WCSSP India Science Plan – 2023/24 and beyond

Introduction

The UK and India 2030 Government Strategic Roadmap highlights the ambition to "*Strengthen joint collaboration through The Weather and Climate Science for Service Partnership India to advance scientific understanding and modelling capabilities that can be translated into services"*.

This Science Plan provides a high-level overview and roadmap to guide the scientific research and capability enhancement across the WCSSP India project. It builds on the previous Science Plan, and project achievements documented through previous Annual Science Highlight Reports. This plan represents an evolution of the project, including areas of ongoing work that continue to meet the long-term project aims, and integrating new areas of scientific collaboration and innovation identified during the 2023 WCSSP India Annual Science Workshop and follow-up discussions between UK and India Work Package leads and the WCSSP India Executive Committee during July 2023.

This Science Plan is anticipated to remain effective for at least two years, encompassing FY23/24 and FY24/25. It will subsequently be revised and updated in agreement across the Partnership, informed by the recommendations of the Science Review Panel.

Project Vision and Outcomes

WCSSP India is focussed on enhanced understanding, methods, and tools for improving risk-based forecasting of natural hazards. These outputs provide a pathway for partners in the Indian Ministry of Earth Sciences (MoES) to deliver improved weather and seasonal climate services.

This is achieved by delivering the following Outcomes:

i) **Developing enhanced modelling capabilities** across time and space scales, in UK and India, that enables improved forecasting system and service development by MoES partners,

ii) **Producing new knowledge** using a range of theoretical, observational, modelling and application research to develop improved understanding and prediction of natural hazards and their impacts in the context of the Indian monsoon,

iii) Sharing knowledge through **joint UK-India research publications** in internationally recognised journals, and a range of other communication methods, recognising the value in bringing together diverse perspectives and skillsets to address problems,

iv) Nurturing **productive and collaborative UK-India partnerships**, through a variety of approaches to facilitating interactions across the project including regular in-person and online engagements between scientists, exchange visits and through relevant scientific fora and conferences,

v) **Co-developing from science to prototype tools** that provide a pathway for MoES partner organizations to develop, implement and routinely support enhanced operational services, with focus on enhanced information on high-impact weather and impact-based forecasting capabilities.

The WCSSP India project is guided by a set of common **Outputs**, that are delivered by undertaking several project **Activities**, and lead to delivery of the project **Outcomes** (see Figure 1).

The activities outlined in this plan are aligned to the science priorities across all partners. The research addresses pioneering scientific challenges to enhance understanding and improve observation and prediction of natural hazards in India and the wider region, as well as opportunities to leverage new scientific innovations to progress the development of impact-based forecasting methods.

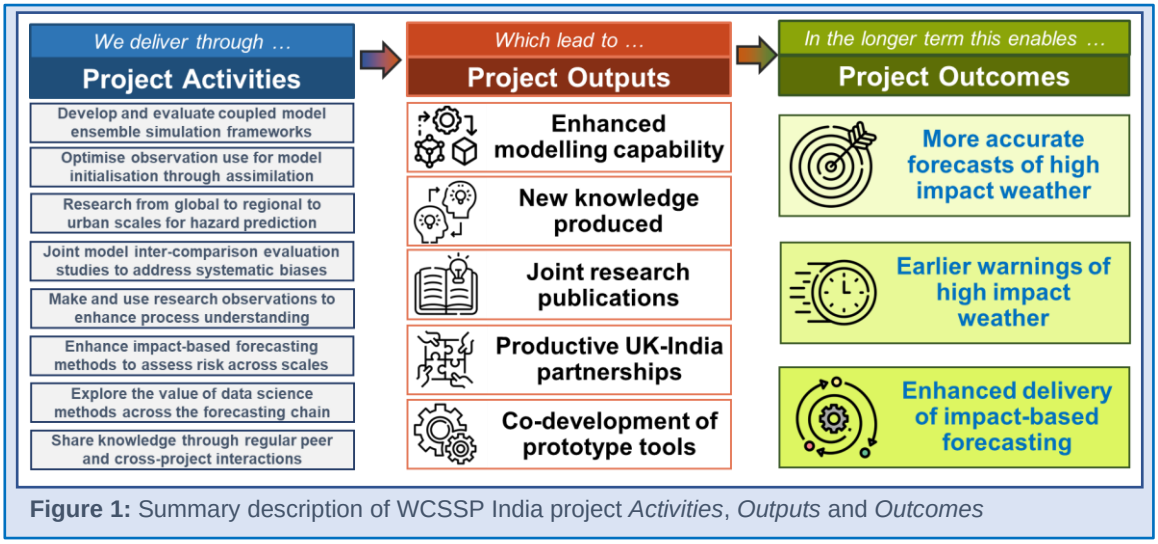

Figure 1: Summary description of WCSSP India project *Activities*, *Outputs* and *Outcomes*

Collaboration

Collaborative work under WCSSP India is based on establishing and maintaining an equitable partnership between Met Office, UK academic and MoES contributions, with benefits to all parties. Knowledge exchange and peer support will be enabled through several complimentary approaches (see Figure 2), including routine peer-to-peer interaction, working group discussions, in-person visits, subject-specific meetings and Annual Workshops.

Research activities will adopt good practice in co-production and consideration of ethical standards, addressing gender equality and social inclusion (GESI) in the design, implementation, and monitoring of activities, and promoting humility in the development and application of science.

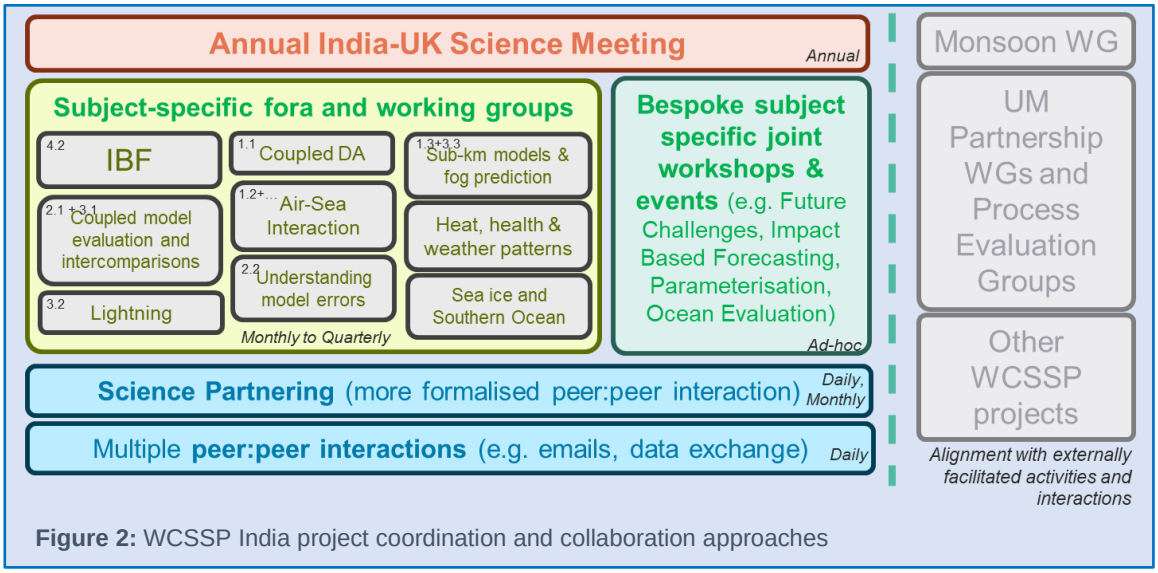

Figure 2: WCSSP India project coordination and collaboration approaches

The project will be delivered with the support of UK and India leads across each of 4 Work Packages (see below), who will facilitate and encourage collaboration between relevant groups. This will be supported by an overarching Executive Committee to help steer the project direction, monitor progress, and address project challenges, recognising the different constraints and challenges faced by different partners at times.

Project Scope

1. **Scientific Innovation:** Advance understanding of India weather and climate processes, hazards, and risks, through innovating new approaches to:
    - numerical weather prediction, post-processing and impact-based forecasting,
    - development of coupled prediction capabilities to enhance environmental predictions and provision of compound hazards,
    - research on global to regional scale drivers of high impact weather, days to seasons ahead,
    - quantify and optimise the costs and benefits of resolution, complexity and ensembles for atmosphere and marine models to enhance predictability,
    - exploit observational evidence for enhancing process understanding, improving model formulations, and advancing model evaluation,
    - machine learning applications and methodology development for weather and climate.

2. **Strengthening UK and India capabilities:** Strengthen scientific and technical capabilities across all partners across the observational and modelling chain, including supporting the evolution towards global and regional coupled prediction capabilities at increasing model resolution, exploitation of urban-scale models for local scale hazards, and enabling optimal use of operational observations through assimilation to enhance forecast skill.

3. **Natural hazard focus:** Natural hazards and weather/climate variability of key importance include:
    - Extreme precipitation events and flash floods, and related hazards such as lightning risk and landslides,
    - Fog, low visibility and air quality,
    - Tropical cyclones and monsoon depression predictability across timescales,
    - Boreal summer intra-seasonal oscillations (BSISO) and active-break cycles,
    - Prolonged heatwaves and dry spells,
    - Flooding from sustained monsoon precipitation,
    - Compound hazards, including across environmental components.

4. **Science to service**: Identifying and testing the effectiveness of methods to translate development of underpinning research to improve the identification and interpretability of model data for impact-oriented forecasting and warnings, including through:
    - Facilitating the development of prototype forecast applications by MoES partner organisations that translate model outputs to identify high-impact weather events,
    - Enhanced understanding of the value, skill, reliability and robustness of different impact-based techniques.

    This in turn provides a basis for MoES to further develop and operationalise the systems and services required to meet user needs in India.

5. **Alignment:** Align activities with other relevant weather and climate programmes and initiatives in the UK and India, and more broadly in the international weather and climate community, leveraging opportunities for joint science to create efficiencies, share learning, and avoid duplication.

Project structure

WCSSP India is composed of four inter-dependent work packages (Figure 3). Work packages 1 to 3 are focused on underpinning research that will advance different areas of observation, process understanding and prediction of natural hazards, in order to improve the quality of the modelling systems that are used for predictions. Work package 4 is focused on developing methods and processes that build on that research to enhance impact-based forecasting capabilities and their effectiveness in India. The work packages and their activities are designed to meet the overall vision and objectives of the project, recognising some activities will be conducted in collaboration across work package boundaries.

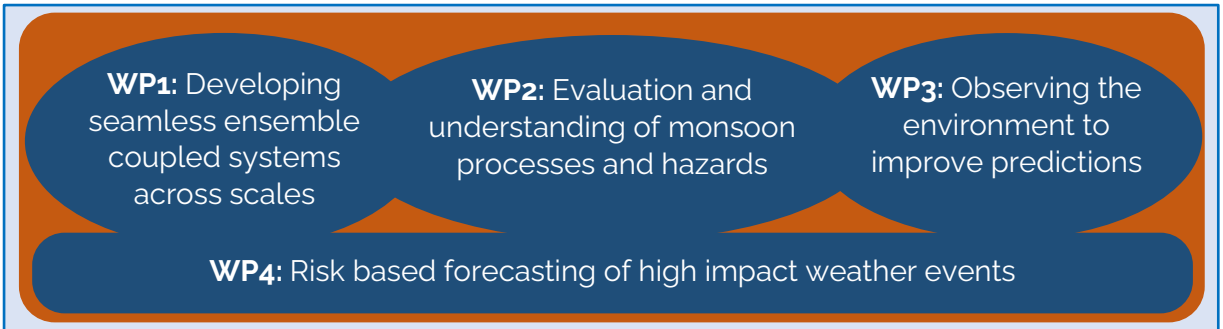

Figure 3: WCSSP India work package structure and themes

WP1: Developing seamless ensemble coupled systems across scales

Aim: In partnership, develop cutting-edge seamless modelling systems that underpin environmental predictions across space scales and time scales from hours to seasons ahead. Specific aims include development of global coupled ensemble systems, regional coupled ensemble systems and improvements to urban-scale atmosphere modelling.

Summary

WCSSP India has delivered enhanced modelling capability including evaluation and implementation of new ocean-atmosphere coupled global and regional configurations using the Unified Model for applications with India focus, along with enhancements to physical parameterisations, assimilation methods, and evaluation tools.

WP1 will focus on developing new modelling, ensemble and data assimilation capabilities using Unified Model and LFRic based model infrastructure, with development learning from other modelling codes also in use across MoES. The overarching theme is to develop a seamless suite of coupled modelling tools spanning from global scale, convective regional to sub-km scales within a consistent ensemble framework across components.

Details

UK lead: Arathy Menon (Met Office)	**India lead:** John George (NCMRWF)
Partners: Met Office, UK academia, NCMRWF, IITM, INCOIS, IMD	
High-level objectives • Develop and evaluate the benefits of high-resolution global coupled ensemble prediction systems to underpin improved synoptic-scale predictions from days to seasons ahead. • Improve the use of satellite and in-situ observations within atmosphere and marine assimilation systems. • Develop and evaluate the benefits of a regional environmental prediction to enhance process understanding and as a path to improved prediction of compound hazards in India. • Develop and evaluate the benefits of urban-scale (sub-km) simulations to predict critical weather phenomena in urban and non-urban environments, including fog, air quality and intense convective rainfall. • Explore the optimal balance and relative value of model resolution, complexity and ensemble to enhance provision of forecast information for high impact weather. • Explore the value for exploiting data science and machine learning methods through the science to service chain. • Support a transition from existing capabilities to next-generation modelling systems ready to exploit exascale computing and increasing use of GPU for numerical prediction.	

WP2: Evaluation and understanding of monsoon processes and hazards

Aim: In partnership, develop novel diagnostic tools and use observations to assess critical processes of monsoon prediction and associated hazards, and carry out process research to understand the predictability and systematic errors of coupled models at seasonal and sub-seasonal timescales.

Summary

WCSSP India has enabled new understanding of monsoon processes through extensive joint model intercomparison, assessment of new diagnostic and evaluation methods, and process studies focussed on land-atmosphere and ocean-atmosphere interactions and development of model biases.

WP2 is focused on underpinning research towards improving global and convective scale coupled models, by evaluating different model configurations, studying the development of model systematic errors, and process research to understand large-scale and regional drivers of monsoon variability and hazards on prediction timescales from hours to a season.

Details

UK lead: Gill Martin (Met Office)	**India lead:** Vinu Valsala (IITM)
Partners: Met Office, UK academia, IITM, INCOIS, NCMRWF, NCPOR	
High-level objectives • Coupled model evaluation and inter-comparison to explore predictability of monsoon characteristics as well as to identify and improve common systematic biases. • Investigate the representation, predictability, variability and impacts of monsoon extreme events (including intense rainfall, dry spells, heatwaves, cold waves). • Investigate interannual drivers of sub-seasonal prediction skill, including ENSO- and IOD-teleconnections, and their sensitivity to model physics and resolution. • Intercomparison of global and regional scale ocean models and their ability to capture key processes of relevance to the Indian region from broad-scale (e.g. inter-basin connections) to local scale (e.g. ocean mixing and internal tides). • Understand ocean processes affecting tropical cyclone evolution and their prediction, including sensitivity to model resolution and wave interactions. • Use sensitivity experiments, process-based diagnostics, model hierarchies and observational frameworks to understand and address key model systematic errors. • Understand the role of ocean-atmosphere and land-atmosphere coupling on the evolution of systematic biases in the Indian region, and sensitivity to model resolution and process representation (e.g. irrigation). • Improve understanding of polar processes and their remote teleconnections influencing tropical meteorology. • Explore the value for exploiting data science and machine learning methods for model evaluation and process understanding.	

WP3: Observing the environment to improve predictions

Aim: In partnership, improve hazard prediction through the collation and use of observations for model evaluation and support development of improved physical parameterizations of sub-gridscale processes, with particular relevance to precipitation, lightning and fog hazards in India.

Summary

WCSSP India has delivered new process understanding and enhanced parameterizations linked to convection, clouds and microphysics, and thereby driving improvements to the prediction and diagnosis of lightning and fog hazards.

WP3 is focused on harnessing observations from unique atmospheric measurement facilities that exist in India to improve local-scale process understanding and thereby feed into enhanced representation of sub-grid processes in global and regional models. Research observations will be combined with modelling approaches, utilising a model hierarchy from global to regional domains at a range of resolutions through to idealised and process-based models. This will lead to development of improved and new parameterizations, both through more traditional physics algorithm development and by exploiting machine learning emulation. With processes associated with the South Asian monsoon posing some of the biggest challenges for existing parameterizations, if this approach is successful, the approach has potential to deliver significantly more accurate forecasts for the Indian subcontinent across timescales.

Details

UK lead: Bernard Claxton (Met Office)	**India leads:** Anupam Hazra, G. Pandithurai (IITM)
Partners: Met Office, UK academia, IITM, NCMRWF	
High-level objectives • Maintaining and using observational in-situ measurements, with focus on the development of super-site observing facilities by MoES in India, to enhance process understanding and model evaluation, including long-term monitoring and intensive observation campaigns. • Translate improved process understanding through to new and improved parameterizations of sub-grid processes in global and regional models. • Focus development on key gaps in the representation of convection, clouds and microphysics. • Explore the utility of intra-model machine learning methods to provide more cost-effective approaches to improving sub-grid parameterizations. • Demonstrate the impact of improved understanding, and of enhanced parameterizations and model diagnostic schemes for provision of guidance on risk of hazards including lightning and fog.	

WP4: Risk based forecasting of high-impact weather events

Aim: In partnership, develop research, methods and processes that underpins the effective translation of global and regional-scale model outputs to improved early warning and communication of high-impact weather events from days to seasons ahead and enhance impact-based forecasting capabilities.

Summary

WCSSP India has supported the co-development from science to prototype tools, including substantial progress to establishing an end-to-end workflow for the Flood Hazard Impact Model as a practical tool that can be used by MoES partners, and establishment of a UK-India Impact-based Forecasting (IbF) Working Group to exchange experience on IbF practices and methodologies. As a fundamental basis of WCSSP India, the increased understanding and enhanced observation and prediction systems delivered across WP1, WP2 and WP3 supports the long-term evolution of weather services and the transition to impact-based forecasting, that is ultimately delivered to end-users in India by MoES.

WP4 will research, develop and improve upon existing methods, which translate global and regional-scale model outputs into forecast products that can facilitate improved early warning and communication of high-impact events. Concentrating on key natural hazards (linking to research under WP1, WP2 and WP3), notably the impacts of heavy rainfall, but potentially including other hazards such as fog, lightning and heatwaves, the work package will focus on developing impact-based forecasting approaches and integrated, multi-hazard warning applications, building on rather than looking to replace existing tools and infrastructure already in place in India. As the maturity of research undertaken within WCSSP India project develops, opportunities will be taken to facilitate co-development of research prototypes that will provide new understanding on the utility of high-impact weather and impact-based forecasting information in support of MoES development of IbF capabilities in India. Collaborative research will aim to enhance the translation of forecasts for improved decision making. There is a key dependency of this activity on access to impact-relevant data (e.g., relating to vulnerability), and approaches to ensuring this dependency can be met will be explored.

Details

UK lead: Seshagirirao Kolusu (Met Office)	**India lead:** Jenamani R K (IMD)
Partners: Met Office, UK academia, IMD, NCCR, NCMRWF	

High-level objectives

- Enhance predictability, post-processing and verification of high-impact weather, with focus on extreme precipitation representation, fluvial flooding associated with tropical cyclones and extreme heat.
- Advance dynamic impact modelling and forecasting techniques to enable easier decision-making, identifying and assessing relevant scientific approaches to impact-based forecasting.
- Support knowledge exchange on application of impact-based forecasting through routine engagement in the Impact-based Working Group.
- Develop evaluation methods and metrics applicable for impact-based forecasts in India.
- Investigate novel approaches to capture information on socio-economic impacts to support the development of impact-based thresholds, impact tables and impact models.
- Facilitate the development of prototype forecast methods to translate ensemble model outputs to identify high-impact weather events, including weather pattern applications.
- Investigate methods for effective translation and communication of impact-based forecasts, focussing on strategies to making impact information useable at different timescales.
- Explore the value for exploiting data science and machine learning methods through the science to service chain, with focus on translation of model outputs for effective decision-making.