Drought Research at Princeton University and University of Southampton

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Outline of Talk

• Background of drought impacts

• Overview of research topics at Princeton/Southampton

• A few quick examples of research

• Focus on drought monitoring and prediction in sub-Saharan Africa
  • Challenges for sub-Saharan Africa
  • Current capabilities (national, regional, international)
  • Princeton African (Flood and) Drought Monitor
  • Approach and Implementation
  • Evaluation and Validation (large-scale and local scale)
  • Translating climate and hydrological information into decision making
  • Challenges, opportunities, …
Droughts arguably cause the most impacts of all natural hazards in terms of the number of people affected and the long-term economic costs and ecosystem stresses.

- Reduced water levels/supply: public, industry and power generation
- Reduced agricultural, forestry and fisheries productivity
- Increased livestock mortality rates
- Increased fire hazard/tree die off
- Damage to wildlife habitat
The Cost of Drought


Sources: NOAA/NCDC (1980 - 2011)
AON Benfield (2012, through October)
Water Availability is Facing Multiple Global Pressures

- Population growth and changing demographics
- Agricultural demand and changing diets
- Unsustainable water use
- Climate Change

We live in a connected world
Regional Hotspots of Water Shortages are Emerging

Kummu et al., 2010
Water scarcity is increasing as driven by human pressures on demand

But supply is also not static and is driven by climate variability

Persistent/severe drought can magnify the impacts, especially for already-stressed systems

And there is potential for climate change to exacerbate problems in the future
Research questions that we are interested in

How does the terrestrial hydrological cycle vary over diurnal to centennial time scales?

Is the hydrological cycle accelerating in response to global warming?

How are extreme events such as drought changing?

What are the mechanisms of drought development and recovery?

What are the uncertainties in future projections of hydrological change?

How do human activities feedback with the climate and water systems?

How can we use this research to improve societal resilience to short term climate variability and adaptation to long-term climate change?
Research Tools that We Use

Remote sensing

Land Surface Modeling

Reanalysis/RCM

Climate Models

Diagnostic Tools

Ground Observations
Example 1: Understanding Drought

1. Drought Reconstruction

2. Drought Mechanisms
   (a) GH500mb DJF (Dry−Clim)
   (b) GH500mb DJF (Wet−Clim)

3. Drought Risk
   (a) SST DJF (Dry−Clim)
   (b) SST DJF (Wet−Clim)

4. Drought Predictability
   (a) Obs Prec. vs. Fcst. PREC
   (b) MW Prec. vs. SVD PREC

- CPC
- CFSv2
- COLA
- GFDL
- IRI−AC
- IRI−DC
- NASA
Drought Reconstruction

Propagation of drought signal from the atmosphere to the land surface to the sub-surface

(a) Moisture flux convergence
(b) Precipitation
(c) Evapotranspiration
(d) Runoff
(e) Soil moisture
Example 2. Impact of Water Use and Management on Drought

- Impact of management (reservoir operations, irrigation, power generation) can be large but relatively unknown

- Incorporation of management and water use into a hydrological model allows us to attribute human influences on drought

California hydrological drought duration and deficit

Return period ratio (natural/human) of 2014/15 drought

\[ r = \frac{T_{\text{Natural}}}{T_{\text{Human}}} \]
Example 3. Climate-Water Impacts on Energy Production

Understanding how drought and heat-waves intersect to affect hydropower and thermoelectric power generation and changes in demand under current and future climates – and the consequences for pollutant and GHG emissions.

van Vliet et al., 2016

Change in hydropower and thermoelectric power usable capacity for the drought, warm year of 2003 in Europe (a) and 2007 in the Eastern North America (b) relative to the average for 1981-2010.
Example 4. Understanding Resilience of Smallholder Farmers in Kenya and Zambia

Intra-seasonal adaptive capacity of smallholder farmers differs under different social, institutional and environmental conditions.

Solving this requires information at the scales of decision making and bringing the skill of models down to this scale.
**Example 5. Understanding cross-scale interactions on drought impacts on food security in Zambia**

(Above) Examples of food security scenarios, illustrating the interactions between droughts of different scale and impact (localized or national coverage; mild or severe), transportation access (isolated or connected), food security policies (fixed or adaptive sub-nationally), and regional trade (free trade, preferential trade or trade barriers), and their impacts on average household dietary mix (ratio of local to imported food) and overall food security.
US Federal Emergency Management Agency (FEMA) and other disaster management organizations estimate that for every $1 spent on reducing vulnerability to disaster $4 is saved.

Managing the risk of impacts relies on a variety of measures to reduce vulnerability that includes forewarning through early-warning systems.
Drought Early Warning System Components

- Scientific Community
- Stake Holders
- Water Managers (site units)

Drought Partnership

Data
- historical
- real time (monitoring)

Tools
- forecasting
- predictions

Drought Watch System

Drought Management
## National/Regional Capability for Drought Monitoring

### One Conceptual Framework

<table>
<thead>
<tr>
<th></th>
<th>Level 1 (NADM Model)</th>
<th>Level 2</th>
<th>Level 3</th>
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</thead>
<tbody>
<tr>
<td><strong>Drought Experts</strong></td>
<td>In-house expertise for monitoring, forecasting, impacts, research, planning, education</td>
<td>Limited in-house expertise</td>
<td>Rely on external expertise</td>
</tr>
<tr>
<td><strong>National Climate Observing Network</strong></td>
<td>Extensive data networks, near-real time daily observations</td>
<td>Limited networks (spatial density and/or timeliness)</td>
<td>Rely on national CLIMAT/ WWW reports and external observations (e.g., satellite obs &amp; global models)</td>
</tr>
<tr>
<td><strong>National Drought Assessments</strong></td>
<td>National Drought Monitor already routinely produced timely (monthly or more frequently)</td>
<td>National assessments produced to support regional/continental monitoring</td>
<td>Rely on external expertise to produce national assessments</td>
</tr>
<tr>
<td><strong>International Data Exchange</strong></td>
<td>Station data exchanged for creation of regional or continental standardized indicators</td>
<td>Limited data exchanged internationally</td>
<td>Only CLIMAT or WWW data exchanged internationally</td>
</tr>
<tr>
<td><strong>International Collaboration</strong></td>
<td>National experts collaborate to create regional or continental Drought Monitor</td>
<td>Some national input to regional or continental Drought Monitor</td>
<td>Rely on external experts to produce national assessment for regional/continental Monitor</td>
</tr>
<tr>
<td><strong>IT Infrastructure</strong></td>
<td>ArcGIS, web, email</td>
<td>Limited ArcGIS, web, and/or email access</td>
<td>No IT infrastructure, rely on alternatives</td>
</tr>
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 Slide from Richard Heim, NCDC, US
Practical Requirements of Regional to Global Early Warning Systems

- extensive data networks with near-real time daily observations
- historical and near-real time data exchange
- operational drought analyses creating National Drought Monitoring products
- collaborative drought monitoring and research
- common IT infrastructure (email, web, GIS; OGC-compliant)
Two Approaches to Regional to Global Drought Early Warning

• Top-down system uses remote sensing and distributed hydrological models at scales down to km
  – Single point of failure with global top down system
  – May not represent local impacts

• Bottom-up system combines drought monitors for each nation’s hydrometeorological or space agency drought monitor
  – Methodology for combining diverse individual drought monitors is required

• Combined Top Down and Bottom Up System
  – Complementary top down application where drought monitoring capability is lacking or where local information can be merged
The Global Drought Early Warning System (GDEWS) is a conceptual framework that is a bottom-up approach that integrates continental, regional and national drought monitors.
Our Top-Down Approach for Drought Monitoring

Continental hydrological modeling and data assimilation of remote sensing
Meeting in the middle: bottom up meets top down

To be useful to stakeholders and decision makers – we need to meet in the middle

Bottom-up Approach
- Stakeholder engagement
- Co-design and co-development
- Local knowledge and experience
- Local data

Top-Down Approach
- Consistent global data products
- International expertise
- International collaboration
- State-of-the-art technologies
Data and Tools for Drought Monitoring and Prediction

Hydrological Modeling

Ground Observations

Satellite Remote Sensing

Reanalysis

Regional/Global Climate Models, Statistical Prediction
Putting it all together: Hydrological and Drought Monitoring and Forecasting System

Real-time Weather and Seasonal Forecasts

Initial Conditions

Land surface (hydrology) models

Hydrological Variables, Streamflow, Drought Indices

Management/Mitigation
Translation of Research into Operational Hydrological Monitoring and Forecasting

US Drought Monitor - 2006

CONUS 4km Monitor - 2016

LAC Drought Monitor – 2014 - 16

ChileFDM – 2019

Eastern Europe – 2020?

CHAD-FDM – 2019

African Drought Monitor – 2010 - 15
Summary and Conclusions

- Our drought research spans time and space scales, and crosses into sectoral impacts, resilience and adaptation

- A key part of addressing drought impacts is provision of early-warning

- Drought monitoring and forecasting is possible anywhere operationally, taking a top-down approach

- AFDM and CHAD-FDM are one set of examples of how this can be done at relatively low cost

- But large challenges in translating this into useful and useable information, particularly in understanding decision making

- New opportunities exist for bringing prediction to the scales relevant for decision making


