High-End Climate Change for Specific Warming Levels and Their Implications in the Ganga River Basin

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Objectives

• What do 4ºC and 6ºC worlds look like in comparison to 1.5ºC and 2ºC
• What are the associated Uncertainties
• What are the plausible Adaptation options
Contributions

• INRM team lead by Dr Sandhya Rao
• This work was done under The High-End Climate Impacts and eXtremes (HELIX), a European Union Collaborative project
Climate Change Scenario Used

- Scenario: IPCC SRES AR5 RCP 8.5
- South Asia Cordex Models for simulated weather data
  - Bias corrected 3 RCMs (11 model runs)
    - CSIRO-CCAM-1391M – (4)
    - MPI-CSC-REMO2009 – (1)
    - SMHI-RCA4 – (6)
- Model Boundary Conditions
  - 9 boundary conditions
- 3 Specific Warming Levels (SWL)
  - SWL:1.5°C
  - SWL:2°C
  - SWL:4°C
- Grid resolution of 0.5° x 0.5°.
Climate Change and its Impact on Water Resources of Ganga Basin

- **Tools used**
  - Modelling: SWAT (Soil and Water Assessment Tool)
  - GIS framework: acts as a pre-processor

- **Data used**
  - Digital Elevation Model: SRTM 90 m
  - Land use: Global data, 1:2M USGS
  - Soil: Global data, 1:5M FAO
  - Drainage: 1:250,000
  - Weather: IPCC AR5 RCP 8.5 scenario, CORDEX Bias Corrected at 0.5°X0.5° resolution from HELIX
  - Existing man made interventions (dams/reservoirs)
  - Current Crop management practices

- **Impacts Studied**
  - Impact on annual water availability
  - Impact on seasonal water availability
  - Impact on inter annual water availability
  - Regional Variability of Water availability
  - Extreme events – Floods and Droughts
Input Data used for Hydrological Modelling

- Digital Elevation Model
- Landuse Layer
- Soil Layer
- Water resources structures implemented
- Sub watershed delineated
- RCM weather grids
Specific Warming Levels, their respective Passing Time and average $\text{CO}_2$ levels

<table>
<thead>
<tr>
<th>CORDEX Models</th>
<th>Driving GCM</th>
<th>SWL:1.5</th>
<th>SWL:2</th>
<th>SWL:4</th>
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<th>SWL Passing Year</th>
<th>30 years To_From around SWL</th>
<th>Average CO2 levels (From global) - RCP8.5</th>
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Average CO2 levels (From global) - RCP8.5

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Model Agreement in Projected Maximum, Minimum and Precipitation

- 11 CORDEX RCMs
Annual Precipitation for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario*

*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece
SWAT Simulated Annual Water Yield for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario*

**Specific Warming Level: 1.5°C**
- RCA4 (CNRM-CMS)
- RCA4 (ICHOR-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MRO-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-MEM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)

**Specific Warming Level: 2°C**
- RCA4 (CNRM-CMS)
- RCA4 (ICHOR-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MRO-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-MEM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)

**Specific Warming Level: 4°C**
- RCA4 (CNRM-CMS)
- RCA4 (ICHOR-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MRO-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-MEM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)

**Water Yield (mm)**

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<th>CORDEX Models</th>
<th>SWL 1.5°C</th>
<th>SWL 2°C</th>
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*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece*
SWAT Simulated Annual Evapotranspiration for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario

Specific Warming Level: 1.5°C
- RCA4 (CNRM-CMS)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CMS-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MPI-ESM-LR)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 2°C
- RCA4 (CNRM-CMS)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CMS-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MPI-ESM-LR)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 4°C
- RCA4 (CNRM-CMS)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CMS-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-M-MPI-ESM-LR)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CMS)
- CCAM 1391 (MPI-ESM-LR)

Evapotranspiration (mm)

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<tr>
<th>Driving GCM</th>
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<th>SWL 1.5°C</th>
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*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece
Monsoon Drought Weeks Based on Agriculture Drought Index at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP8.5 Scenario

**Specific Warming Level : 1.5 °C**

- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)

**Specific Warming Level : 2 °C**

- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)

**Specific Warming Level : 4 °C**

- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)
- CCAM 1391 (CCSM4)

**Number of Monsoon Drought Weeks**

- < 2
- 3 - 4
- 5 - 6
- 7 - 8
- 8 - 16

*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece*
Monsoon Drought Weeks Based on Agriculture Drought Index ranging from -2 to -4 (moderate to extreme soil moisture stress during critical growth stages of crops) at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP 8.5 Scenario

Specific Warming Level: 1.5°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-M-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 2°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-M-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 4°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROC5)
- RCA4 (MPI-M-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Number of Monsoon Drought Weeks

*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece
SWAT Simulated Annual Maximum Flow Based on Daily Stream Flow at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP8.5 Scenario

Specific Warming Level: 1.5°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 2°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Specific Warming Level: 4°C
- RCA4 (CNRM-CM5)
- RCA4 (ICHEC-EC-EARTH)
- RCA4 (IPSL-CM5-MR)
- RCA4 (MIROC-MIROCS)
- RCA4 (MPI-MPI-ESM-LR)
- RCA4 (NOAA-GFDL-ESM2M)
- REMO 2009 (MPI-ESM-LR)
- CCAM 1391 (ACCESS)
- CCAM 1391 (CCSM4)
- CCAM 1391 (CNRM-CM5)
- CCAM 1391 (MPI-ESM-LR)

Maximum Discharge (CMS)

*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece
Spatial Representation of SEVI- Rank, Cluster
Key Inferences

- At annual level precipitation, water yield and evapotranspiration, extreme events ranges for 11 models

<table>
<thead>
<tr>
<th></th>
<th>Precipitation (mm)</th>
<th>Water Yield (mm)</th>
<th>Evapotranspiration (mm)</th>
<th>Drought (weeks)</th>
<th>Flood Magnitude (cumecs)</th>
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<td>BL</td>
<td>1089 - 1189</td>
<td>388 - 473</td>
<td>554 - 569</td>
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<td>554 - 592</td>
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<td>498 – 599</td>
<td>1.3 – 4.5</td>
<td>242800 – 525500</td>
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- ACCESS1-0_CSIRO-CCAM-1391M (highest), MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009 (lowest)
Dissemination Tool Developed

- [http://inrm.co.in/climatechange/helix/homepage.html](http://inrm.co.in/climatechange/helix/homepage.html)
Thank You