Emerging Water Resources Modeling Technologies to Understand Climate Change Impacts on Various Sectors and to Develop Adaptation Strategies

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Outline

- Global water use
  - Climate change
  - Hydrologic cycle
- Hydrologic modeling
  - Integration of a suite of models
- Emerging remote sensing based observation techniques
- Uncertainties in hydrologic modeling
- Adaptation strategies
- Key challenges
How much flow for ecological needs??

Source: http://www.unwater.org/ IAFOE 2014
Floods and Droughts
A Watershed
Class of watershed Models

Traditional Models
Empirical
Deterministic
Lumped
Single event

Current state of the art
Physical
Deterministic/Stochastic
Distributed
Single / Continuous Event

Lumped
Semi Distributed
Fully Distributed

Traditional Models
Current state of the art

Class of watershed Models

Lumped
Semi Distributed
Fully Distributed

IAFOE 2014
Model Scale

Source: http://amma-international.org/
Integration of a suite of models
Model Inputs

- Variables
  - Precipitation, temperature, relative humidity, wind speed, solar radiation

- Parameters
  - Drainage
  - Soils and Geology
  - Landuse/Landcover
  - Land / Water Management

- 100’s of parameters with at least 20 sensitive parameters
Precipitation
Topography

Reflected radar signals collected at two antennas, providing two sets of radar signals separated by a distance.

Space Shuttle Endeavour during the 11-day in February 2000
Topography - LIDAR

Traditional single lightwave LIDAR for Topographic surveys

Dual light wave bathymetric LIDAR systems

Source: http://www.fugro-pelagos.com/l

Source: www.dot.state.oh.us

May 19, 2014
Flood Modeling and Damage Assessment

Structure Inventory

Perspective view of 500 yr Flood event

Clear Creek Normal pool level

US Army Corps of Engineers
Streamflow

- Almost always ground-based measurements

Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.

Example of a typical stage-discharge relation; here, the discharge of the river is 40 cubic feet per second (ft³/s) when the stage is 3.30 feet (ft). The dots on the curve represent concurrent measurement of stage and discharge.

Source: https://water.usgs.gov

May 19, 2014
Soil Moisture - In-situ measurement
Soil moisture – from satellite

<table>
<thead>
<tr>
<th>Frequency (GHz), Wavelength (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8 to 7 GHz, ~4.3 cm</td>
</tr>
<tr>
<td>10 GHz, 3 cm</td>
</tr>
<tr>
<td>19, 23.8 GHz, ~1.3 cm</td>
</tr>
<tr>
<td>85, 89 GHz, ~0.34 cm</td>
</tr>
</tbody>
</table>

Emitted microwave radiation

dry vs. wet surface

Soil Penetration Depth

Lower frequency/longer wavelength

Higher frequency/shorter wavelength
Hydrologic Parameters

- Vegetation cover
  - Remote Sensing

- Soil Properties
  - Hydraulic conductivity
  - Bulk density
  - Porosity
  - Available water holding capacity

Parameter adjustment through model Calibration

In-situ Measurement + Mapping soil units from high resolution Satellite imagery
Uncertainty Source Diagram

Real-time observed hydrometeorological data (data uncertainty)

Streamflow model (model structure uncertainty)

Model calibration (parameter uncertainty)

User/forecaster (forecaster uncertainty)

Forecast meteorological input (forcings) (hydrometeorological uncertainty)

Current model states (model states uncertainty)

Output of “raw” streamflow ensembles (cumulative uncertainty)

http://www.meted.ucar.edu/
The NWS Hydrologic Ensemble Forecast System

Begin here
Input data, carryover conditions, model runtime modifications, initial conditions

Data Assimilator
Recently observed temp, precipitation, streamflow, snow conditions...

Input Ensembles
Hydrologic, hydraulic and reservoir models, interactive forecast and calibration systems

Pre-processor
Reduce bias, account for met. uncertainty, create forcing data ensembles

Hydrologic processor
Hydrologic, hydraulic, and reservoir models, interactive forecast and calibration systems

Ensemble streamflow values
Unadjusted (raw) ensembles

Post processor
Reduce bias, account for residual hydrologic uncertainty

Forecast Verification System
Determine verification metrics compared to some reference

Product Generation System
Compare single forecast flow with verifying observed/historic flow, develop statistics

End result
Hydrologic ensemble product suite
- Various hydromet products
- Hours to years into the future
- Reflects meteorological and hydrologic uncertainties

Verified single forecast
Single streamflow value

http://www.meted.ucar.edu/
Comparison of Simulated Stream Flow under Climate Change with Various Model Biases

Source: Eugene S. Takle of Iowa State University
Figure SPM.8a,b
Maps of CMIP5 multi-model mean results

(a) Change in average surface temperature (1986–2005 to 2081–2100)

(b) Change in average precipitation (1986–2005 to 2081–2100)

Source: AR5, WG1 report
Impact of Climate Change
Source: IPCC AR5 report

POLAR REGIONS
- Risks for Ecosystems
- Risks for Health and Well-Being
- Unprecedented Challenges, Especially from Rate of Change

NORTH AMERICA
- Increased Risks from Wildfires
- Heat-Related Human Mortality
- Damages from River and Coastal Urban Floods

THE OCEAN
- Reduced Fisheries Catch Potential at Low Latitudes

CENTRAL AND SOUTH AMERICA
- Reduced Water Availability and Increased Flooding and Landslides
- Reduced Crop Productivity and Livelihood and Food Security
- Vector- and Water-Borne Diseases

AFRICA
- Compounded Stress on Water Resources

SMALL ISLANDS
- Loss of Livelihoods, Settlements, Infrastructure, Ecosystem Services, and Economic Stability
- Vector- and Water-Borne Diseases

EUROPE
- Increased Flood Losses and Impacts
- Increased Losses and Impacts from Extreme Heat Events
- Increased Water Restrictions

ASIA
- Increased Flood Damage to Infrastructure, Livelihoods, and Settlements
- Heat-Related Human Mortality
- Increased Drought-Related Water and Food Shortage

AUSTRALASIA
- Significant Change in Composition and Structure of Coral Reef Systems
- Increased Risks from Wildfires
- Heat-Related Human Mortality

THE OCEAN
- Unprecedented Challenges, Especially from Rate of Change

POLAR REGIONS
- Risk Level with Current Adaptation
- Potential for Additional Adaptation to Reduce Risk
- Risk Level with High Adaptation

Source: IPCC AR5 report
Significant quantum of water is used in the cultivation of paddy

More than 65% of available water in Tamil Nadu used for Paddy cultivation

Will there be enough water in the future to cultivate paddy?
Krishna Basin

Salient features

- Length: 1,400 km
- Drainage area: 258,948 sq.km
- Population: 76.5 million
  - Density: 287/sq.km
Average rainfall intensity

Annual (Baseline Scenario)

Rainfall Intensity (mm/day)
- <4
- 4 - 6
- 7 - 10
- 11 - 12
- 13 - 15
- 16 - 32
- >32

Annual (End Century Scenario)

Rainfall Intensity (mm/day)
- <4
- 4 - 6
- 7 - 10
- 11 - 12
- 13 - 15
- 16 - 32
- >32
Spatial Distribution of Average Annual Water Yield

Baseline Scenario 1981 - 2000

Y1B Scenario 2021 - 2050

A1B Scenario 2081 - 2100

Percentage Change in Irrigation Demand for Rice crop from Baseline to End Century A1B Scenario
Adaptation strategies

- Changing operation policies of existing reservoirs
  - Power generation
  - Irrigation
  - Ecological flows
- Construction of more reservoirs??
- Construction of levees, height of levees
- Severe weather warning systems
- Low-impact development techniques for urban areas
  - Rainwater harvesting
- Our food habits and lifestyle!!
Key challenges

- Ecological flows
- Space based techniques for retrieving channel cross section across a river basin
  - Channel cross sections undergo changes with time (LIDAR or RADAR)
- Soil moisture retrieval with vegetation cover and from deeper regions within the soil
- Parallelizing the traditionally serial hydrologic models
  - Improving spatial resolution and performing uncertainty analysis take a large computational effort
THANK YOU