Climate Change Modelling: 
**Basics and Case Studies**

TERI-APN’s Training program on building Urban Climate Change Resilience

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“Unaware” of Climate Change

“How much do you know about global warming or climate change?”
(I’ve never heard of it; don’t know; refused)

n = 269,913 in 132 countries (2007-2009)

Leiserowitz (2011)
The non-linear interaction among the components leads to climate variability at a range of spatial and temporal scales.
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How do we quantify the response of the climate?

• The response of the climate system to this forcing agents is complicated by:
  - feedbacks
  - the non-linearity of many processes
  - different response times of the different components to a given perturbation

• The only means available to calculate the response is by using numerical models of the climate system.
What is a Model?

“a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predictions”

- dictionary

How do we define a Climate Model?

“A climate model is a mathematical representation of the physical processes that determine climate”

Why do we need Climate Models?

- To create an understanding of the climate processes.
- To create plausible-scenarios, reflecting the current state of scientific understanding.
- To plan for the future.
All the physical processes occurring in the climate system are resolved at individual grid and the coupling occurs at these grids.

Source: NASA
Framework for a Model

Source: MPI, Germany
Process of Model Simulation

Model development
- Physical, chemical, biological principles
- Approximations, parameterizations
- Numerical resolution

Generation of model source code

Model Simulation

Simulation
- Model
- Results
- Forcings
- Boundary conditions
- Observations

Analysis of the results
- Test of the validity of the model
- Projections and analysis of mechanisms

Supply of Initial and boundary conditions

Source: Goosse et al 2010
Improvements in Grid resolution

• The evaluation of the Climate models has become an essential prerequisite to understand the Earth’s climate system.

• A Model Inter-comparison Project is an approach to model verification and they are part of community analysis and verification/activity.

• Intergovernmental Panel for Climate Change has started its MIP programs with Atmospheric Models in 1995 till today with CMIP (Coupled Ocean Atmospheric Models).
Simulations using a Global Coupled Model:

The simulations of a model should be comparable to the observations, this step is called as Validation of the model outputs.

Source: TERI (2011)
Need for Regional Climate Modeling Tool

Most of AR4 coupled models even with high spatial resolution of 110km x 110km were unable to represent the mean monsoon pattern similar to observations.

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Downscaling from GCMs

- Downscaling is a way to obtain higher spatial resolution output based on GCMs.
- Options include:
  - Combine low-resolution monthly GCM output with high-resolution observations
  - Use statistical downscaling
    - Easier to apply
    - Assumes fixed relationships across spatial scales
  - Use regional climate models (RCMs)
    - High resolution
    - Capture more complexity
    - Limited applications
    - Computationally very demanding
Downscaling

Dynamical Downscaling

Global Input

Regional Output

GCM

RCM

Global Input
Regional Climate Models (RCMs)

- These are high resolution models that are “nested” within GCMs
- A common grid resolution is 50 km or lesser.
- RCMs are run with boundary conditions from GCMs
- They give much higher resolution output than GCMs
- Hence, much greater sensitivity to smaller scale factors such as mountains, lakes
Regional Modelling Product

RCM is able to capture the major features but overestimates the rainfall in few regions.

Source: TERI (2011)
Lack of observations: poor model result

Observed rainfall climatology compared with IPRC_RegCM over peninsular India

Reanalysis – temporal variability of atmospheric states and internal variability preserved – yet, results are not encouraging

Monsoon region – lack of 3-D moisture observations – severe constraint

Annamalai, 2012
Climate Modelling: Global to Regional
**Evidences**

- **Relative sea level over the last 300 years**
- **Simulated annual global mean surface temperatures**
  - Natural
  - Anthropogenic
- **Global and Continental Temperature Change**
- **Global average surface temperature change**
- **Human Attribution**

*Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 for all scenarios*
Observed variability in India’s Monsoonal Climate

All-India Summer Monsoon Rainfall, 1871-2009

(Based on HTM Homogeneous Indian Monthly Rainfall Data Set)

Rainfall Anomaly (% of Mean)

Years

Krishna Kumar, 2009
All-India monsoon season rainfall time series shows NO long term trends. It is marked by large year to year variations. There is a tendency of occurrence of more droughts in some epochs (for example, 1901-1930, 1961-1990).

Rajeevan, 2013
Regional Rainfall Trends

Guhathakurta et al. 2014, Int J. Climatology

Fig. S2: (A) Frequency Histogram of daily rainfall over CI during summer monsoon for two periods, 1950-1970 and 1980-2000. The regions marked by the shaded rectangles in A are magnified in B, C, and D. For the sake of clarity, rain intensities larger than 250 mm/day have been shown by symbols (blue circles and red triangles) in panel (D).
Rainfall Extremes and Trends for 1951-2004

MoEF, 2010
PROJECTIONS
Simulations over India for the 1901–2098 period

(a) Annual surface temperature over India

The grey lines indicate the ensemble, the black line is the ensemble mean and the blue line is the observed. The red line is the ensemble member corresponding to the Hadley Center coupled model.

(b) Monsoon rainfall over India

Annual cycle of temperature and rainfall over India

Standard deviation (mm) and monsoon-ENSO correlation, for the observational (1901–2000) period

Krishna Kumar et al., 2009
Projected changes in daily maximum temperature and daily rainfall


Projected future change in number of rainy days (rainfall >2.5 mm) during monsoon season (JJAS).

Projected change in the intensity (mm/day) of rainfall on a rainy day.


Krishna Kumar et al., 2009
CMIP5 projections for India

Temperature Change

Rainfall Change

Chaturvedi et al. 2012, Current Science
But how good are the models?

Observations Versus Ensemble mean for 1971-1990

Temperature

Rainfall

Chaturvedi et al. 2012, Current Science
Clear indication of Warming

Ensemble mean from 18 models

Chaturvedi et al. 2012, Current Science
% change in rainfall

Ensemble mean from 18 models

Chaturvedi et al. 2012, Current Science
Modelling Products and Case studies
Approach

- High Resolution Regional Model Selection

- Initial conditions and Boundary conditions from Global Models and suitable scenario selection from IPCC scenarios

- Grid resolution and model physics selection

- Baseline and Future simulations for 2050s. using the similar LBCs as baseline for 2050s and 2080s.

- Post-processing and analysis of baseline and future assessments.
Modelling Products/Services

Extreme Scenario

Increase in Extreme rainfall in 2030s relative to baseline (in %)

Moderate Scenario

Number of low rainfall days in 2030s relative to baseline

Vulnerability Index for agriculture in Rajasthan (2030)
Coastal vulnerability assessment and strategies for better preparedness towards impacts of climate change and sea level rise:

State of West Bengal

Rainfall and Temperature
(Future)
A1B scenario
Comparison of Storm frequency over BoB and AS of North Indian Ocean region from 1891-2008

Case study of a Cyclone in Baseline PRECIS model

Laplacian of PMSL for the case study cyclone

May Cyclone Tracks
(a) Baseline
(b) A2 scenario

June Cyclone Tracks
(b) Baseline
(b) A2 scenario

September Cyclone Tracks
(c) Baseline
(d) A2 scenario

October Cyclone Tracks
(d) Baseline
(e) A2 scenario
Storm Surge Modelling
An integrated impacts and vulnerabilities assessment of communities dependent on forest resources for livelihoods (NER-India)
Rajasthan Vulnerability Assessment

Temperature Difference (2030s-Baseline in °C)

Percentage Precipitation Change (2030s-Baseline)

Vulnerability Index for health in Rajasthan (2030)

Vulnerability Index for animal husbandry in Rajasthan (2030)

Vulnerability Index for agriculture in Rajasthan (2030)
PM’s address at 101st Indian Science Congress in Jammu

“Our advances in meteorology were evident during the recent cyclone in Odisha, when we received accurate forecasts of the landfall point that were more accurate than the forecasts of well known international bodies. Our decision to set up a new Ministry of Earth Sciences following the Indian Ocean Tsunami in 2004 and to invest in world-class tsunami forewarning systems in 2007 has been amply rewarded. We now have the ability to issue alerts within 13 minutes of a tsunami-genic event. This has established India’s scientific leadership in the Indian Ocean region. I would also like to see continuous improvement in our monsoon prediction capability through the recently launched Monsoon Mission so that we avert the kind of calamities that we saw in Uttarakhand last year.”
Thank you

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