

Early warning of hydrological extremes in India

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WATER & CLIMATE LAB.
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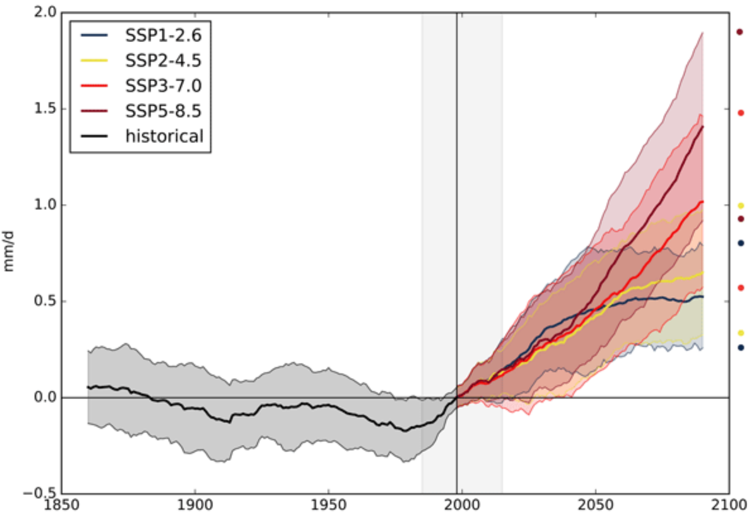
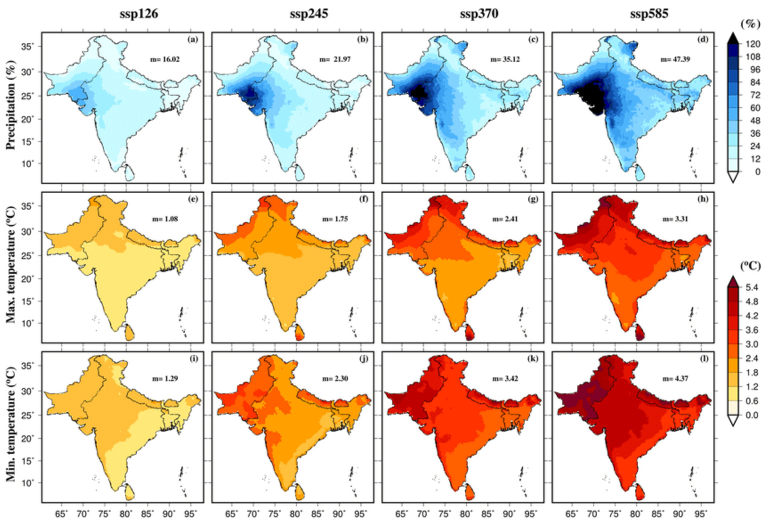
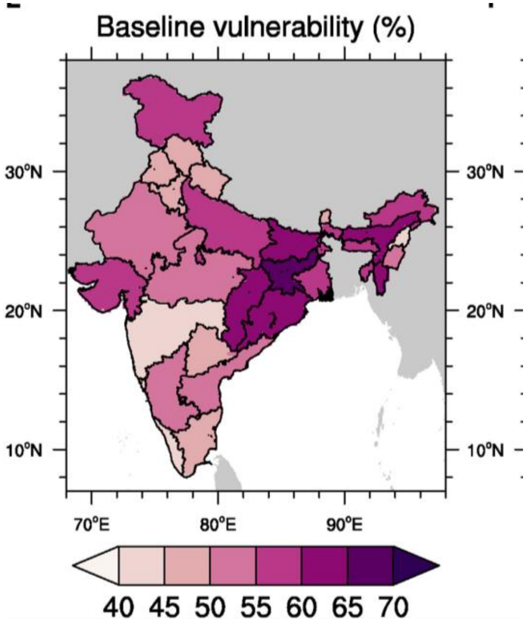
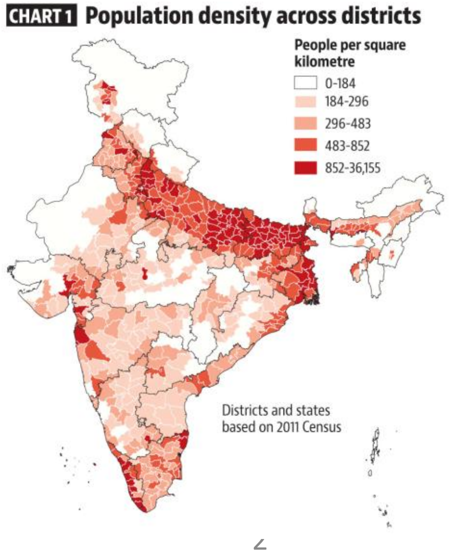
Early warning: why?





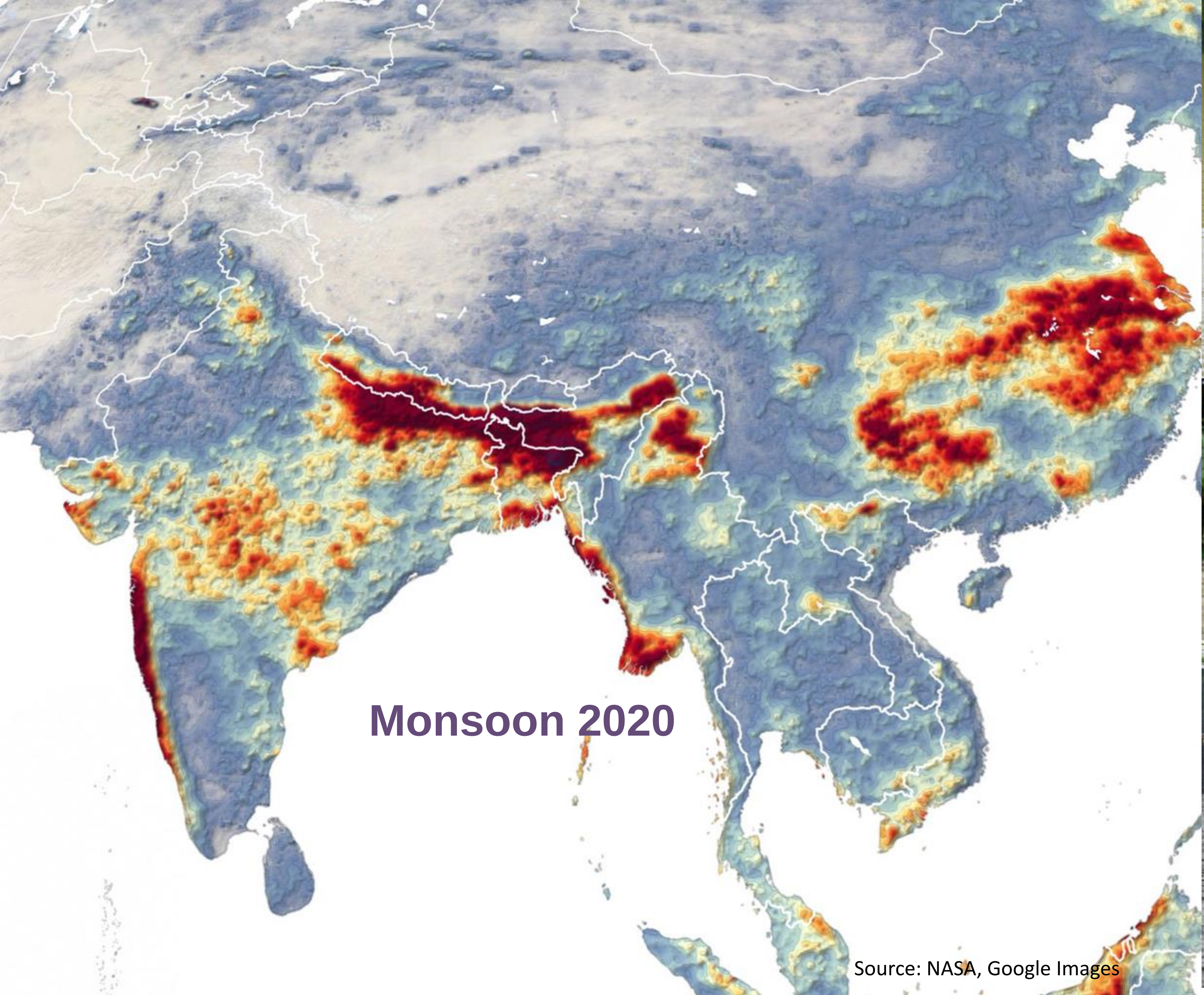




Risk of hydroclimatic extremes

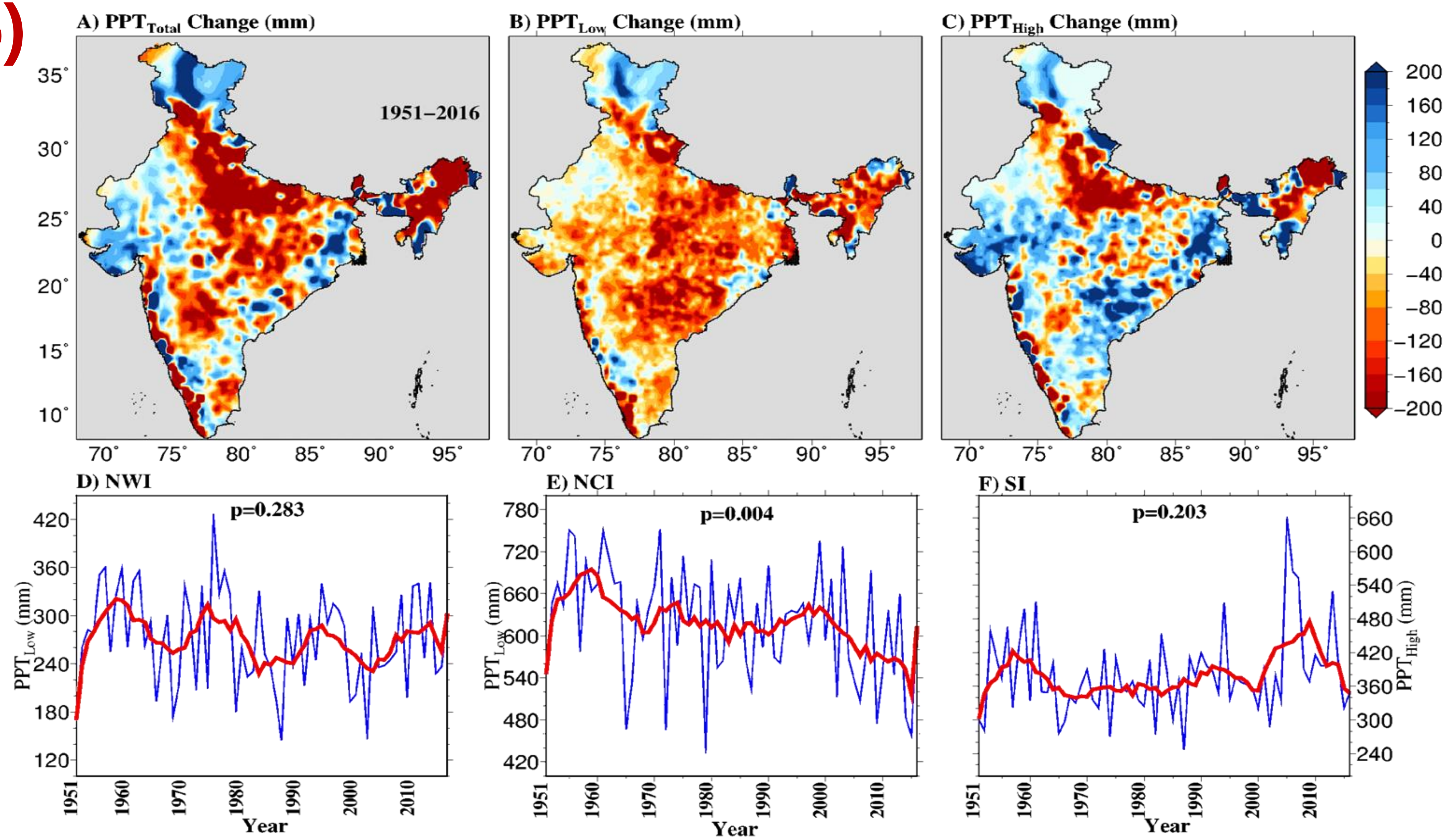
- Air temperature (rise, irrigation/aerosols)
- Precipitation (mixed trends, more variability)
- Floods/flash floods (rise, more impacts)
- Droughts/flash droughts (intense, spatial/temporal variability
- Compound extremes (hot-dry, wet-humid)
- Dry and moist heatwaves (rise, larger extents)

Monsoon 2020



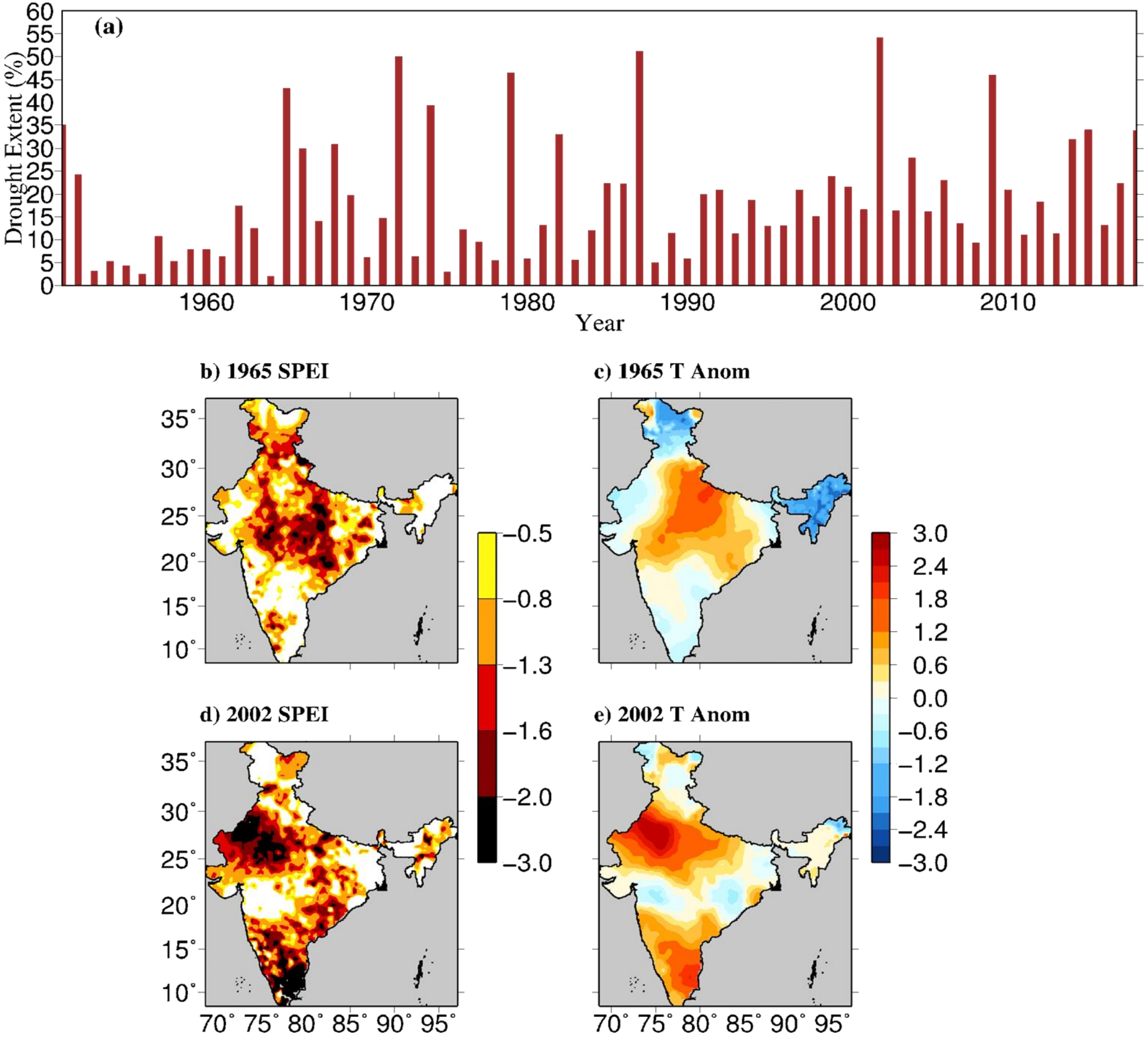
Source: NASA, Google Images

Observed changes in rainfall characteristics (1951-2015)



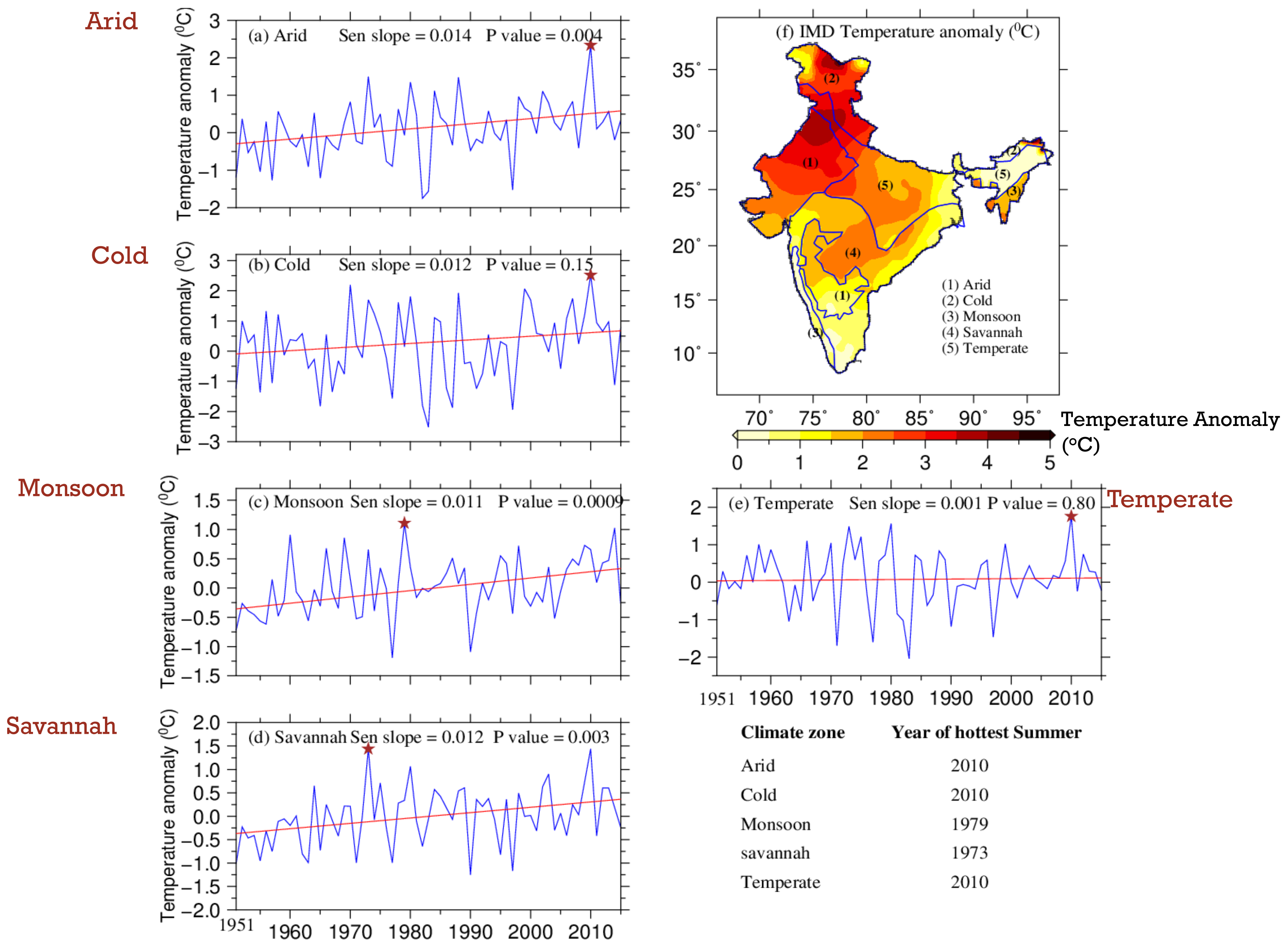
Asoka et al. 2018, GRL

Monsoon season droughts in India



Mishra et al. (2020), npj Climate and Atmospheric Sciences

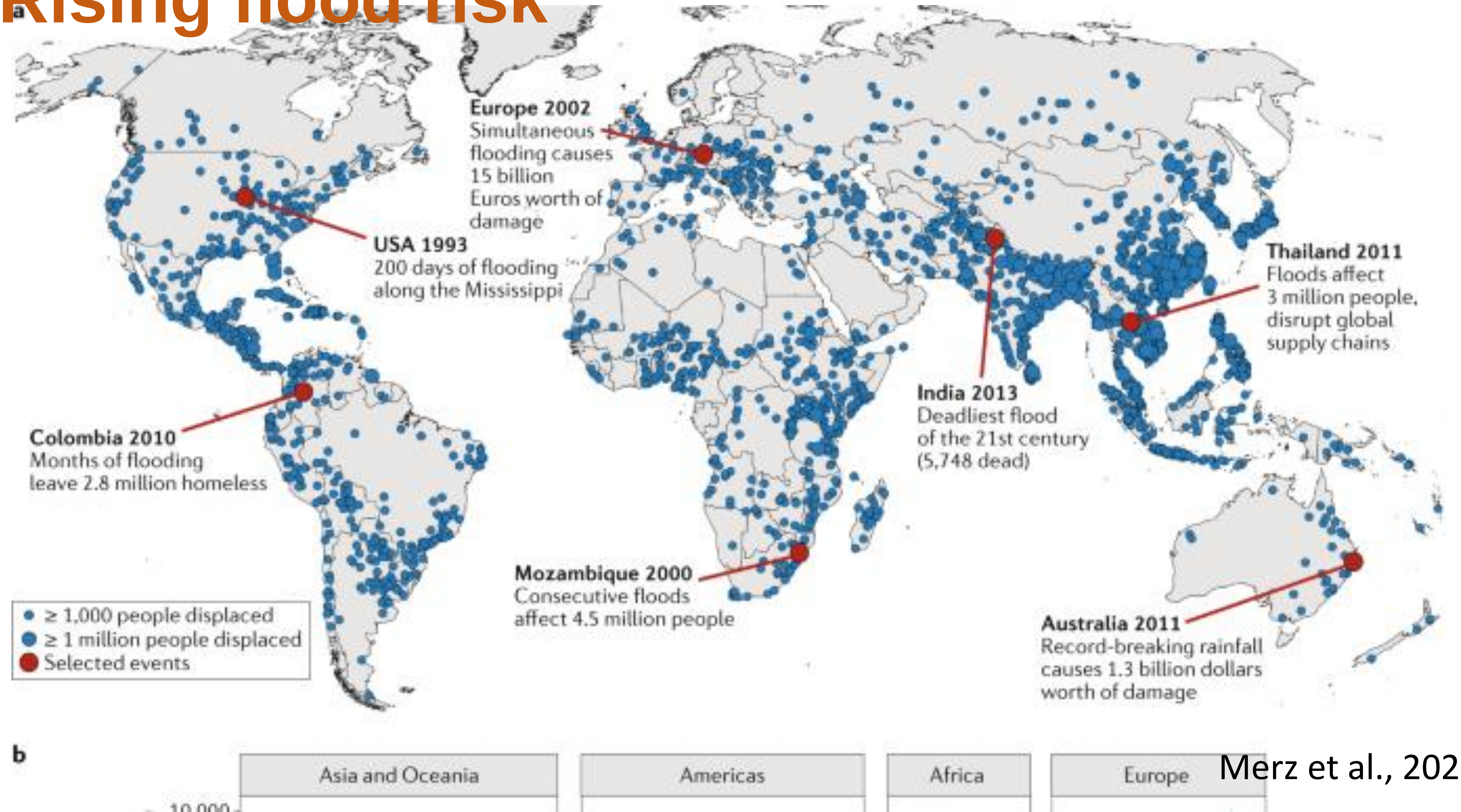
Rising temperature and hottest summers



Climate zone	Year of hottest Summer
Arid	2010
Cold	2010
Monsoon	1979
savannah	1973
Temperate	2010

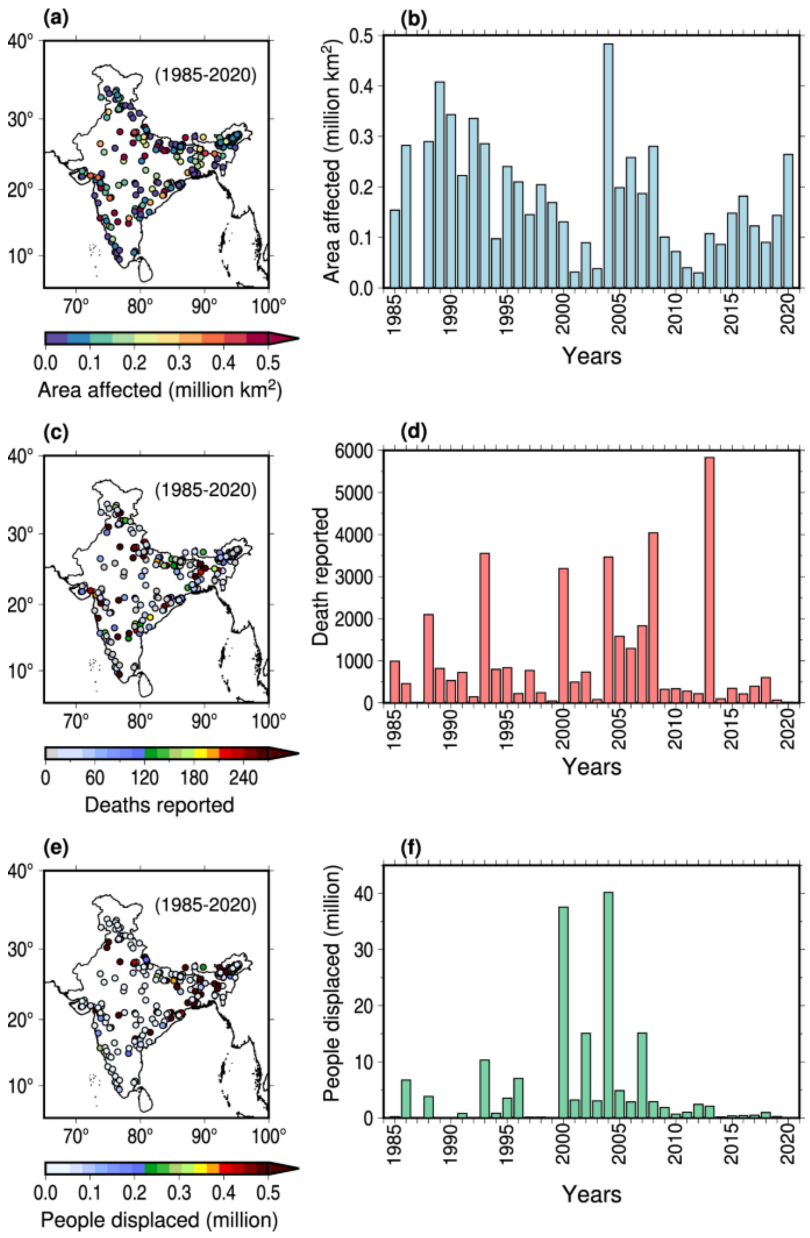
Nanditha et al., 2020, ERL

Rising flood risk



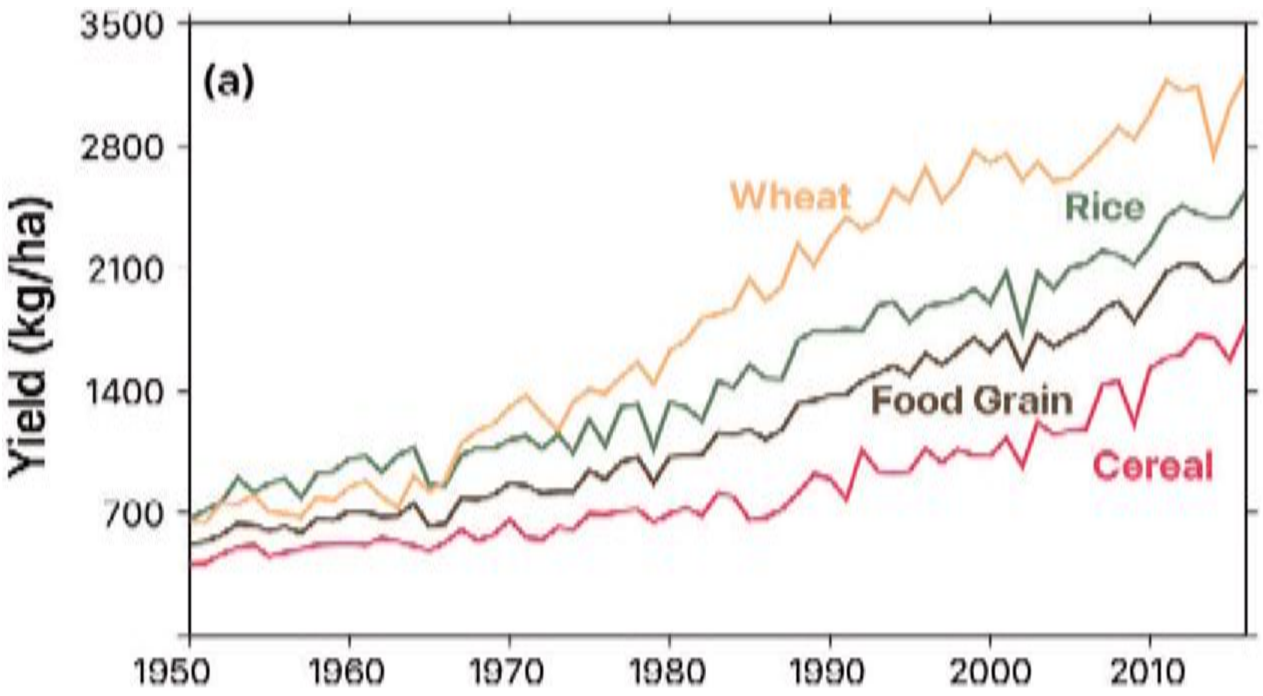
Merz et al., 2022

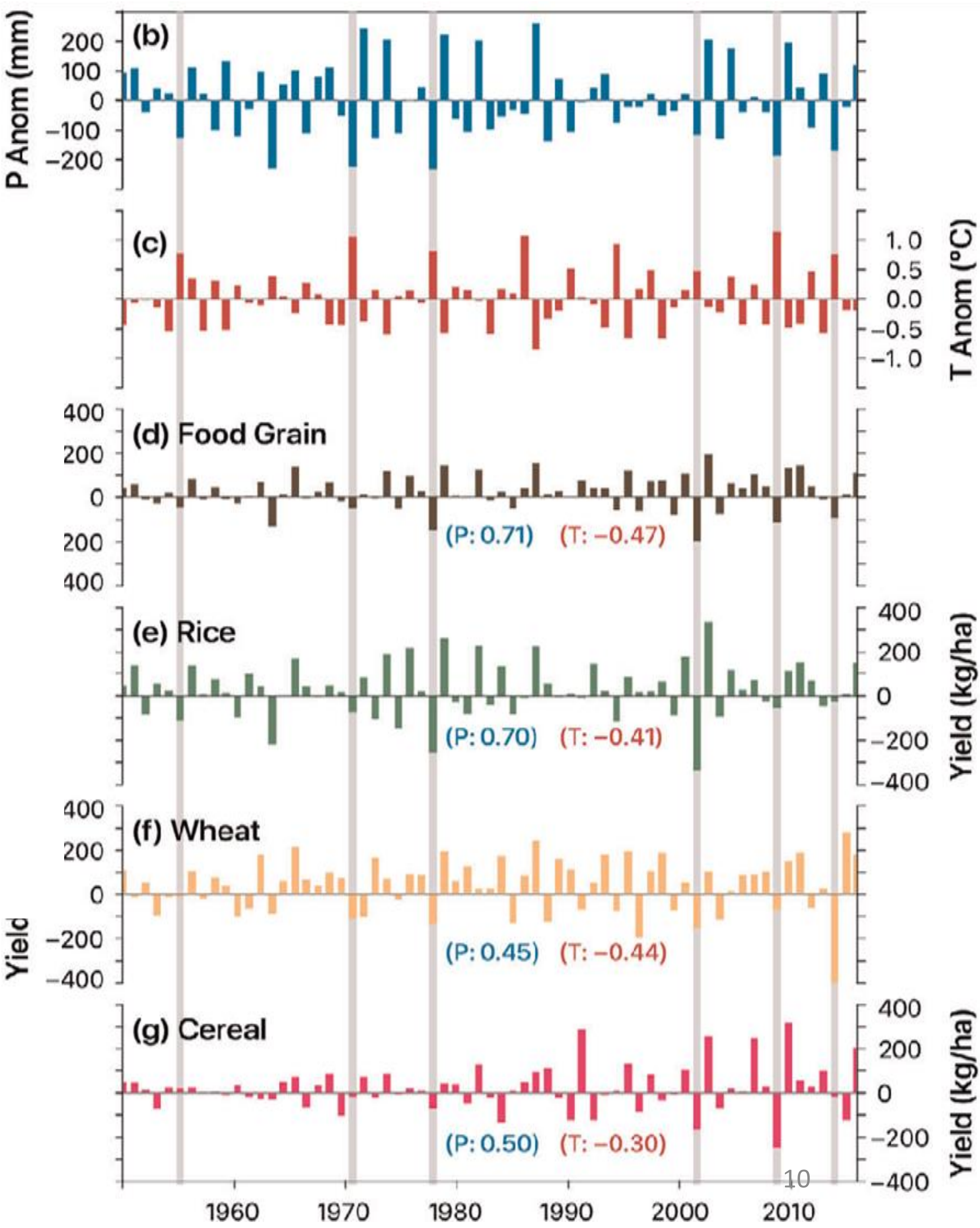
Floods in India: area affected, mortality, and migration



Mahato et al. 2023

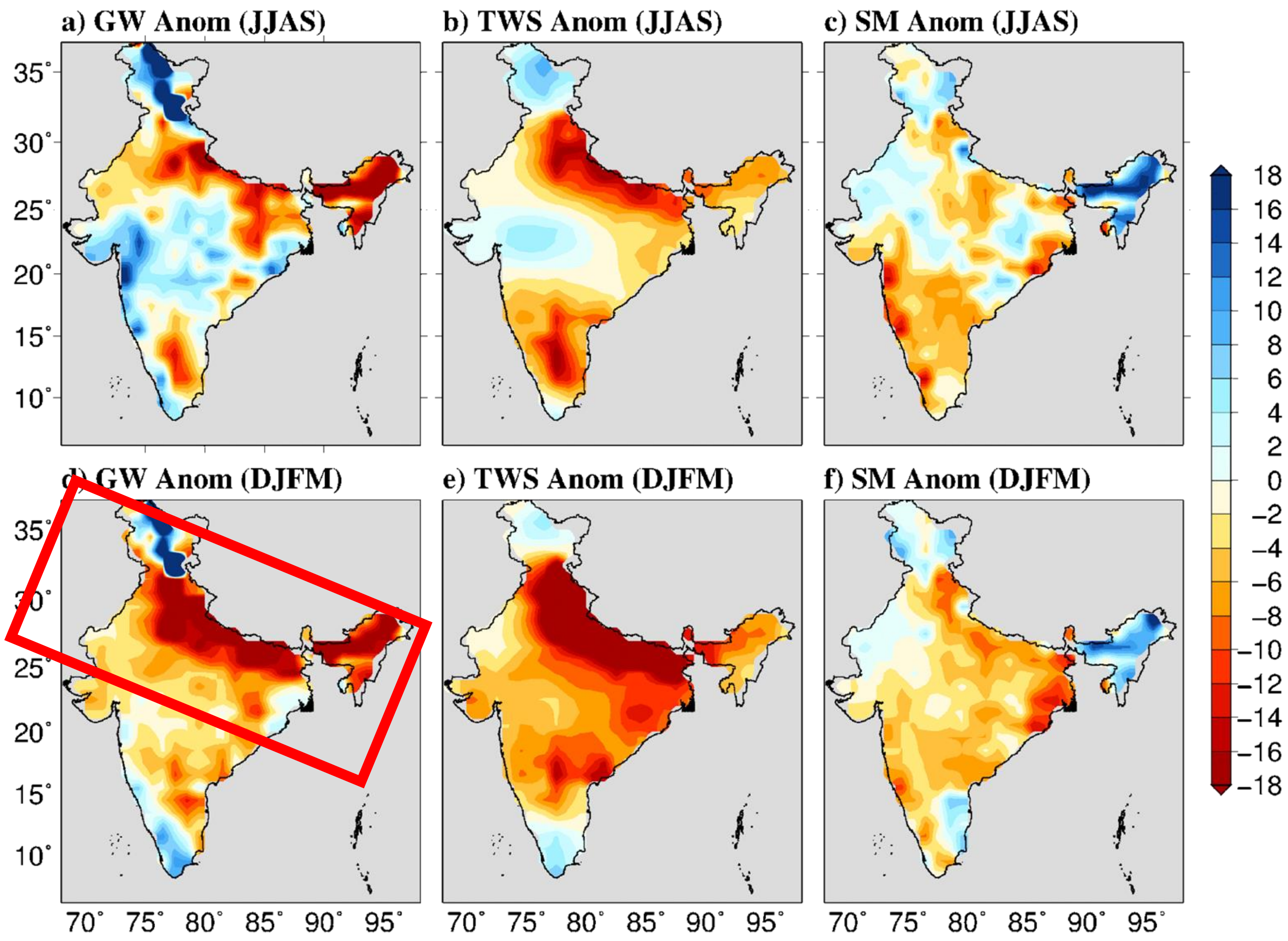
Hot and dry monsoons and food grain yields





Changes in food production and associated links with monsoon precipitation and temperature over India.

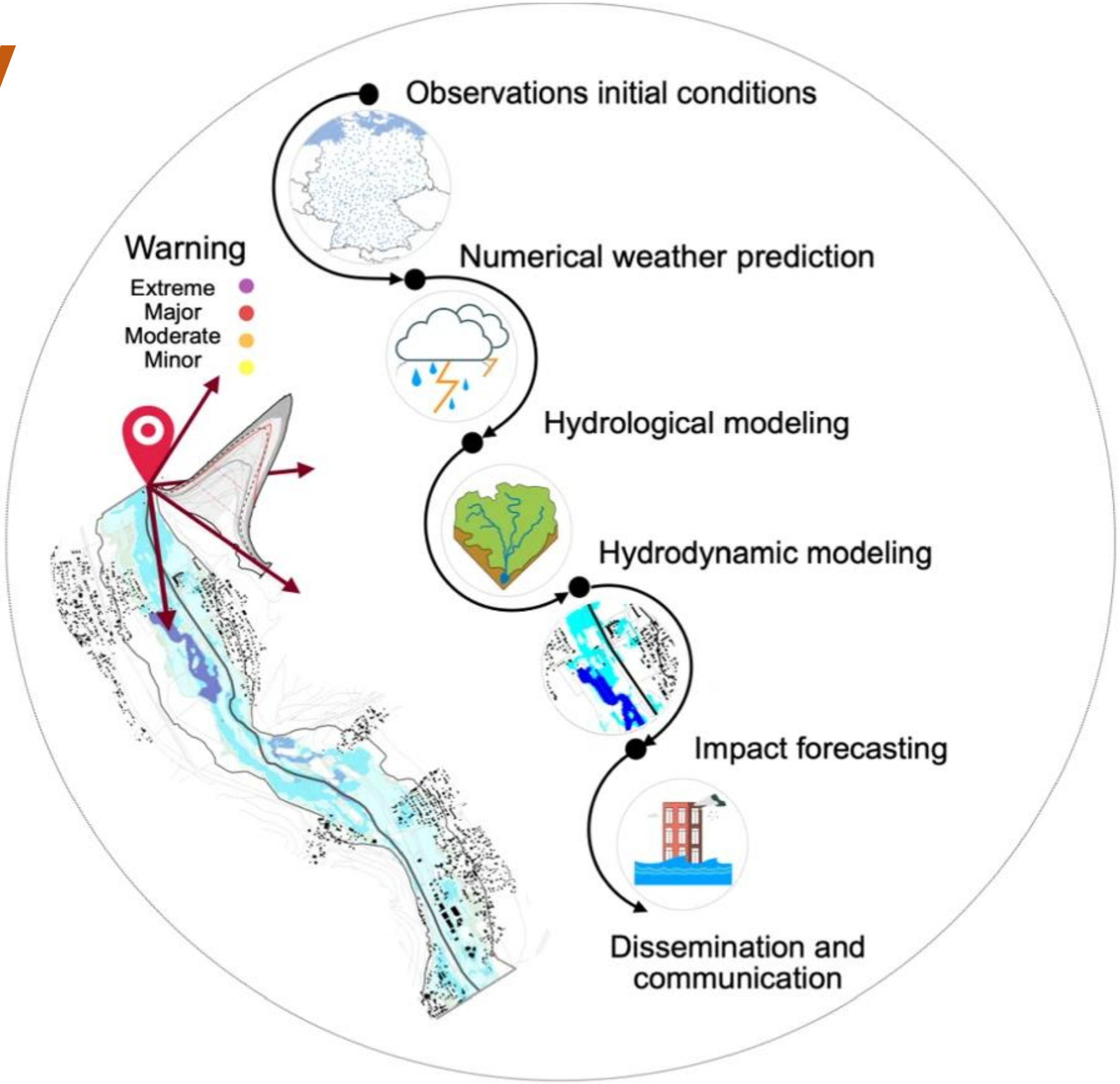
The 2015 drought caused significant GW depletion in Gangetic Plain



Mishra et al. 2016, GRL

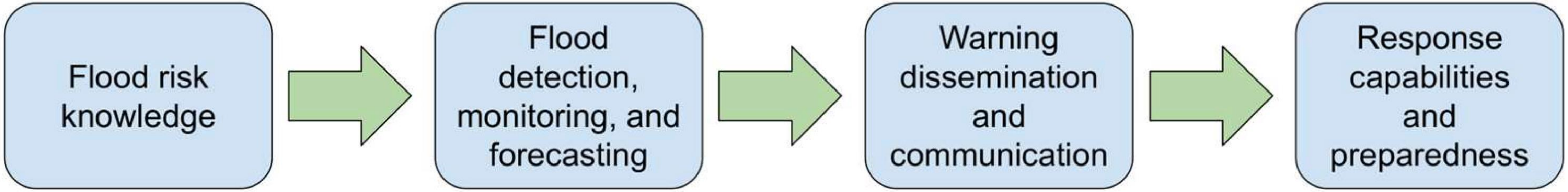
Components of Early Warning System

1. Knowledge of the event
2. Modelling of the event
3. Detection, Monitoring, and Forecasting
4. Dissemination & Communication
5. Disaster Risk preparedness



[Fig: A holistic end-to-end impact-based flood forecasting modelling chain. | Nature Communications]

Components of Early Warning System



Flood risk knowledge

- ➔ Information on the flood hazards and vulnerabilities in the area.
- ➔ Systematic collection and analysis of flood data.
- ➔ Evaluation of population and economical assets at risk.
- ➔ Development of hazard maps.

Flood detection, monitoring, and forecasting

- ➔ Continuous measurement and forecasting of meteorological data.
- ➔ Continuous measurement and forecasting of streamflow data.
- ➔ River flow and flood forecasts generated by hydrologic and hydraulic models.

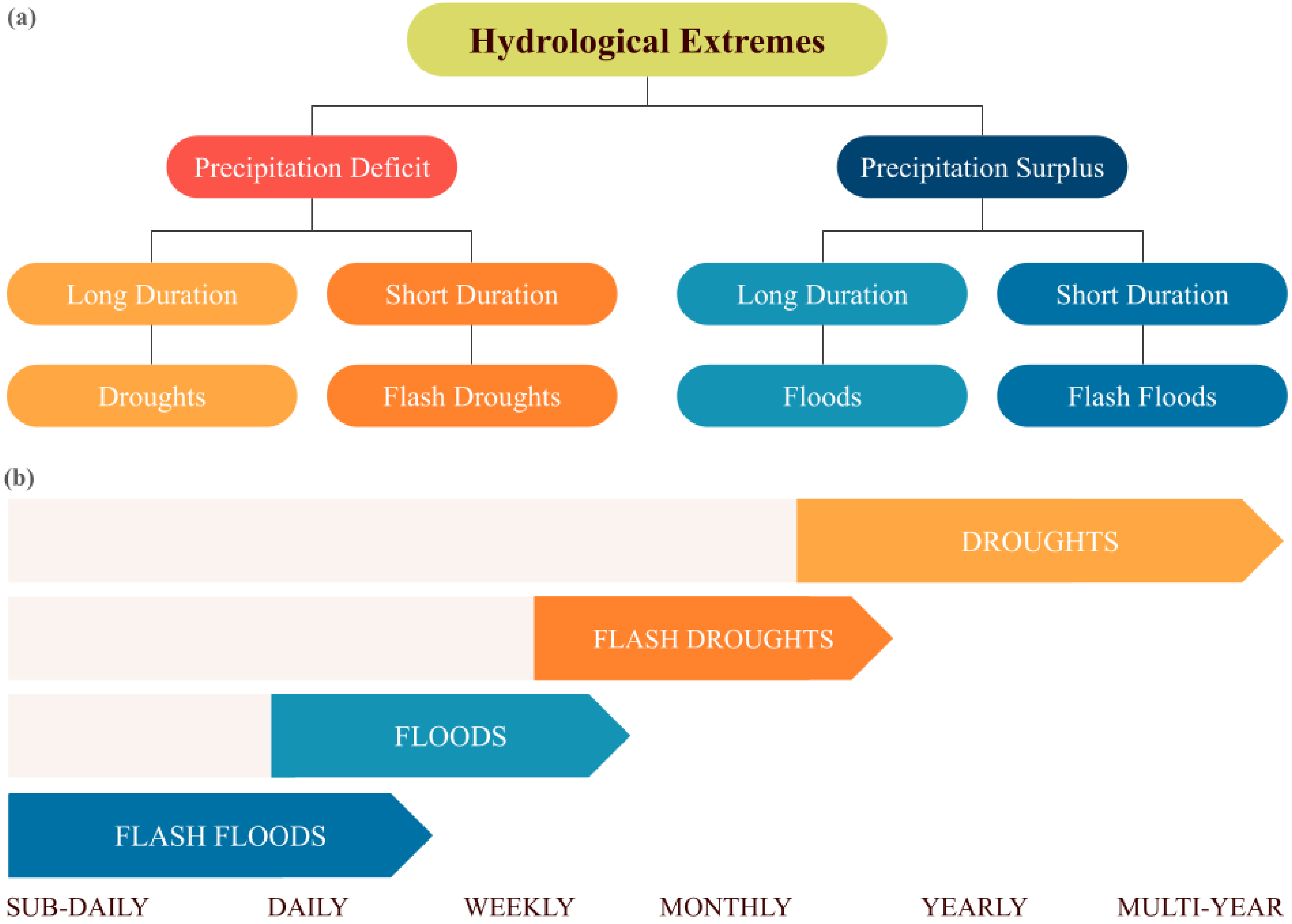
Warning dissemination and communication

- ➔ Communication to authorities.
- ➔ Multichannel dissemination to people at risk.
- ➔ Clear and useful information to facilitate appropriate responses.

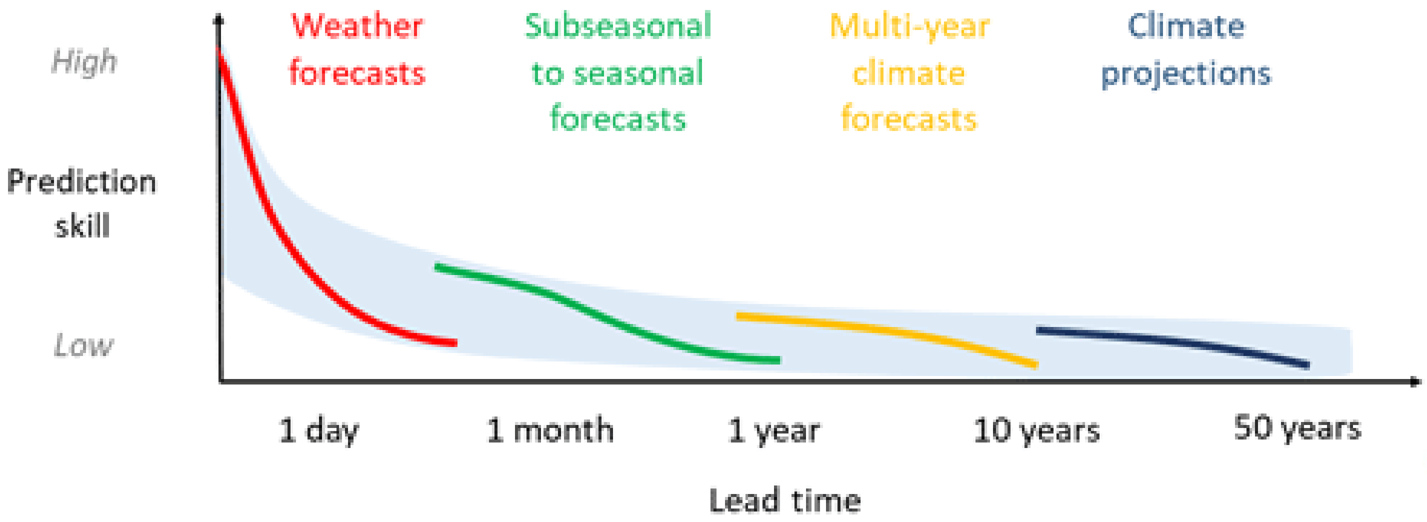
Response capabilities and preparedness

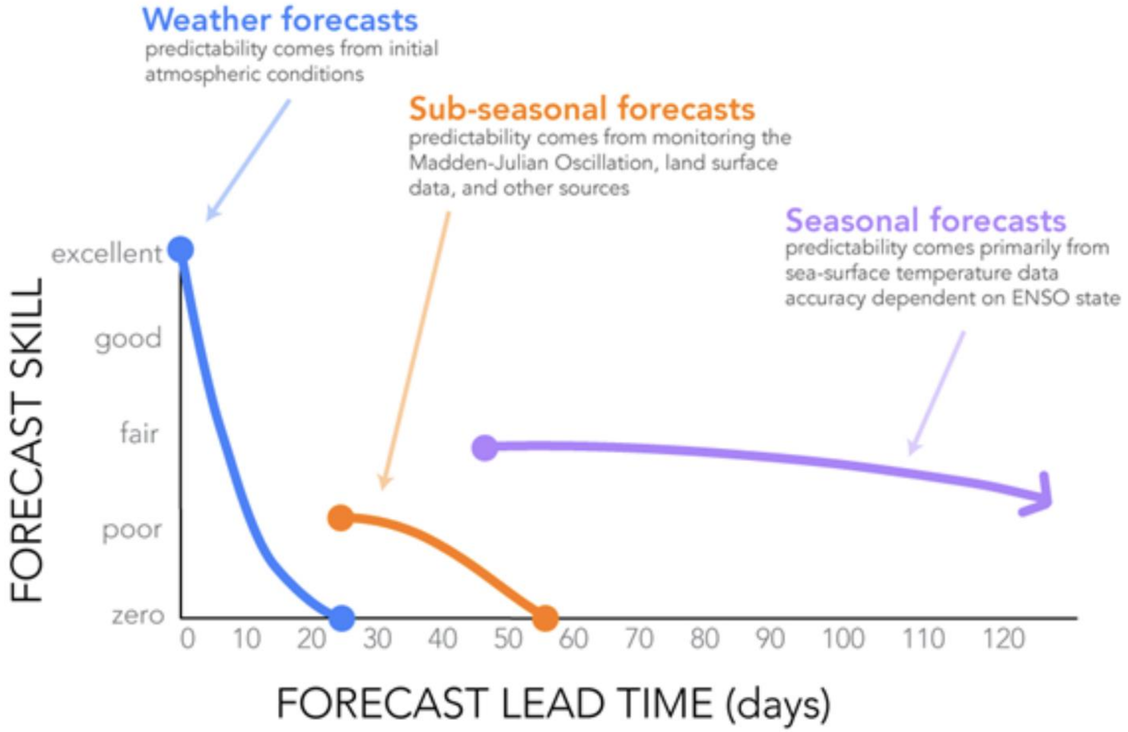
- ➔ Systematic training, readiness, and education programmes.
- ➔ Disaster preparedness and awareness plans.

Hydrological extremes: durations

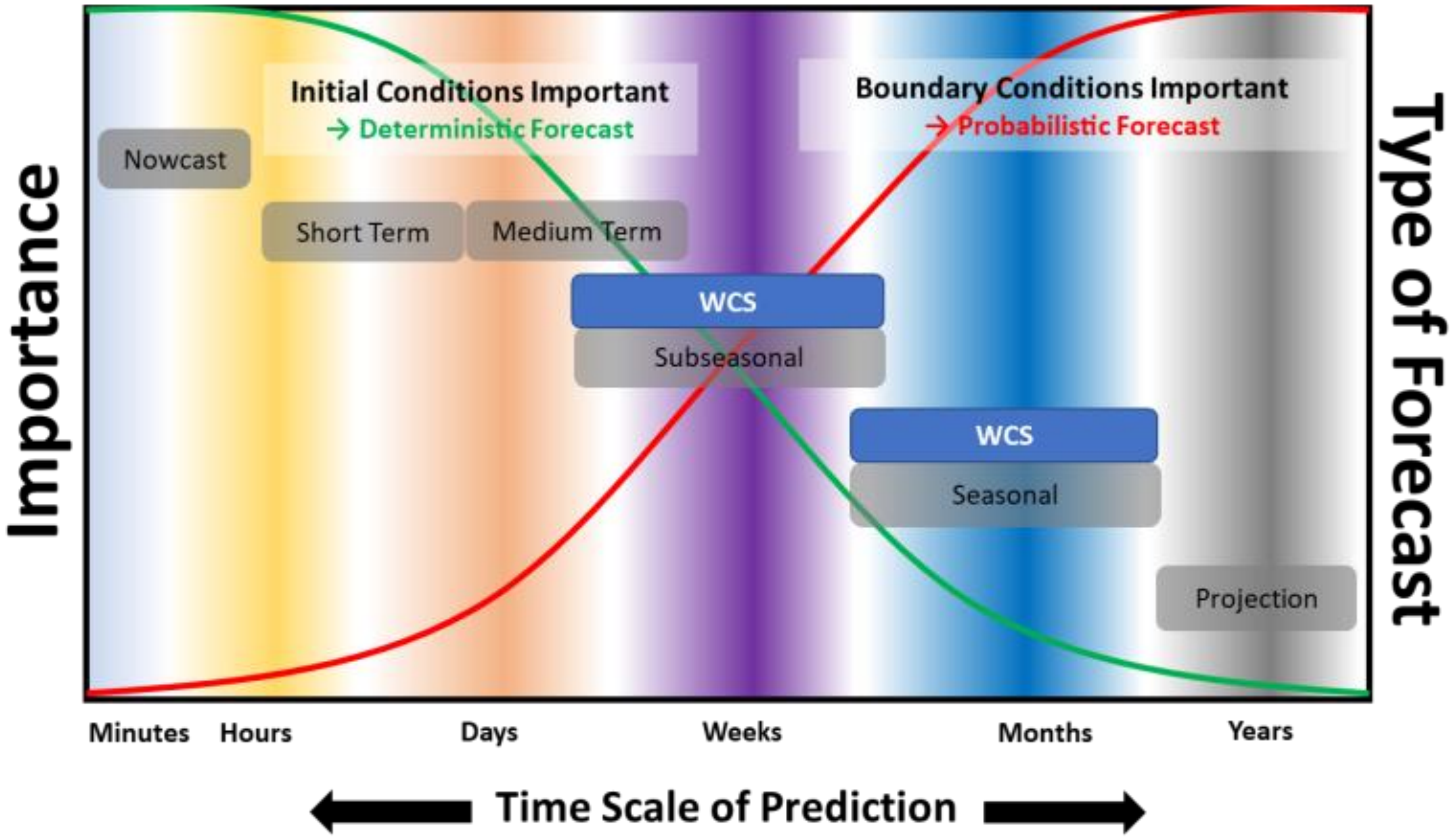


Forecast lead time





Hydrological prediction: role of initial condition



Hydrological Ensemble Prediction

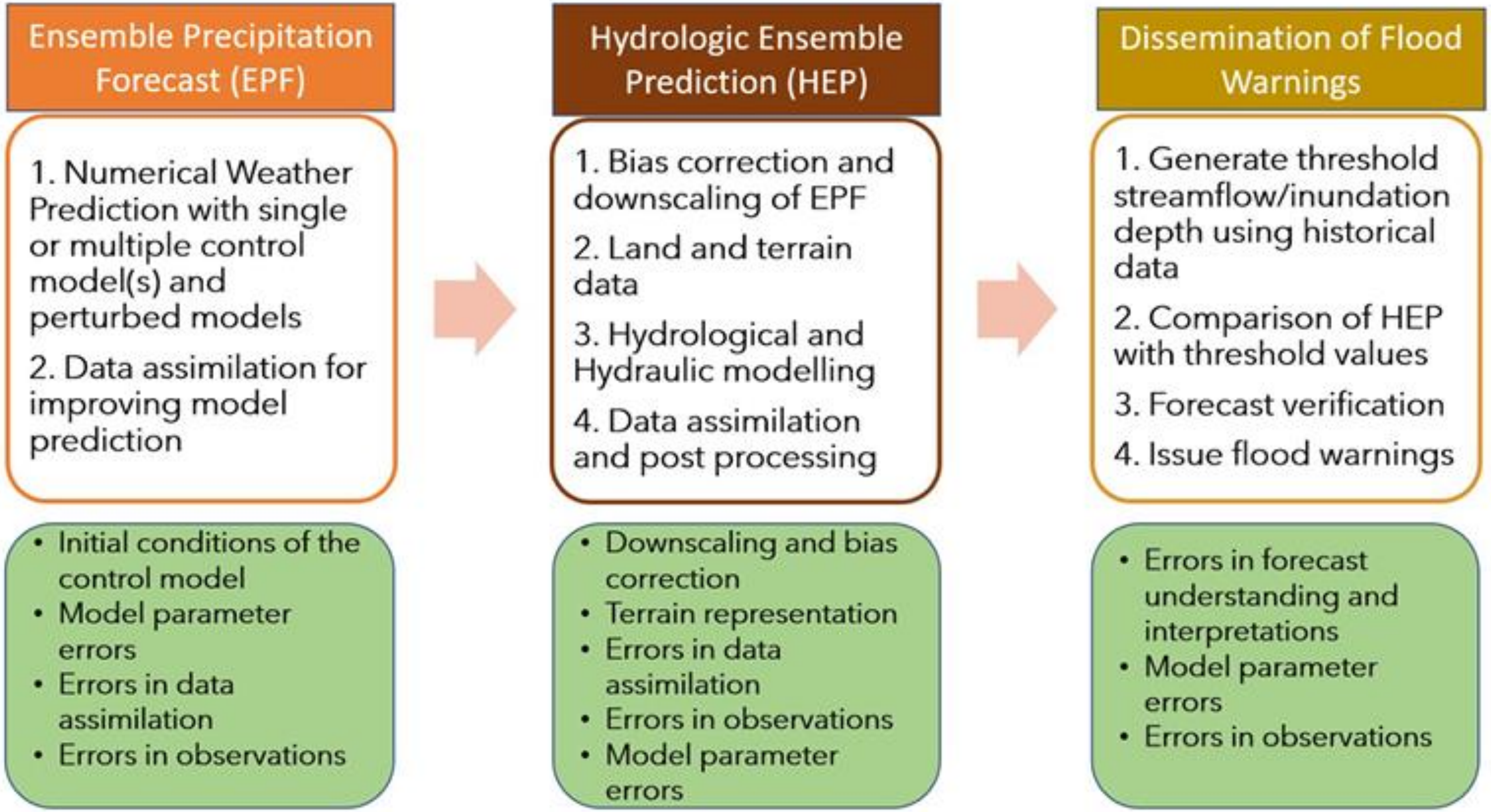
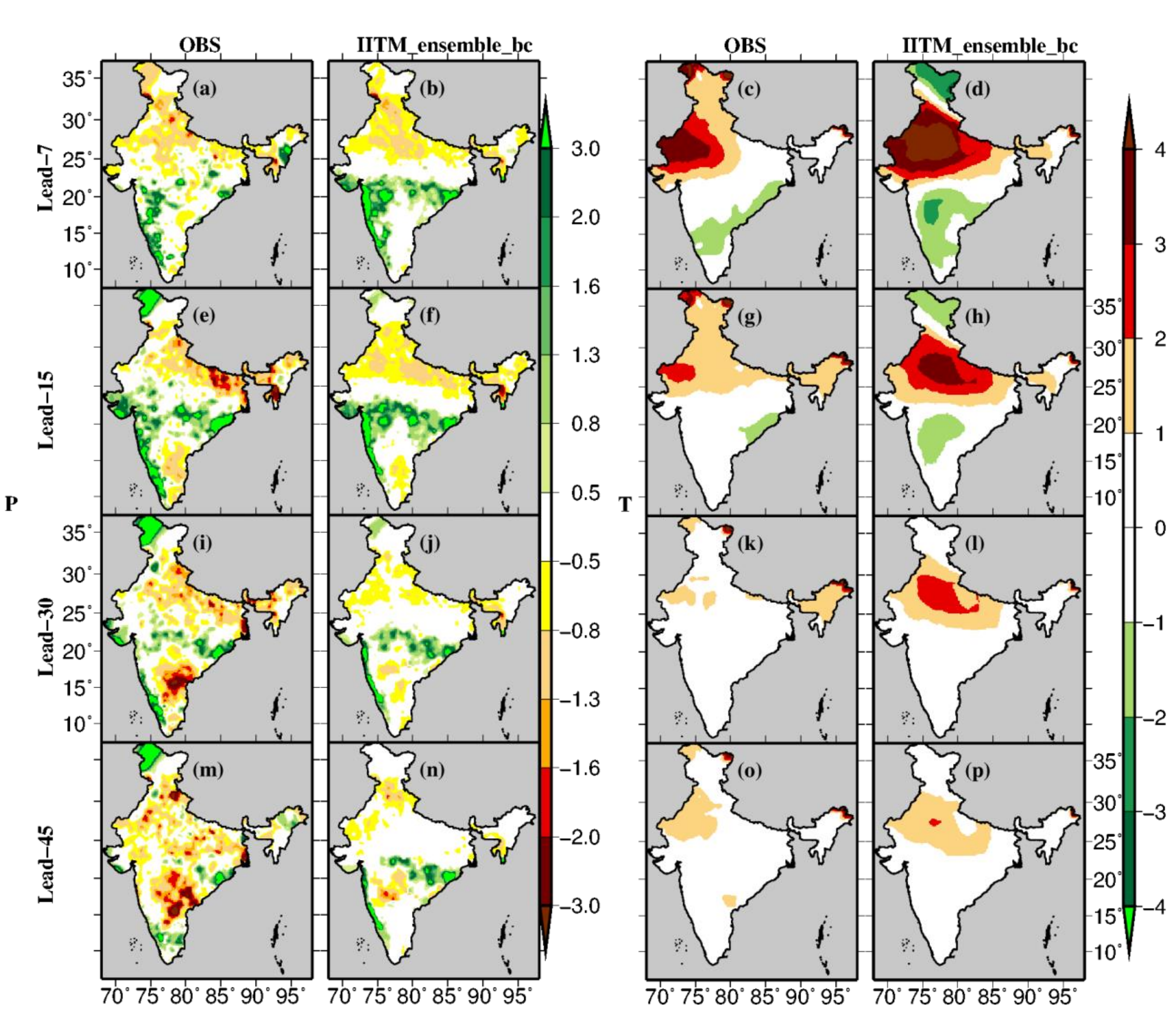
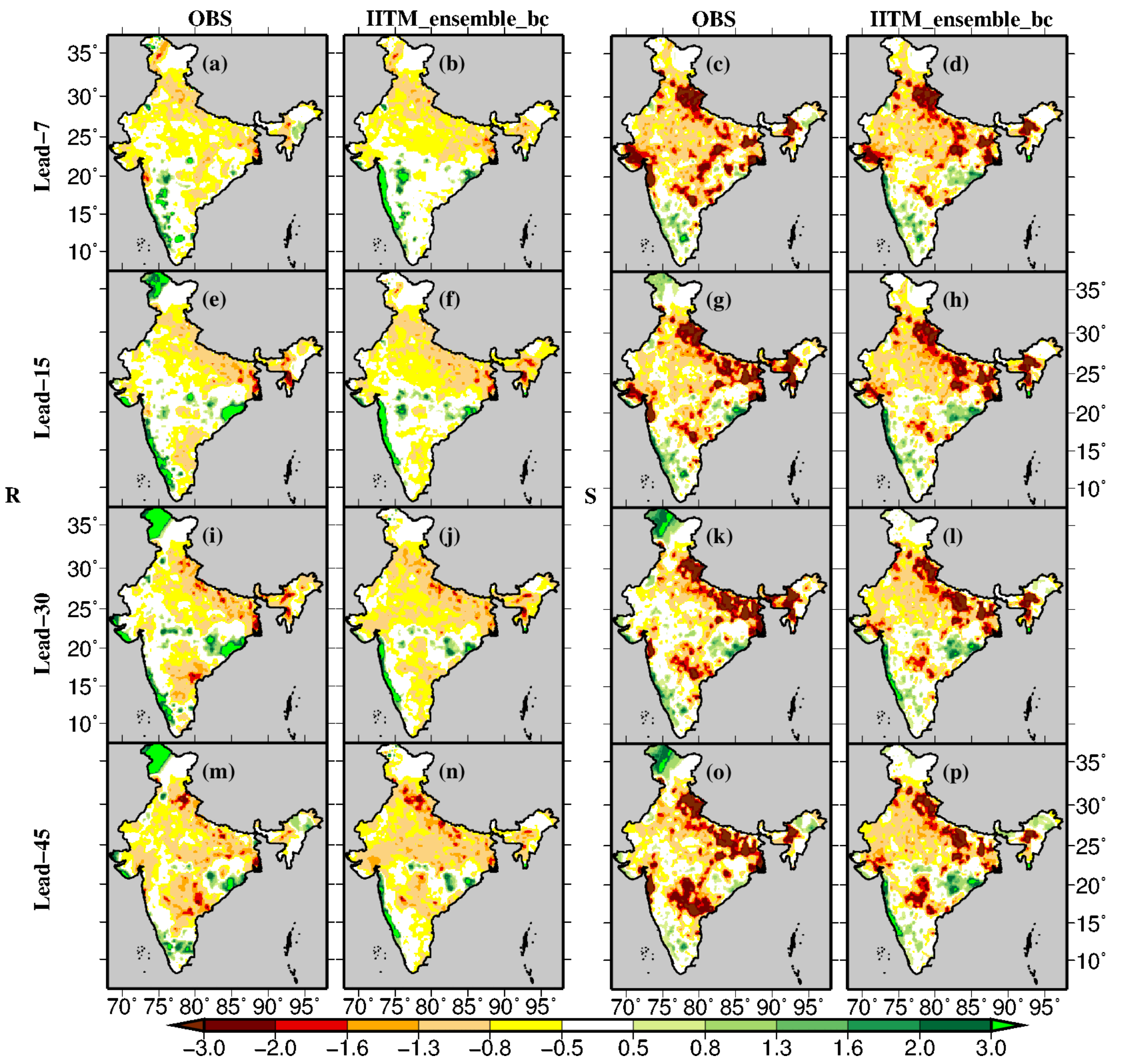


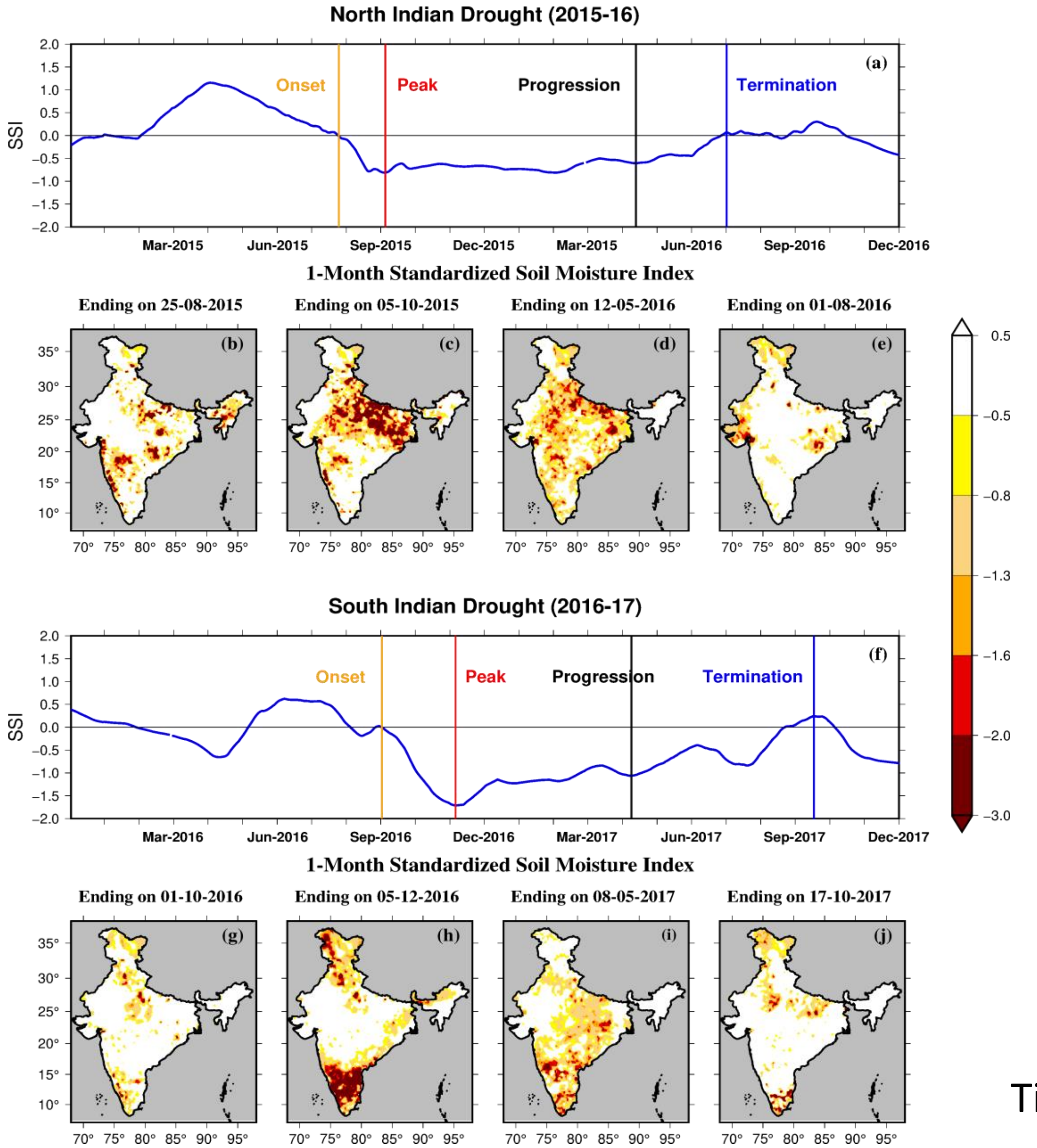
Figure. Schematic representation of hydrologic ensemble prediction (HEP) system used in flood forecasting.

Prediction of Drought : 15th July 2009



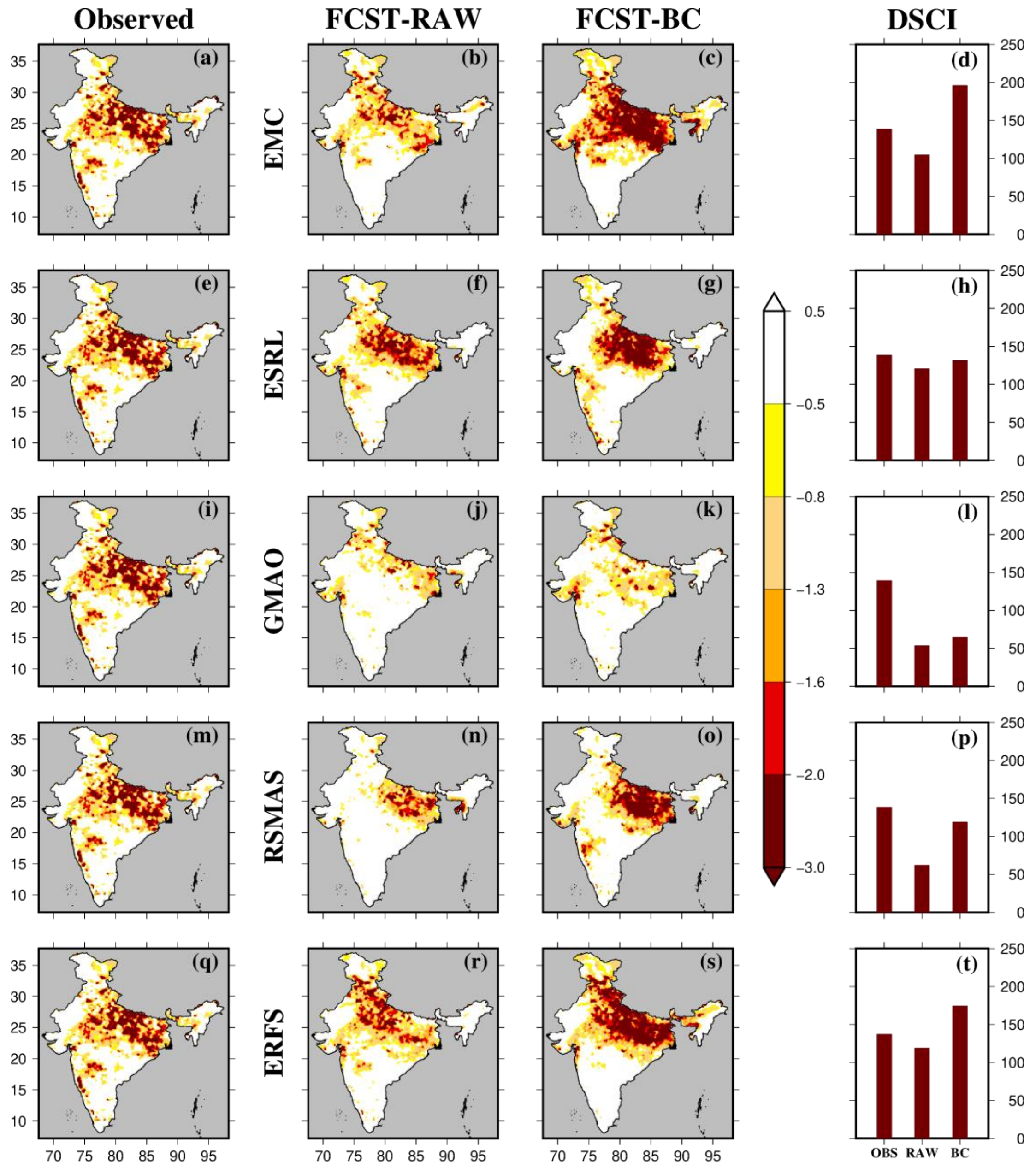


Recent droughts (2015-2017)



Tiwari and Mishra, 2022 (JGR)

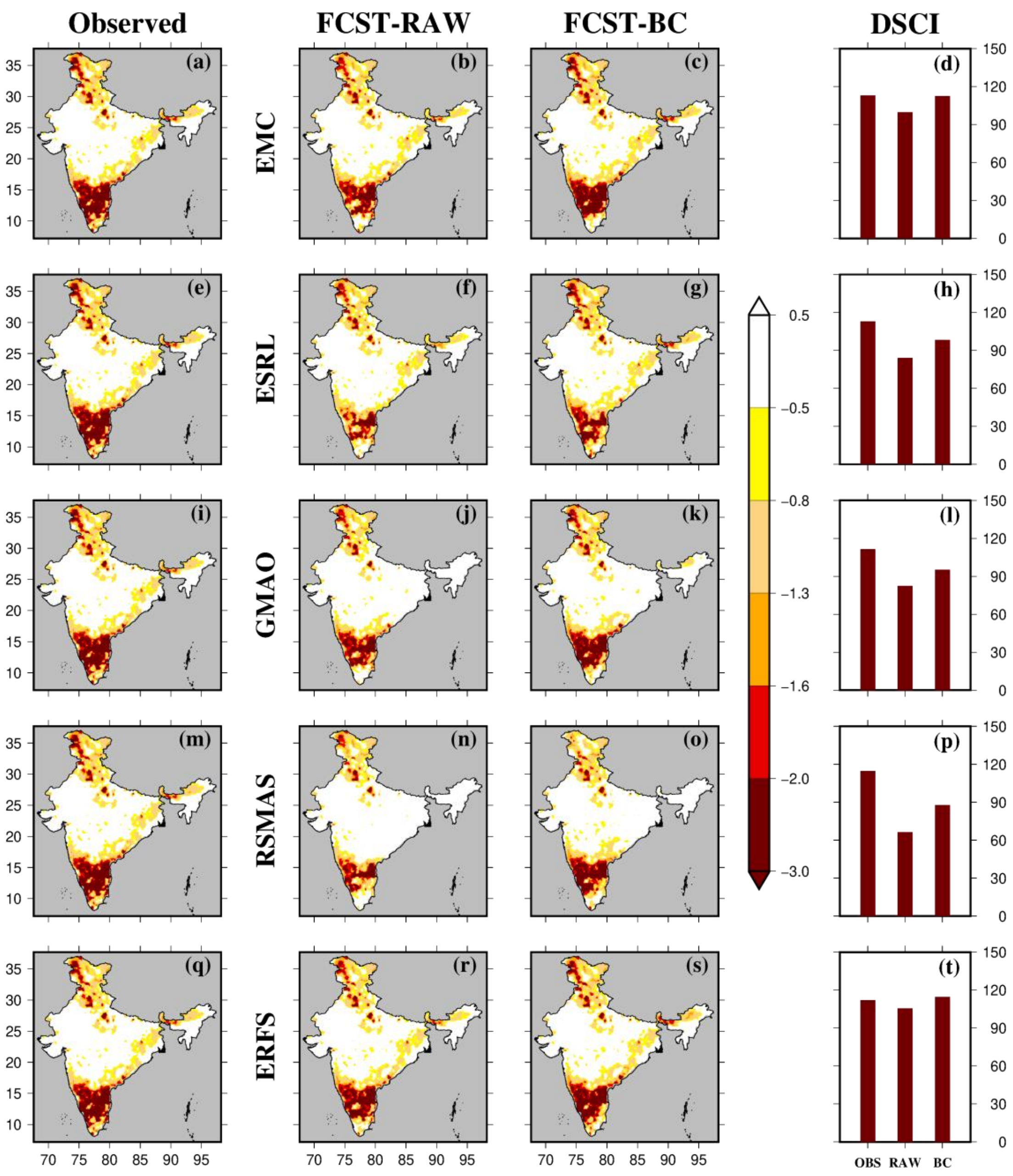
Drought forecast of NIR



- FCST-RAW underestimated the intensity and areal extent of drought for all the models in NIR.
- FCST-BC slightly overestimated the drought intensity except for the GMAO and RSMAS models.
- Bias correction of meteorological forecast products showed a significant improvement in the skill of drought forecast in NIR.
- ESRL model performed best while GMAO model underestimated.

Fig. (a-c) Comparison of peak drought based on FCST-RAW SSI and FCST-BC SSI against observed SSI for North Indian drought in 2015-16. (d) DSCI values for observed, FCST-RAW and FCST-BC SSI

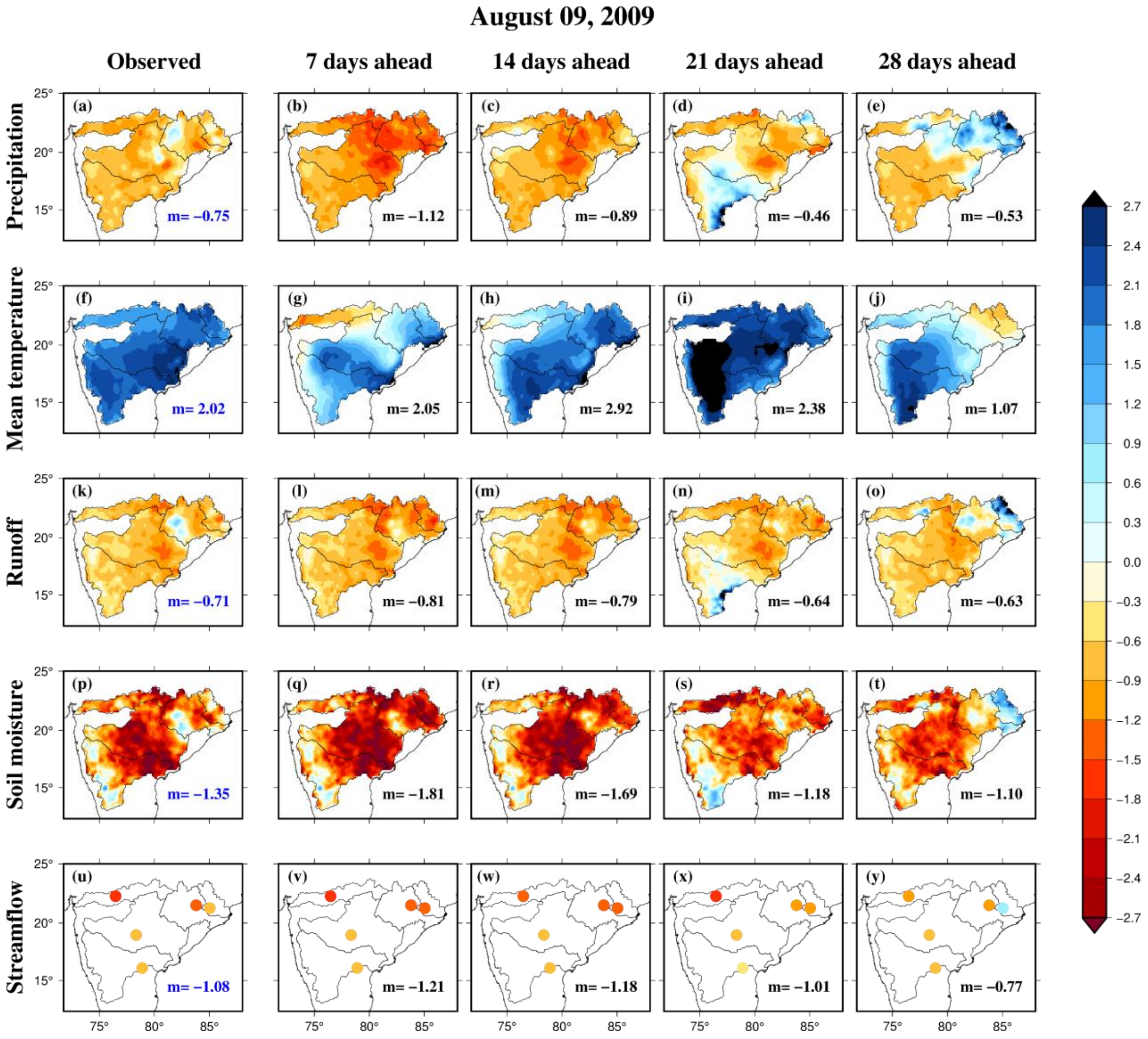
Drought forecast of SIR



- FCST-RAW underestimated the intensity and areal extent of drought for all the models in SIR
- Bias correction of meteorological forecast products showed a significant improvement in the skill of drought forecast in SIR
- EMC model performed best while GMAO model underestimated

Fig. (a-c) Comparison of peak drought based on FCST-RAW SSI and FCST-BC SSI against observed SSI for South Indian drought in 2016-17. (d) DSCI values for observed, FCST-RAW and FCST-BC SSI

Hydrological outlook



- Outlook is able to forecast the meteorological and hydrological variables well ahead 28 days lead time.

Fig. Comparison of observed and 7-, 14-, 21-, and 28-days ahead forecasted anomalies for hydrologic outlook for precipitation (FCST-BC), mean temperature (FCST-BC), runoff (FCST-BC-MET-HYD), soil moisture (FCST-BC-MET-HYD), and streamflow (FCST-BC-PP) for a selected extreme dry event occurred on August 09, 2009.

Streamflow forecast

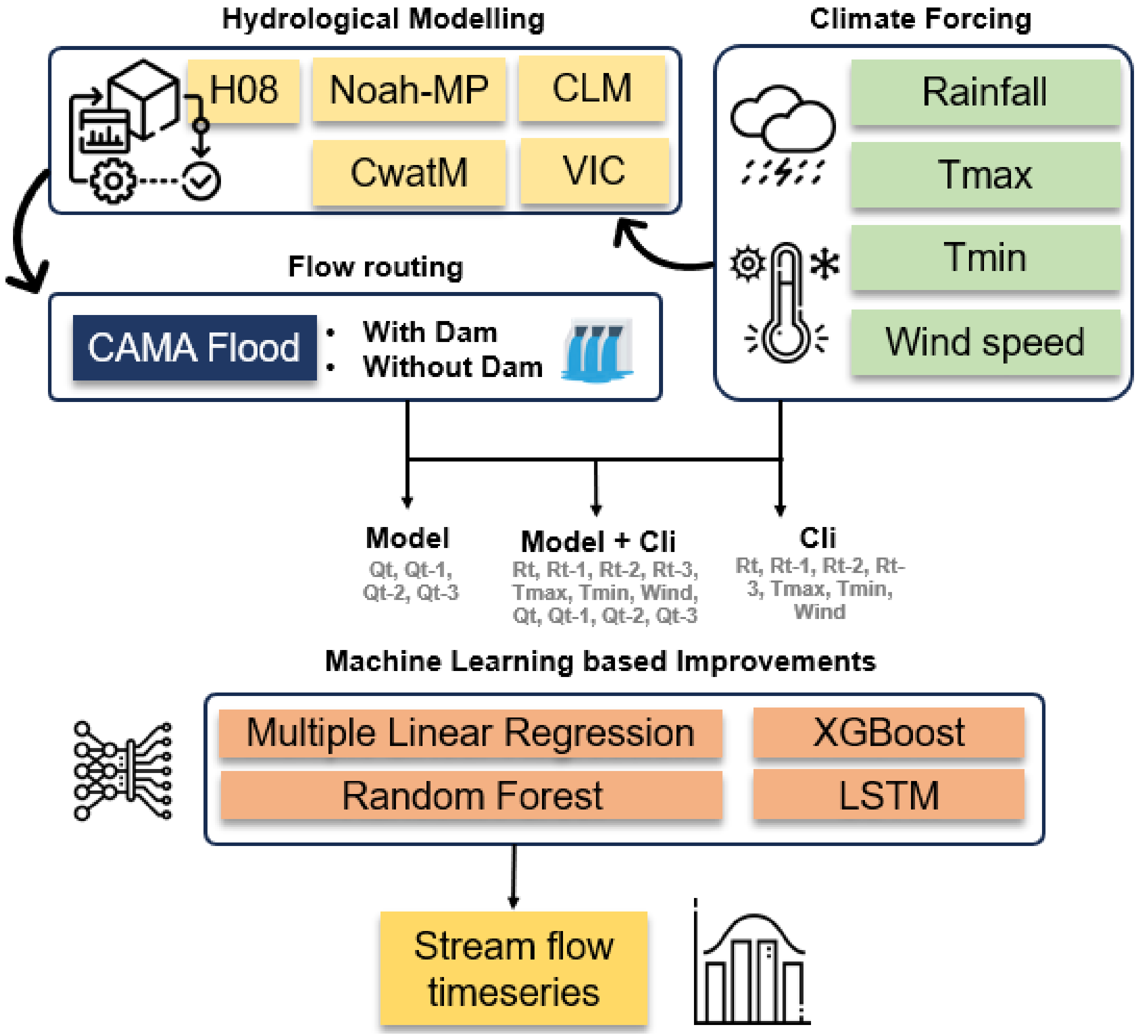
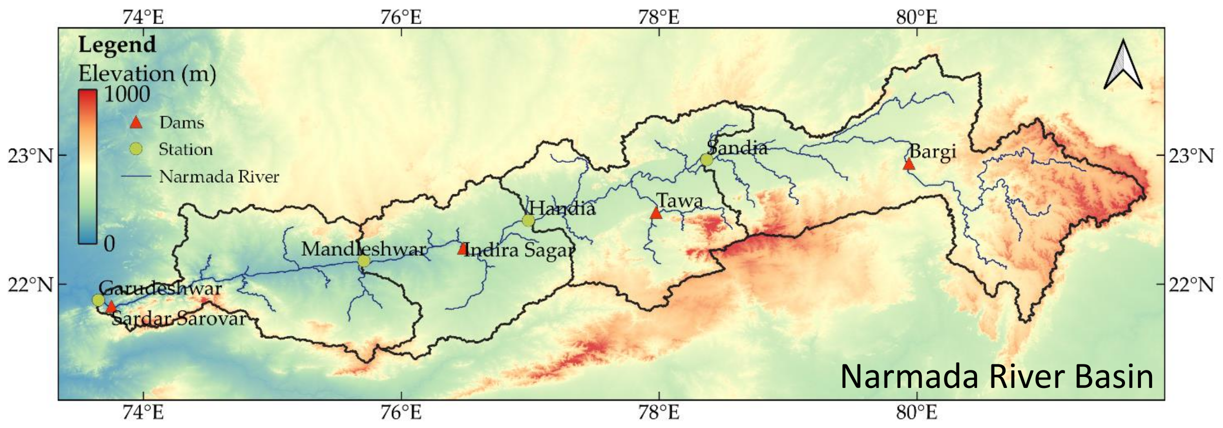


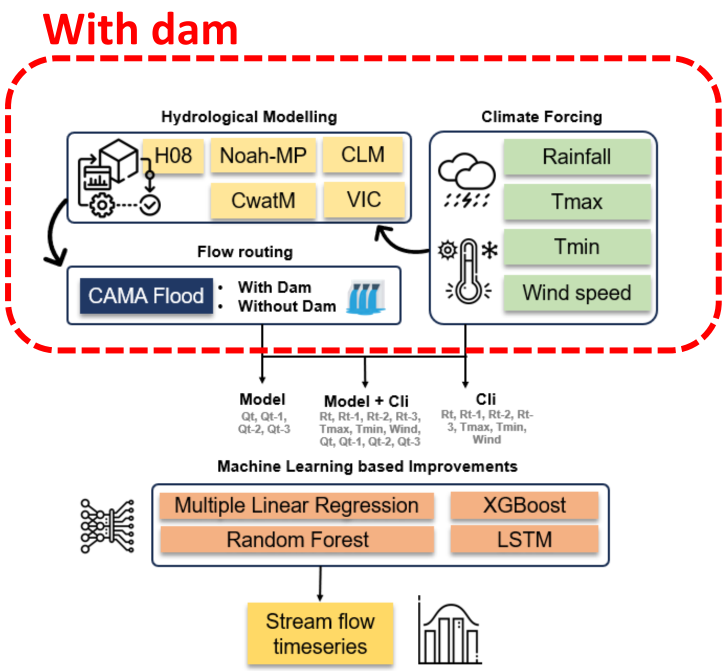
Figure. Proposed Methodology



Data and Models

Climate Data	Source	Spatial Resolution	Temporal Resolution
Rainfall	IMD	0.25˚x 0.25˚	Daily (1986-2020)
Maximum Temperature	IMD	0.25˚x 0.25˚	Daily (1986-2020)
Minimum Temperature	IMD	0.25˚x 0.25˚	Daily (1986-2020)
Wind Speed	ERA5	0.25˚x 0.25˚	Daily (1986-2020)
Observed Discharge	India-WRIS	Station based at Sandia, Handia, Mandleshwar, and Garudeshwar Stations	Daily (1986-2016)
Model Discharge (H08, Noah-MP, CLM, CwatM, VIC)	(Kushwaha et al., 2021)		Daily (1986-2020)

Performance Evaluation of Hydrological Models



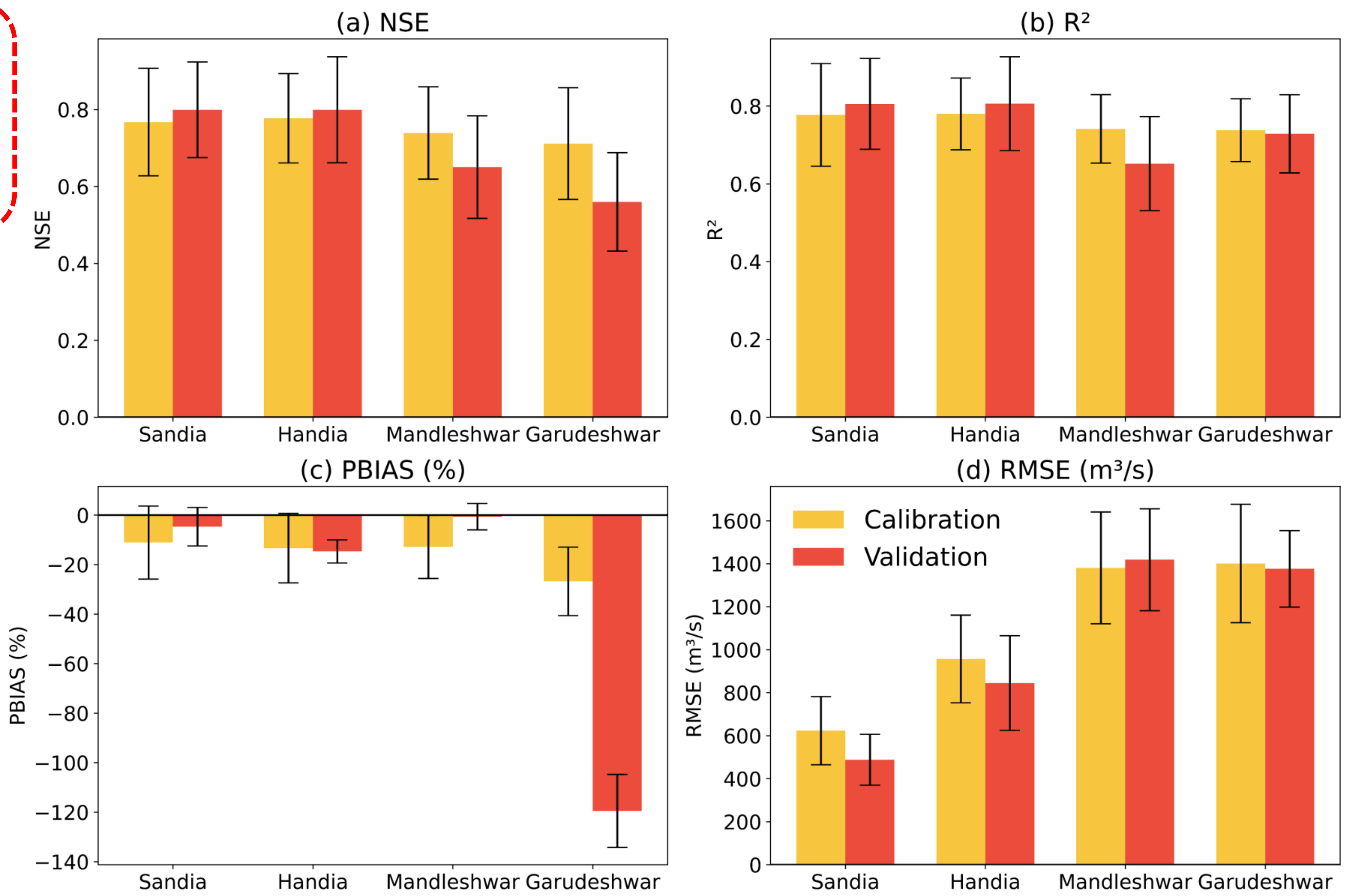
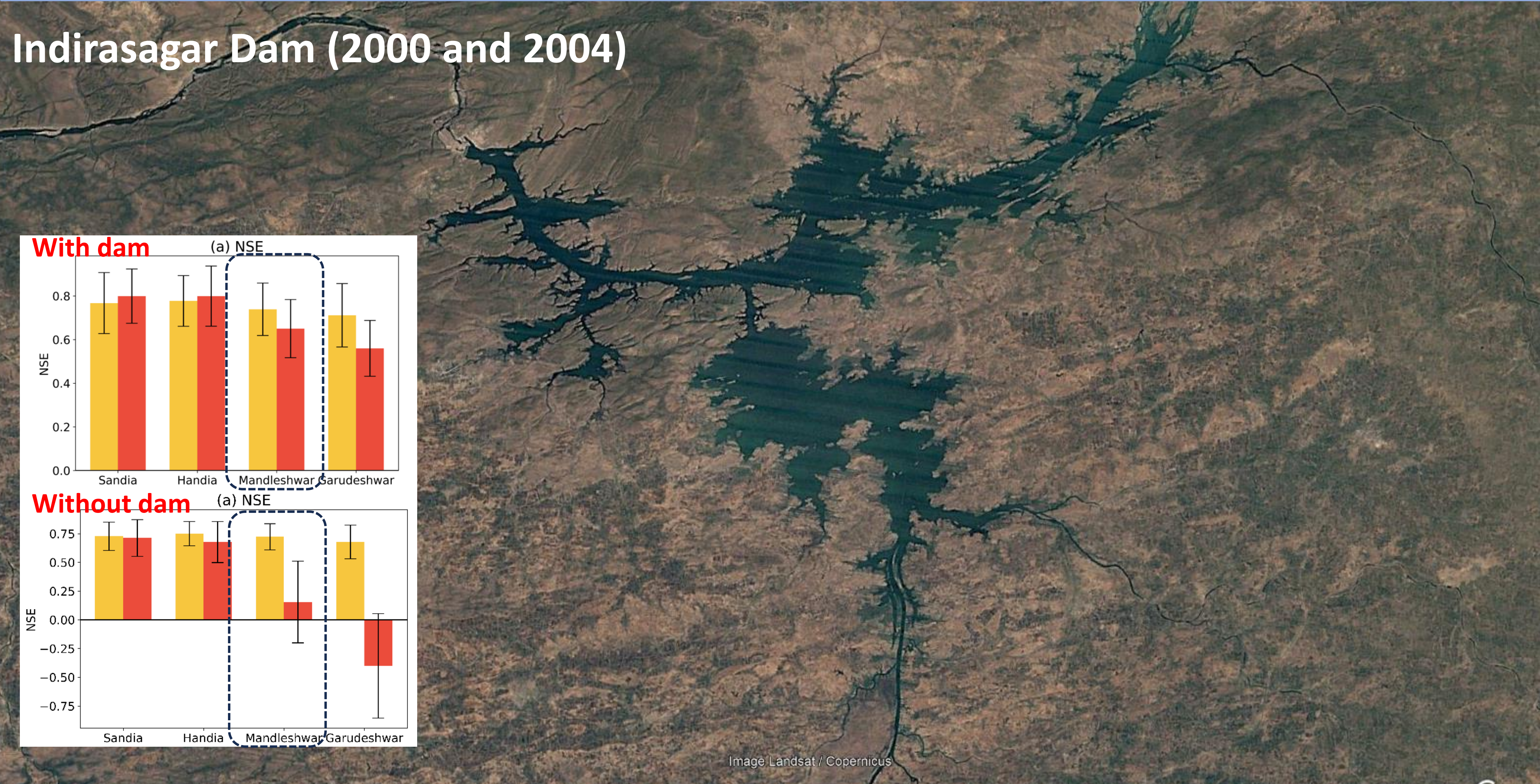
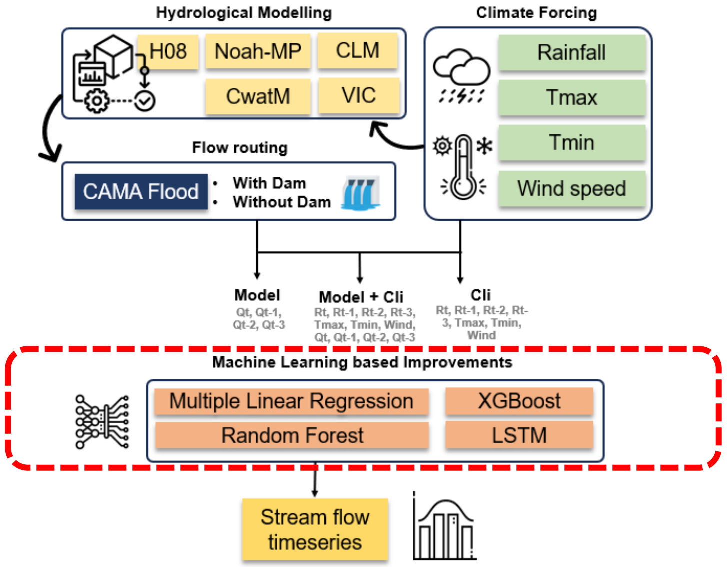


Figure. Model performance parameters for traditional hydrological models. Evaluation of multi-model simulated streamflow for with dam scenario at Sandia, Handia, Mandleshwar, and Garudeshwar using (a) NSE, (b) R^2, (c) PBIAS, and (d) RMSE. Yellow color shows statistics during the calibration, while orange shows during the evaluation. Error bars show variation within different HMs using one standard deviation.

Reservoir Influence



ML based enhancements



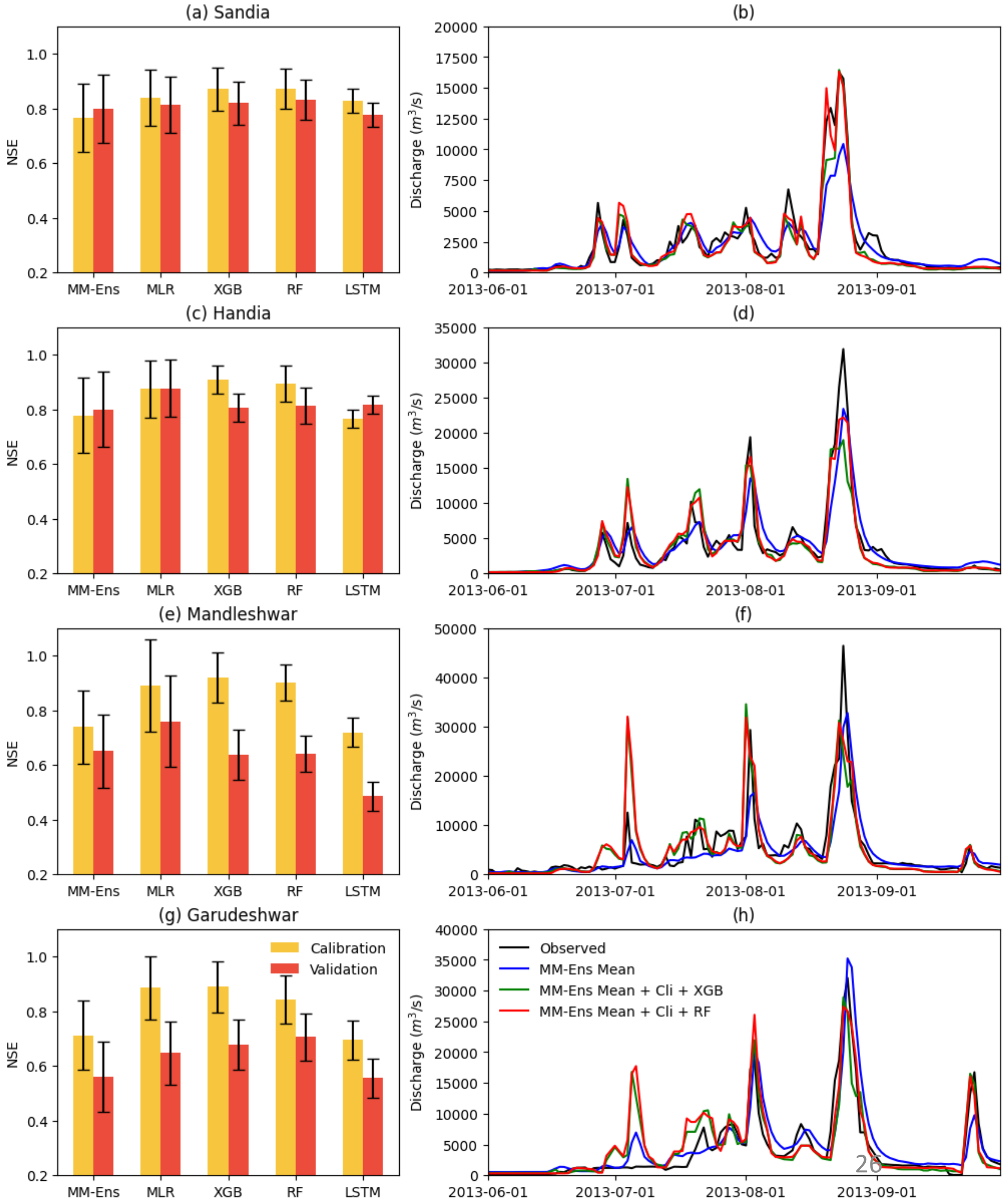


Figure. Multi-model ensemble mean NSE and its improvement using ML methods. Left panel shows multi-model ensemble mean NSE values with one standard deviation between various HMs using ML algorithms, including MLR, XGB, RF, and LSTM during calibration (yellow) and evaluation (orange) stage at (a) Sandia, (c) Handia, (e) Mandleshwar, and (g) Garudeshwar. Right panel shows timeseries of observed data (black), ensemble mean streamflow from multi models (blue), and XGB and RF based improvements (green and red, respectively) for the monsoon season (JJAS) of 2013 at (b) Sandia, (d) Handia, (f) Mandleshwar, and (h) Garudeshwar stations.

Multi-model ensemble streamflow forecast

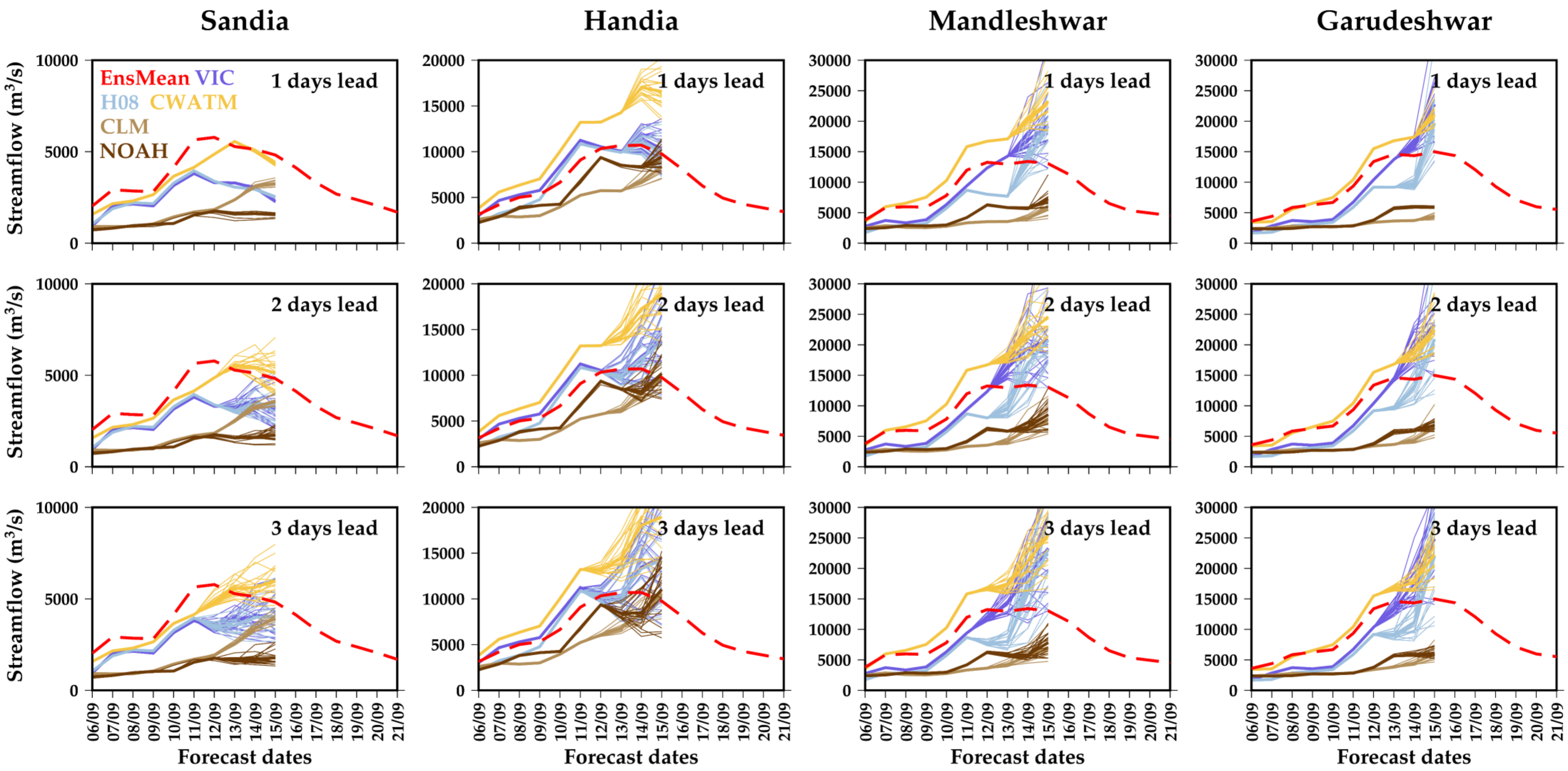
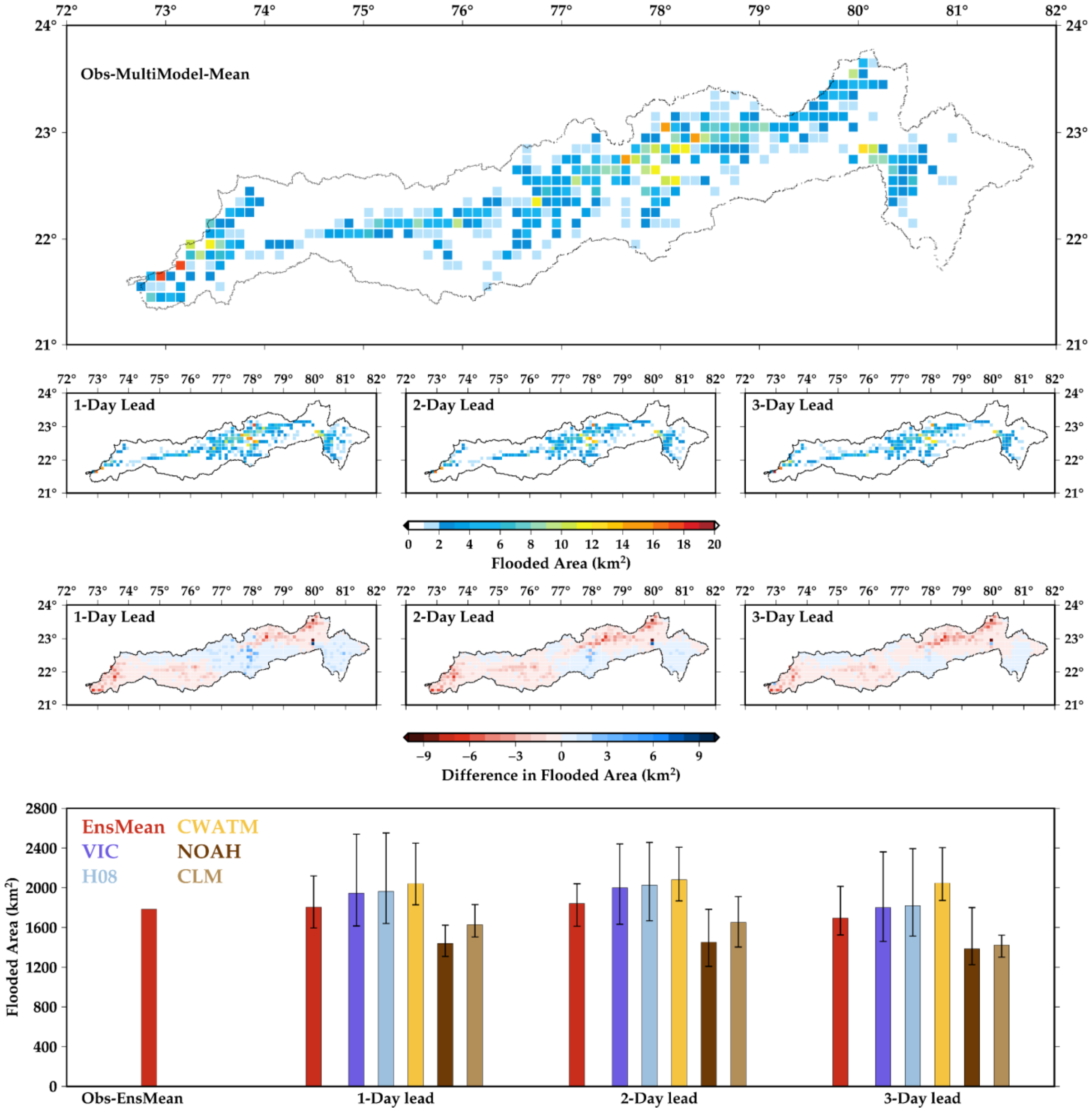


Figure. Streamflow forecasting in the Narmada basin using GEFS data for 2019 flood event.

Multi-model ensemble forecast of flood inundation



Strengthening early warning: what we need?

1. High-resolution (5km), reliable precipitation and temperature forecast (Lead: sub-daily, daily, short-term, extended range, and sub-seasonal)
2. Spatial and temporal resolutions (high resolution helps but accuracy is more important)
3. Near-real time monitoring and availability of observations (data assimilation, ML based enhancements)
4. Hydrological models with proper representations of human interventions (irrigation, reservoirs, groundwater pumping)
5. Better forecast skills for extremes (AI/ML can help and so as improving the models)
6. Impact data
7. Need to move from deterministic to multi-model based probabilistic forecast