Climate Change, Urbanization, and the Indian Monsoon Rainfall: Toward Informing Climate Science, Adaptation Decisions, and Mitigation Policies with Data-Guided Methods

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Contributors acknowledged on websites:
NSF “Expeditions in Computing”
http://climatechange.cs.umn.edu/
ORNL “Climate Extremes”
http://www.ornl.gov/knowledgediscovery/ClimateExtremes/

PS: We’re moving!
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Challenge: translate climate model derived insights to decision and policy tools

Knowledge Discovery & Translation Process

- Multiple Fossil Fuel Emission Storylines
- Multiple Models
- Critical Infrastructures
- Population
- Climate Observations

Database

Data Integration

Data Analytics

New Insights

GIS Visualization & Science for Decision Support

Decision Scales

- Global Models ~62 miles
- Local Models ~e.g., 2.5 miles

Inclusive definition of “Climate extremes”:

1. severe hydrological or weather events or large shifts in regional climate patterns
2. caused or exacerbated by climate change and/or natural climate variability
3. leading to extreme stresses on natural, engineered and human systems

Arguably the largest knowledge gap in climate science relevant for informing adaptation and policy

Knowledge Discovery & Translation Process
Weather Stations/Radar

Observational Data

“Reanalysis” Surrogate Observations – used especially for areas lacking past data

IPCC Global Models:
- 20th century
- 21st century

Regional Models:
- 20th century
- 21st century

Step 1: Multi-Model Evaluation of Climate Extremes
- Compare extremes from models and observations
- Assess uncertainty

Step 2: Data-Guided Prediction and Uncertainty
Example:
- Can better-simulated variables (temperature) enhance predictions and reduce high uncertainty in precipitation extremes?

Step 3: Multi-Scale Assessment
Regional & Decadal / Extremes & Change
- Characterize uncertainty
- Develop assessments for climate extremes

Step 4: Demonstrable End-User Value
a. Threat Assessment
Regional Risk Analyses
What-If? Scenarios
Climate-Energy Connection

b. Readiness Levels
Natural Infrastructures
Built Infrastructures
Human Health Impacts

Model Simulation Data
Climate extremes: *Science, impacts, policy*

- **Science**
  - Extremes characterizations
  - Uncertainty assessments
  - Enhanced predictions

- **Impacts**
  - Natural resources
  - Hazards risks
  - Regional preparedness

- **Policy Relevance**
  - Emissions policy
  - Preparedness decisions
  - National security concerns

Temperature and Heat Waves (Ganguly, 2009)
Indian monsoon rainfall extremes: disagreement over trends in literature

Contradictory results over many parts of central India

Fig. 3. Temporal variation (1951 to 2000) in the number ($N$) of (A) heavy ($R \geq 100$ mm/day, bold line) and moderate ($5 \leq R < 100$ mm/day, thin line) daily rain events and (B) very heavy events ($R \geq 150$ mm/day) during the summer monsoon season over CI. The statistical significance of the trends (dashed lines) was calculated as in Fig. 2.

EVT - Increasing trends in spatiotemporal variability

Diversity in trends of return levels – more positive than negative – contradicts Goswami et al.

Significant increase in spatial variability over time

Predominance of regional > global drivers
EVT - Increasing trends in spatiotemporal variability (2)

Mean monsoon

- a(i) 7% 4%
- a(ii) 4% 3%

Annual maxima

- b(i) 2% 2%
- b(ii) 1% 2%

30 years return levels

- c(i) 50% 30% 20%
- c(ii) 55% 32% 14%

100 years return levels

- d(i) 45% 30% 21%
- d(ii) 46% 32% 16%

Exceedances above 100 mm/day

- e(i) < 1% 34% 34%
- e(ii) < 1% 38% 38%

Exceedances above 99 percentile

- f(i) 4% 96% 96%
- f(ii) 1% 95% 95%

Percentage of total grid points having increasing trend
Percentage of total grid points having decreasing trend
Percentage of total grid points having no statistically significant trend

Study 1
Global climate model selection for regional climate assessment

Recent studies imply overarching benefit of equal-weighted climate model averaging

Low frequency Indian monsoon behavior

Maximum temperature trends

Study 2
Monsoon rainfall periodicity: degradation of results with additional models

Convergence to a suboptimal hindcast

Multimodel average not better in every case
Not as clear for maximum temperature trends

No clear cut best climate model

One model is clearly suboptimal – why include it?
Process based evaluations of climate models

Q: How do we know if a model gets it right “by chance”?

- Rainfall - clearer
  - Atlantic multi-decadal oscillation (AMO) periodicity 65-70 years
- T-Max
  - Natural climate variability
    1. Teleconnection with climate oscillators
    2. Low frequency variability
  - Anthropogenic global (non-climate) change
    1. Urbanization/Land use change
    2. Non GHG emissions/Aerosol

- Meridional gradient of tropospheric temperature (difference of 200 hPa and 600 hPa temperature between a north [30° E -100° E, 10° N - 35° N] and a south box [30° E -100° E, 15° S - 10° N])
- Temperature anomaly
  - In Eurasia
- All India Monsoon (JJAS) Rainfall (AIMR)
  - Periodicity: 67 years
- All India minimum temperature (MAM) (TMIN)
  - Periodicity: 60 years

Global warming
  - Trend: 0.74°C/century
 Continental (Asia) warming
  - Trend: 1.3°C/century
 Regional (India) warming
  - Trend: 0.68°C/century

Increasing uncertainty

Model skills typically low
  a) in the tropics and
  b) for finer resolution processes
Going forward

Policy and Science Implications

- Stakeholders may be better off preparing for increasing variability (uncertainty) than increasing trends
- Regional drivers > “global warming” in some cases
- Definitions of extremes can make a difference
- Importance of physical process evaluation in climate model selection

Challenges

- Spatial and temporal resolution differences → conflicting results?
- Adaptation/mitigation in the face of increasing variability
- Importance of physical process evaluation in climate model selection
- Regional prediction?
Thanks to....

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- Shih-Chieh Kao (Research Scientist, Environmental Sciences Division, Oak Ridge National Lab, study 1)
- Evan Kodra (GRA, CEE, University of Tennessee, study 2)

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