interpreting Heatwave Science for All

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Meteora weatherservice

ABSTRACT

The world is increasingly experiencing heatwaves which are more frequent and more severe, posing a tremendous threat to communities. The understanding of the science behind heatwaves is essential in providing community guidance that ensures safety and well being. This piece aims to explore effective translation of heatwave science targeting everyone, with the objective of giving communities the knowledge they need to navigate extreme heat events. Simply stated, a heatwave would occur when temperatures in a given area rise above normalcy for an extended period. It combines meteorological factors such as atmospheric pressure systems, humidity and climate patterns that bring about high temperatures. To translate this complex science into something digestible by all communities we must break it down to easily digestible information. Explaining the causes of heatwaves without using jargon is one of the first things to do. For instance, when weather systems cause a build up of heat within a territory, it becomes easier for locals to comprehend why temperature goes up. Inclusion of simple examples whereby an object like a pot cover would capture heat during cooking can make this idea easily understood. Another crucial thing is about the possible health threats that could arise. This means that their effects on vulnerable groups such as older people, kids and individuals with chronic illnesses should be well elucidated. By highlighting how staying hydrated, finding shade and identifying symptoms of heat-related diseases are important; communities will be in a position to preventively care for themselves. Moreover, practical advice on dealing with extreme temperatures should be part of community guidance. This includes the meaning behind cooling centers, appropriate dressing selection and energy saving measures. Breaking down scientific facts about overheating into practical stages allows persons or groups to ready up hence making immediate steps possible. Additionally, it is important that community guidance includes a range of practical ideas that can help individuals adapt to extremely high temperatures. Some of the suggestions in this area might be about cooling centres, proper clothes choices and energy conservation techniques. This would include translating the science of heatwaves into steps that people can take to better prepare themselves and their communities.To ensure comprehensibility of such information by all; one needs to communicate effectively. With effective communication, messages targeted at different audiences are easily accessible.In conclusion, if resilience to rising temperatures is to be attained, there needs to be a functional translation system for heatwave science intended for community guidance. We can help communities deal with the risks associated with heat waves by breaking down complex concepts into simpler terms, emphasising health risks, and providing guidance. At the same time, we can work towards creating a future that is more resilient to high temperatures.

Evaluation of tree-rings as proxies for ecosystem productivity in India through observations and model products

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ABSTRACT

Terrestrial ecosystems are one of the major sinks of atmospheric CO2 and play a key role in climate change mitigation. Forest ecosystems offset nearly 25% of the global annual CO2 emissions and a large part of this is stored in the aboveground woody biomass. Several studies have focused on understanding the carbon sequestration processes in forest ecosystems and their response to climate change using the Eddy Covariance (EC) technique and remotely sensed vegetation indices. However, very few of them address the linkage of tree-ring growth with the ecosystem-atmosphere carbon exchange and nearly none have tested this linkage over a long term (>100 years) — limited by the short-term (<50 years) availability of measured ecosystem carbon flux. Nevertheless, tree-ring indices can potentially act as proxies for ecosystem productivity. We utilise the Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP) model outputs (a project under CMIP6) for its 140-year-long simulated records of mean monthly gross primary productivity (GPP) and compare them with the tree-ring growth indices over the northwestern Himalayan region in India. By examining their correlation with climate variables, and other statistical measures, we establish confidence in tree-ring growth indices as proxies for estimating ecosystem productivity in the long term. Effect of climatic variables like temperature, precipitation, short wave radiation etc., on the correlation of tree-ring and GPP is also explored. The tree-ring correlations can be affected by extreme temperatures or heatwaves. The control of climate variables on the correlations varies between different tree species.

Analysis of Marine Heat Waves in The Bay of Bengal

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ABSTRACT

Marine heat waves (MHW) are extreme rises in ocean temperature for an extended period of time. As the overall temperature of the oceans rises, it is reflected in higher sea surface temperatures. They can occur at different locations in the ocean, and their magnitude and frequency have increased over the last decades. The most direct and dramatic impact of marine heat waves is the triggering of mass mortality events affecting an increasing number of species and habitats. Non-mobile species, such as coral, algae, and sponges, that cannot escape the harsh environmental circumstances, are especially vulnerable to excessive temperature stress. This study focuses on the use of SeaDAS (SeaWiFS Data Analysis System) software for retrieving and analyzing SST in the Bay of Bengal from MODIS satellite observations. The SeaDAS software provides a comprehensive suite of tools for processing ocean color data, offering a robust platform for extracting accurate and reliable SST information. Ocean warming and SST are two interrelated components of climate change, with rising temperatures influencing marine ecosystems, weather patterns, and global climate dynamics. Monitoring these changes is crucial for determining the health of the seas and forecasting future climate scenarios. Thus the integration of MODIS-derived SST data into broader Earth observation frameworks enhances the capability to monitor and respond to changes in the marine environment, supporting sustainable management and conservation efforts.

Keywords : SST, MODIS, SeaDAS, Marine heat waves, Ocean warming

A Case Study of Heatwaves in Karnataka: Assessing Impacts, Vulnerabilities, and Mitigation Strategies

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ABSTRACT

There is a growing body of evidence from the published literature worldwide suggesting that climate change is likely to escalate the occurrence of extreme weather events. Such occurrences pose heightened risks of both communicable and non-communicable diseases. Given its demography and population density, India is particularly vulnerable to these impacts. The burden of diseases resulting from extreme weather events varies spatially and temporally, necessitating effective strategies for mitigation and adaptation. One crucial approach to address these challenges is the development of early warning systems and the implementation of effective communication strategies to disseminate risk information to stakeholders, ranging from governmental authorities to field workers.

In this study, we focus on Karnataka as a prototype state (based on its climatic diversity) and conduct a historical analysis of past heat waves. Karnataka's diverse climatic zones, including its hot and dry northern region, relatively cooler southern interior region, significant orography, and warm moist coastal plain, make it an ideal prototype for understanding the complexities of heatwave impacts and adaptation strategies. Through a scoping review, we examine the actions taken under heatwave action plans. Additionally, we assess the vulnerable sectors, including the population, and quantify the burden of heatwaves in Karnataka. In particular, we also explore the impact on other critical sectors such as drinking water and electricity.

Keywords: Heatwave, Karnataka, Scoping Review.

The Progression of Maximum Near-Surface Temperature Extremes in Summer Over the Main Airports in India

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ABSTRACT

The increasing magnitude and frequency of extreme temperature events in the experience of climate change can significantly impact aviation operations. Near-surface air temperature plays a significant role in the civil aircraft landing and take-off performance. The estimation of the future impact of increasing high temperatures on aircraft take-off and landing has been done by a combination of climate data and technical flight data. Previous study results show that decrease in maximum takeoff weights and the lengthening of takeoff distances. The Indian region is one of the main regions that is notified by extremely high temperatures. In this study, the trends of the daily maximum near-surface temperature extremes in summer were analysed over major airports in India. Trends in the period 1951–2015 were analysed from observations. Future changes by 2024–2060 with respect to 1951–2005, were analysed from simulations performed with regional climate model CORDEX RegCM4 IITM-CCCR. The functioning of airports would be impacted by this increase in high temperatures. Policies for mitigation or adaptation would then be required.

Keywords: Heatwaves, Aviation Meteorology, Surface Temperature, Regional climate models

Analysis of the Impacts of Extreme Heat on the Aircraft operation

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ABSTRACT

Flight delays and cancellations commonly happen due to weather conditions such as fog in winter (DJF) and heat waves during summer (MAM). Heat waves are usually the last type of weather in aircraft operation challenges. The heat wave caused extreme temperatures on the runways, which were too hot for the aircraft to take off. The heat waves significantly affect larger Boeing and cargo aircraft in the form of weight restrictions that often result in fewer passengers and potential delays in departure. The present study aims to have overviews of how heat significantly affects both small and large aircraft at Indira Gandhi International (IGI) Airport, New Delhi. The possible solution to mitigate the negative impacts of extreme heat on aviation is increasing runway lengths, adjusting departure times, and decreasing onboard weight.

Keywords: Heat waves, aviation, airport reference temperature and IGI airport.

Analysis of Heat Waves in the Northwest Regions of India using UTCI in Conjunction with Synoptic Features

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ABSTRACT

India is extremely susceptible to climate change and is anticipated to experience the greatest increase in annual average temperature over the next few decades. There is a tendency for heat waves to be frequent during the summer season (March to June) and sometime in July, mainly in the Northwest, Eastern and Central regions of India. The frequent rise in the occurrence of heat wave events is primarily attributable to the acceleration of global warming, the spread of urbanization, and the effects of human activity. This study examines heat waves as a function of the Universal Thermal Climate Index (UTCI) and associated synoptic features that contribute to high thermal stress and Mortality. The UTCI, which was derived from the Human Thermal Comfort (ERA5-HEAT) dataset, was utilized for the period of time spanning from 2010 to 2020 and reanalysis data for accumulating the synoptic features has been utilized. The UTCI values are significantly higher during the peak summer months in hot, arid regions like the north-western part of India, reflecting the increased thermal stress that people exposed to these extreme heat conditions experience.

Keywords: Universal Thermal Climate Index (UTCI), Heat Waves, Synoptic Features.

Land Surface Temperature Trends and Extreme Heat Events in Maharashtra, India

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ABSTRACT

Land Surface Temperature (LST) serves as a pivotal metric in understanding global heat dynamics, surface temperature fluctuations, and their implications for environmental sustainability. This study delves into the escalating trends of LST within Maharashtra's semi-arid regions, elucidating their profound impacts on agricultural output, water resources, and ecological equilibrium. Leveraging MODIS LST satellite data for meticulous analysis, the research unveils alarming spikes in LST, surpassing 50 degrees Celsius in select locales, thereby exacerbating prevailing challenges and necessitating urgent interventions. Central to addressing escalating LST levels are sustainable land and water management strategies, imperative for mitigating adverse consequences. Additionally, the study underscores the significance of cultivating climate-resilient agricultural practices and bolstering preparedness measures against heatwaves, vital for safeguarding agricultural productivity and public health. Collaboration among governmental bodies, local communities, and stakeholders emerges as pivotal in effectuating these measures, underscoring the need for concerted efforts to navigate the multifaceted challenges posed by rising land surface temperatures. Prioritizing sustainable development and climate adaptation initiatives is paramount for Maharashtra to enhance its resilience against mounting LST levels, thereby safeguarding its populace and natural resources. It is incumbent upon policymakers to seamlessly integrate these strategies into policy frameworks, fostering synergistic partnerships to confront the nuanced intricacies of escalating land surface temperatures. Through concerted endeavors, Maharashtra can chart a trajectory towards a more resilient and sustainable future in the face of escalating climate change dynamics. In essence, this study provides critical insights into the escalating trends of LST within Maharashtra's semi-arid regions, shedding light on their far-reaching implications for agricultural sustainability, water security, and ecological balance. By delineating actionable strategies and advocating for collaborative approaches, the research underscores the imperative of proactive measures in navigating the challenges posed by rising land surface temperatures.

Keywords: LST, Heatwave

Heatwave and its collateral impact and mitigation

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ABSTRACT

A heat wave is a dangerous air temperature condition where exposure can be fatal. It is defined by temperature thresholds over a region, including actual or deviation from normal temperatures. Heat waves are considered fatal if the maximum temperature reaches 40 degrees Celsius or more for Plains and 30 degrees Celsius or more for Hilly regions. The heatwaves during 1998 and 2015 caused more than 2000 deaths each in India. India is facing a significant increase in heatwaves, heat stress, and heat-related mortality due to the increasing risk of health issues such as diabetes, renal , respiratory and cardiovascular disorders. High temperatures can cause physiological stress, public health emergencies, increased mortality, and socioeconomic effects over time. Heatwaves also disrupt health services due to power outages affecting transportation, water infrastructure, and medical facilities. Heat stress also leads to a shortened life cycle and reduced plant productivity. For every 1°C increase in temperature, yield of wheat, soybean, mustard, groundnut and potato are expected to decline by 3-7%. Livestock experience mild heat stress when the thermal heat index exceeds 72, moderate at 80, and severe at 90. This stress affects broiler comfort, productivity, growth, feed conversion, and weight gain due to changes in behavioural, physiological, and immunological responses. Heatwaves in India increase evaporation rates, causing a rise in water demand for general use and agriculture. Indirectly, sustenance of crops and farm animals become difficult during heat wave period. Power outages are triggered by the disproportionally high electricity demand due to air-conditioning during heat waves. India's urban Heat Island phenomenon, characterized by heat-absorbing surfaces, building trapping, and poor vegetation, increases air conditioner usage during heat wave conditions, posing health risks. Heat wave intensification in coastal, interior peninsular, and north central regions will lead to severe urban planning challenges in India, requiring "climate-smart" cities.

Impact of Marine Heatwaves on Oceanic Ecosystems

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ABSTRACT

Marine heatwaves (MHWs) are increasingly recognized as significant drivers of ecological change in the world's oceans, posing substantial threats to marine biodiversity and ecosystem function. This review synthesizes current knowledge on the impacts of MHWs on oceanic ecosystems, drawing on recent scientific literature and case studies from around the globe. We discuss the physical processes underlying MHW formation and explore the ecological consequences of these extreme events across various marine habitats.

Key findings indicate that MHWs exert widespread and diverse effects on marine organisms, from coral reefs to polar ecosystems. Coral bleaching, shifts in species distributions, changes in productivity, and alterations in reproduction and recruitment patterns are among the documented impacts of MHWs. Furthermore, MHWs can exacerbate ocean acidification and contribute to the loss of biodiversity, with significant socio-economic ramifications for coastal communities reliant on marine resources.
We highlight the interconnected nature of MHW impacts, emphasizing the cascading effects through marine food webs and ecosystem services. Despite the growing recognition of MHWs as a critical concern for ocean health, significant gaps remain in our understanding of their long-term ecological consequences and the mechanisms driving ecosystem responses. Addressing these knowledge gaps will be essential for improving predictive capabilities and informing effective management strategies to mitigate the impacts of MHWs on oceanic ecosystems.

Keywords: Heatwave, Heat Stress, SST, Ecosystem.

Reliable CMIP6 projections of heat stress over India

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ABSTRACT

The anomalous episodes of extremely high surface temperature are known as heat waves. It causes disastrous impacts to human health, agriculture, ecosystem, economy etc. It is vitally important to develop effective intervention strategies to reduce the heat stress exposure. Reliable future projections at the regional level is essential for climate risk management. Current study deals with the projected heat stress over India which is addressed over seven temperature homogeneous zones (THZ) of India, viz. North West (NW), North Central (NC), West Coast (WC), East Coast (EC), Interior Peninsula (IP), Western Himalaya (WH), and North East (NE). In this study we have used the historical data for the period 1951 to 2014 and projections from 2015 to 2100 of the Coupled Model Intercomparison Project phase-6 (CMIP6). The projections of CMIP6 are based on Shared Socioeconomic Pathways (SSP) such as SSP126, SSP245, SSP370, and SSP585. Even though there is a wide dispersion is found between the climate models, most of the studies on projections are carried out on the multi-model mean. In this study, we have identified the suitable reliable model for each THZ. The selected model composite exhibited modest skill than all model composite, under the multiple characteristics of observed heat waves over each zone. The heat stress is analyzed with the metric EHF severity. The health hazard is projected to increase in all THZ, while the days with moderate heat stress increases homogeneously under all scenarios, while the days with severe heat stress will increase significantly during 2076-2100 (far future) and is maximum under SSP585. Beyond 2051, the moderate heat stress days are expected to increase about 20-30 days across most of the THZ. In the far future, severe heat stress days are projected to increase to 45 days in WC, EC, and IP under SSP585, while NE and NC is about 35 days and in NW and WH the increase is less than 20 days. The study highlights that the days with extreme heat stress are exacerbated in the southernmost India (south of WC, EC, and IP). Although currently, southern peninsular India experiences comparatively lesser impacts to heat waves, it is likely to be more susceptible to heat exposure in future.

Keywords : Heat waves, heat stress, CMIP6, Projections

Investigating the effects of the Indian Monsoon on Energy demand and Stock Performance

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ABSTRACT

Climate change impacts our society across the globe by disrupting the natural, economic and social systems we depend on. India's economic growth is significantly influenced by the temporal and spatial patterns and distribution of various weather factors, mainly temperature, humidity, and rainfall. The meteorological impacts on the energy sector are substantial and reported in several studies. This study investigates the intricate trio of energy demand, stock market performance, and weather patterns in India. This paper examines the complex nexus where these three factors intersect – an interdisciplinary domain comprising the ebb and flow of monsoonal rains, trends and patterns in energy demands, and the dynamic movements of the NIFTY index converge. This study compares the relationship between annual data on electricity demand, wind movements, humidity, rainfall, and NIFTY index data. The rationale for such an interdisciplinary dataset is that the Indian economy is expecting energy-driven growth, in which energy demand is influenced by the dynamic nature of weather factors, mainly temperature, humidity, and rainfall. At present, a combination of non-renewable and renewable sources meets the energy demand. As per the contemporary policy of the government regarding international commitments, the driving factor of economic growth is to shift to renewable energy sources. The volatility in energy demand has the potential to act as a major challenge towards the shift to renewable energy. Hence, this paper estimates the strength of the instability in energy demand concerning the changing meteorological factors. Further, the empirical understanding of the impact of the factors mentioned above on the NIFTY index of energy industries shows the direction and efforts required to frame energy policies with a comprehensive and realistic statistical estimation. This paper presents results from an AR- GARCH model study of Nifty Energy Stock returns as a function of rainfall, temperature, and energy demand. The effects of the Indian monsoon and Energy Demand on the Nifty Energy Stock returns during 2019-2023 are investigated with the Ordinary Least Squares method and the results are also reported.

Keywords: Energy Demand, Weather, NIFTY Index, Economic Growth, AR- GARCH

Marine Heatwaves in the Bay of Bengal and possible Impacts

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ABSTRACT

Marine Heat Waves (MHWs), a prolonged warmer ocean condition over 5 days, have economic and societal impacts as they influence marine environment and modulate air-sea interaction. Study using different datasets showed that the number of MHW counts and duration, the GHRSST (36 and 382 days) and OISST (33 and 294 days) overestimate these quantities with respect to RAMA buoy at 15°N (RM15) (25 and 287 days) for the duration (2008 – 2020). This results RM15 having a higher duration per MHW event (11.48 days) than GHRSST (10.61 days) and OISST (8.91 days). GHRSST exhibited its highest counts (duration) of 7 (82 days) during 2020 (2010), whereas RM15 showed only 3 (55 days) counts (duration) during 2020 (2010). Moreover, the mean daily intensities from satellite-derived SSTs (0.86 °C) are comparable to RM15 (0.87°C). The findings show that the MHWs become more prominent during El Niño/positive IOD events due to weakened winds, increased net heat flux input towards the ocean, increased stratification and warming tendency through vertical processes in the presence of inversion. This, in turn, affects the surface biological productivity in the region. Additionally, surface MHWs were also found to be driven by surface currents and eddies. Another study found that from 2007 to 2021, the area associated with Sea Surface Temperature greater than 31°C increased from 0.1 percent to 29 percent. The warming in 2021 is primarily linked with Marine Heat Wave events, which extensively cover the north BoB for a longer duration starting from the first week of May. Such warming extends even to the subsurface, providing the heat required to convert the depression into VSCS Yaas within two days. The development of the MHWs during the pre-monsoon have possible linkage with the heatwave conditions over land.

Cause and Economic impact of Marine Heatwaves

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ABSTRACT

An marine heatwaves (MHW) is a prolonged period of significantly higher than normal water temperature in a specific small or large area of the ocean. Which is the result of long term weather and climate change and some natural factors. As a result of these ocean heatwaves, there are some short and long term harmful effects on marine life and ecosystems. Also, due to the significant impact of seasonal and weather variations across continents, directly and indirectly, economic losses are incurred. Due to global warming change, direct and indirect effects of El-Niño in the Pacific Ocean and Indian Oceanic Dipole in the Indian Ocean due to unimaginable weather changes, prolonged rainless sea levels in tropical or subtropical regions and increase in sunshine hours, are responsible for oceanic heatwaves. Seasonal sea water temperature anomalies due to these oceanic heat currents are significantly noticeable and 50% increase MHWs in the past 10 years. Which is not only confined to the eastern Pacific region, but also extends over long stretches of the Atlantic and Indian Oceans.

As a result of these MHW, not only marine animals and biodiversity are harmed. This has directly led to a desynchronization of countries and continents in terms of seasonal weather patterns, resulting in rapid melting of polar ice caps and abnormal sea level rise, creating an existential crisis for small and low-lying areas. On the other hand, excessive rainfall in short-period rainfall areas, long-term low rainfall in long-term rainfall areas has resulted in agricultural losses, depleting groundwater supplies. The warm sea surface temperature meets the energy needs of tropical cyclones. MHW continue to help these tropical cyclones become more intense and increase in the number of storms. This effect of MHW is enough to weaken the economic infrastructure of the country and abroad in this way. For example, with prolonged above-normal water temperatures in most parts of the northern Bay of Bengal, there is a gradual decline in marine fish populations. Likewise, due to deficiency and inconsistency in monsoon rains, loss in agriculture is the cause of loss of economy of any country and region.

Characteristics of Marine Heat Waves during the Pre-Monsoon Season and its association with Chlorophyll-a concentration in the Arabian Sea and the Bay of Bengal

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ABSTRACT

Indian Ocean has experienced rapid warming in recent years, which increases the likelihood of Marine heatwave (MHW) occurrences in its basins. MHWs are extreme warm ocean surface conditions and are defined here when the sea surface temperature (SST) exceeds the 95th percentile value for three or more consecutive days. This study specifically examines MHW events that occurred in the Arabian Sea (AS) and the Bay of Bengal (BoB) during the pre-monsoon season (April–May) from 1982 to 2021, investigating their effects on Chlorophyll-a (Chl-a) and net primary productivity (NPP) in these oceanic regions. Throughout the study period, there were 42 MHW events occurred in AS and 68 in BoB with significant positive trends of about 8.1 and 6.3 MHW days dec^{-1}. Additionally, the study identifies a strong correlation between MHW duration and dominant climate modes. A noticeable decrease in Chl-a concentration was observed during MHW events in both basins, particularly for medium (7–14 days) and long duration (> 14 days) events, resulting in an average reduction of approximately 10% in the AS and 2% in the BoB. In general, AS and BoB have witnessed more frequent and long-lasting MHWs in the past few decades (2002–2021), which have substantially reduced the primary productivity of the north Indian Ocean.

Keywords: Marine heatwaves; Net primary productivity; Pre-Monsoon; Chlorophyll-a; SST; NIO

Analysis of Lightning Activity and thermodynamic parameters in a Region of High Lightning Incidents during the Pre-Monsoon Season

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ABSTRACT

The study primarily investigates the relationship between lightning activity and meteorological factors in the active lightning state of India, Kerala. Based on a 16-year lightning climatological analysis for the region, it is revealed that the active lightning period predominantly occurs in April, during the pre-monsoon season. Consequently, the study focuses on analysing the meteorological factors during this specific season. The analysis explores the influence of Convective Available Potential Energy (CAPE), Sea Surface Temperature (SST), vertical velocity and moisture transport from 1000 to 300 hPa on lightning activity. The diurnal climatology of lightning activity is uncovered, with a distinct peak at 3 PM local time, attributed to the presence of thunderclouds formed during the morning hours. The study establishes a clear link between CAPE, SST, and lightning activity, particularly during the pre-monsoon season, as revealed by the monthly climatology analysis. Vertical velocity at 500 hPa indicates the highest atmospheric instability in active lightning regions within the state of Kerala. In addition to that, the moisture transport during active lightning periods provides insights into thundercloud formation that results subsequent lightning activity. This study enhances the understanding of the how the meteorological parameters, including CAPE, vertical velocity, SST and moisture transport related to the lightning activity in Kerala.

Keywords: Lightning activity, Sea Surface Temperature, Moisture transport.

Does Convergence of Climate Change and Economic Headway Predict Fish Production? Theory and Cross-State Evidence from India.

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ABSTRACT

This study aims to evaluate the repercussions of climate change and economic indicators on India's fish production while delving into the causal relationship between these indicators and total fish production. The model incorporates two innovative techniques, namely, a two-stage instrumental-variables approach and Juodis, Karavias and Sarafids (JKS) causality test, to carefully examine the impact of these indicators on the overall fish production. An empirical analysis of annual data from 32 Indian states spanning the years 2000 to 2020 suggests that various climate change indicators, including carbon dioxide emissions, mean maximum temperature, and total rainfall, in conjunction with economic indicators such as net state GDP and per capita fish consumption, can provide valuable insights into forecasting India's total fish production, surpassing the information available from past production figures alone. Moreover, the study affirms a Granger-causal relationship between carbon dioxide emissions, net state GDP, fish consumption, and total fish production.

Keywords: Fish Production, Carbon Dioxide emissions, Mean Temperature, rainfall, JKS Granger Causality Test

Exploring Concurrent Hazards of Marine Heatwaves & Tropical Cyclones in North Indian Ocean

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ABSTRACT

India, surrounded by the Bay of Bengal, Arabian Sea, and Indian Ocean, faces profound economic and environmental impacts from oceanic anomalies. Most importantly, even individual Tropical cyclones or Marine heatwaves present a great threat to India. Concurrent or sequential occurrence of these two extremes can hugely exacerbate the associated risk. This study explores the simultaneous occurrence of Marine Heatwaves (MHWs) and Tropical Cyclones (low-pressure systems) in the North Indian Ocean (NIO) region, revealing potential risks arising from their concurrent or sequential incidence. The methodology employs sea surface temperature (SST) and mean sea level pressure (MSLP) datasets from ECMWF Re-Analysis (ERA5) data spanning 1979 to 2018. MHWs, characterized as discrete, prolonged periods of anomalously warm oceanic water, are rigorously defined through quantitative criteria based on sustained SST values. The study establishes crucial climatology and threshold values for identifying MHW events. Intensity of low-pressure systems is gauged using MSLP data, and a meticulous return period analysis is applied to assess days exhibiting extreme SST and MSLP concurrently. The study further investigates SST anomalies preceding major cyclonic events through composite plots, offering insights into the potential association between MHWs and TCs. Results indicate an average annual occurrence of 2 to 12 concurrent extreme SST and MSLP days. Trend analyses reveal a declining return period for SST, yet composite plots suggest no consistent significant association between Marine Heatwaves (MHWs) and Tropical Cyclones (TCs). Methodological variations yield consistent results, aligning with analogous studies in the northwest Pacific basin and emphasizing the importance of understanding regional climate intricacies.

Keywords: Concurrent events, ERA5, Marine Heatwave, North Indian Ocean, Tropical cyclone.

Seasonal forecasts of Marine Heat Waves

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ABSTRACT

The Monsoon Mission Climate Forecast System (MMCFS) has been instrumental in providing operational seasonal forecasts. The forecasts include long-range forecasts of rainfall, the El-Nino and Southern Oscillation (ENSO) state, the Indian Ocean dipole, surface air temperature, etc. Marine heatwaves (MHW) are known to disrupt the marine ecosystem and can potentially impact the human population living in coastal areas. Considering an increase in the frequency, intensity and duration of MHW under a warming scenario, their reliable seasonal forecasts can be vital for risk mitigation. In this study, we assess the capability of India's operational seasonal forecast system in predicting marine heatwaves at different lead times. Using thirty-seven-year-long hindcasts from the MMCFS, it is found that the model possesses significant skill at predicting the number of MHW days in a season. As is the case with rainfall over India, MHW skill also depends on large-scale drivers of tropical variability such as the ENSO. Even at long lead times, the seasonal forecasts are more skilful than climatology. Coupled model development activities, including increased ocean model resolution and improved model physics, are underway to enhance the indigenous MHW forecasting capabilities. This study paves the way for operationalizing the MHW forecasts in India.

Keywords: Marine heatwaves, seasonal forecasts, coupled ocean-atmosphere modeling.

Climate Change and Marine Heatwaves: Impacts on Ecosystems and Human-Ocean Interactions

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ABSTRACT

Anthropogenic climate change has led to profound alterations in marine ecosystems, primarily through the absorption of excess heat by the oceans. Over the past four decades, surface waters have warmed significantly, with a notable increase in the frequency and severity of marine heatwaves (MHWs). These events, driven by rising carbon emissions, are potent disruptors of marine ecosystems, causing shifts in species distributions, mass mortalities, and alterations in food webs and species interactions.

While our understanding of the physical drivers and biological impacts of MHWs has improved, there is a notable gap in comprehending their broader implications for human-ocean interactions. Regional studies have highlighted socioeconomic consequences such as reduced fisheries income, loss of essential ecosystem services, and conflicts arising from ecological disruptions. However, comprehensive analyses linking MHW impacts to human well-being and potential adaptation strategies are limited.

This presentation aims to address this gap by examining the implications of MHWs for human-ocean interactions. By elucidating the associated costs and risks, we seek to inform the development of adaptation and mitigation measures essential for safeguarding both marine ecosystems and the communities dependent on them. Through a comprehensive review of existing literature and case studies, we aim to provide insights into the multifaceted impacts of MHWs on human societies and the urgent need for proactive measures to mitigate these effects.

Keywords: Heatwave, Heat Stress, SST, Ecosystem.

Historical and future projection of marine heatwaves over the Arabian Sea and Bay of Bengal using CMIP6 Models

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ABSTRACT

The Indian Ocean has been undergoing rapid warming in recent years, which increases the likelihood of Marine heatwave (MHW). These are extreme warm ocean surface conditions that last for days to months and can extend up to thousands of kilometers reporting severe impacts on marine ecosystems which led to losses of marine biodiversity or changes in world fisheries. Events in which temperature exceeds the 95th percentile for three or more consecutive days are considered as MHWs. Climate models are the key tool for studying and projecting MHWs. In this study, we used 22 models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) and out of those 4 best models were selected based on the taylor diagram and were used to identify MHWs during the historical period (1982-2014) along with the daily Optimum Interpolation Sea Surface Temperature (OISST) dataset. MHWs were examined using the spatial patterns and temporal variations. Higher SST thresholds are estimated at the lower latitudes. The Bay of Bengal is found to have a higher threshold value when compared with the Arabian Sea. Then, we estimate future changes until the end of the 21st century under four shared socioeconomic pathways (SSPs).

Keywords: Marine Heatwave, Sea Surface Temperature,

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