Inter Disciplinary Programme in Climate Studies (IDPCS) Indian Institute of Technology (IIT) Bombay

We strive to foster fundamental understanding and problem centered research in climate science, solutions and policy across local, regional and global scales
Contact:

Prof. Subimal Ghosh
Convener, IDP in Climate Studies
IIT Bombay, Powai
Mumbai - 400 076, India
Tel: +91-22 2576 5141

head.climate@iitb.ac.in
http://www.climate.iitb.ac.in
The Interdisciplinary Programme in Climate Studies (IDPCS) was initiated at the Indian Institute of Technology Bombay (IIT Bombay), in January 2012, as one of the first doctoral programmes in India addressing research related to climate change. Over 32 faculty participants are drawn from 11 departments across IIT Bombay, who increasingly apply a depth of expertise in their fields to address the complexity of climate change. Currently, 65 PhD students and 2 Postdoctoral researchers are enrolled at IDP in Climate Studies.

**MISSION**

**Education:** To evolve an interdisciplinary doctoral curriculum, special courses for undergraduate and postgraduate students and to serve continuing education needs of professionals.

**Research:** To undertake high-impact, multi-disciplinary, problem-driven research for end-to-end solutions to climate change. To build long-term scientific capacity and systems for study of regional climate change and climate futures.

**Government:** To provide critical assessments to support policy and governmental decision-making. To provide strategic knowledge support to public and private sector entities catering clean energy and climate.

**Human Resource Development and Industry Interaction:** To enable the creation of a pool of multi-disciplinary researchers to serve the growing need for climate change professionals.
The PhD curriculum includes a set of courses on fundamental and applied topics designed to provide intellectual grounding for critical research, analysis and application.

**CORE COURSES:**

CM 803: Introduction to Climate Change  
CM 402: Earth’s Climate: Past, Present and Future

**SCIENCE TRACK COURSES:**

CM 801: Introduction to Risk Analysis  
CM 802: Atmosphere and Climate Change  
CM 701: Geophysical Fluid Dynamics  
CM 604: Remote sensing for Environmental and Climate Change Studies  
CM 608: Sustainable Engineering Principles  
CE 608: Ecohydroclimatology  
CE 605: Applied Statistics  
CE 701: Remote Sensing Technology  
CE 712: Digital Image Processing of Remotely Sensed Data  
CE 764: Hydroinformatics  
US 604: Management Techniques for Urban Systems  
US 607: Sustainability Assessment of Urban Systems

**POLICY TRACK COURSES:**

CM 607: Energy & Climate  
CM 609: Environmental Planning and Development  
CM 610: Policy Responses to Climate Change  
CM 606: Energy Resources, Economics and Environment  
CM 702: Law, Governance, Rights and Development  
CM 605: Public Policy & Governance
The PhD programme attracts highly accomplished students from diverse backgrounds including Atmospheric Sciences, Environmental studies, Engineering (Civil, Chemical, Computer Science, Information Technology), Economics, Planning & Architecture. Assistantships are available from MHRD funds to the Institute and multi-faculty research initiatives.

Currently, 65 students are enrolled for the PhD programme at IDP Climate Studies. The annual and cumulative student intake can be seen below:
The details of students from IDP in Climate Studies who have been placed with various industries and academic institutions can be found below. Over 15 students have graduated so far.

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<tr>
<th>ACADEMIA</th>
<th>INDUSTRY</th>
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<tr>
<td><strong>Dr. Pankaj Sadavarte</strong></td>
<td><strong>Dr. Nitin Patil</strong></td>
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<tr>
<td>Post-doctoral Fellow, Institute for Advanced Sustainability Studies e.v., Potsdam, Germany</td>
<td>Weather Modelling Group, Hewlett-Packard, Bangalore, India</td>
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<tr>
<td><strong>Dr. Hiteshri Shastri</strong></td>
<td><strong>Dr. Prashant Dave</strong></td>
</tr>
<tr>
<td>Asst. Professor, Charotar University of Science &amp; Technology, Gujarat, India</td>
<td>Sr. Quantitative Analyst, CRISIL, Mumbai, India</td>
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<tr>
<td><strong>Dr. Ankur Pandit</strong></td>
<td><strong>Dr. Tarul U Sharma</strong></td>
</tr>
<tr>
<td>Assistant Professor- R&amp;D, Welingkar Institute of Management Development and Research, Mumbai</td>
<td>Associate, GIST Advisory Pvt. Ltd.</td>
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<tr>
<td><strong>Dr. Aparna Dwivedi</strong></td>
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<tr>
<td>Principal, Dr Baliram Hiray College of Architecture, Mumbai</td>
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<td><strong>Dr. Manisha Jain</strong></td>
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<tr>
<td>Visiting Assistant Professor, IGIDR, Mumbai, India</td>
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<tr>
<td><strong>Dr. Supantha Paul</strong></td>
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<tr>
<td>Asst. Professor, Dept. of Civil Engineering, TIT Narsingarh, Agartala</td>
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<th>RESEARCH &amp; DEVELOPMENT</th>
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<tr>
<td><strong>Dr. Pratiman Patel</strong>, Postdoctoral Fellow, National University of Singapore, <em>Singapore</em></td>
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<tr>
<td><strong>Dr. Pankaj Kumar</strong>, Postdoctoral fellow, Qatar Environment and Energy Research Institute, <em>Qatar</em></td>
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<tr>
<td><strong>Dr. Piyali Chowdhury</strong>, Postdoctoral Fellow, University of Plymouth, <em>United Kingdom</em></td>
</tr>
<tr>
<td><strong>Dr. Deepika Swami</strong>, EMPRI fellow-Climate Change, Environmental Management and Policy Research Institute, Dept of Forest, Ecology and Environment, Govt of Karnataka, <em>Karnataka</em></td>
</tr>
<tr>
<td><strong>Dr. Swati Singh</strong>, Postdoctoral Fellow, IISER <em>Bhopal</em></td>
</tr>
<tr>
<td><strong>Dr. Krishna Malakar</strong>, Postdoctoral Researcher, College of Water Conservancy &amp; Hydropower Engineering, Hohai University, Nanjing, <em>China</em></td>
</tr>
<tr>
<td><strong>Dr Rakesh Sinha</strong>, Project Manager, Dept of Civil Engineering, IIT Bombay</td>
</tr>
<tr>
<td><strong>Dr. Anjana Devanand</strong>, Postdoctoral Researcher, School of Civil, Environmental and Mining Engineering, University of Adelaide, <em>Australia</em></td>
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<tr>
<td><strong>Dr. Jaysankar. T</strong>, Research Associate, IDP in Climate Studies, IIT Bombay</td>
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Special value is placed on the diversity of knowledge among the faculty who apply their expertise to interdisciplinary challenges that cross traditional academic boundaries to address climate change not only through earth and environmental science but also through economics and engineering. Around 32 faculty participants drawn from 11 departments across IIT Bombay are associated with IDPCS:

- Prof. Subimal Ghosh, Convener, IDPCS
- Prof. Chandra Venkataraman
- Prof. Subhankar Karmakar
- Prof. Mani Bhushan
- Prof. Yogendra Shastri
- Prof. Manasa Ranjan Behera
- Prof. T I Eldho
- Prof. D Parthasarathy
- Prof. Indu J
- Prof. Arpita Mondal
- Prof. RAAJ Ramsankaran
- Prof. Manne Janga Reddy
- Prof. Arun B Inamdar
- Prof. Harish Phuleria
- Prof. N C Narayanan
- Prof. Anand Rao
- Prof. Bakul Rao
- Prof. Rangan Banerjee
- Prof. K Narayanan
- Prof. Sridhar Balasubramanian
- Prof. S Gopalakrishnan
- Prof. Trupti Mishra
- Prof. Pradip Kalbar
- Prof. Eswar Rajasekaran
- Prof. Abhishek Chakraborty
- Prof. Karthikeyan Lanka
- Prof. Basudeb Biswal
- Prof. Manoranjan Sahu
- Prof. Vikram Vishal

Civil Engineering
Chemical Engineering
Environmental Science and Engineering Department
Chemical Engineering
Chemical Engineering
Civil Engineering
Civil Engineering
Humanities and Social Sciences
Civil Engineering
Civil Engineering
Civil Engineering
Civil Engineering
Centre of Studies in Resources Engineering
Environmental Science and Engineering Department
Centre for Technology Alternatives for Rural Areas
Centre for Technology Alternatives for Rural Areas
Department of Energy Science and Engineering
Humanities and Social Sciences
Mechanical Engineering
Mechanical Engineering
Shailesh J Mehta School of Management
Centre for Urban Science and Engineering
Civil Engineering
Environmental Science and Engineering Department
Centre of Studies in Resources Engineering
Civil Engineering
Environmental Science and Engineering Department
Department of Earth Sciences
The distribution of faculty members from various departments can be seen below:

- Chemical Engg: 3
- Mechanical Engg: 2
- Civil Engg: 10
- Environmental Sc and Engg: 5
- HSS: 2
- CSRE: 1
- Energy Sc and Engg: 2
- SIMSOM: 1
- CUSE: 1
- CTARA: 4
- Earth Sc: 1

- Environmental Science and Engineering Department
- Department of Energy Science and Engineering
- Civil Engineering
Cluster and components: Dedicated data-server with computer cluster (Master Nodes-2, I/O Nodes-2, One Storage/Controller-, Compute Nodes-24, cluster compilers and software.

Modelling software: Modelling platforms - ECHAM6-HAM2, WRF, MIKEFLOOD,SMS SWAT, Aqua Modelling System, Urbawind; Assessment tools - Aspen Plus, Nlogit, NVIVO, TIMES-VEDA ; Data handling/visualization -FERRET, GrADS, SigmaPlot, CDO, NCO, NCL, Xmgrace, Python; Mathematical/statistical -R, Matlab; Geospatial modelling - Arc GIS, ERDAS IMAGINE, QGIS, ENVI Sarscape.
Many sectors and regions in India are highly vulnerable to climate change impacts. Of particular importance is the fact that India is highly exposed to the risk of a number of natural hazards of climatic and hydro-meteorological origin including, for example, extremes of temperature and rainfall perturbation. Research activities at IDP in Climate studies offer a firm foundation in many leading-edge areas related to climate change. Research areas include prediction of climate perturbation and extremes, modelling of processes in the atmosphere and biosphere, climate change impacts on hydrology, climate mitigation technologies, technology assessment for competitiveness and sustainability, strategies for low-carbon development, mitigation and adaptation policies, vulnerability assessment, climate sensitive sectors and poverty, natural disasters, and human impacts. A broad framework for the integration of climate science to impacts (on socio-economic sectors) and responses (adaptation and mitigation through technology response) is laid out in the figure below.

[Diagram]

- **Climate Science**
  - Prediction of climate extremes
  - Factors affecting the Indian monsoon
  - Aerosol radiative processes, effects on clouds and rainfall
  - LES of cloud processes
  - Causality analysis and data assimilation
  - Impacts on hydrology and water resources
  - Climate change impacts on ocean processes

- **Mitigation and Policy**
  - Competitiveness and sustainability for climate mitigation
  - Strategies for low-carbon development
  - Assessment of climate change policies and mechanisms
  - Enhanced carbon capture systems
  - Multi-criteria mitigation assessment

- **Vulnerability Assessment and Adaptation**
  - Climate sensitive sectors and poverty
  - Natural disaster and human impacts
  - Climate change impacts on cities
  - Social and economic implications of climate change
  - Climate change policy and governance
  - Low carbon development

[Diagram]: A flowchart illustrating the integration of climate science to impacts and responses (adaptation and mitigation through technology response).
Department of Science and Technology sponsored Centre of Excellence in Climate Studies (DST-CoECS), IIT Bombay

For Continuation and Advancement of the Centre of Excellence in Climate Studies, IITB (Phase – II)

Project Investigators: Prof. Subhankar Karmakar

Co-Project Investigators:
Prof. Chandra Venkataraman
Prof. Subimal Ghosh
Prof. Trupti Mishra

Total project cost: Rs. 6.71 Cr

Duration: 5 years (2018-2023)

Broad areas and Sub-areas

Climate Change Science: Indian Monsoon, Aerosol Atmosphere Interactions, Land atmosphere interactions, Oceanic and Coastal processes, Land Surface processes

Climate Change Adaptation: Sector specific impacts assessment, Resources Management, Vulnerability and risk analysis

Climate Mitigation: Carbon sequestration, Climate finance, Carbon cycle and role of vegetation, Carbon emissions, Technology assessment
The project management is organized around a three tier structure involving 17 institutions. This includes a Lead institution, 8 Associate institutions and 8 field research institutions. A multi-pronged approach will be adopted towards building scientific capacity, as well as creation of infrastructure and systems (for measurements and modelling) at participating institutions.
It is a multi-institutional, coordinated project, with the following goals:

➢ To understand the sources, fate and impacts of carbonaceous aerosols, on climate and air quality, in the Indian region, through interdisciplinary research.
➢ To reduce uncertainties in our understanding of the impacts of carbonaceous aerosols on regional scales over India, through adoption of robust methodologies.
➢ To inform scientific communities, policy makers and the public regarding carbonaceous aerosol influence on climate change and climate stresses, and their implications.
➢ To promote training and learning about aspects of aerosol measurement and modelling through workshops on research methods.
OTHER RESEARCH INITIATIVES

- Understanding recent extreme events in India in the context of climate change | Funded by DST-UKIERI | Grant amount 30.71 lakhs | Duration: 2017-2019

- Meso-scale subsurface mixing dynamics in the Indian Ocean region using Modular Ocean Model (MOM) | Funded by DST | Grant amount 41.77 lakhs | Duration: 2017-19

- Extended Range Hydro-meteorological Forecasts for West Bengal at a District Level | Funded by Dept. of Environment, Govt. of West Bengal | Grant amount 99 lakhs | Duration: 2017-2019

- Transformation as Praxis: Exploring Socially Just and Transdisciplinary Pathways to Sustainability in Marginal Environments | Funded by BELMONT Forum, Netherlands | Grant amount 1 Crore | Duration: 2018-21

- Coastal Transformation and Fisher Wellbeing | Funded by EU- India Platform for Social Sciences and Humanities | Grant amount Rs. 17 lakhs

- A systematic large-scale assessment for potential of CO₂ enhanced oil and natural gas recovery in key sedimentary basins in India | Funded by DST | Grant amount Rs. 1.44 Crores
NETWORKS AND COLLABORATIONS

**Workshops on specialized themes**

International workshop on Green Finance Opportunities and Challenges, April 25 - 26, 2013.

1st Climate-Science and Policy Workshop, March 6-7, 2014.

Climate Modelling Workshop, March 20, 2015.

**Institutional linkages**

MoU with Indian Institute of Tropical Meteorology, Pune.

Co-advising of PhD students, from among staff scientists. Research collaboration to support the ESM evaluation and development.

International visiting lecturers from U. Maryland, U. British Columbia, Northeastern U., U. Oklahoma, Purdue U., Chinese U. of Hong Kong

Collaborative guidance of PhD students with scientists from CSIR-4PI, IITM, Cardiff U., U. Maryland, Columbia. U, Purdue. U.

**Linkage with policy makers**

Preparation of State Action Plan on Climate Change (SAPCC) for Rajasthan

Development of a Flood Forecasting System for Chennai.

Project on climate change in coastal districts of Maharashtra (GEF UNDP).

Participation in research and implementation of Maharashtra State Action Plan on Climate Change.

Research for Maharashtra’s State Knowledge Management Centre on Climate Change (SKMCCC) on Agriculture, Disaster Risk Management, Coastal Management & Rural Development

IPCC AR6

**Training initiatives**

CEP (Continuing Education Programme) courses offered to assist industry professionals in improving their skills.

Summer School: To create an awareness about the climate research for undergraduate and post graduate students. 6 summer schools organized and 101 students participated.

E school on Climate Science and Policy: virtual summer-school organised in August 2020 due to ongoing pandemic, received overwhelmingly positive response.

**Industry Linkage**

Course on ‘Sustainable Finance’ in Jan-2020 in collaboration Climate Bonds Initiative
The 7th summer school was organised virtually due to ongoing pandemic from August 17-28, 2021 and 1300+ students from various backgrounds participated. Prof. Pradip Kalbar was the co-ordinator for this year’s summer school. The summer school aims to draw the attention of outstanding students towards exciting research areas in Climate Studies. The course content includes lectures and tutorials on climate science and policy by faculty members from IITB and other renowned institutes.
The Interdisciplinary Programme in Climate Studies (IDPCS) organizes a number of lectures/talks by eminent faculty members/researchers from various institutes. The seminar series is envisaged as weekly lectures on a variety of topics relevant to Climate Studies. The audience is primarily students and faculty of the Climate Studies programme. However, we transitioned to virtual webinars during the 2020 pandemic, thus making the series accessible to all interested. Some glimpses below:

In Photo: 6th summer school, July 2019

**IDPCS WEBINAR SERIES**

The Interdisciplinary Programme in Climate Studies (IDPCS) organizes a number of lectures/talks by eminent faculty members/researchers from various institutes. The seminar series is envisaged as weekly lectures on a variety of topics relevant to Climate Studies. The audience is primarily students and faculty of the Climate Studies programme. However, we transitioned to virtual webinars during the 2020 pandemic, thus making the series accessible to all interested. Some glimpses below:

IDPCS WEBINAR SERIES

China-India Webinar on Climate Policy & Governance. Speaker: Prof. Yuan Xu, The Chinese University of Hong Kong
Scope for Technology Development & Entrepreneurship in Climate Studies

17 March 2021
5:00 – 6:30 PM (IST)
Register FREE: https://cutt.ly/IzHAIit

Organized by IDP in Climate Studies (IDPCS)
IIT Bombay
https://www.climate.iitb.ac.in/

M A N E U R A T O R S

Prof. Chandra Venkataraman
Professor
Chemical Engineering & IDPCS
IIT Bombay

Prof. Sridhar Balasubramanian
Associate Professor
Mechanical Engineering & IDPCS
IIT Bombay

P A N E L I S T S

Dr. Akhilish Gupta
Advisor & Head, SPLICE & CCP
Department of Science and Technology, Govt. of India

Mrs. Amita Sharma
Former ADD Secretary
Ministry of Human Resource Development, Govt. of India

Prof. Auroop Ganguly
Director, Sustainability and Data Sciences Laboratory, Civil and Environmental Engineering, Northeastern University, Boston, USA

Dr. Amir Bazaz
Senior Lead – Practice
Indian Institute of Human Settlements, India

Mr. Jatin Singh
Managing Director
Skymat Weather Services Private Limited, India

Dr. Additi Mukherji
Principal Researcher
International Water Management Institute, India

Funded by SPLICE, Department of Science & Technology (DST), Government of India

A Panel Discussion on Scope for Technology Development & Entrepreneurship in Climate Studies | Funded by DST, GoI
EVENTS

Workshop with team SPLICE, DST, GoI | 12th March 2020

Official launch of book “Climate Change Signals and Response: A strategic knowledge compendium for India” | 19 March 2019
EU Day event on “EU Policies and EU-INDIA Engagement on Sustainability, Environment, Climate Policies” | 27 February 2020 | Chief Guest: Ambassador of the European Union to India and Bhutan, H. E. Ugo Astuto
CLIMATE CO-BENEFITS OF AIR QUALITY AND CLEAN ENERGY POLICY IN INDIA

Sustainable development goals connect policies addressing air quality and energy efficiency with complementary benefits for climate mitigation. However, a typically fragmented approach across these domains hinders effectiveness in addressing short-lived climate forcers (SLCFs)—including methane, carbon monoxide, non-methane volatile organic compounds and black carbon—to supplement CO₂ mitigation. Here, to support policy coordination in India, we assess climate co-benefits of air quality and clean energy policies, using multiple metrics (global warming and temperature change potentials). We estimate an emission reduction potential of −0.1 to −1.8 GtCO₂e yr⁻¹ in 2030. The largest benefits accrue from residential clean energy policy (biomass cooking) and air pollution regulation (curbing brick production and agricultural residue burning emissions), which cut black carbon. In the next few decades (using global warming potential—GWP20), emission reduction potentials of warming SLCFs exceed those of CO₂, which is not evident on longer timescales. Concurrently, policies in the electricity generation and transport sectors reduce cooling SLCFs (SO₂ and NOₓ), potentially unmasking 0.1–2.4 GtCO₂e yr⁻¹. Integrating these interventions into national climate policies can strengthen both climate action and sustainability. The crucial impact of black carbon suggests that it should be included in the international climate accord.

CHOICE OF IRRIGATION WATER MANAGEMENT PRACTICE AFFECTS INDIAN SUMMER MONSOON RAINFALL AND ITS EXTREMES

There is an emerging understanding toward the importance of land-atmosphere interactions in the monsoon system, but the effects of specific land and water management practices remain unclear. Here, using regional process-based experiments, we demonstrate that monsoon precipitation is sensitive to the choice of irrigation practices in South Asia. Experiments with realistic representation of unmanaged irrigation and paddy cultivation over north-northwest India exhibit substantially different spatial patterns in experiments with a well-managed irrigation system, indicating that increase in unmanaged irrigation might be a factor driving the observed changes in the intraseasonal monsoon characteristics. Our finding stress the need for accurate representation of irrigation practices to improve the reliability of earth system modeling over South Asia.
The impacts of hazard events such as extreme rainfall, heatwaves, and droughts are substantial and represent an increasing threat over India. Effective adaptations to these hazards require an in-depth understanding of their physical and socioeconomic drivers. While hazard characteristic models have been substantially improved, compelling evidence of the spatio-temporal analysis of social vulnerability (SoV) throughout India are still lacking. Here, we provide the first analysis of the SoV to disasters at a national-scale for the past two decades using a robust data envelopment analysis framework, which eliminates subjectivity associated with indicator weighting. An interesting result is that SoV has decreased over past decade, which is primarily due to an increase in literacy rate and conversion rate of marginalized groups to main working population, and a decrease in child population due to use of birth control. Contrarily, while analysing hydroclimatic hazards over India, we notice an increase in probability of their occurrence over significantly large portions all over India, particularly in Karnataka, Maharashtra, Odisha, North-Eastern states and Telangana. The spatial pattern of increase is surprisingly similar for all three considered hazards, viz. extreme precipitation, heatwaves, and drought. Combining the information from SoV and hazard analysis, we further estimate the risk to hydro-climatic extremes. A notable observation is the synchronized increase in hazard and risk in these regions, indicating that hazards are contributing significantly to the increasing risk and not SoV. Further analyses of mortalities induced by different hazards indicate that deaths per million on a decadal-scale have either decreased or remained constant in recent decades, which suggests that mortality is decreasing despite the increasing risk of hazards over India. This also indicates an enhanced capacity for adaptation, which can be attributed to the decadal decrease in SoV observed in the present study.

Indian agriculture is globally well-documented to reflect the impacts of changing climate significantly. However, climate adaptation efforts are often hindered due to the inadequate assessment of coupled human-environment interactions. In this study, we propose a novel unified country-level framework to quantify the decadal agricultural risks derived from multiple hydro-meteorological exposures and adaptive consequences. We identify, for the first time, that rice and wheat risks have increased in the recent decade, with wheat at a twofold higher magnitude than rice. Increasing crops risk is found to be predominantly driven by the decreasing number of cultivators; in particular, the wheat risk is also attributed to increasing minimum
temperatures during the crop growing season. We provide convincing evidence indicating that the hydro-climatic hazards related to precipitation extremes and droughts are specifically alarming the crops risk as compared to temperature extremes. These observation-based results highlight the sensitivity of India’s agriculture and the risk associated with multiple agro-ecological and climatic components. We recommend these findings to facilitate the informed planning of adaptive measures and ensure sustainable food security of the nation.

SIMULATION OF PASSIVE MICROWAVE DATA TOWARD EFFICIENT ASSIMILATION OVER INDIAN SUBCONTINENT

Brightness temperature (Tb) is sensitive to soil moisture (SM) estimates and has the advantage of increasing the spatial coverage of SM measurements. This letter focuses on the simulation of Tb from the land surface variables generated by Noah with multiparameterized (Noah-MP) and a forward observation operator, community microwave emission model (CMEM) over the Indian subcontinent with a spatial resolution of $0.25^\circ \times 0.25^\circ$. Traditionally, soil dielectric constant and vegetation optical depth are the most important parameters that affect the sensitivity of the top of the atmosphere Tb. Hence, the results of the simulated Tb are presented for a total of 12 configurations and the one with better result (C12) is compared against the microwave polarization difference index (MPDI)-based Tb and observed SM and ocean salinity (SMOS) Tb. The simulated SM from the land surface model (LSM) is also compared with the observed SMOS SM to examine the sensitivity of the simulated Tb with SM. The results reveal that MPDI approach has immense potential in simulating the observed Tb and can be used toward the development of an efficient Tb assimilation system.

ON THE ROLE OF RAINFALL DEFICITS AND CROPPING CHOICES IN LOSS OF AGRICULTURAL YIELD IN MARATHWADA, INDIA

Crop loss and ensuing social crises can be detrimental for the agriculture-driven economy of India. Though some studies identify country-wide increasing temperatures as the dominant factor for crop loss, the agro-climatic diversity within the country necessitates an understanding of the influence of climate variability on yields at regional scales. We report a complex interplay among rainfall, temperature and cropping choices, with a focus on the drought-prone Marathwada region in Maharashtra. Our analysis based on observations, as well as statistical and rocess-based modelling experiments, and temperature projections of 1.5°C and 2°C warmer worlds show that for the two major cropping seasons, rainfall deficit is the primary cause of crop failure, as compared to rising temperatures. The gradual shift from drought resilient food crops, such as sorghum and pearl-millet to water-intensive cash crops such as sugarcane in recent years, is seemingly responsible for aggravating this crisis. Our findings warrant strategies promoting drought-resilient food crops, that will be useful, not only for mitigating the immediate agrarian
crisis, but also for curbing impending threats to food security in the region under future climate change.

ANALYSIS OF TEMPERATURE VARIABILITY AND EXTREMES WITH RESPECT TO CROP THRESHOLD TEMPERATURE FOR MAHARASHTRA, INDIA

Temperature is one of the prime factors affecting crop yield and thereby, in changing climate, it is imperative to investigate the co-variability of crop yield and temperature change. Temperature change can manifest itself in multiple factors such as deviation from long-period average, daily scale variability and frequency/intensity of extreme temperature events. To add to the complexity, each of these factors can affect the crop yield differently which necessitates understanding their effect on crop yield individually as well as collectively. Concerning this, we evaluated their distinct and combined impact with respect to threshold temperature of three major crops, i.e. sorghum, sugarcane and millet sown across the Maharashtra State of India. Further, the temperature parameters were conflated using confirmatory factor analysis to formulate a temperature variability index (TVI) that helped in identifying the collective impact of these multiple factors on each crop. Results show that the TVI and sugarcane yield for Nagpur and Bhandara districts of the Vidarbha region exhibited negative co-variability (−0.30/year), implying the negative impact of temperature change on sugarcane. For sorghum, Wardha and Bhandara of Vidarbha region, Solapur of Pune region and Ratnagiri of Konkan region exhibited negative co-variability with TVI (~−0.2 to −0.4/year). Contrary to sugarcane and sorghum, for millets, Akola, Amravati and Chandarpur districts in Vidarbha region; Hingoli, Parbhani, Nanded and Osmanabad in Marathwada region; Satara and Sangli in Pune region; Jalgaon in Nashik region and Ratnagiri; and Sindhudurg in Konkan region exhibited positive co-variability (0.50/year), signifying the favourable temperature conditions for sowing millet. Overall, due to the high exposure of districts to temperature change in Vidarbha and Pune regions, farmers in these districts are advised to refrain from sowing sorghum and sugarcane; instead, farmers can moderate the adverse effects of climate change by sowing millet due to the existence of conducive temperature for millet in Maharashtra. Further, analysis was used to suggest the region and climate-specific cropping pattern for other districts of Maharashtra that can be used by the policy makers to improve the situation of agriculture, farmers and economy of India.
Increasing trends in summer-time temperature maxima (Tmax) over India, show consequent increases in the intensity and frequency of heatwave events in recent years. Heat waves have been largely attributed to large-scale meteorological blocking, characterized by subsidence, clear skies and low soil moisture, in observational studies, or greenhouse gas enhancements in model studies. While radiative effects of absorbing aerosols are acknowledged, the association of absorbing aerosols with temperature maxima has not been investigated comprehensively. In the current study, statistical tools (such as correlation and Granger causality) were applied to long term (1979–2013) satellite and ground based observations to evaluate influence of absorbing aerosols on Tmax in north-west India (Tmax-NW). Regional absorbing aerosol index (AAI) in the north-west (AAI-NW) and central-India (AAI-CI) showed co-variability with Tmax-NW, implying connections to both local and non-local absorbing aerosols. The effects persisted on seasonal and heatwave event scales, becoming stronger on heatwave days with presence of enhanced AAI loadings. Causal effects of AAI-NW and AAI-CI were identified on Tmax-NW with a lag of 1–11 days, across multiple years, thereby establishing the influence of absorbing aerosols on heatwave events. The absence of confounding effects of surface pressure on these links suggests that, even during heat wave events linked to atmospheric blocking, absorbing aerosols can further enhance temperature maxima and related heatwave intensity.

SPATIOTEMPORAL ANALYSIS OF WATER BALANCE COMPONENTS AND THEIR PROJECTED CHANGES IN NEAR-FUTURE UNDER CLIMATE CHANGE OVER SINA BASIN, INDIA

Quantification of water-budget components is an essential step in the planning and management of water resources in any river basin. Recently several studies emphasized that climate change would inevitably affect terrestrial hydrology. This study applies distributed hydrological modeling using the Variable Infiltration Capacity (VIC) model to simulate the water balance components in the Sina basin, a drought-prone region in India. We analyzed the long-term spatiotemporal dynamics of precipitation, evapotranspiration, surface runoff, and baseflow components, and their alterations due to impending climate change. The study employed the Mann-Kendall test and Sen’s slope estimators to analyze the spatiotemporal trends of the water balance components during the baseline (1980–2010) and for the near future (2019–2040) periods. For the baseline period, precipitation exhibited an increasing
trend, particularly during the monsoon season. On the evaluation of the annual water balance components, it showed that the basin has a low annual rainfall (~ 718 mm) and relatively a very high annual evapotranspiration (~ 572 mm) during 1980–2010, which might be the main reason for frequent droughts in the study basin. Further, for analysing the climate change impacts on the water budget in the Sina basin, the VIC model was forced with outputs from a set of global climate models for near future (2019–2040) for two emission scenarios RCP4.5 and RCP8.5. Analysis of the results revealed that the water balance components in the near future would be negatively affected by climate change despite their increasing pattern in the baseline period. In comparison to the baseline (1980–2010), the surface runoff would decrease by as much as 32% for the near future, which stresses for planning and adaptation of appropriate mitigation measures in the basin.

**ABSORBING AEROSOLS AND HIGH-TEMPERATURE EXTREMES IN INDIA**

Heat waves in India during the pre-monsoon months have significant impacts on human health, productivity and mortality. While greenhouse gas-induced global warming is believed to accentuate high temperature extremes, anthropogenic aerosols predominantly constituted by radiation-scattering sulfate are believed to cause an overall cooling in most world regions. However, the Indian region is marked by an abundance of absorbing aerosols, such as black carbon (BC) and dust. The goal of this work was to understand the association between aerosols, particularly those that are absorbing in nature, and high-temperature extremes in north-central India during the pre-monsoon season. We use 30-year simulations from a chemistry-coupled atmosphere-only general circulation model (GCM), ECHAM6-HAM2, forced with evolving aerosol emissions in an interactive aerosol module, along with observed evolving SSTs. A composite of high-temperature extremes in the model simulations, compared to climatology, shows large-scale conditions conducive to heat waves. Importantly, it reveals concurrent positive anomalies of BC and dust aerosol optical depths. Changes in near-surface properties include a reduction in single scattering albedo (implying greater absorption) and enhancement in short-wave heating rate, compared to climatological conditions. Alterations in surface energy balance include reduced latent heat flux, but increased sensible heat flux, consistent with enhanced temperatures. Thus, chemistry-coupled GCM simulations capture an association of absorbing aerosols with high-temperature extremes in north India, arising from radiative heating in the surface layer.
The Himalayan ecosystem is a global biodiversity hotspot and a vital component of the global water cycle. However, the studies characterizing the ecohydrological processes of the Himalayas are still limited. Looking at a system as a network, having nonlinear couplings, can give us better insights into its dynamics. Here, using an information-theoretic approach on the variables, Precipitation (P), Temperature (T), Enhanced Vegetation Index (EVI), Latent Heat Flux (LH), Sensible Heat Flux (SH), Wind Speed (WS), Incoming Shortwave Radiation (SWL), and Relative Humidity (Q), we represent the ecohydrological processes of the Himalayas in the form of networks for three seasons: summer (MAM), monsoon (JJASO), and winters (NDJF). The networks have two types of links between variables: real-time and memory-driven. We show that the couplings between ecohydrological variables in the Western Himalaya are more memory dominant that the Eastern Himalaya. Precipitation interacts with vegetation in the Himalayas using both real-time associations as well as memory-based connections. The dominance of memory varies spatially and temporally. The Temperature, on the other hand, influences vegetation in near real-time, and it also has memory-based links in Central Himalaya and at the higher elevations of the Eastern Himalaya. We find that the real-time interactions (zero lagged connections) among ecohydrological variables are high during the monsoon as opposed to winters, which are dominated by memory-based associations. These findings provide the foundation for further analysis of the trajectory of Himalayan ecohydrological systems under natural and human-induced climate stresses.
During 2012-2020, several high-impact publications resulted from the ongoing research and many citations were received in the peer-reviewed literature with our research also getting highlighted in the media.


REACH OUT TO US

Convener, IDP in Climate Studies
IIT Bombay, Powai
Mumbai - 400076

Phone: +91 22 2576 5141
+91 22 2576 5142
E-mail: office.climate@iitb.ac.in

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A short Video about IDPCS: https://vimeo.com/iitbombay/idpcs
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CREDITS

Prof. Subimal Ghosh - Convener, IDP in Climate Studies

Associated Faculty, IDPCS, IITB:
Prof. Harish Phuleria | Prof. J Indu | Prof. Pradip Kalbar

PhD Scholars, IDPCS, IITB: Srinath Haran Iyer | Shrabani Tripathy | Sindhuja Kasthala

Archismita Banerjee - Project Manager, IDP in Climate Studies
Sheeba Sekharan - Research Associate, IDP in Climate Studies

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