Use of CORDEX Downscaled Data for Hydrologic Impact Assessment

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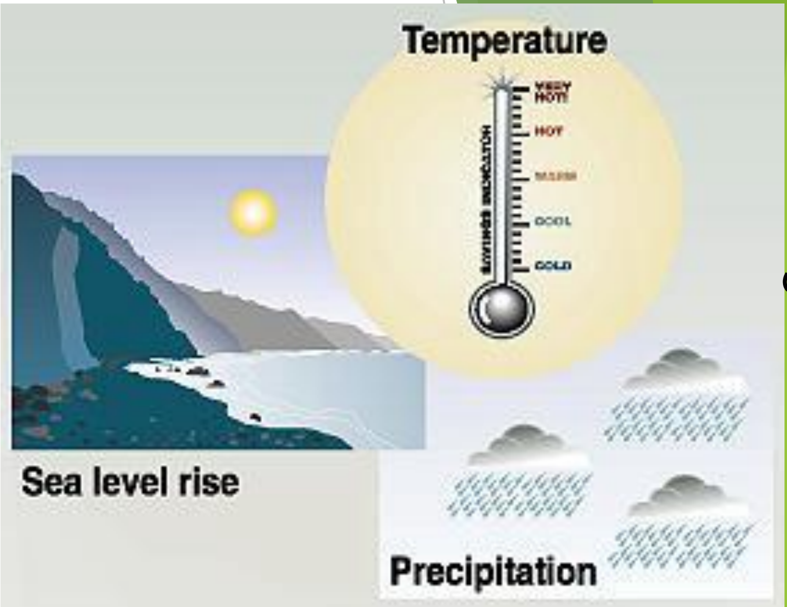
Climate Change – Hydrologic Implications

- Increasing Temperatures
  - Evapotranspiration
  - Water Quality
- Change in Precipitation Patterns
  - Streamflow; Water availability
  - Intensity, Frequency and Magnitude of Floods and Droughts
  - Groundwater Recharge
- Rise in Sea Levels
  - Inundation of coastal areas
  - Salinity Intrusion



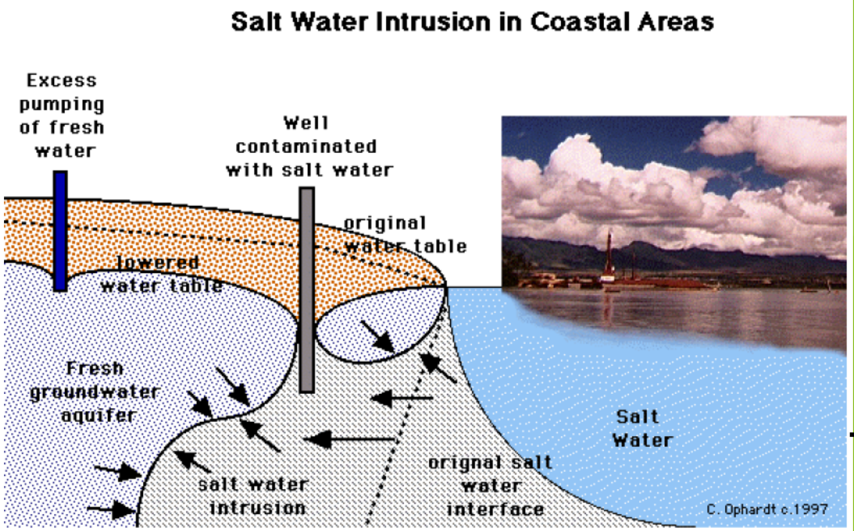
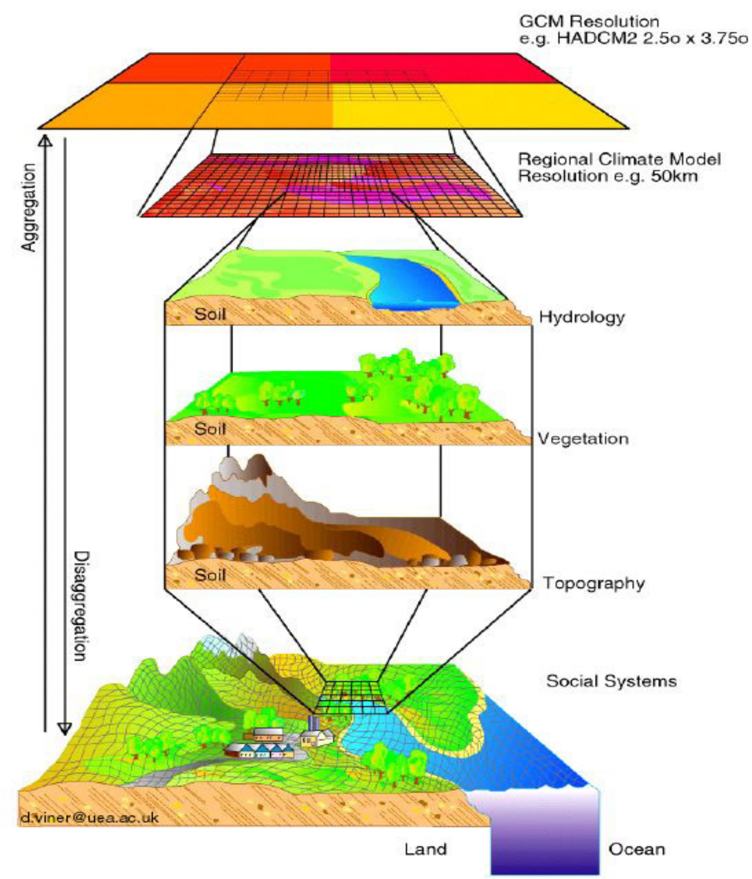


Fig. Source: ww.engr.uconn.edulanboG229Lect111SWIntru.pdf

Need for Downscaling – Hydrologic Impact Assessment

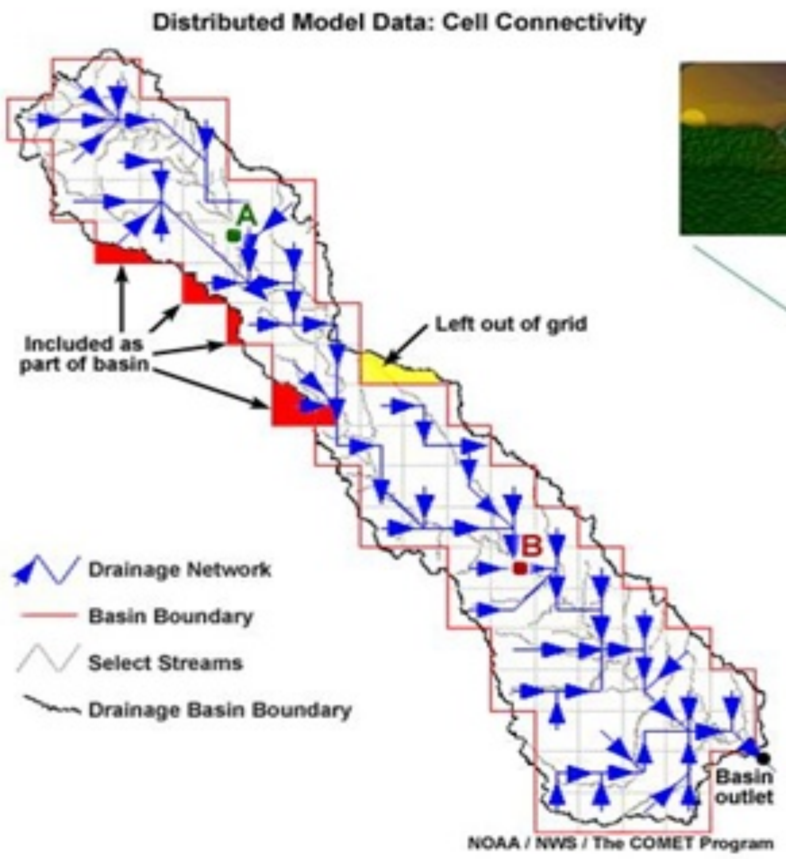
Some existing gaps between GCMs' ability and hydrology need

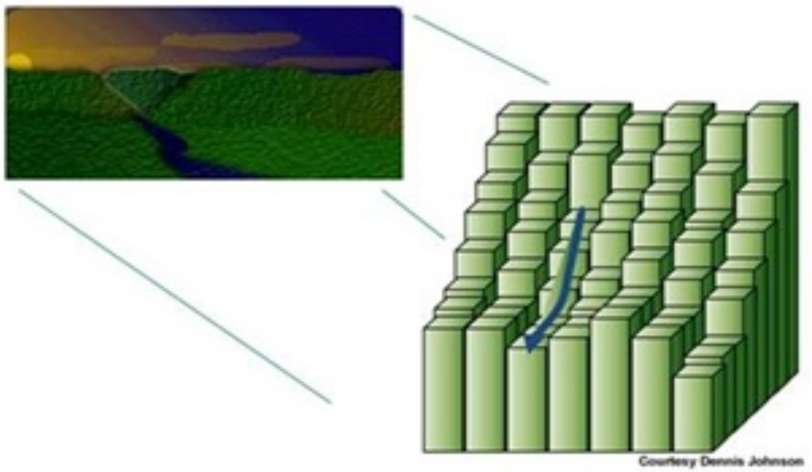
	Better simulated	Less-well simulated	Not well simulated
Spatial scales Mismatch	Global 500×500 km	Regional 50×50 km	Local 0–50 km
Temporal scales Mismatch	Mean annual and seasonal	Mean monthly	Mean daily
Vertical scale Mismatch	500 hPa	800 hPa	Earth surface
Working variables Mismatch	Wind Temperature Air pressure	Cloudiness Precipitation Humidity	Evapotranspiration Runoff Soil moisture
GCMs' ability declines			
Hydrological importance increases			



Source: Xu Chong-Yu, Water Resources Management 13: 369–382, 1999.

Distributed hydrologic models

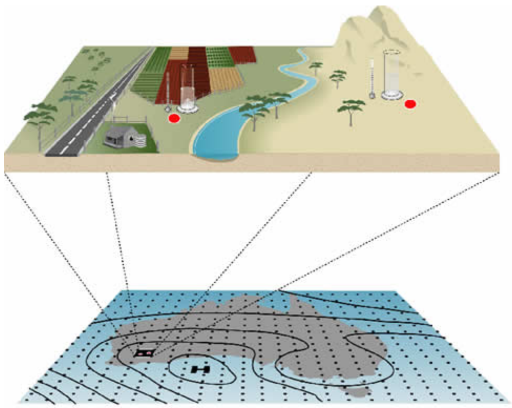


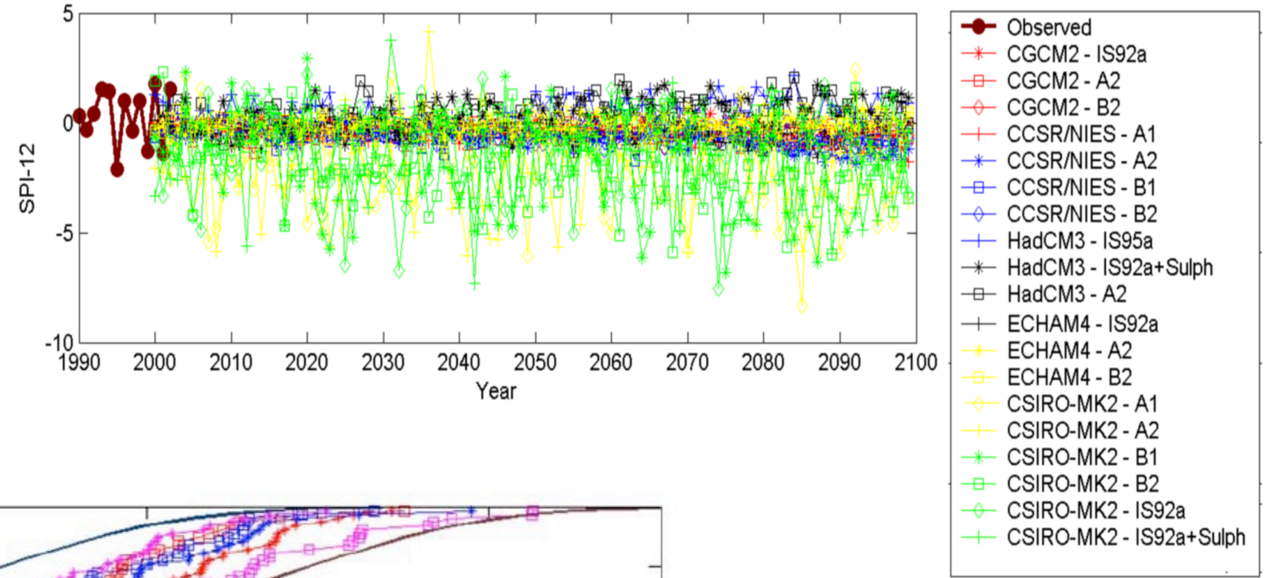


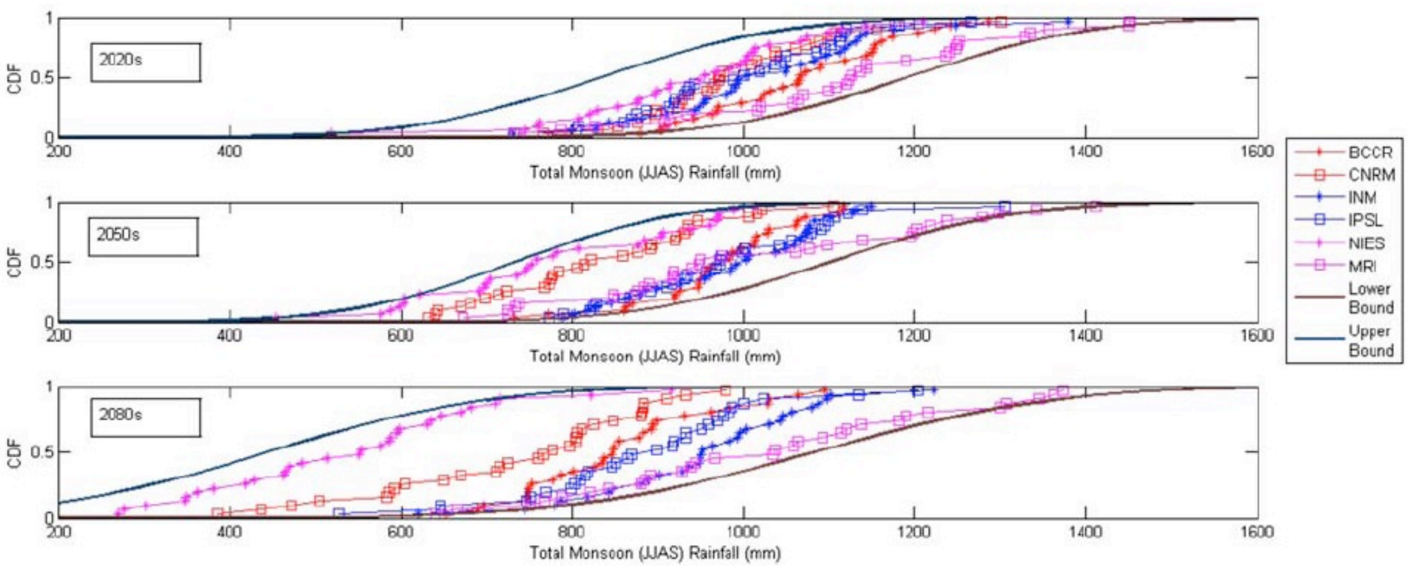
Simulate Streamflow, Evapotranspiration, Soil Moisture, Deep percolation, Detention Storage and other surface water processes

Source: University Corporation for Atmospheric Research (UCAR)

Downscaling & uncertainties of the GCM outputs to the river basin scales

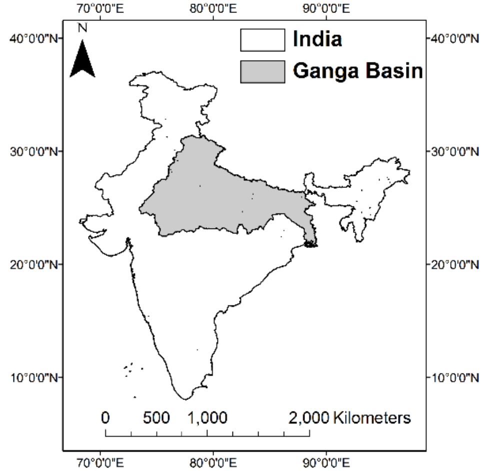


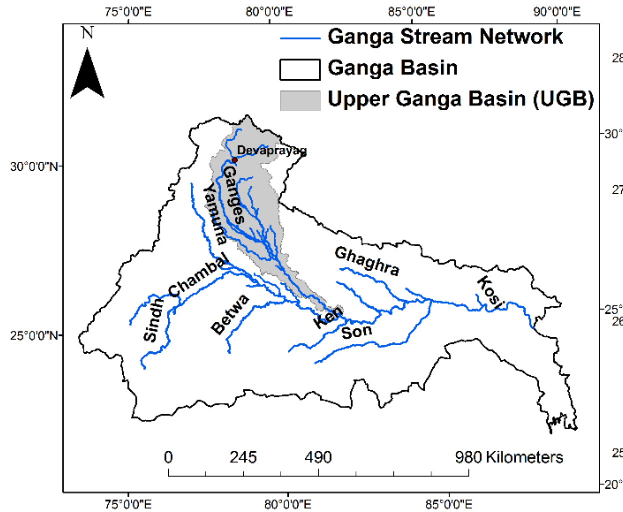


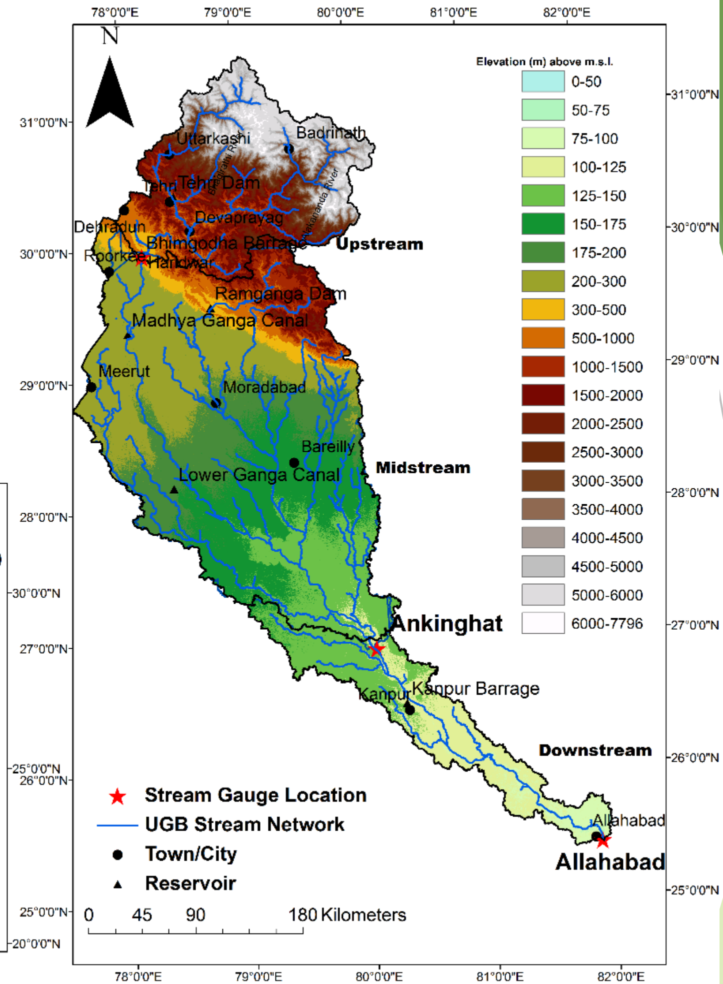


Challenge: Quantification and Reduction of Uncertainties

Study Area: Upper Ganga Basin (UGB)







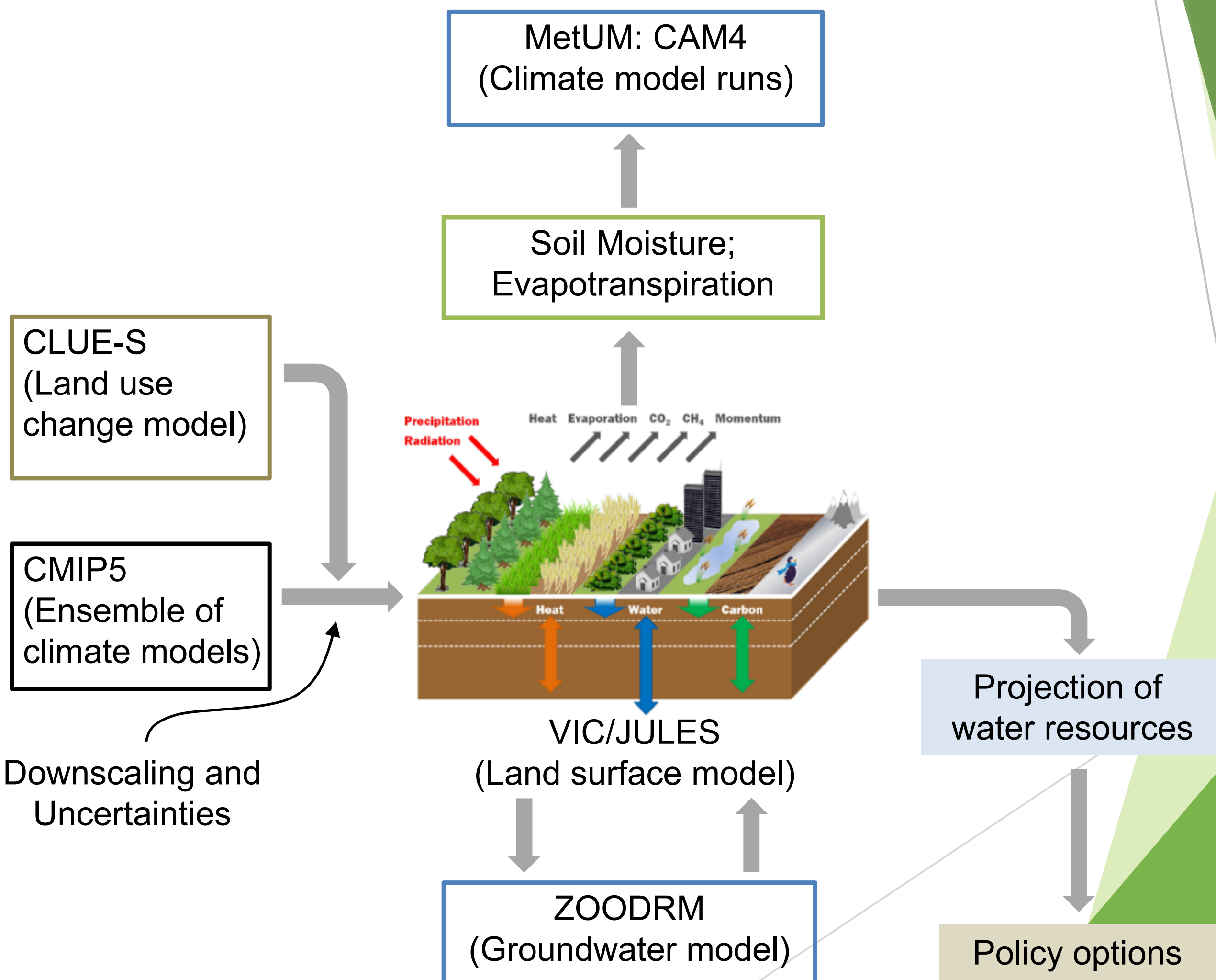
- Latitude: 25°30'N to 31°30'N; Longitude: 77°30'E to 80°E
- Catchment area – 95,593 km^2
- Elevation profile – 21 m to 7796 m

❖ Average annual rainfall over the UGB varies from 500 mm to 2500 mm.

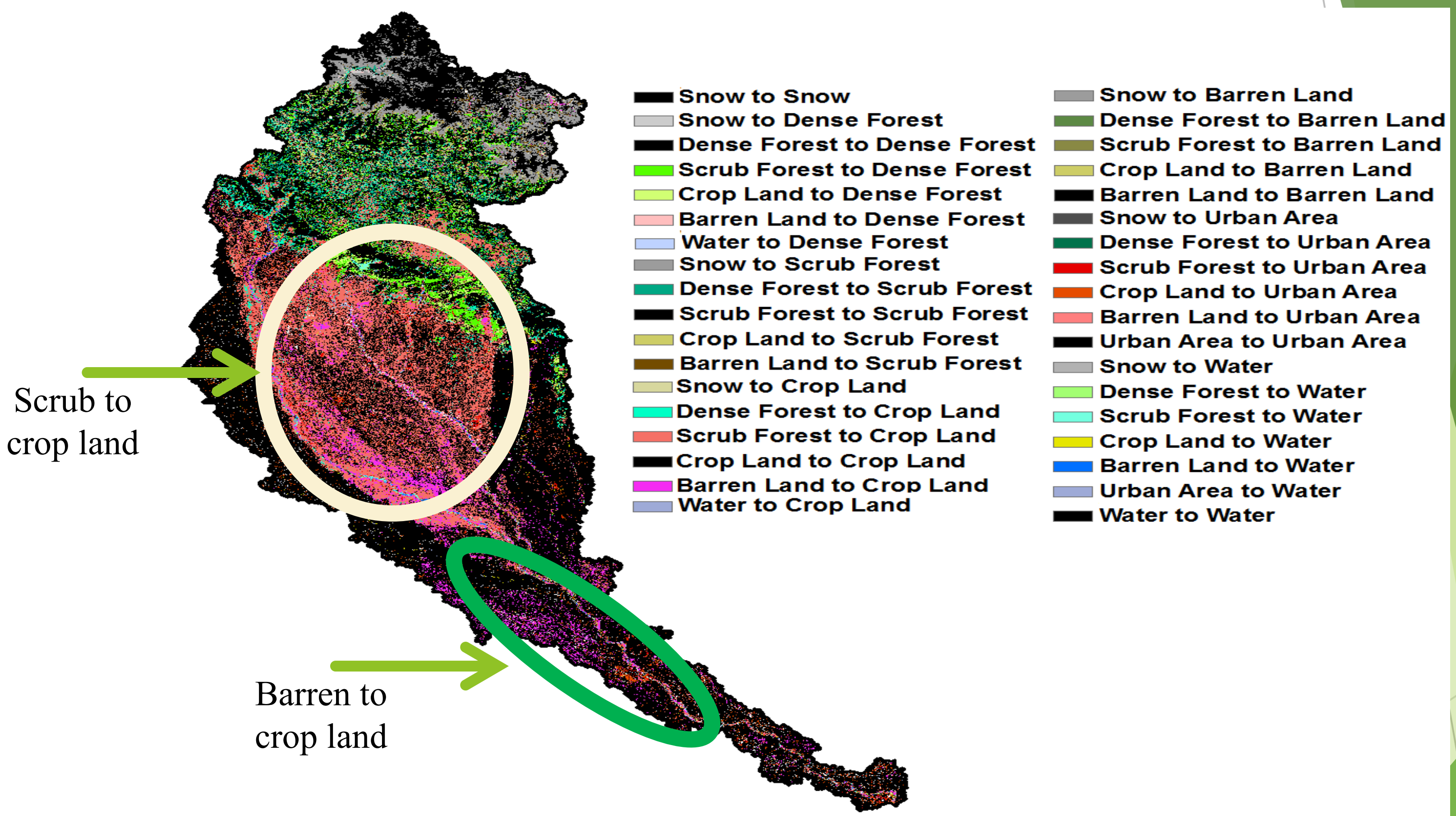
❖ Average annual temperature of the basin is around 21°C.

Model Structure

A systems approach with coupling between atmosphere, land surface and groundwater systems.



LULC Analysis: Change Location Map



Change location map of UGB between 1973-2011

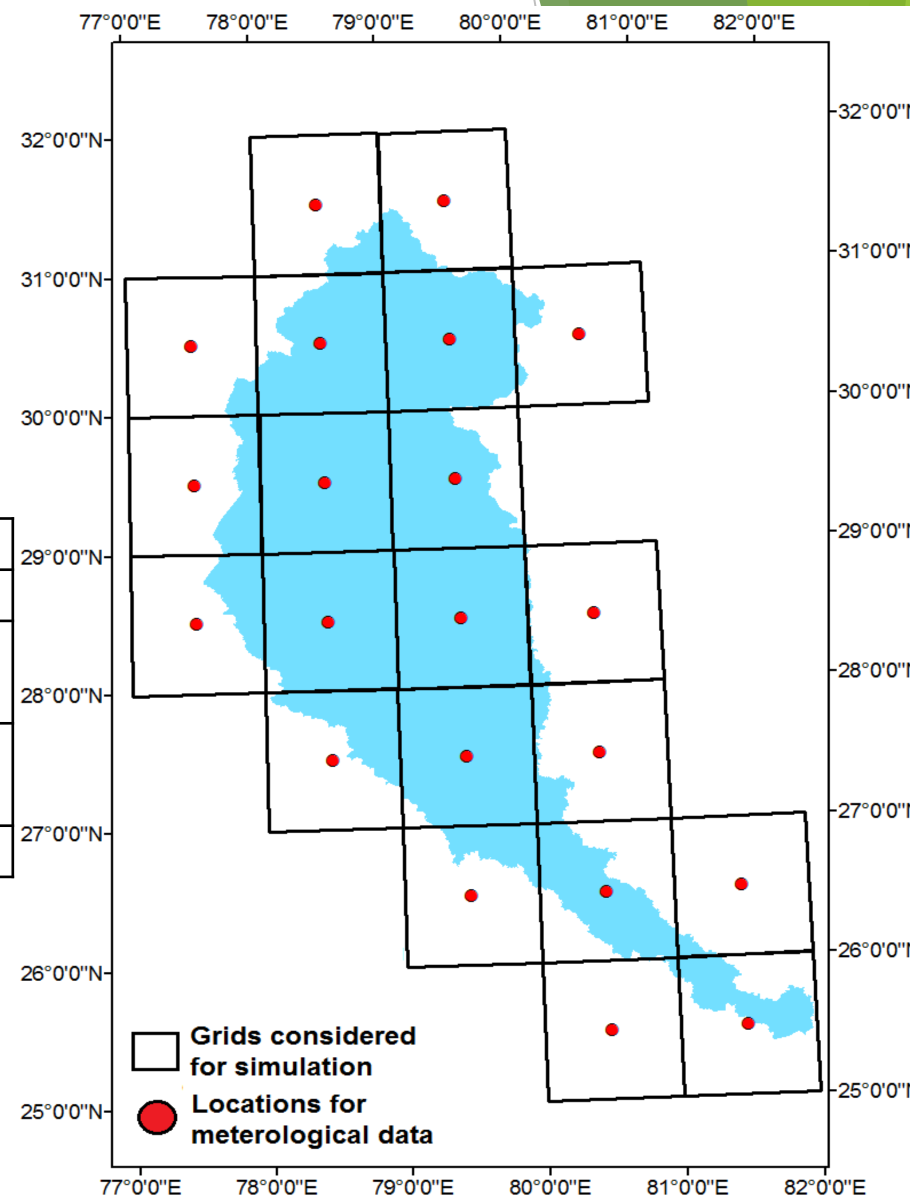
Hydrologic Modeling: Meteorological Input

Meteorological Data

- For each grid four meteorological variables are considered at daily time scale

List of meteorological variables

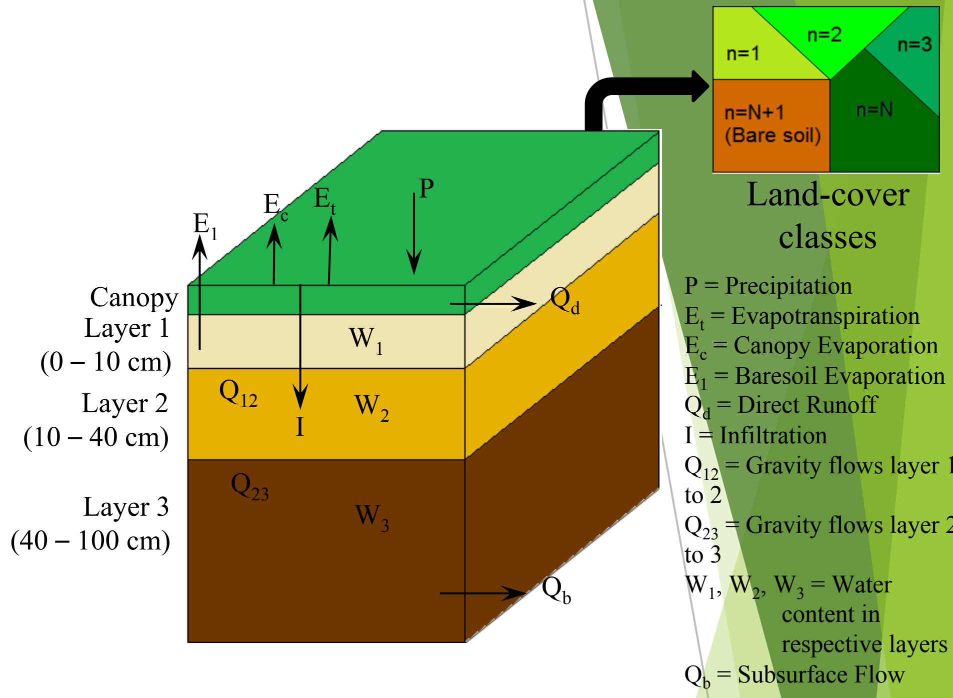
S. No.	Variable	Unit	Source
1	Precipitation	mm	IMD
2	Maximum Temperature	°C	IMD
3	Minimum Temperature	°C	IMD
4	Wind Speed	m/s	Princeton University

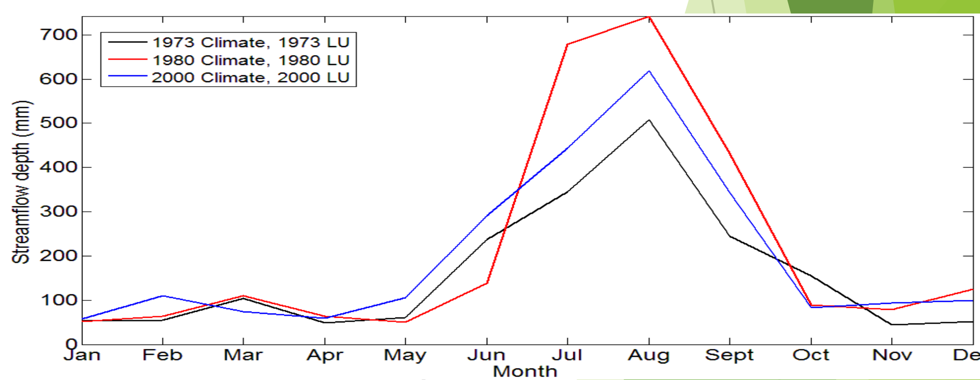


Map of the UGB showing the meteorological data grid points along with VIC grids

Hydrologic Modelling

- Carried out at IISc, Bangalore and Imperial College, London
- IISc :
  - Setting up the Variable Infiltration Capacity (VIC) hydrologic model at 0.5 degree resolution over the Upper Ganga basin
  - Evaluating the effect of land use and climate on hydrological regime of the basin using VIC model.
  - Isolating the individual impact of land use and climate change on streamflow
  - Climate change is the dominant contributor to the observed streamflow changes





Hydrologic impacts of LULC and climate

Projecting Climate Change Impacts on Hydrology

Climate Change Projections (precipitation, temperature, radiation, humidity)

Topography, Land-use/Land Cover ; Soil characteristics; Other catchment data

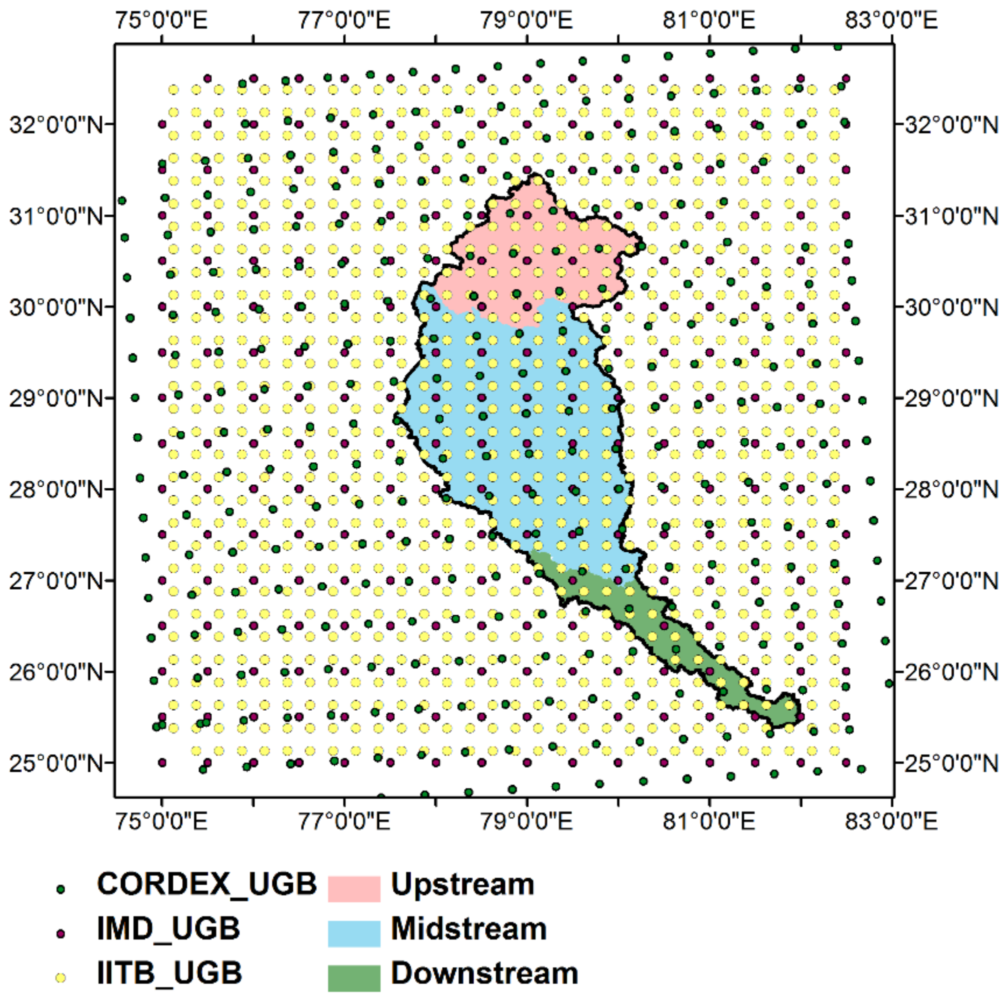
Downscaling

Hydrologic Model

Possible Future Hydrologic Scenarios on Basin Scale

(Streamflow, Evapotranspiration, Soil Moisture, Infiltration, Groundwater Recharge etc.)

Location of IIT-B and Cordex Downscaled Data Grid Points along with IMD Grid Points



Resolution of IMD data: 0.5° × 0.5 °
Resolution of downscaled IIT-B data: 0.25 ° ×0.25 °
Resolution of cordex data: ~0.44 ° ×0.44 °

Climate Data from CORDEX

- Projections of Rainfall (P), maximum temperature (T_{max}), minimum temperature (T_{min}) and wind speed (W) – procured from CORDEX South Asia group at daily scale

GCMs from the CORDEX project used in the study

Modeling Center-Experiment Name	Driving GCM (Abbreviation)	Institution
Commonwealth Scientific and Industrial Research Organization, (CSIRO) Australia CCAM	ACCESS1.0 (ACC)	CSIRO
	CNRM-CM5 (CNR)	Centre National de Recherches Meteorologiques
	CCSM4 (CCS)	National Center for Atmospheric Research
	GFDL-CM3 (GFD)	Geophysical Fluid Dynamics Laboratory
	MPI-ESM-LR (MPI)	Max Planck Institute for Meteorology (MPI-M)
	NorESM1-M (NOR)	Norwegian Climate Centre

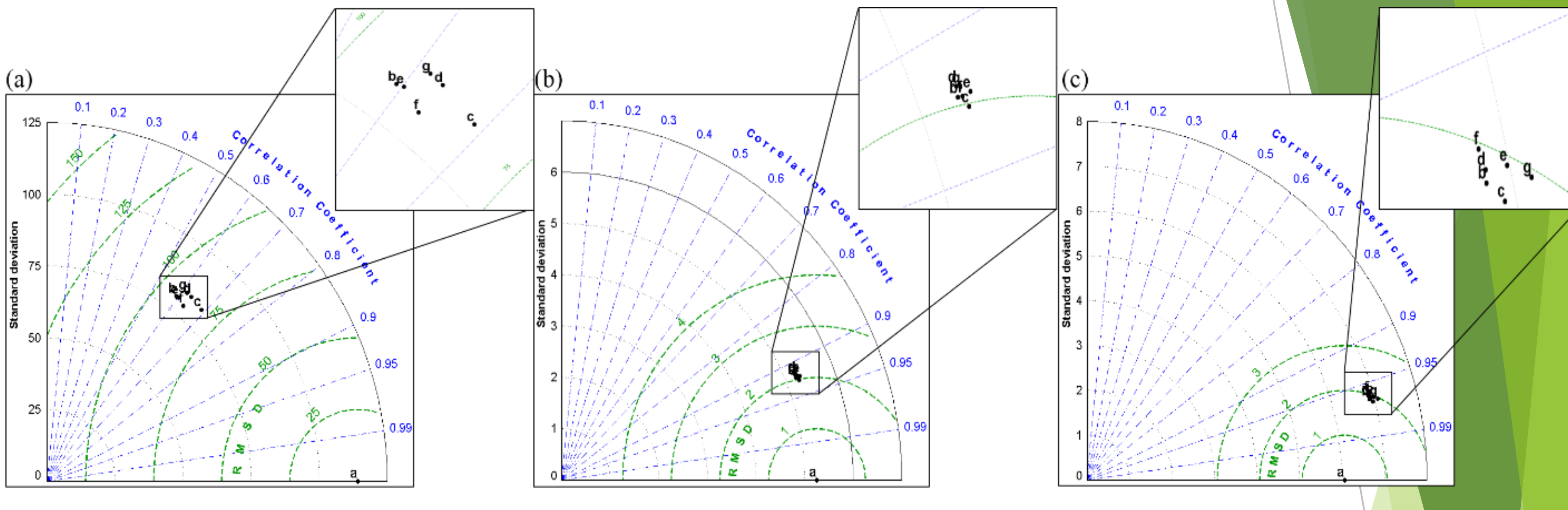
- Climate variables obtained from the GCMs were bias corrected with respect to the IMD gridded data at daily scale.

Summary Measures for Upstream Region – Future Projections (2010-2099)

Observed Discharge Mean (Historical) = 776.97 cumecs
Observed Discharge Std. Dev. (Historical) = 802.85 cumecs

		RCP 2.6		RCP 4.5		RCP 8.5	
		Mean (cumecs)	Std. Dev. (cumecs)	Mean (cumecs)	Std. Dev. (cumecs)	Mean (cumecs)	Std. Dev. (cumecs)
CORDEX - CSIRO	ACCESS1.0	-		1041.42	795.00	1069.94	841.89
	CCSM4			1096.24	1076.87	1058.91	833.90
	GFDL-CM3			792.93	678.61	1071.20	839.43
	CNRM-CM5			1049.56	791.20	1049.87	834.20
	MPI-ESM-LR			1040.74	797.05	1082.43	878.48
	Nor-ESM-M			1046.66	789.09	1084.37	813.19
IITB - Models	BCC	880.34	622.96	868.68	611.38	870.87	602.27
	CCCMA	874.86	607.87	895.97	632.23	879.68	610.76
	IPSL	876.63	633.12	893.98	623.28	908.27	620.27
	MIROC	845.29	570.38	835.93	560.14	859.81	590.88
	Nor-ESM-M	886.86	621.64	879.95	605.09	896.12	613.65
	Ensemble	Mean (cumecs)			Std. Dev. (cumecs)		
		944.52			597.14		

Analysis of Climate Data from CORDEX - Overall



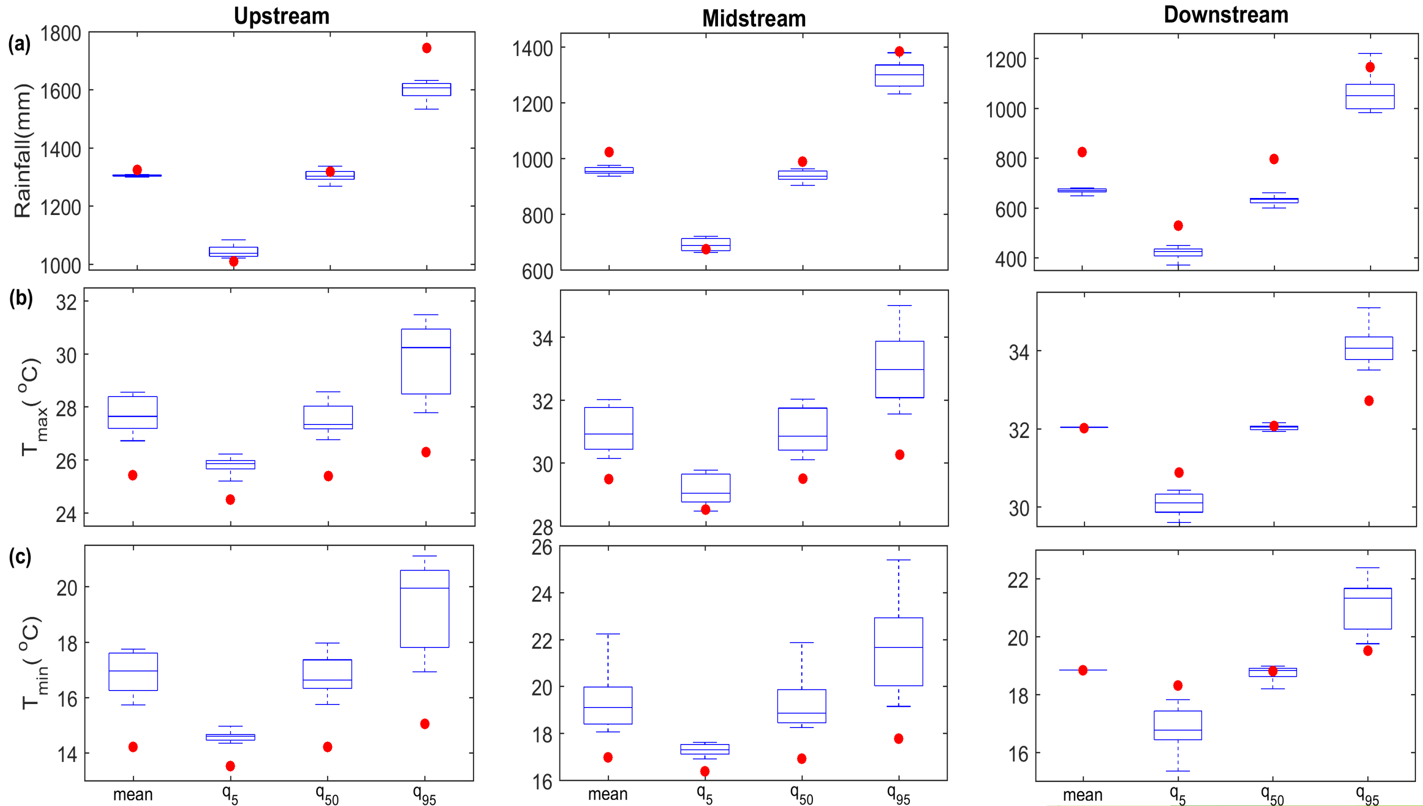
a-observed data, b-ACC, c-CCS, d-CNR, e-GFD, f-MPI, g-NOR

Taylor diagram for (a) P (mm) (b) T_{max} (°C) and (c) T_{min} (°C) for upstream region

- Models are observed to be clustered - all the GCM outputs are from the same modelling center
- Model outputs for T_{max} and T_{min} are closer to the observed data (represented by point ‘a’) - reflecting better quality of GCM outputs for T
- Correlation of 0.6-0.7 was obtained between GCM P and observed P – considered acceptable

Analysis of Climate Data from CORDEX – Overall at Annual Scale

- In general, annual *P* may decrease across all the three regions in the UGB in future compared to historic/observed values.
- Annual T_{max} and T_{min} in upstream and midstream region is found to increase in future time periods.
- Higher variability amongst the model values is observed for q_{95} – higher uncertainty in the GCMs to simulate extreme events.

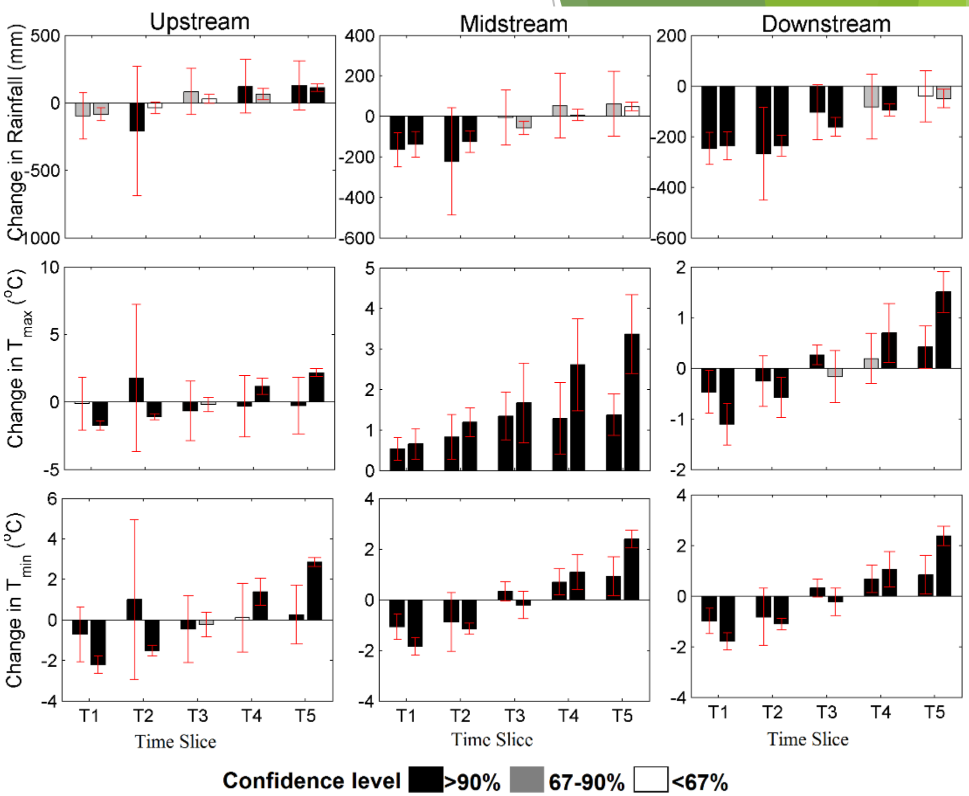


Comparison between annual (a) rainfall; (b) maximum temperature; and (c) minimum temperature during historic and future time periods for upstream; midstream; and downstream regions of the UGB

Red dots : observed data

Analysis of Climate Data from CORDEX

- GCM outputs for future time period – aggregated into five time slices: T1 (2010-2020), T2 (2021-2040), T3 (2041-2060), T4 (2061-2080) and T5 (2081-2100).
- Comparisons made between the annual means of the future time slices' and the baseline period (1971-2005)
- Monthly variability in P – decline during monsoon months and increase during winter months – result in shift in seasonal pattern of P
- Longitudinally from upstream to downstream – variations in P in downstream region are much more severe.



Change in ensemble mean of P, T_{max} and T_{min} from the baseline period for RCR 4.5 (first bar of every time slice of all the plots) and RCP 8.5 (second bar of every time slice of all the plots) scenarios at each time slice

- Monthly mean T_{max} and T_{min} – increase significantly during winter months and decline during April to September in all the regions.
- Longitudinally from upstream to downstream – downstream region may experience maximum increase in the mean T_{max} and T_{min}.

Climate Change Effect on Streamflow

- LU is kept fixed for 1971 – climate varied continuously for the baseline period (1971-2005) and future scenarios (2010-2100).
- Simulation results obtained were compared with the baseline simulation results.
- Runoff ratio (*RR*) is computed:

$$RR = \frac{Q}{P}\ where, Q\ is\ average\ annual\ runoff\ and\ P\ is\ precipitation$$

Runoff Ratio across time slices for upstream, midstream and downstream regions (terms in parentheses indicate the percent change from the baseline values)

Region	Time Period	Rainfall (mm)		Runoff (mm)		Runoff Ratio	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Upstream	Baseline	1294	1294	772	772	0.60	0.60
	T1	1196±172 (-8)	1210±46 (-7)	697±84 (-10)	683±32 (-12)	0.58 (-2)	0.56 (-4)
	T2	1084±480 (-16)	1257±43 (-3)	619±287 (-20)	715±30 (-7)	0.57 (-3)	0.57 (-3)
	T3	1377±171 (+6)	1323±32 (+2)	816±137 (+6)	771±26 (0)	0.59 (-1)	0.58 (-2)
	T4	1416±198 (+9)	1357±42 (+5)	845±163 (+9)	800±38 (+4)	0.60 (0)	0.59 (-1)
	T5	1424±182 (+10)	1405±27 (+9)	854±148 (+11)	842±26 (+9)	0.60 (0)	0.60 (0)

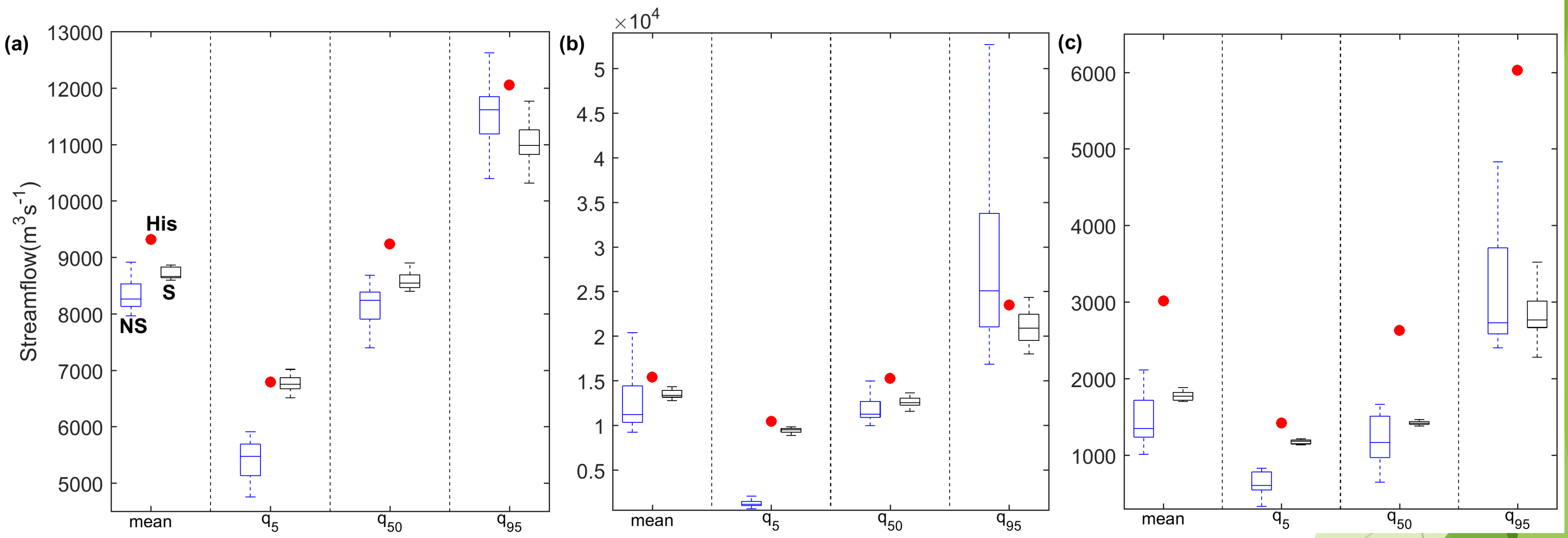
Climate Change Effect on Streamflow

- *RR* – 60% for the upstream region, 44% for the midstream region and 23% for the downstream region during the baseline period.
- Upstream region – characterized by mountainous terrain and steep slopes, most of the *P* gets converted to Q_{clim} (high *RR*).
- Downstream region – flat terrain, much of the *P* get evaporated or infiltrated into soil and little gets converted to Q_{clim} (low *RR*).
- ***P* does not change significantly from the baseline period, increase in *T* results in reduced *RR*.**
- The *RR* is observed to increase and approach towards baseline *RR* with slight increase in *P* (irrespective of change in *T*)
- T3 and T4 (RCP 4.5 and RCP 8.5) for downstream region, *P* is observed to reduce accompanied by an increase in *T* – reduction in *RR* is not observed
- This anomaly could be attributed to occurrence of short duration dense rainfall events in the region.

Region	Time Period	Rainfall (mm)		Runoff (mm)		Runoff Ratio	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Midstream	Baseline	1009	1009	441	441	0.44	0.44
	T1	844±84 (-16)	871±63 (-14)	323±31 (-27)	328±56 (-25)	0.38 (-12)	0.38 (-4)
	T2	787±265 (-22)	884±53 (-12)	296±115 (-33)	332±52 (-25)	0.38 (-12)	0.38 (-12)
	T3	1003±135 (-1)	952±31 (-6)	413±77 (-6)	378±20 (-14)	0.41 (-3)	0.40 (-4)
	T4	1062±159 (+5)	1016±28 (+1)	462±101 (+5)	427±23 (-3)	0.44 (0)	0.42 (-2)
	T5	1071±160 (+6)	1058±21 (+5)	471±121 (+7)	452±21 (+3)	0.44 (0)	0.43 (-1)
Downstream	Baseline	826	826	192	192	0.23	0.23
	T1	579±63 (-30)	590±55 (-29)	102±13 (-47)	107±19 (-44)	0.18 (-5)	0.18 (-5)
	T2	557±183 (-32)	589±40 (-29)	89±43 (-54)	104±13 (-46)	0.16 (-7)	0.18 (-5)
	T3	721±108 (-13)	663±38 (-20)	141±34 (-27)	127±13 (-34)	0.20 (-3)	0.19 (-4)
	T4	743±128 (-10)	731±23 (-11)	150±46 (-22)	148±7 (-23)	0.20 (-3)	0.20 (-3)
	T5	785±101 (-5)	771±37 (-6)	173±36 (-10)	167±16 (-13)	0.22 (-1)	0.21 (-2)

Hydrologic Impacts of Future Land Use and Climate Change

- 48 streamflow simulations under each nonstationary and stationary model conditions are obtained – 6 GCMs * 2 emission scenarios * 4 LU scenarios
  - Nonstationary : Model parameters are varied for future simulations
  - Stationary: Model parameters, as obtained for historic time period are used for future simulations

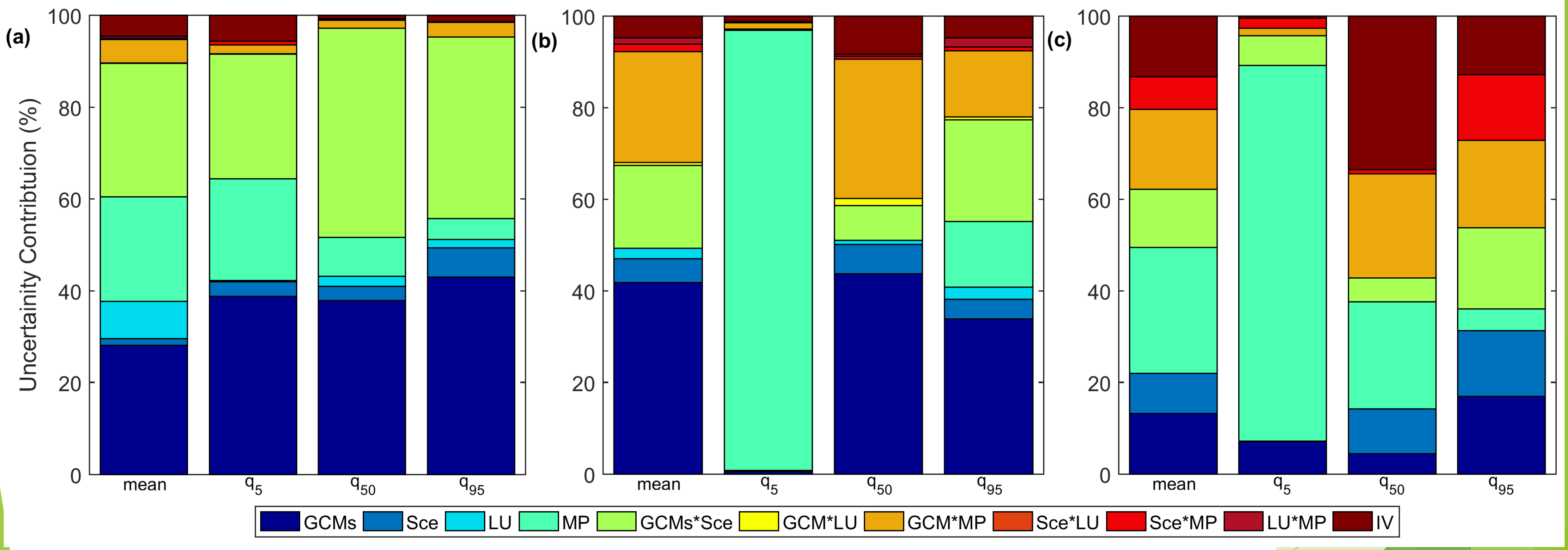


Annual mean and quantile values of streamflow for (a) Upstream; (b) Midstream; and (c) Downstream regions of the UGB under future conditions with stationary (S) and nonstationary (NS) model conditions and historic (His) time periods

- Streamflow is noticed to decrease in future for both nonstationary and stationary conditions – decrease in rainfall and increase in temperature obtained for future projections

Uncertainty Contribution from Different Sources

- Total uncertainty in the streamflow projections is decomposed to individual components – (i) GCMs, (ii) emission scenarios (Sce), (iii) Land Use (LU), (iv) hydrologic model parameters (MP) – assumed to be stationary or nonstationary, and (v) and internal variability (IV) of the system using the ANOVA approach

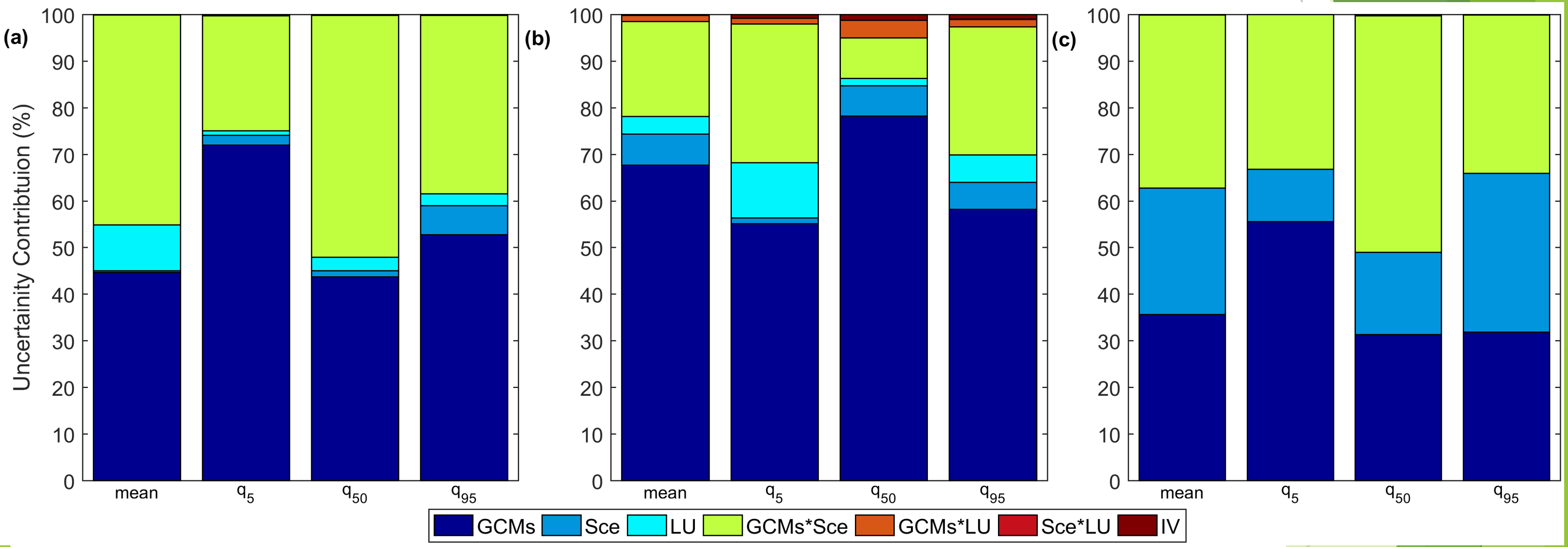


Contribution of different factors to total uncertainty of annual streamflow projections (change in mean, 5th quantile, 50th quantile and 95th quantile) for (a) Upstream; (b) Midstream; and (c) Downstream regions of the UGB under both stationary and nonstationary model conditions

- GCMs + Scenarios and Model Parameter assumption of nonstationarity and stationarity are observed to be significant sources of uncertainty

Uncertainty Contribution from Different Sources

- In the nonstationary case, GCMs and Sce are observed to be the dominant contributor to total uncertainty in streamflow across all the cases.
- Contribution from LU is also noticeable across all the cases



Contribution of different sources to total uncertainty of annual streamflow projections (change in Mean, 5th quantile, 50th quantile and 95th quantile) obtained under nonstationary model condition for (a) Upstream; (b) Midstream; and (c) Downstream regions of the UGB

Concluding Remarks

- CORDEX output is useful in assessing hydrologic impacts – a larger number of GCMs and scenarios would be useful in addressing uncertainties.
- It is possible to partition the uncertainties arising from different sources, in the Hydrologic Impacts : Climate Models, Scenarios, Hydrologic Model Parameters, Land Use Change
- Quantification and reduction of uncertainties in the impact assessment models is critical.