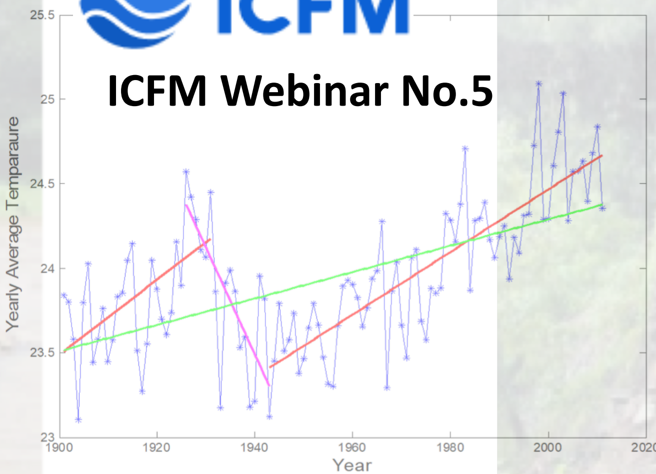
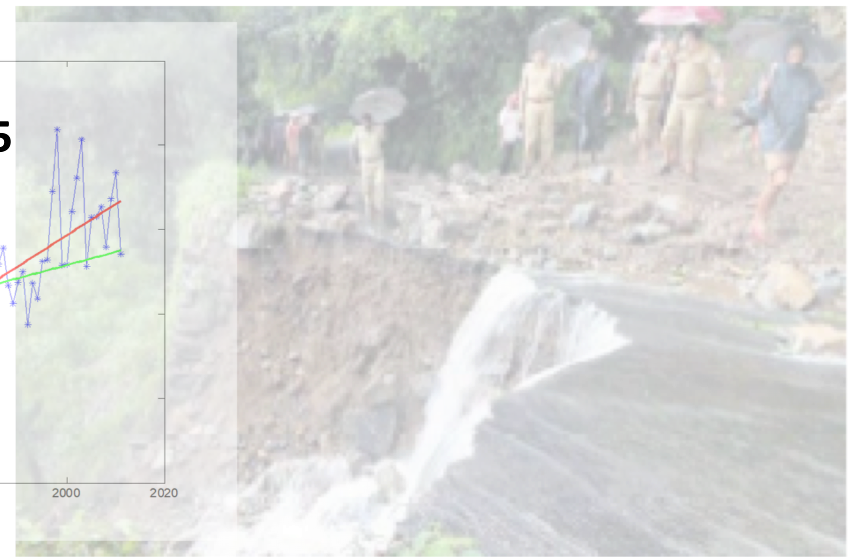
Floods in a Changing Climate

ICFM

ICFM Webinar No.5





Interdisciplinary Centre for Water Research

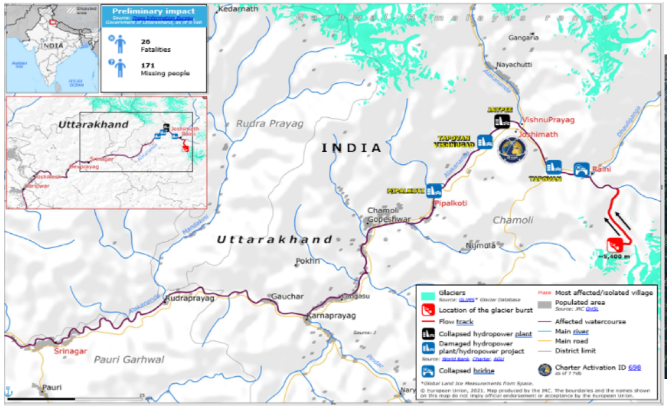
INDIAN INSTITUTE OF SCIENCE

भारतीय विज्ञान संस्थान

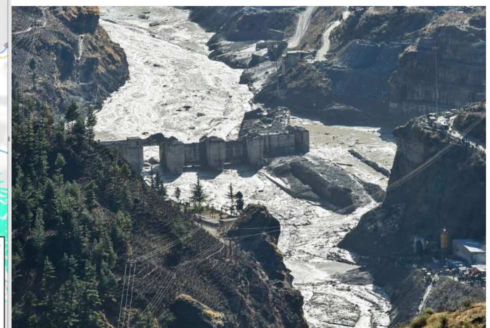
ICWaR

Pradeep Mujumdar
IISc Bangalore

Himalayan Floods (Uttarakhand) Feb 2021



Source: reliefweb.int



Hydropower plant in Uttarakhand damage the flash floods
Source: indiatoday.in

Glacier break off in Uttarakhand
Source: newindianexpress.com

Rescue Operations in Chamoli
Source: business-standard.com

Overview:

- Date of occurrence: 7th February 2021
- Location: Garhwal Himalayas in Uttarakhand state, India - Tapovan area of Joshimath in Chamoli district
- 70 deaths
- Area affected: 60 square kms
- Flood occurred in the Rishiganga River, tributary of Dhauliganga River, originating from Raikhana glacier
- Disruption of 4 hydropower projects: Rishiganga HP, Tapovan Vishnugad HP, Vishnuprayag HP, Vishnugad Pipalkoti HP
- Deluge wiped out 5 bridges, some of which ran 40 feet above typical river levels

(Possible) Causes of the Flood:

- It is believed to have been caused by a landslide, an avalanche or a glacial lake outburst flood

- Initial reports suggested that the flood was caused due to the Glacier Lake Outburst (GLOF) however there were no lakes visible in the satellite images upstream of the area flooded;

- Rockslide that occurred 22kms upstream of the river lead to a cascading impact, carrying debris, ice, snowmelt and running river water, causing sedimentation all along the way and damaging four hydropower projects in the flood path.

- **Rockslide is possibly caused by the avalanche**, occurred somewhere between 19 September to 9 October 2016, that displaced huge mass of ice, debuttressing a huge surface area of the rock, exposing it to frequent freeze-thaw cycles (however, this cannot explain the 150m depth of the rock displaced, as freezing and thawing would only affect first 10 m of the rock), possibly combined with a seismic activity.

- It is also suggested that a hanging glacier "15 football fields long and five across" had separated from a mountain and plummeted into the Ronti Gad, a tributary of the Rishiganga (Source : Wikipedia; Scientific American, Feb 2021)

Sources: www.icimod.org, www.sciencenews.org, www.business-standard.com

Economic Losses (Damaged Infrastructure)

Sl. No.	Description	Amount in INR (Crores)	Amount in USD (Millions)
1	Four Hydropower projects	1500	206.85
2	53 Road Projects	12072	1664.71

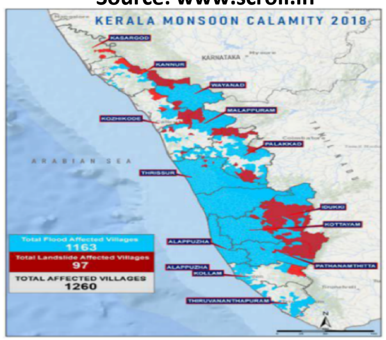
Source: www.business-standard.com

Kerala Flood 2018

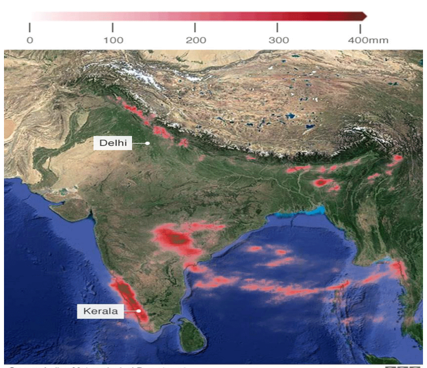
An aerial view of partially submerged houses in Kerala
Source : www.bbc.com

Cyclonic storm near the coastal area due to depression in Arabian sea
Source: www.scroll.in

Transportation of residents to emergency relief camps
Source : www.theguardian.com



Flood affected and landslide affected villages
Source : www.sdma.kerala.gov.in



Cumulative rainfall recorded from 10th to 16th August 2018
Source : www.bbc.com

Kerala before and after the floods, released by NASA. The images are false-colour, which makes flood water appear dark blue and vegetation bright green.
Source : www.wikipedia.org

Overview:

- Period: July - August 2018
- 11 of Kerala's 14 districts were severely affected
- 433 deaths; over 5.4 million people affected, displaced 1.4 million people
- Kerala received 2346.6 mm rainfall between June 1 and August 19, 2018, which is about 42% higher than the normal rainfall of 1649.5 mm during the same period
- 1260 out of 1664 villages were affected, 687 km^2 land flooded, 14315 houses fully damaged, 270000 houses partially affected, 0.15 Million Ha of standing crops damaged, 751000 poultry, and 7953 domestic animals lost, 3 million electric connections damaged, 510 bridges and culverts damaged, 9538 km of major roads and 77328 km of rural roads destroyed
- Total economic loss approximately Rs.31000 Crore

Sources: www.business-standard.com, reliefweb.int, india.mongabay.com,

Causes:

- Rainfall during June, July, and August 1-19, 2018 was 15%, 18% and 164% respectively above normal rainfall
- Flood was due to the combined effects of perigean spring tide and strong onshore winds
- Alteration in land use during the past decades with increase in built up area and reduction in water bodies and vegetation also majorly contributed to the floods

Sources: thewire.in, reliefweb.int, india.mongabay.com, Hunt, et. Al. 2020

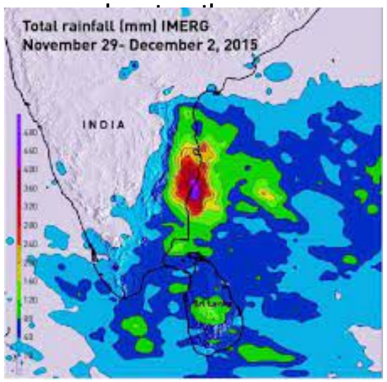
Economic losses

Sl. No.	Description	Amount in INR (Crores)	Amount in USD (Millions)
1	Tea industry	35-40	4.82-5.52
2	Rubber sector	420	57.92
3	Airport	40	5.52
4	Roads	12000	1654.76

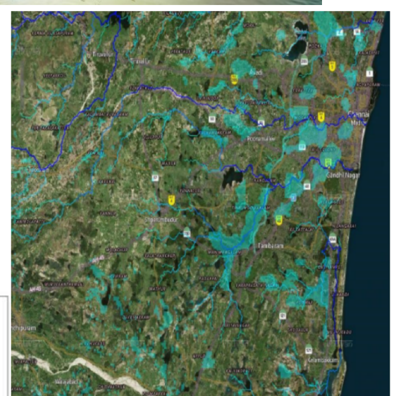
Source : www.business-

Chennai Floods 2015

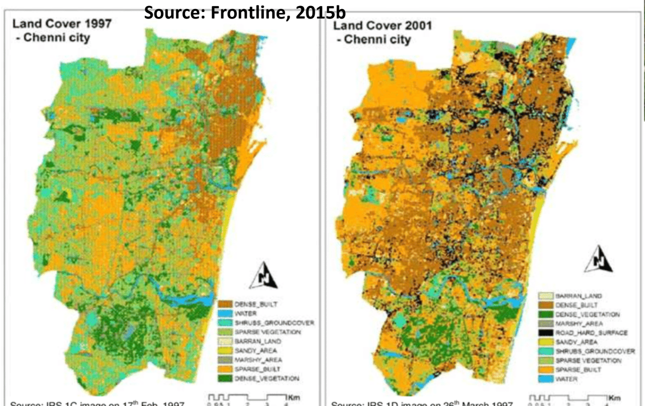
Photos from the devastating Chennai floods of 2015
Source: indiatimes.com,



Accumulated rainfall between November 29 and December 2 over Chennai and neighbourhood measured by NASA's GPM satellites
Source: Frontline, 2015b



Flood inundation map of Chennai Floods 2015
Source: Citizen's report on the 2015 floods in Chennai



Chennai city's land-cover
Source: Sundaram, map India, 2009

Overview:

- Duration: November 2015 to December 2015
- Over 400 deaths ; 2.3 million houses inundated
- Caused disruption of power and telecommunication services, halted air, rail and road transport, and extensive public and private property damage

- Rainfall received in November 2015 was 121.86, which was thrice the usual rainfall, 40.74 cm
- The rainfall received on December 1st , 2015 was 19.1 cm, a 100 year record breaking rainfall event

- Extremely high releases from two upstream reservoirs aggravated the floods

Sources: www.cag.org.in, Audit report on Chennai Floods

Economic Losses – Chennai Floods, 2015

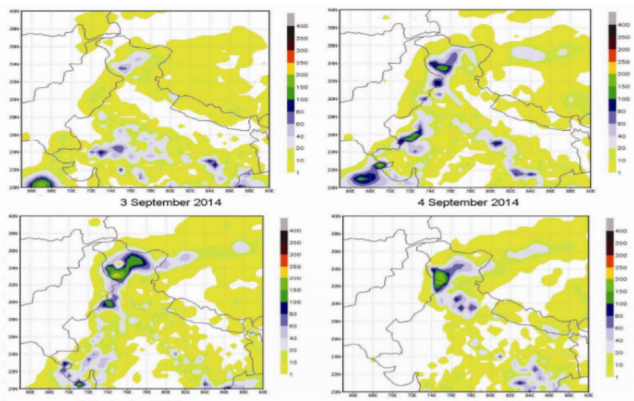
Sl. No.	Description	Amount in INR (Crores)	Amount in USD (Millions)
1	Chennai Real Estate	30000	4136.94
2	Small & Medium Industrial Units(Entire Tamil Nadu)	14000	1930.57
3	Insurance Companies	4800	661.91
4	Street vendors	225	31.03

B. Narasimham et. al., 2016

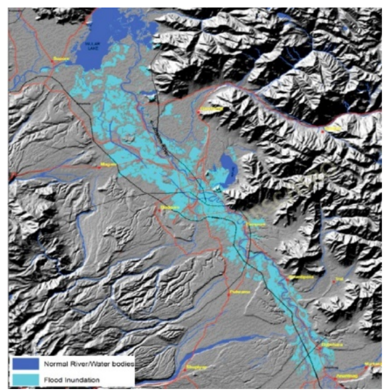
Kashmir Floods 2014

Transportation of residents to emergency relief camps
Source: www.oneindia.com

Tens of thousands of homes have been destroyed by flash floods and landslides on the border of India and Pakistan
Source : www.dailymail.co.uk



Precipitation analysis (mm) formed from the merger of IMD rain-gauge data with the TRMM TMPA satellite-derived rainfall estimates from 3 to 6 September 2014
Source: Ray et al.,(2015)



Cumulative flood inundation spatial extent (light blue colour) observed in Kashmir Valley between 8 and 25 September 2014.
Source : Bhatt et al., (2017)

Overview:

- Duration: 2nd to 26th September 2014
- Heavy monsoon rainfall commenced on 2nd September 2014 and continued for 5 days and led to unprecedented widespread flooding and landslide
- 277 people in India died due to the floods with economic losses of 1 trillion INR
- Banks of the river Jhelum, Chenab, Tawi and many other streams were burst
- About 557 km^2 of the Kashmir Valley's geographical area was inundated
- 5642 villages were affected across the state with 2489 in Kashmir valley, 3153 in Jammu division and 800 villages remained sub-merged for over two weeks
- Damaged 2,61,361 structures, 3,27,000 hectares of agricultural land and 3,96,000 hectares of horticultural land

Sources: scroll.in, reliefweb.int, hwnews.in

Causes:

- As per IMD, Jammu and Kashmir received 1645 mm rainfall in South Kashmir area which was way above the normal rainfall (124.9 mm) from 28th August to 10th September 2014

- Manmade rampant alteration on the natural landscape, increasing global temperature, an increase in habitation in high slope zones and deforestation were the main causes

- Rapid urbanisation, degradation and depletion of wetlands and unrestrained land-use changes with a huge increase in built up area from 18.10 sq. km to 84.50 sq. km (29.20%) between the year 1972-2004 also favoured the flood conditions

- Flat topography of the basin and blockage of natural drainage channel with dense settlement caused water logging in the area

Sources: Ray, Kamaljit, et. Al., 2015, http://www.iwrs.org.in, www.ncbi.nlm.nih.gov, http://www.mcrhrdi.gov.in

Economic losses

Sl. No.	Description	Amount in INR (Crores)	Amount in USD (Millions)
1	Housing sector	30,000	4137.69
2	Business sector	70,000	9654.62
3	Horticulture sector	5,611	773.886
4	Tourism infrastructure and government residential colonies	5,000	689.615

Source : Tabish et al.,(2015)

“Value of Water” : Issues of of Interest

- **We must account for the mammoth losses due to floods within the framework of “Value of Water”, in a Changing Climate.**

Research Questions:

- **Are the high intensity precipitation events increasing – globally, regionally, locally? If yes, is such an increase due to climate change?**

- **How do we estimate the changing frequencies of high intensity precipitation/streamflow; changing flood risk and vulnerability?**

- **Has the hydrologic response of the catchments deteriorated over the years because of landuse change?**

- **Can we use hydrologic models with high resolution NWP models to reconstruct past floods and forecast the future ones?**

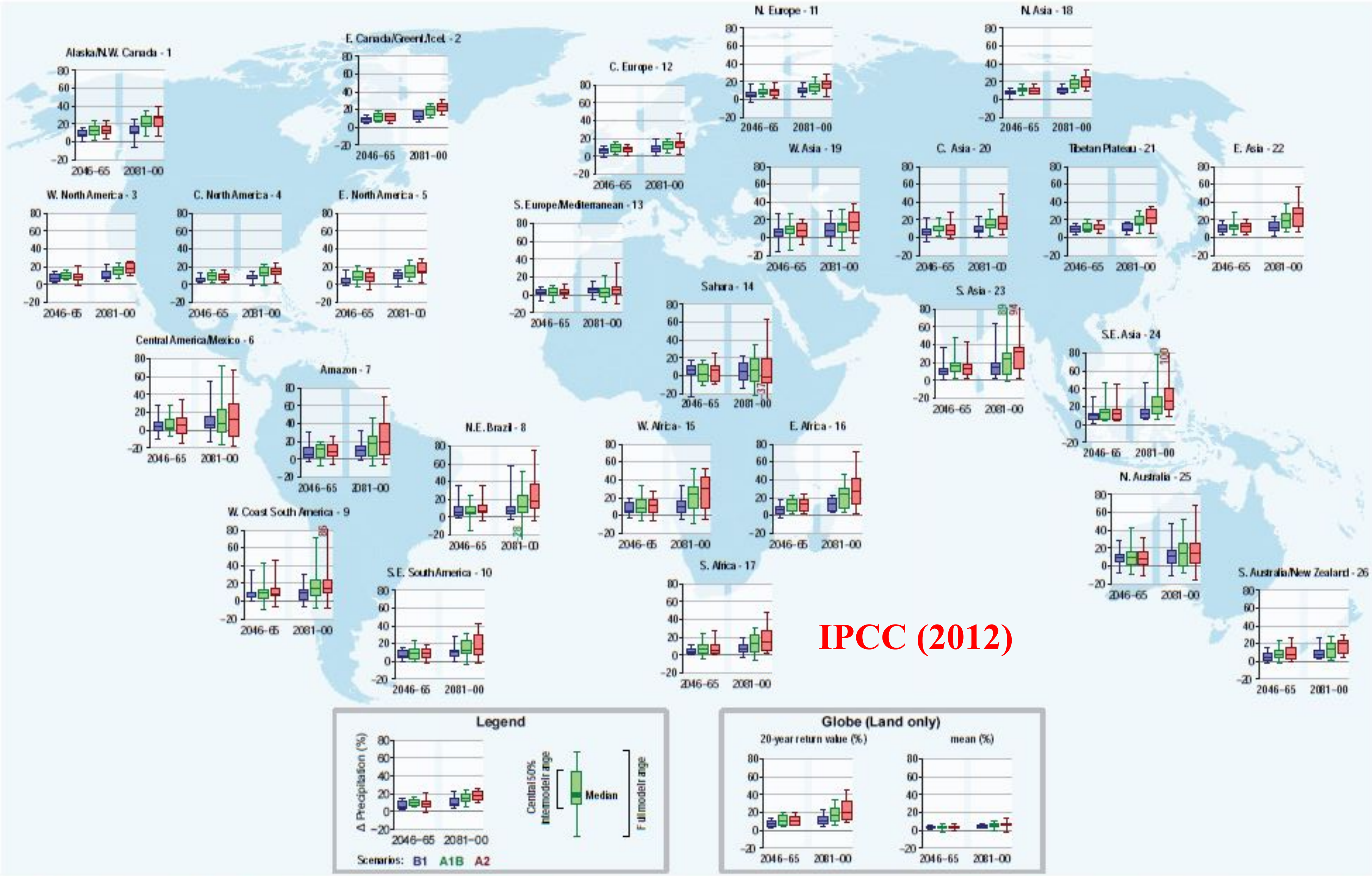
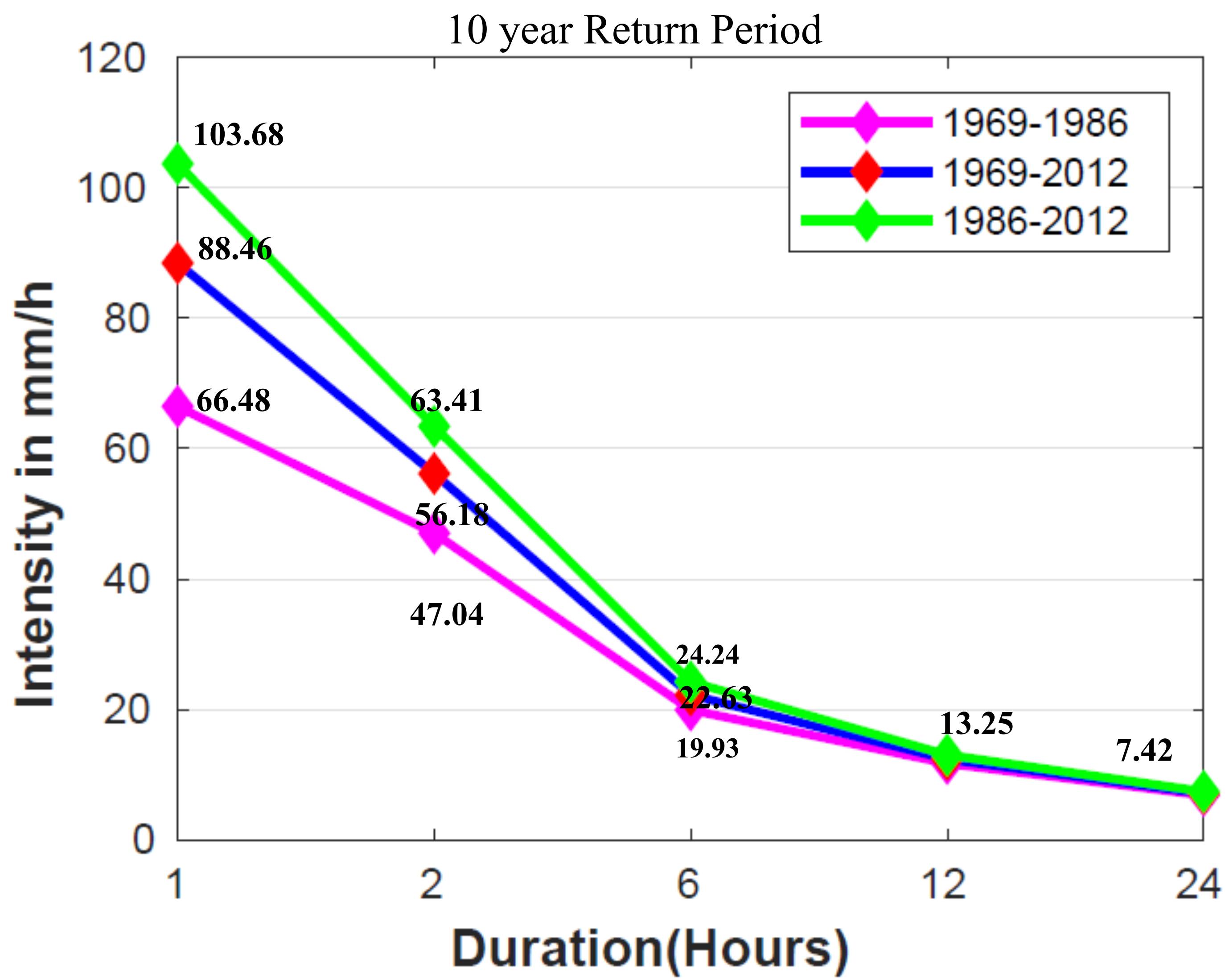


Figure 3-7a | Projected changes (%) in 20-year return values of annual maximum 24-hour precipitation rates. The bar plots (see legend for more information) show results for regionally averaged projections for two time horizons, 2046 to 2065 and 2081 to 2100, as compared to the late 20th century (1981-2000), and for three different SRES emission scenarios (B1, A1B, A2). Results are based on 14 GCMs contributing to the CMIP3. See Figure 3-1 for defined extent of regions. Values are computed for land points only. The 'Globe' analysis (inset box) displays the change in 20-year return values of the annual maximum 24-hour precipitation rates computed using all land grid points (left), and the change in annual mean 24-hour precipitation rates computed using all land grid points (right). Adapted from the analysis of Kharin et al. (2007). For more details, see Appendix 3.A.

Increase in Urban Precipitation Intensities: Bangalore city



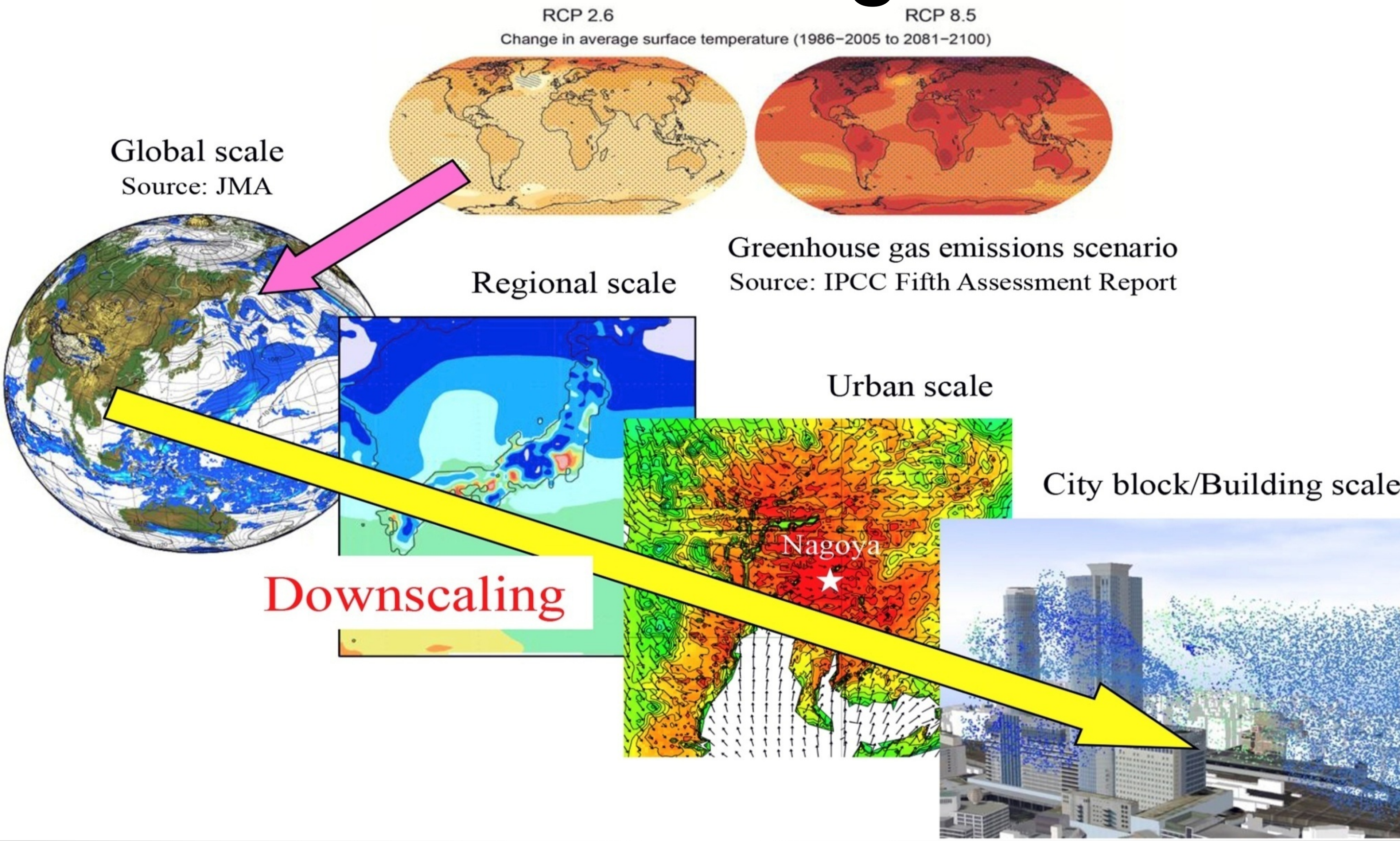
Bangalore Floods

How do the short term intensities of rainfall respond to the climate change?

Urban Flooding

Likely changes in IDF (Intensity-Duration-Frequency) relationships due to climate change

Downscaling



The developing culture of prophesising the future, guided by deterministic climate modelling approaches, has seriously affected hydrology. Therefore, aspired advances are related to abandoning the certainties of deterministic approaches and returning to stochastic descriptions, seeking in the latter theoretical consistency and optimal use of available data.

Demetris Koutsoyiannis (2021)

Advances in stochastics of hydroclimatic extremes, L' ACQUA 1/2021

Model Uncertainty

GCM model with future climate scenarios and latitude-longitude

Model Name	Latitude	Longitude	Abbreviation	Climate Scenarios
ACCESS1_0	12.5 N	76.875 E	A1	RCP 4.5, RCP 8.5
BCC-CSM1-1	12.55 N	78.75 E	BC1	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
BCC-CSM1-1-M	12.89 N	77.6 E	BC1M	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
BNU-ESM	12.55 N	78.75 E	BNU	RCP 2.6, RCP 4.5, RCP 8.5
CanESM2	12.55 N	78.7 E	CAN	RCP 2.6, RCP 4.5, RCP 8.5
CCSM4	12.7225 N	77.5 E	C4	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
CMCC-CMS	12.1 N	76.8 E	CMS	RCP 4.5, RCP 8.5
CNRM-CM5	11.9 N	77.34 E	CN5	RCP 4.5, RCP 8.5
CSIRO-MK3-6-0	12.12 N	76.875 E	CM60	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
FGOALS-G2	12.55 N	78.75 E	FG2	RCP 2.6, RCP 4.5, RCP 8.5
FGOALS-S2	12.4 N	75.9 E	FS2	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GFDL-CM3	13 N	78.75 E	GF3	RCP 2.6, RCP 6.0
GFDL-ESM2G	13.14 N	76.25 E	GF2G	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GFDL-ESM2M	13.14 N	76.25 E	GF2M	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GISS-E2-R	13 N	76.25 E	GISS	RCP 4.5
HadGEM2-CC	12.5 N	76.87 E	HADC	RCP 4.5, RCP 8.5
HadGEM2-ES	12.5 N	76.875 E	HADE	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
INMCM4	12.75 N	78 E	IN4	RCP 4.5, RCP 8.5
IPSL-CM5A-LR	12.31 N	78.75 E	IPCL	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
IPSL-CM5A-MR	12.6 N	77.5 E	IPCM	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
MIROC5	11.9 N	78.75 E	MI5	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
MIROC-ESM-CHEM	12.55 N	78.75 E	MIEC	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
MIROC-ESM	12.55 N	78.75 E	MIE	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
MPI-ESM-LR	12.12 N	78.75 E	MPI	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
MRI-CGCM3	12.89 N.	77.62 E	MRI	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
NorESM1-M	12.31 N	77.5 E	NEM	RCP 2.6., RCP 4.5, RCP 6.0, RCP 8.5

CLIMATE CHANGE IMPACTS

Bangalore City : Projected change in the IDF Relationship :- CMIP5 models with AR5 scenarios (85 simulations; uncertainty with REA)

CMIP 5 Ensemble

↓

Downscaling (Daily Scale) Rainfall

↓

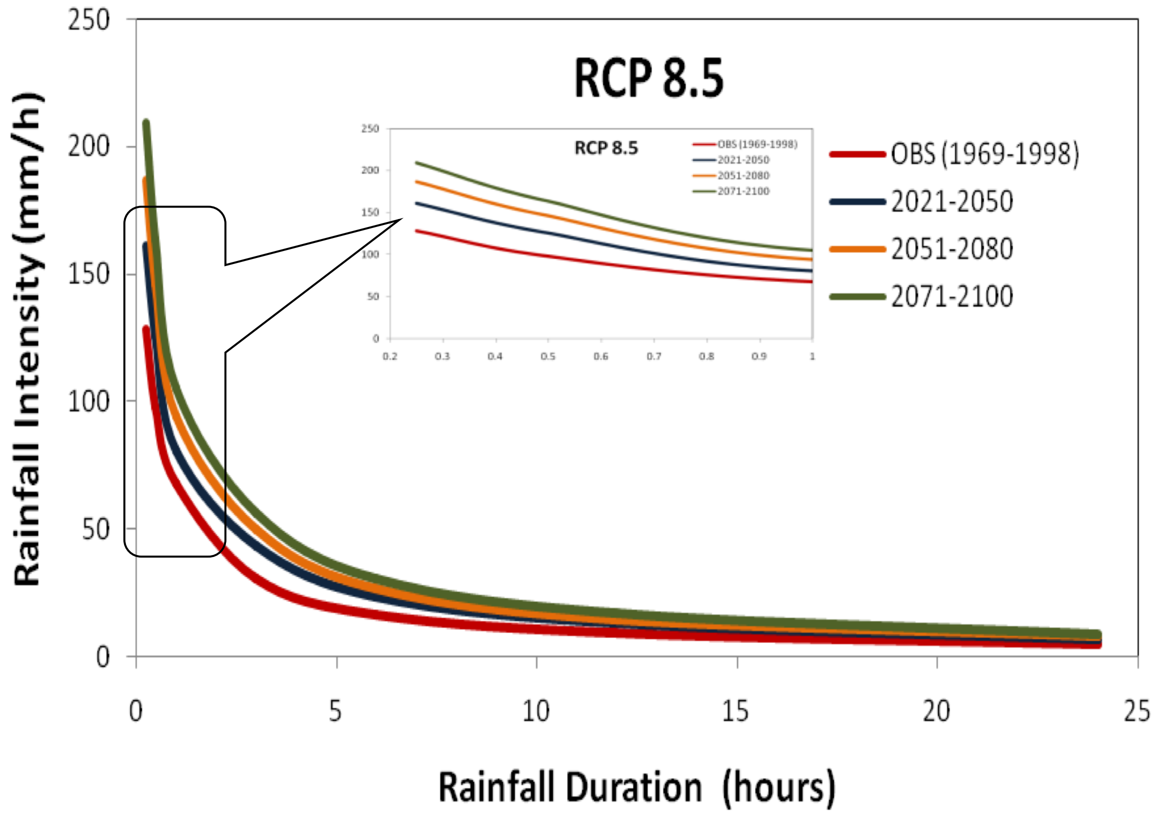
Stochastic Disaggregation

↓

Hourly and Sub-hourly Scale Rainfall Intensity

↓

Ensemble Averaged Projections

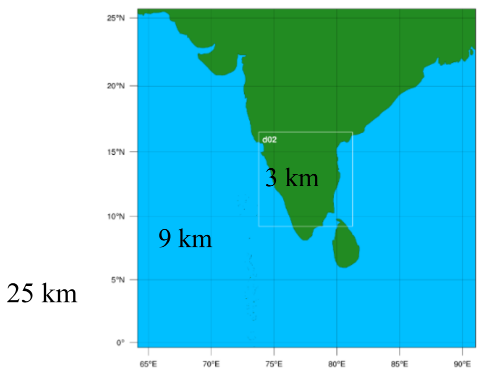


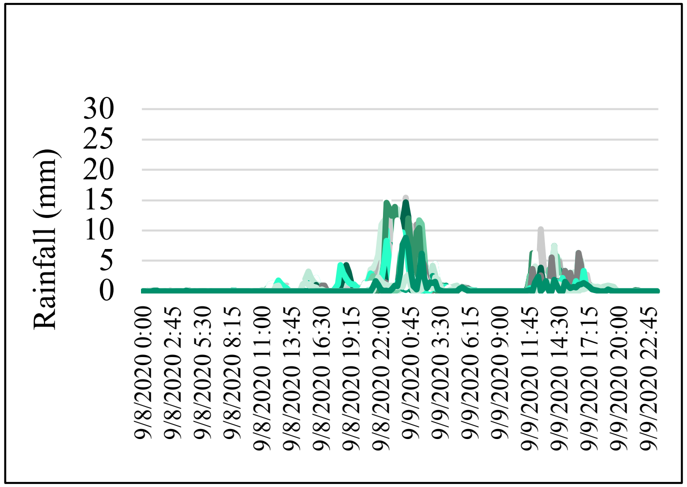
$$E\left[Z_{\lambda t}^{\ d}\right] = \lambda^{d\beta} E\left[Z_t^d\right]$$

Scale invariance

The quantiles and raw moments of any order are scale invariant; *d* is the order of the moment.

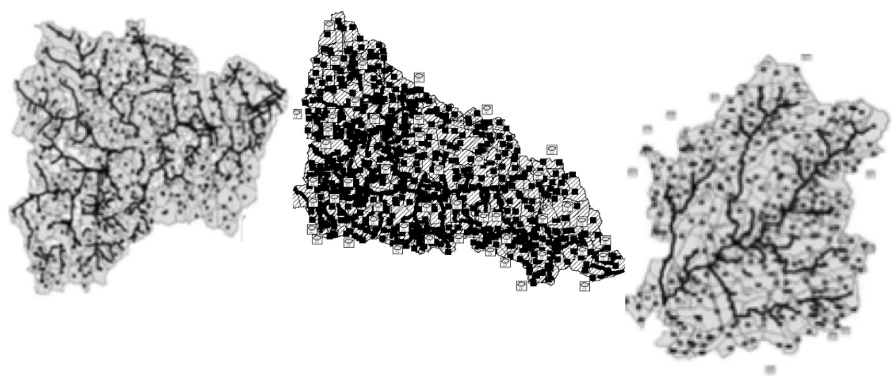
Hydromet Model Simulation Workflow for Sep 8-9, 2020 Extreme Event over Bangalore



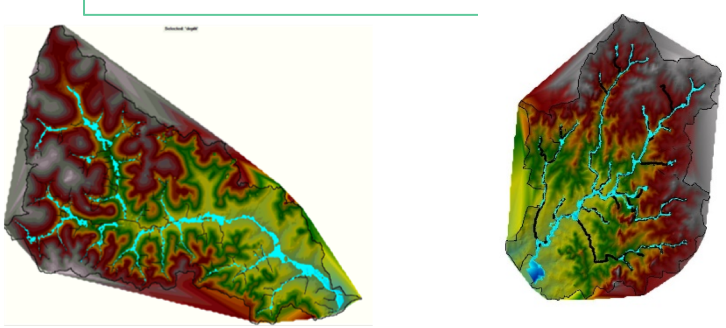


The rainfall corresponding to each station is extracted from the WRF 3 km gridded output.

Forecast data generated at Sep 7, 2020, 6 pm for the next 72 hours is given as boundary conditions to run the WRF model.

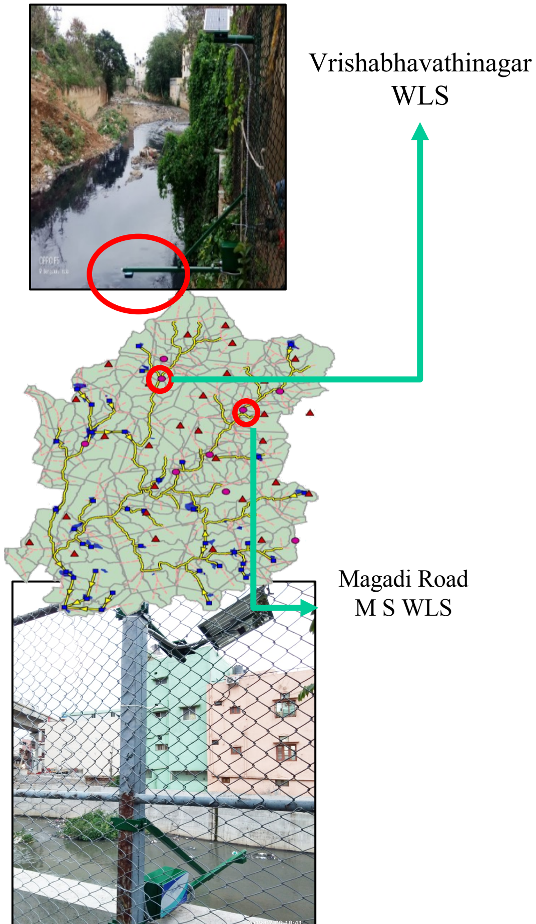


One dimensional model using SWMM which are calibrated and validated using various rainfall events

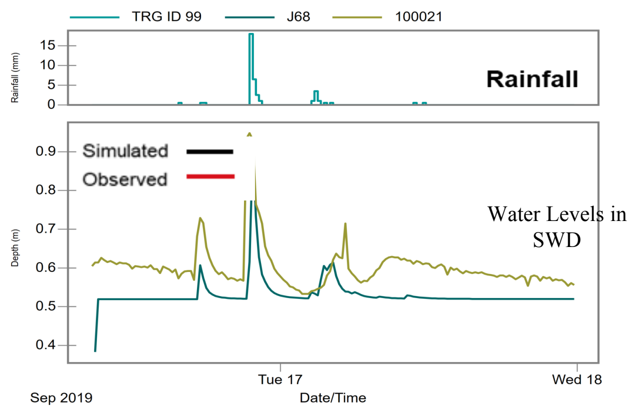


HECRAS 2D Model is developed for flood inundation

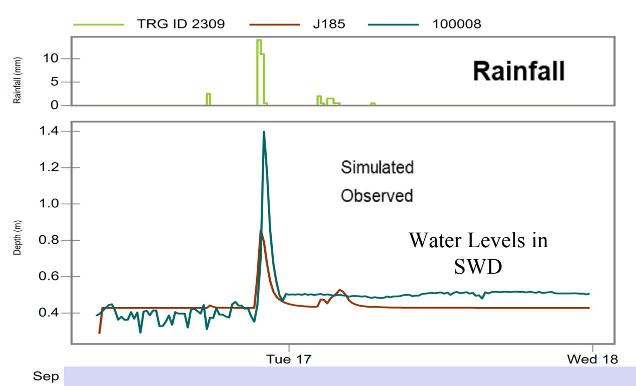
Flood Modelling using PCSWMM



September 16, 2019

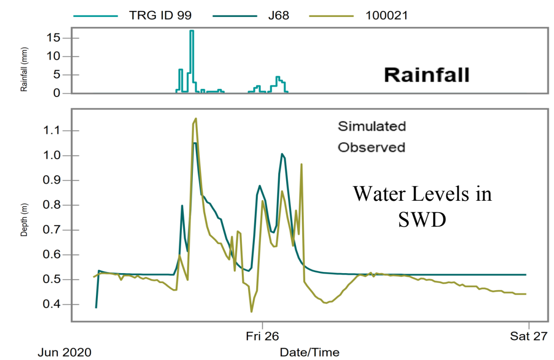


RMSE = 0.693 R square = 0.367

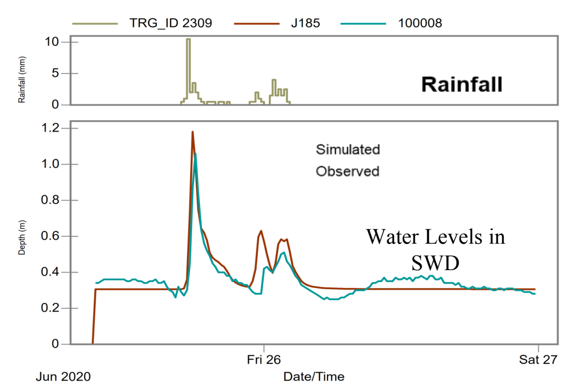


RMSE = 0.833 R square = 0.518

June 25, 2020



RMSE = 0.536 R square = 0.729



RMSE = 0.718 R square = 0.705

The model is capable to capture peak flows in comparison with the observed water levels as shown.

Probability of extreme hydrometeorological events - a different approach

V. KLEMEŠ
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Abstract A criticism of the standard approach to frequency analysis is presented and a different rationale is proposed based on treating the variable of interest as a compound event and synthesizing its distribution function by enumerating all physically plausible combinations of its major components for which data are available. Since only the order

- **Traditional frequency analysis cannot reveal anything about the interacting processes.**
- **Therefore, statistical approaches which can enhance process based understanding are required in hydrology to improve the prediction of floods and droughts.**

- River flooding is not merely the result of high rainfall.
- Other mechanisms such as antecedent soil moisture conditions and snowmelt contributes to excess runoff in most of the catchments.

1) Which flood generating mechanism is dominant in the river basin?
2) Are the interactions of multiple processes causing floods?
3) Out of multiple interacting physical mechanisms, which interaction is dominant?

How often an extreme event can be equalled or exceeded?

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL062308

Key Points:
- Univariate return period analysis underestimates risk of concurrent extremes
- A concurrent extreme viewpoint is necessary in a warming climate
- A framework is discussed for assessing the risk of concurrent extremes

Supporting Information:
- Figure S1

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Citation:
AghaKouchak, A., L. Cheng, O. Mazdiyasni, and A. Farahmand (2014), Global warming and changes in risk of concurrent climate extremes: Insights

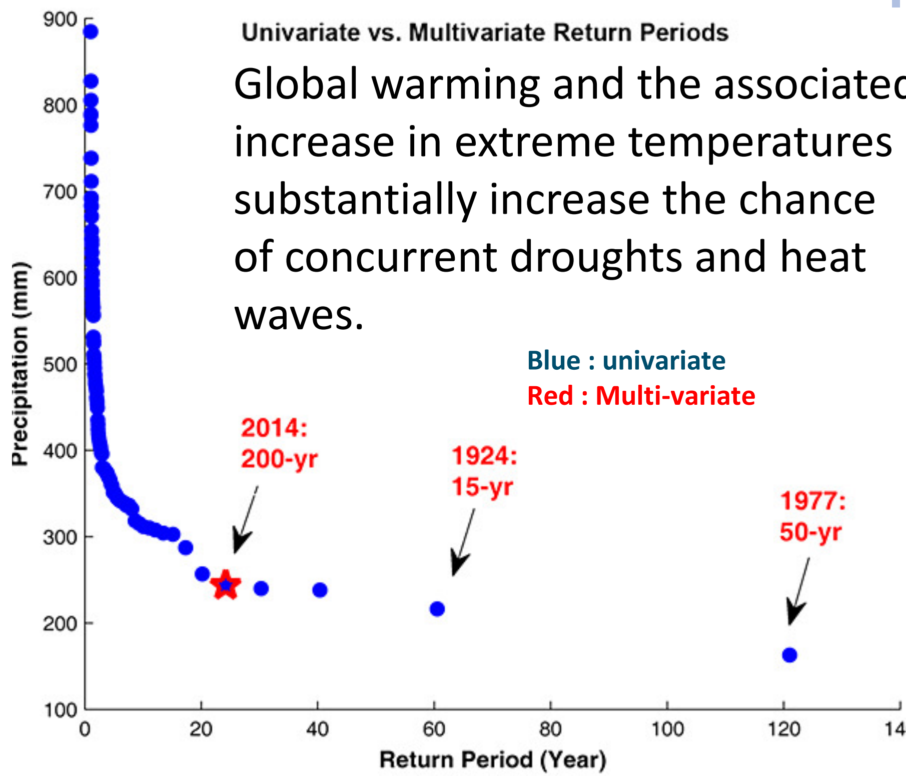
Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought

Amir AghaKouchak[1], Linyin Cheng[1], Omid Mazdiyasni[1], and Alireza Farahmand[1]

[1]Center for Hydrometeorology and Remote Sensing, University of California, Irvine, California, USA

Abstract Global warming and the associated rise in extreme temperatures substantially increase the chance of concurrent droughts and heat waves. The 2014 California drought is an archetype of an event characterized by not only low precipitation but also extreme high temperatures. From the raging wildfires, to record low storage levels and snowpack conditions, the impacts of this event can be felt throughout California. Wintertime water shortages worry decision-makers the most because it is the season to build up water supplies for the rest of the year. Here we show that the traditional univariate risk assessment methods based on precipitation condition may substantially underestimate the risk of extreme events such as the 2014 California drought because of ignoring the effects of temperature. We argue that a multivariate viewpoint is necessary for assessing risk of extreme events, especially in a warming climate. This study discusses a methodology for assessing the risk of concurrent extremes such as droughts and extreme temperatures.

- Recent high impact extremes provide evidences for interconnections of extremes.



Univariate vs multivariate return periods. From: AghaKouchak et al. (2014)

Slide credit : Shailza Sharma

Accurate estimation of probabilities of extremes is essential for planning risk management strategies and taking preventive actions.

Compounding effects of sea level rise and fluvial flooding

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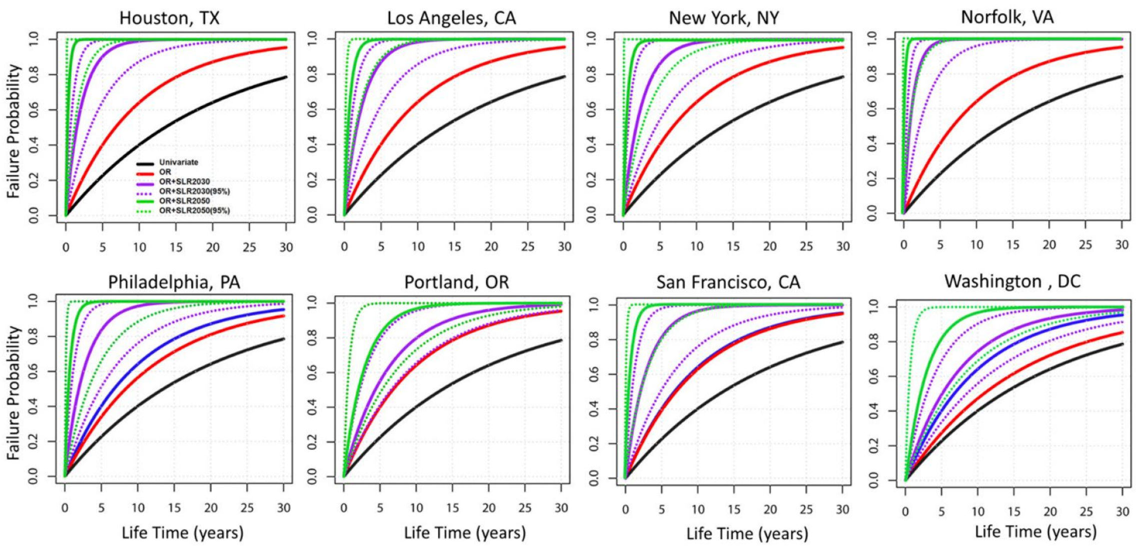
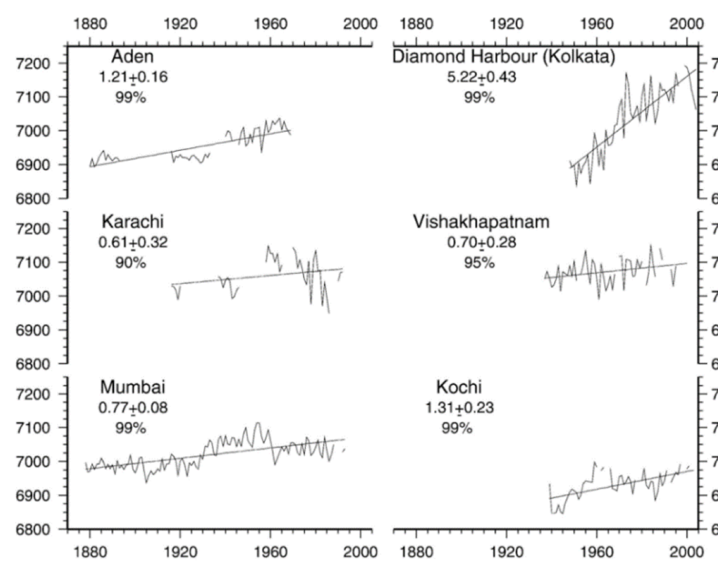
Edited by Anny Cazenave, Centre National d'Etudes Spatiales, Toulouse, France, and approved July 24, 2017 (received for review December 19, 2016)



Black : Univariate, present climate
Red : Bivariate, Present Climate
Other colors (except blue) : future climate

Sea level rise in India



Source: Unnikrishnan and Shankar (2007)

SCIENCE ADVANCES | RESEARCH ARTICLE

CLIMATOLOGY

Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change

E. Bevacqua[1*†], D. Maraun[1], M. I. Vousdoukas[2,3], E. Voukouvalas[4], M. Vrac[5], L. Mentaschi[2], M. Widmann[6]

Storm Surge : a rising of the sea as a result of wind and atmospheric pressure changes associated with a storm.

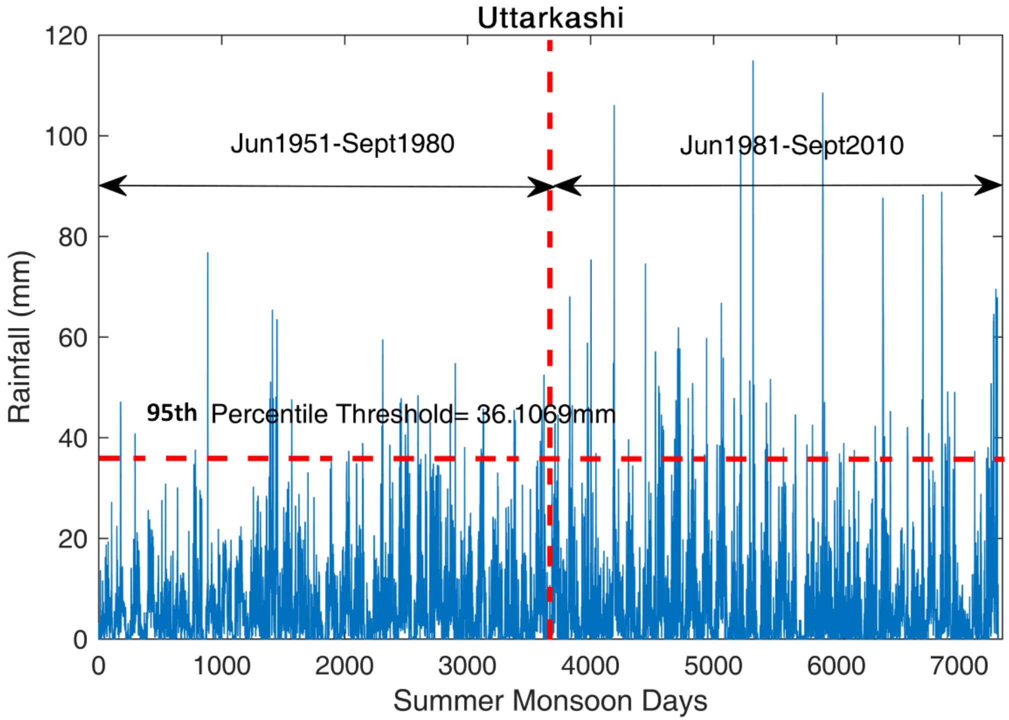
A continuous spell of extreme rainfall has devastating consequences compared to a single day extreme rainfall event.

Heavy rainfall for 4 consecutive days
(June 14 to June 17)
(Uttarakhand 2013 Floods)

Incessant heavy rainfall
(Sept 2 to Sept 6)
(Kashmir 2014 Floods)

Prolonged high intensity rainfall
(July-August)
(Kerala 2018 Floods)

- Extreme rainfall for a few consecutive days leads to saturation of soil, which reduces infiltration and increases surface runoff.
- This excess runoff results in stagnation of water in urban areas and increase in water levels of rivers.
- Such flooding situations are arising more frequently; therefore it is important to include such changes in frequency analysis



Heavy rainfall for 4 consecutive days (June 14 to June 17)

(Uttarakhand 2013 Floods)

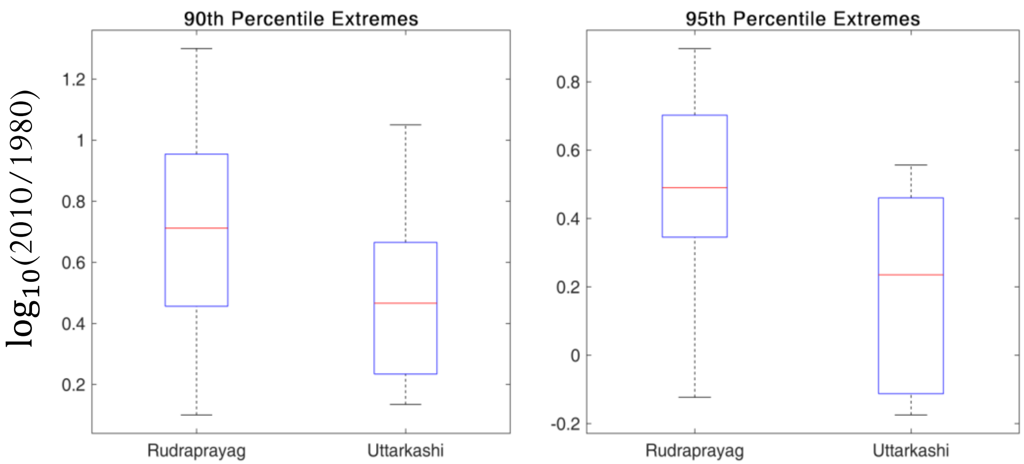


Figure: Posterior distribution of the ratio of probabilities of extreme rainfall spells of 4 days for 2010 relative to 1980.

An increase is observed in the probabilities of extreme rainfall spells for both the sites.

What happens to the concept of ‘return period’ under non-stationarity?

Amir AghaKouchak · David Easterling
Kuolin Hsu · Siegfried Schubert
Soroosh Sorooshian *Editors*

Extremes in a Changing Climate

Detection, Analysis and Uncertainty

Chapter 4
Return Periods and Return Levels Under Climate Change

Daniel Cooley

Abstract We investigate the notions of return period and return level for a nonstationary climate. We discuss two general methods for communicating risk. The first eschews the term return period and instead communicates yearly risk in terms of a probability of exceedance. The second extends the notion of return period to the non-stationary setting. We examine two different definitions of return period under non-stationarity. The first, which appears in Olsen et al. (Risk Anal 18:497–510,
expected waiting
Parey et al. (Clim
:698–718, 2010),
number of events
nications with an

Revisiting the Concepts of Return Period and Risk for Nonstationary Hydrologic Extreme Events

Jose D. Salas, M.ASCE[1]; and Jayantha Obeysekera, M.ASCE[2]

Abstract: Current practice using probabilistic methods applied for designing hydraulic structures generally assume that extreme events are stationary. However, many studies in the past decades have shown that hydrological records exhibit some type of nonstationarity such as trends and shifts. Human intervention in river basins (e.g., urbanization), the effect of low-frequency climatic variability (e.g., Pacific Decadal Oscillation), and climate change due to increased greenhouse gasses in the atmosphere have been suggested to be the leading causes of
changes in the
sea levels. To t
analysis, in whi
and methods us
work. In partic
exceeding prob
present a simpl
applications so
for nonstationar

Quantifying the Uncertainty of Design Floods under Nonstationary Conditions

Jayantha Obeysekera, M.ASCE[1]; and Jose D. Salas, M.ASCE[2]

Abstract: Estimating design quantiles for extreme floods in river basins under nonstationary conditions is an emerging field. Nonstationarities could arise from a variety of human and natural factors such as urbanization and climate change. Concepts of return period, design

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Return levels of hydrologic droughts under climate change

Arpita Mondal[a], P.P. Mujumdar[a,b,*]

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A R T I C L E I N F O

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Non-stationary
Transient return levels
Detection

A B S T R A C T

Developments in the statistical extreme value theory, which allow non-stationary modeling of changes
the frequency and severity of extremes, are explored to analyze changes in return levels of droughts f
the Colorado River. The transient future return levels (conditional quantiles) derived from region
drought projections using appropriate extreme value models, are compared with those from observ
naturalized streamflows. The time of detection is computed as the time at which significant differenc
exist between the observed and future extreme drought levels, accounting for the uncertainties in the
estimates. Projections from multiple climate model-scenario combinations are considered; no unifor
pattern of changes in drought quantiles is observed across all the projections. While some projectio
indicate shifting to another stationary regime, for many projections which are found to be non-stationar
detection of change in tail quantiles of droughts occurs within the 21st century with no unanimity in t
time of detection. Earlier detection is observed in droughts levels of higher probability of exceedance

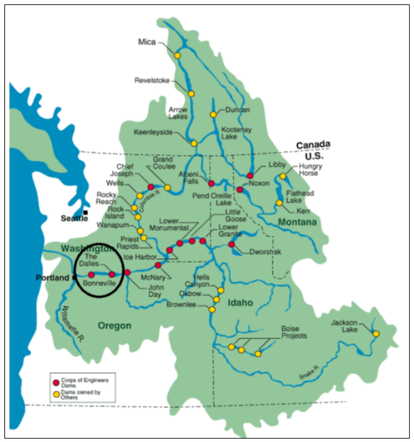
Detection of Change in Flood Return Levels under Global Warming

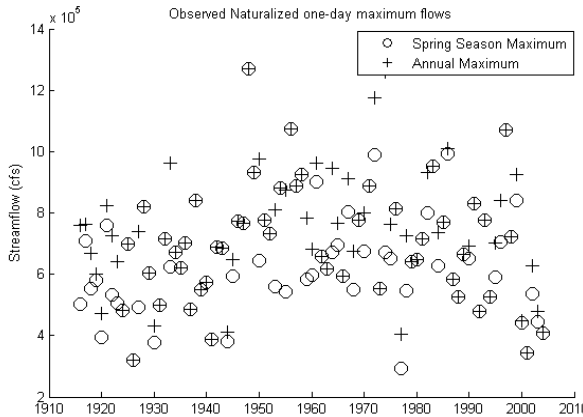
Arpita Mondal[1] and P. P. Mujumdar[2]

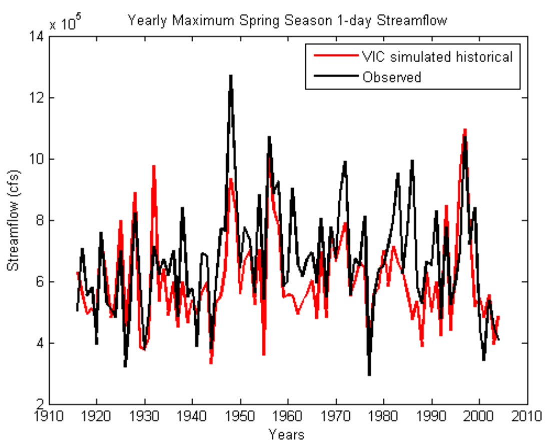
Abstract: Using recent advancements in the statistical extreme value theory, this study proposes a methodology for detection of change
flood return levels under climate change. Nonstationary scaling of regional projected peak flows with global warming is first tested by
likelihood ratio test. For nonstationary possible future realizations, the authors then investigate how long the stationary historical desi
magnitudes or return levels of floods will remain valid, taking into account the uncertainties in the estimation of observed and project
return levels. Although some flood projections are found to be nonstationary, many are stationary in nature. No coherent change in flo
return level across the projections is detected in the case study of floods in the Columbia River using available streamflow projections. M
projections yield flood quantiles that are not likely to be critical in the coming century. However, for some simulations detection is achieve
with earlier detection in design magnitudes of lower return periods. A possible worst-case scenario considering the maximum of all t
projections shows detection of change in floods of higher return periods in the 21st century. **DOI:** 10.1061/(ASCE)HE.1943-55
.0001326. *© 2016 American Society of Civil Engineers.*

Author keywords: Floods; Climate change; Non stationary; Extreme value theory; Detection.

Columbia River: Projections



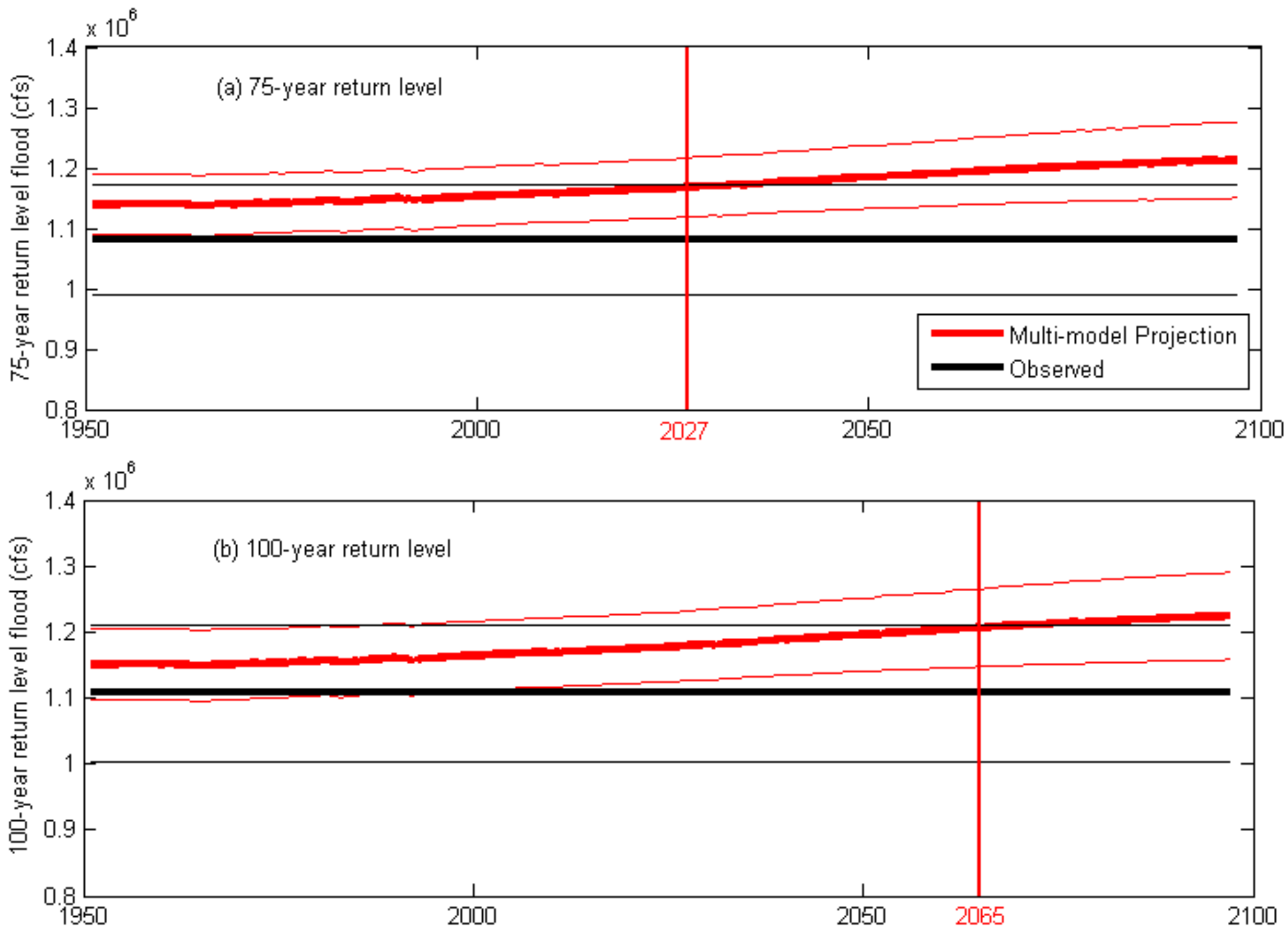




- The macroscale VIC model is run at a spatial resolution of 1/16th degree latitude and longitude (Hamlet and Lettenmaier (2005))
- Bias corrected and spatially downscaled (BCSD) meteorological forcings used in the VIC for the IPCC A1B and B1 scenarios for 1950-2097

Slide credit : Arpita Mondal

Time of detection – floods in the Columbia River



Model Reconstruction of Uttarakhand Floods 2013

Upper Ganga Basin (UGB)

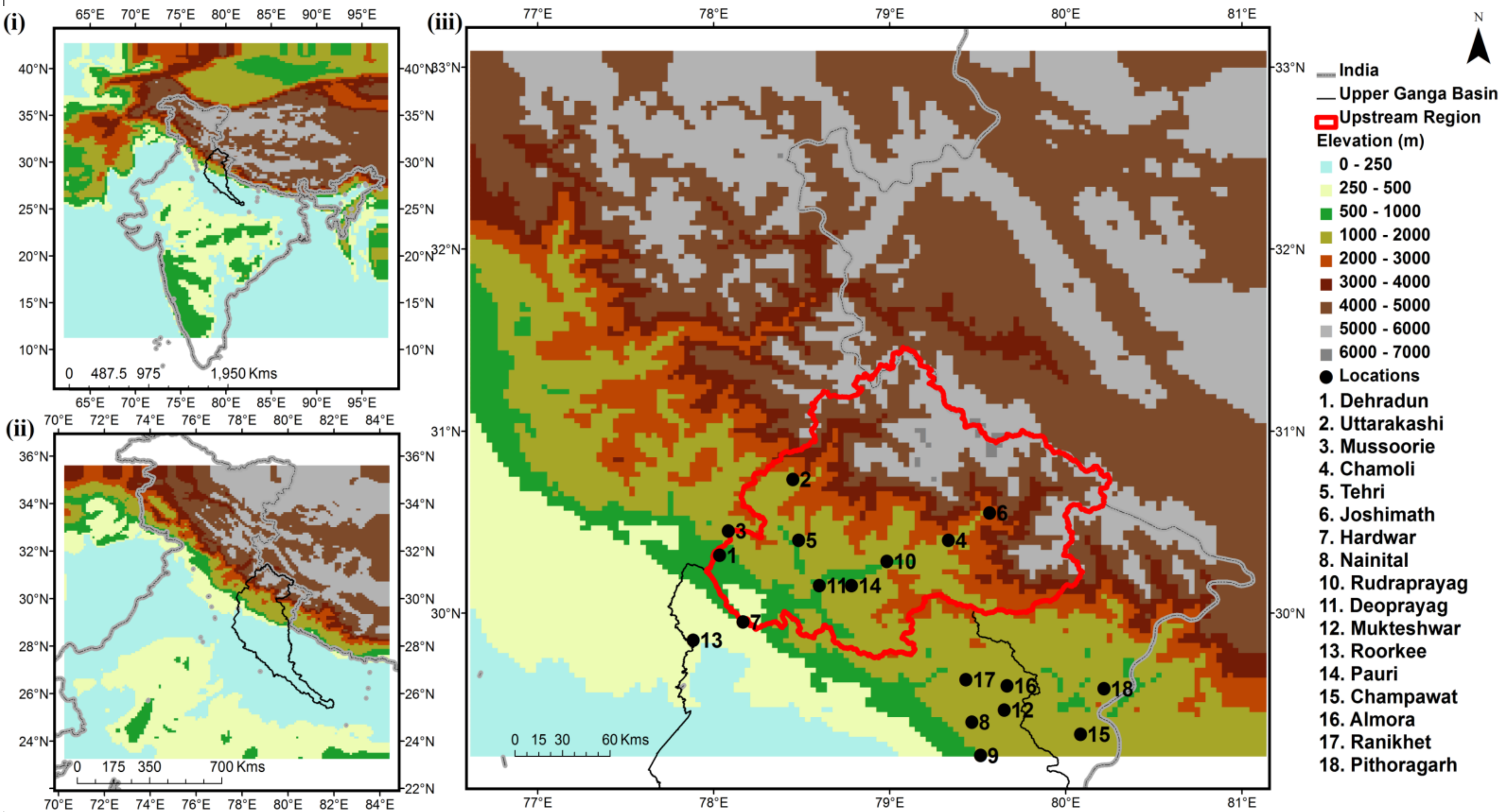
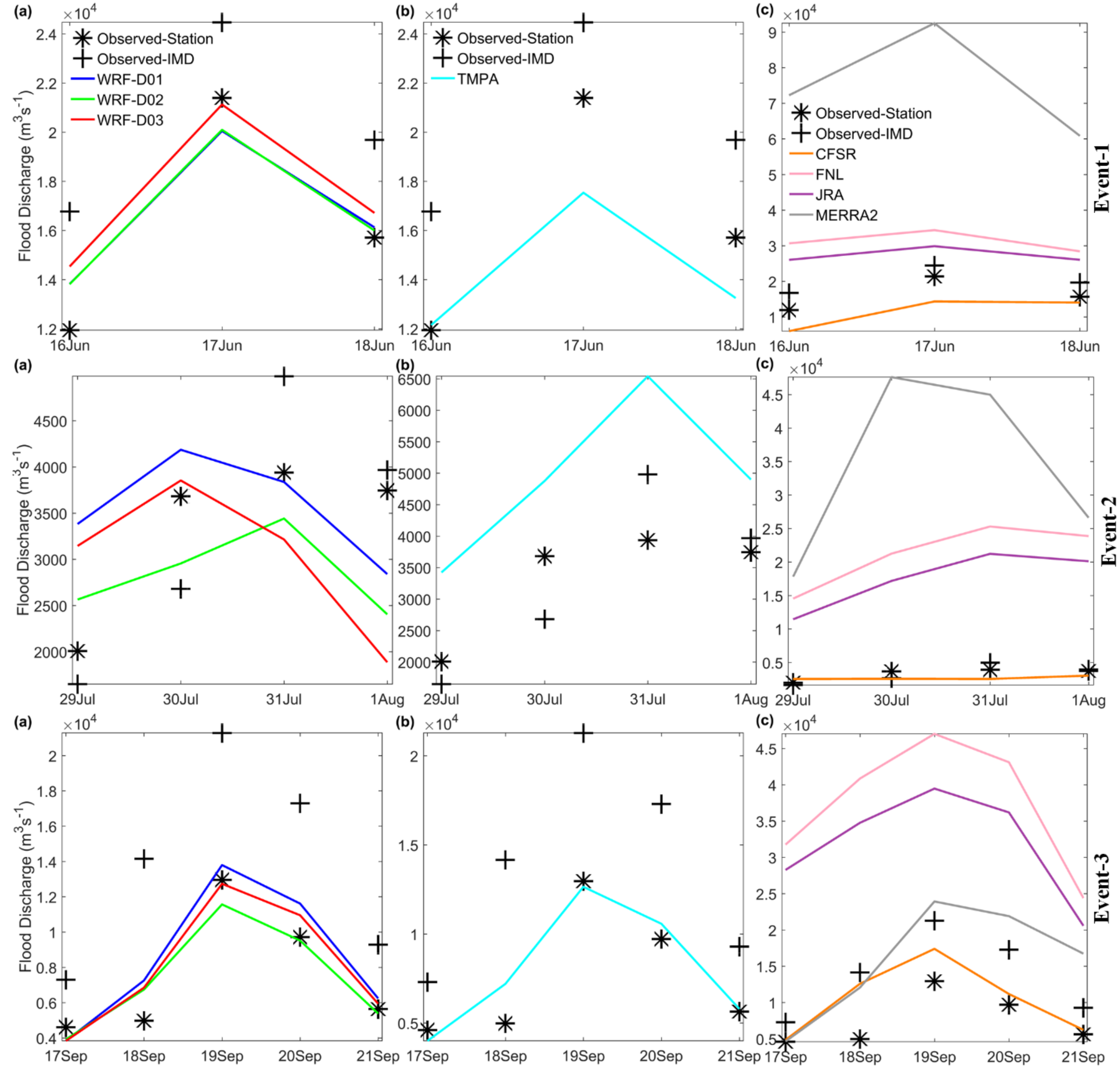


Figure 1: Topography of the study region (shown with black outline) as represented in the WRF model for (i) Domain 1 – 27 km grid spacing; (ii) Domain 2a – 9 km grid spacing (downscaling ratio – 1:3); and (iii) Domain 2b – 3 km grid spacing (downscaling ratio – 1:9). Locations of the rain gauge stations within the UGB are presented as black dots in Figure 1 (iii).

Simulation of Flood Events



WRF Model for Rainfall Simulation

VIC Hydrologic Model for Flow Simulation

Figure. *Flood discharge simulations obtained from (a) the WRF-VIC coupled model, and the stand-alone VIC model driven using (b) the TMPA data, and (c) the reanalysis datasets for the three events under consideration. The coupled WRF-VIC system is seen to give least bias in the simulated flood discharges.*

Summary

- **The concept of "Value of Water" must account for the mammoth losses due to floods. This necessitates an improved assessment of evolving flood risk and vulnerability at a range of space-time scales.**
- **Intensities of rainfall are known to be increasing across different space-time scales.**
- **Scale issues and uncertainties need to be addressed in quantification of the likely changes in the flood risk and vulnerability under climate change.**
- **Coupled weather forecasting and hydrologic models are needed for developing reliable flood forecasts.**

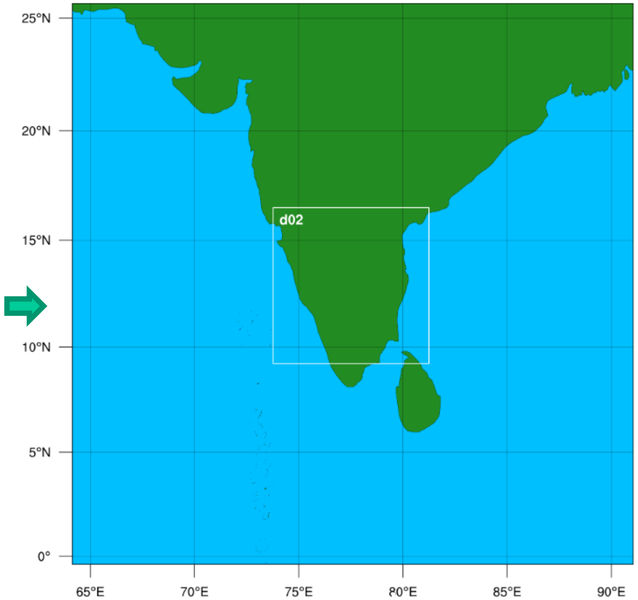
Thank You

Flood Event in Bangalore, Sep 8-9, 2020 : Reconstruction with WRF

WRF Model Setup

Boundary Conditions from GFS Forecast Grid

25 km

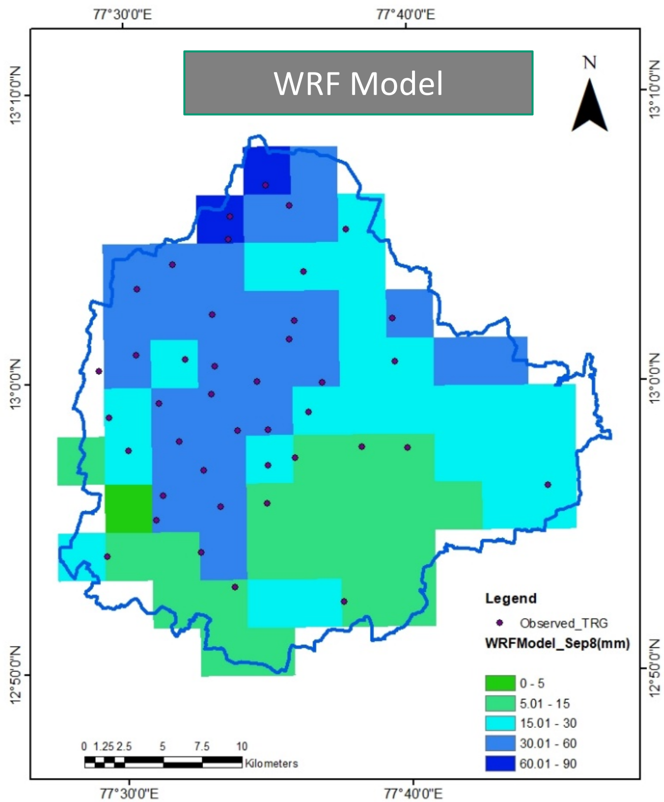


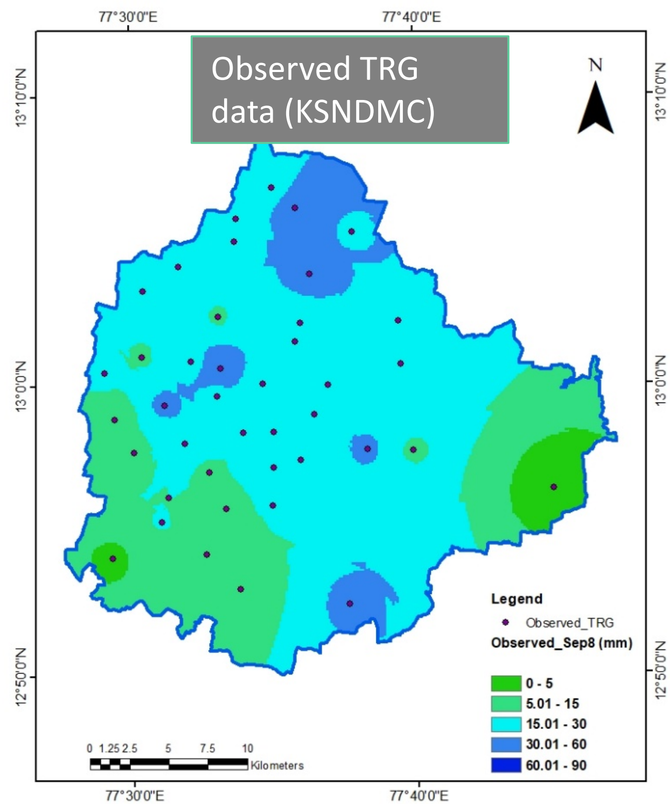
	Domain1	Domain2
Resolution (km)	9	3
Number of Grids (e_we)	325	271
Number of Grids (e_sn)	325	271

- RDA dataset ds084.1 - 'NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive' is given as input ; 3 hourly forecast data is given as boundary conditions

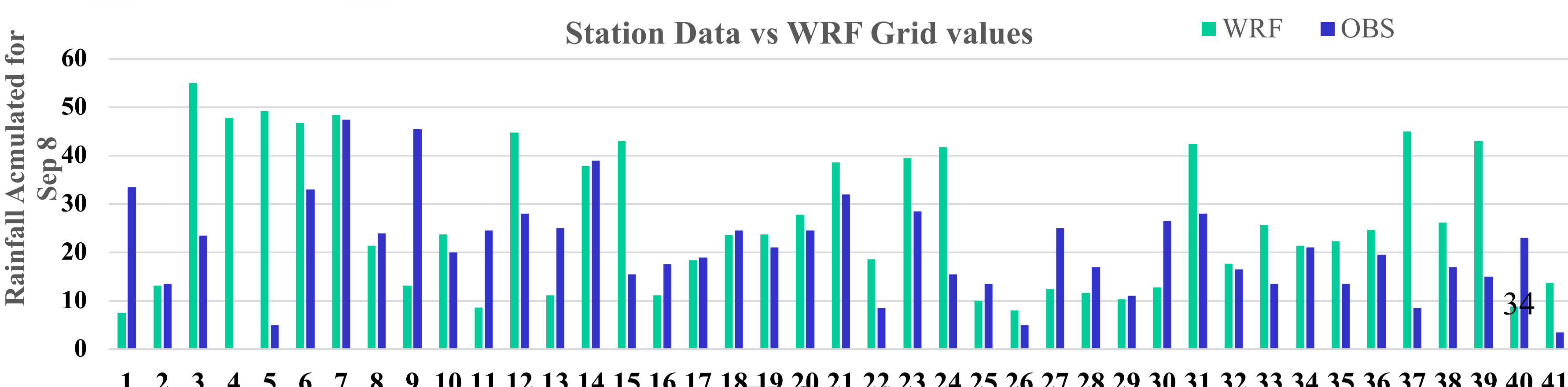
Parameterization Schemes	
Planetary Boundary Layer	Yonsei University PBL scheme
Microphysics Scheme	WSM6 scheme
Cumulus Parameterisation Scheme	Kain Fritsch
Radiation Scheme	RRTM Scheme
Surface Layer Parameterization	Thermal diffusion scheme

Spatial Distribution of Rainfall on September 8, 2020





RMSE (%)	MAE (%)
17.82	12.81



Rainfall Data – June 2013

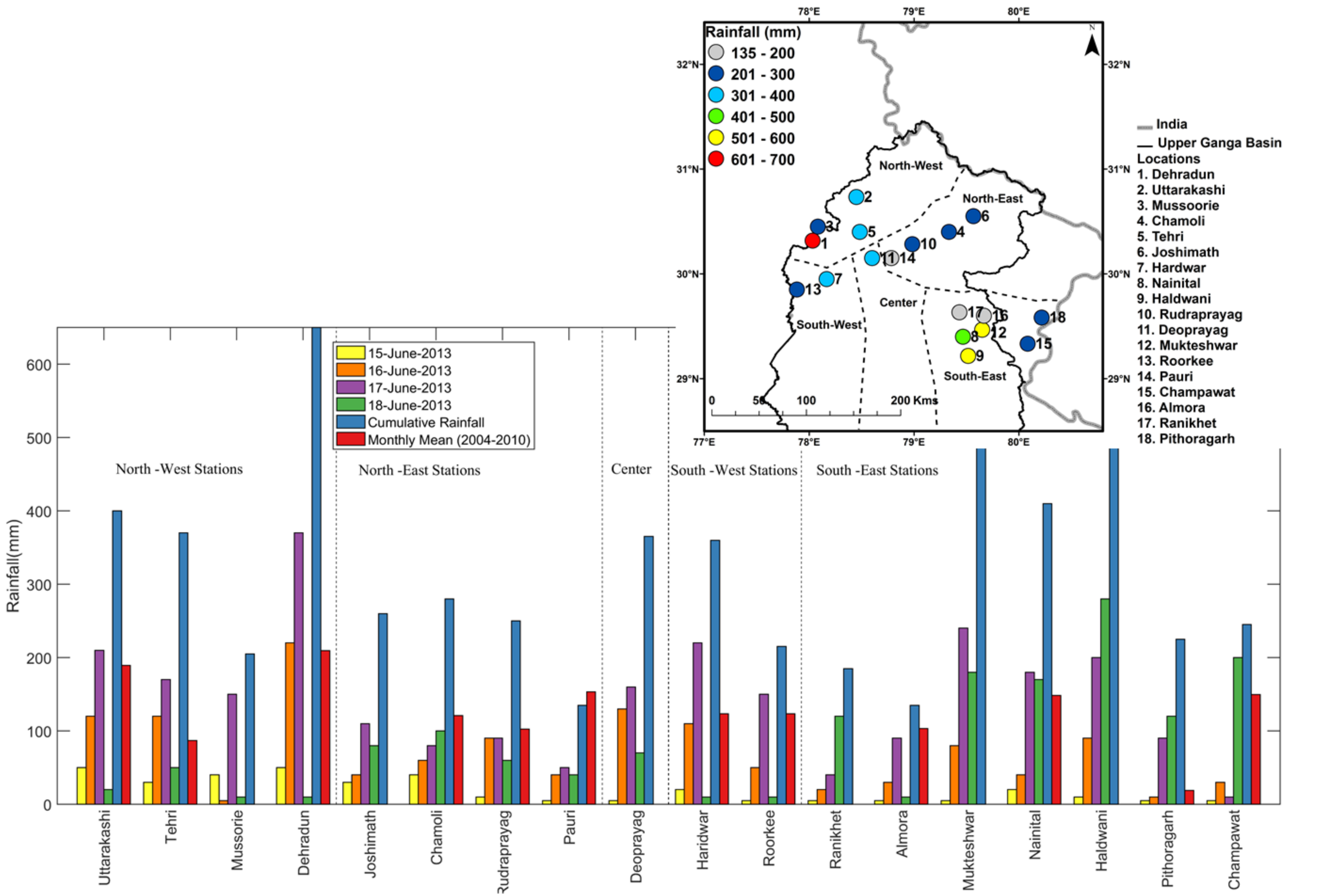
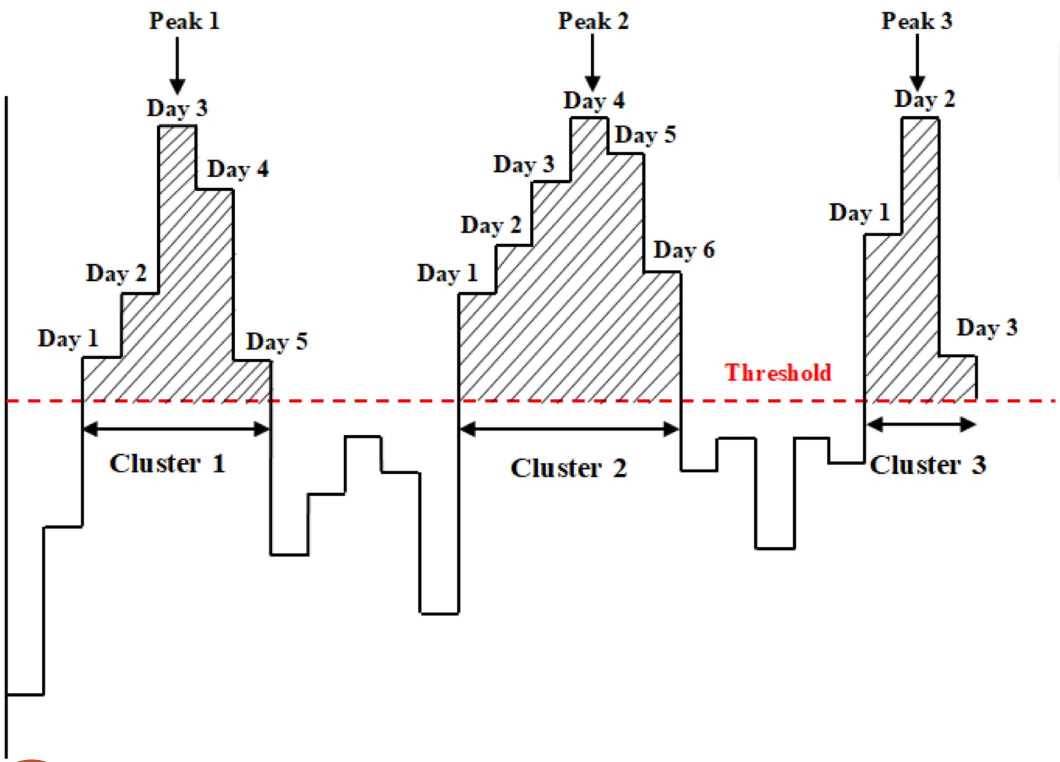


Figure 2: Observed daily and cumulative rainfall along with historic monthly mean (2004–2010) values at the 18 rain gauges in the upstream region of the UGB.

Do we have methods for statistical analysis of extreme rainfall spells?

- Two widely used approaches for modeling extremes are: Block maxima approach and Peaks-over-threshold.
- Block maxima does not account for the duration of the event and Generalized Pareto Distribution (GPD), widely used for modeling the exceedances models the peaks of cluster to meet the independence assumption.
- Hence, these two procedures are unsuitable for statistical analysis of extreme rainfall spells.



Challenges

1) How to quantify the serial or temporal dependence of extreme rainfall spells?
2) Are extreme rainfall spells clustering more now than expected?
3) Are such serially dependent rainfall extremes going to increase in the future?

…ure: Definition of extreme rainfall spell as a cluster of …ceedances above high threshold

compound events can be (1) two or more extreme
events occurring simultaneously or successively, (2) combinations of
extreme events with underlying conditions that amplify the impact of
the events, or (3) combinations of events that are not themselves
extremes but lead to an extreme event or impact when combined.

A changing climate can be expected to lead to changes in climate and weather extremes. But it is challenging to associate a single extreme event with a specific cause such as increasing greenhouse gases because a wide range of extreme events could occur even in an unchanging climate, and because extreme events are usually caused by a combination of factors. Despite this, it may be possible to make an attribution statement about a specific weather event by attributing the changed probability of its occurrence to a particular cause. For example, it has been estimated that human influences have more than doubled the probability of a very hot European summer like that of 2003.

PMP – It is the greatest or the extreme **rainfall** for a given duration that is physically possible **over** a raingauge station or a **basin**. It is that **rainfall over a basin** which would produce a flood with no risk of being exceeded.

Probable Maximum Flood (PMF). The largest flood that could conceivably be expected to occur at a particular location, usually estimated from probable maximum precipitation. The PMF defines the maximum extent of flood prone land, that is, the floodplain. It is difficult to define a meaningful Annual Exceedance Probability for the PMF, but it is commonly assumed to be of the order of 104 to 107(once in 10,000 to 10,000,000 years) (10).

For multivariate analysis, copulas (which are non-parametric models) are used to address the dependence among different variables. Shailzas work deals with developing parametric models.