Drought Research at Princeton University and University of Southampton

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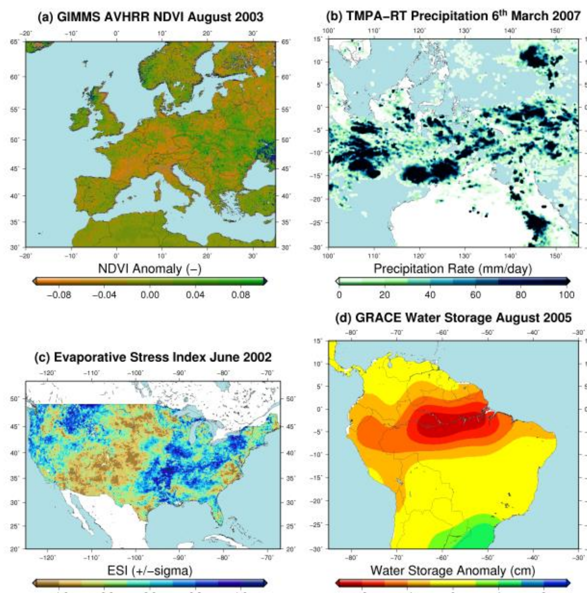
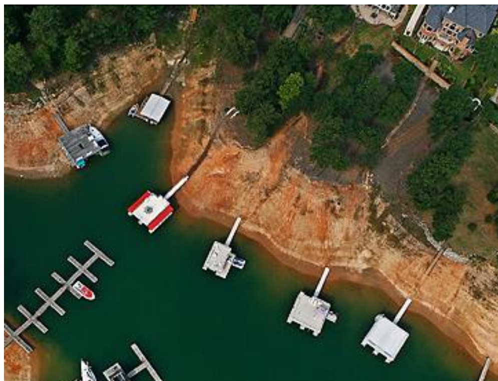


Outline of Talk

- 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


NY Times

Reduced agricultural, forestry
and fisheries productivity


BBC

Increased livestock mortality rates

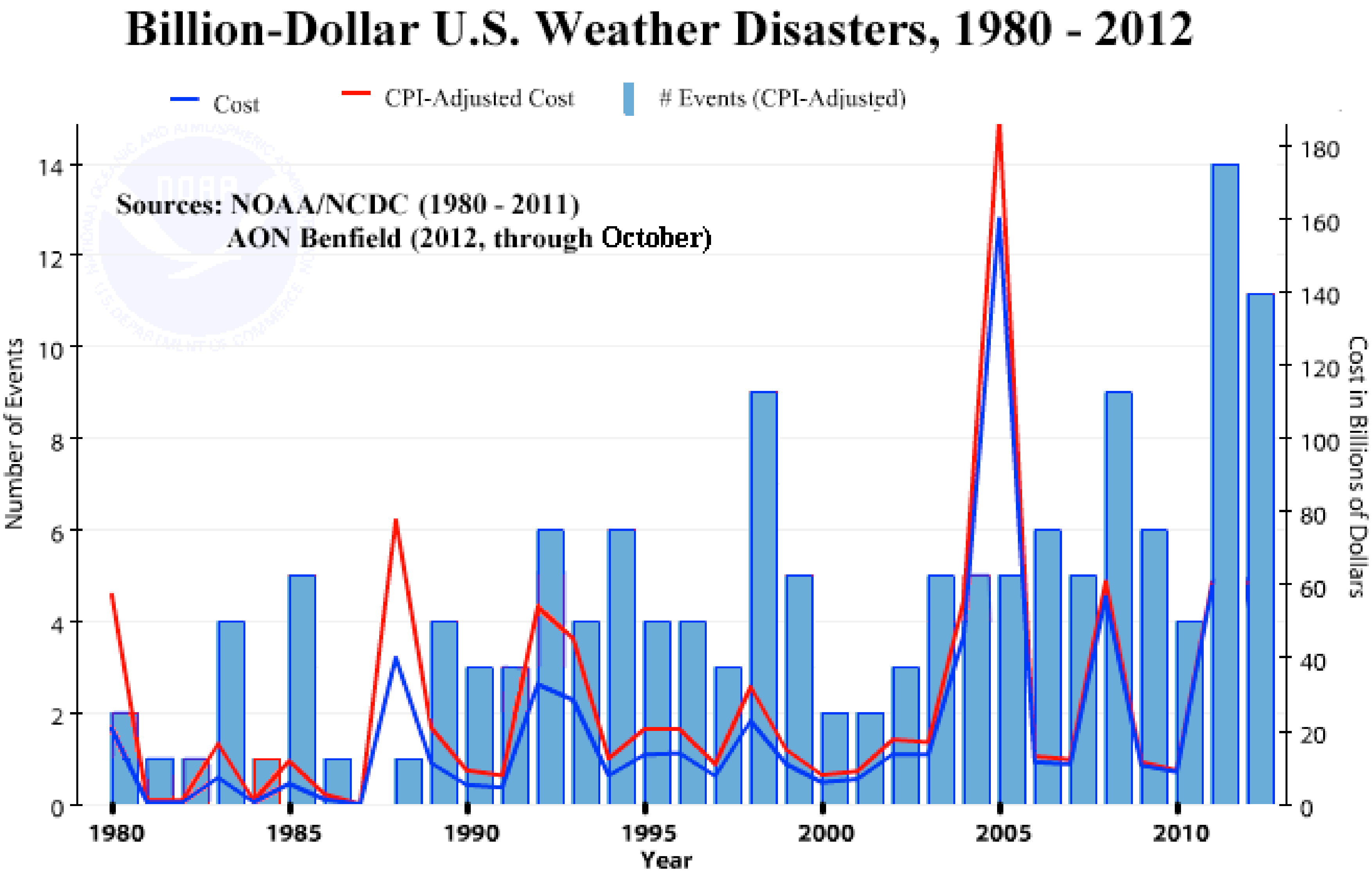

John Mccolgan/US Forest Service

Increased fire hazard/tree die off

Damage to wildlife habitat


BBC

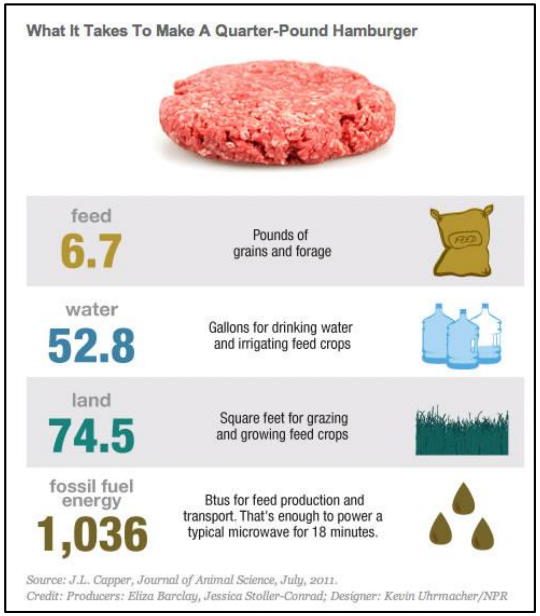
The Cost of Drought



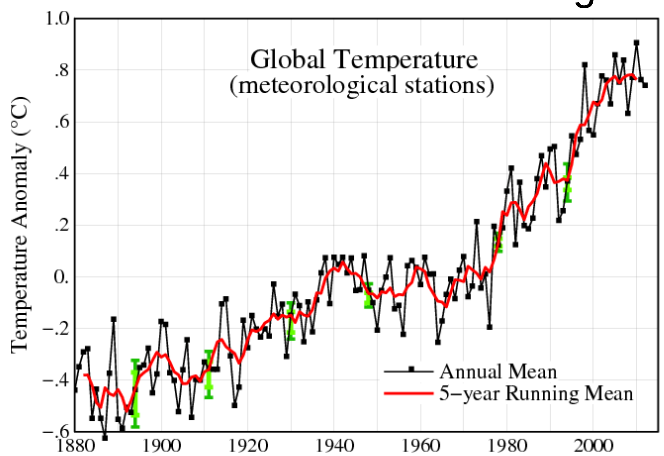
Water Availability is Facing Multiple Global Pressures

Population growth and changing demographics

Agricultural demand and changing diets

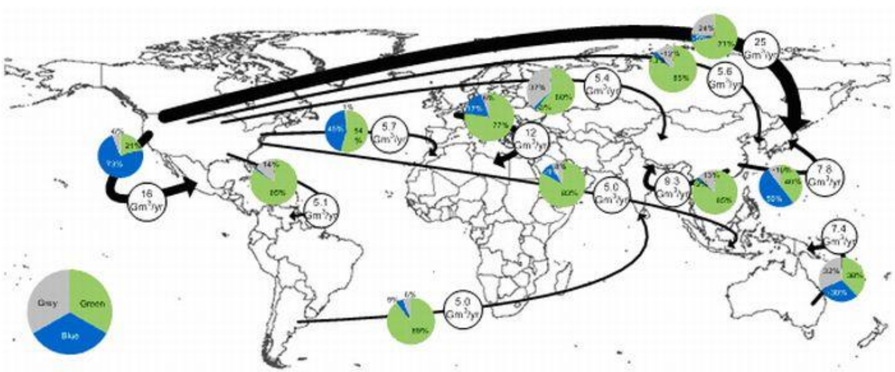


Climate Change

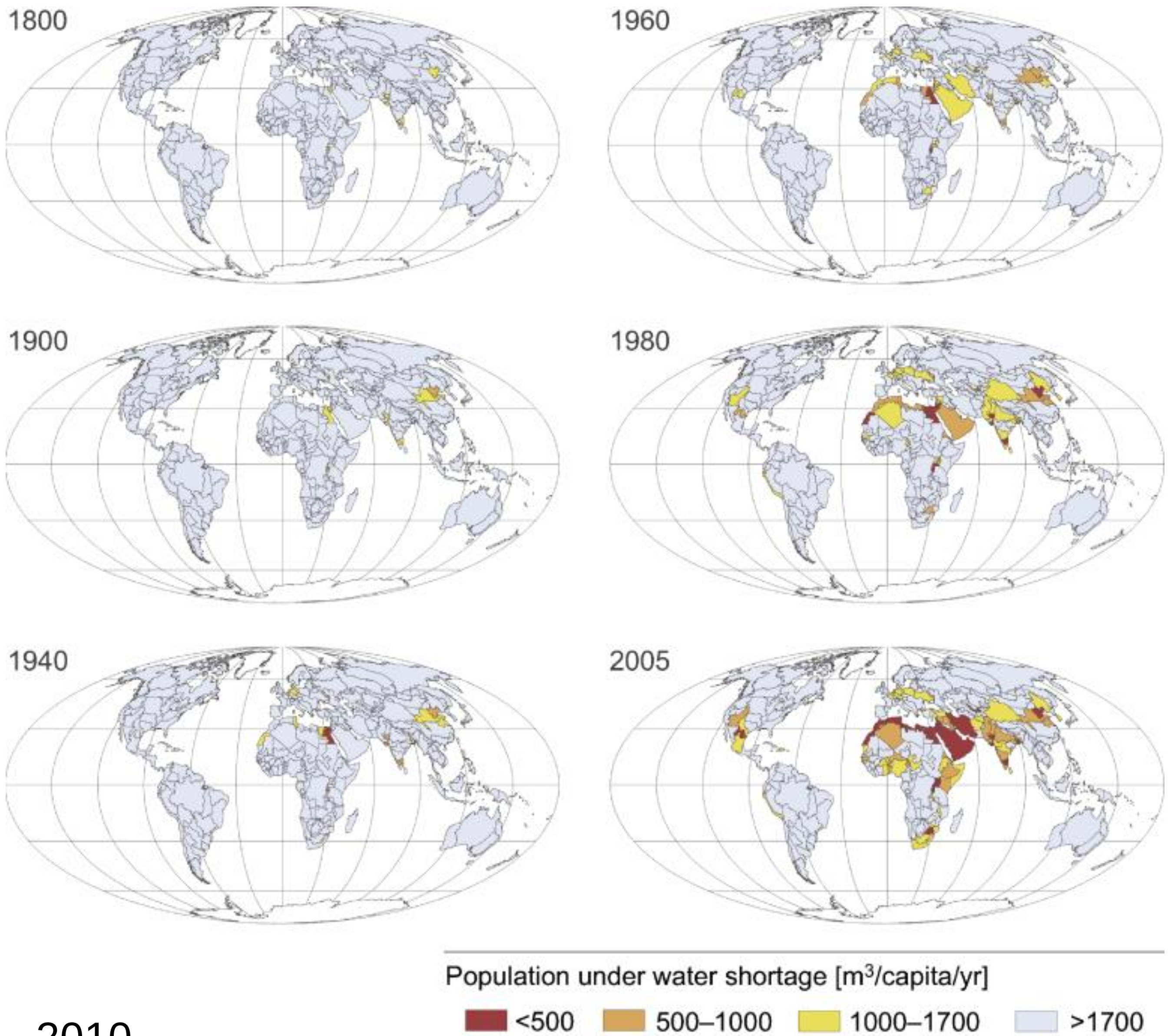


Unsustainable water use

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?

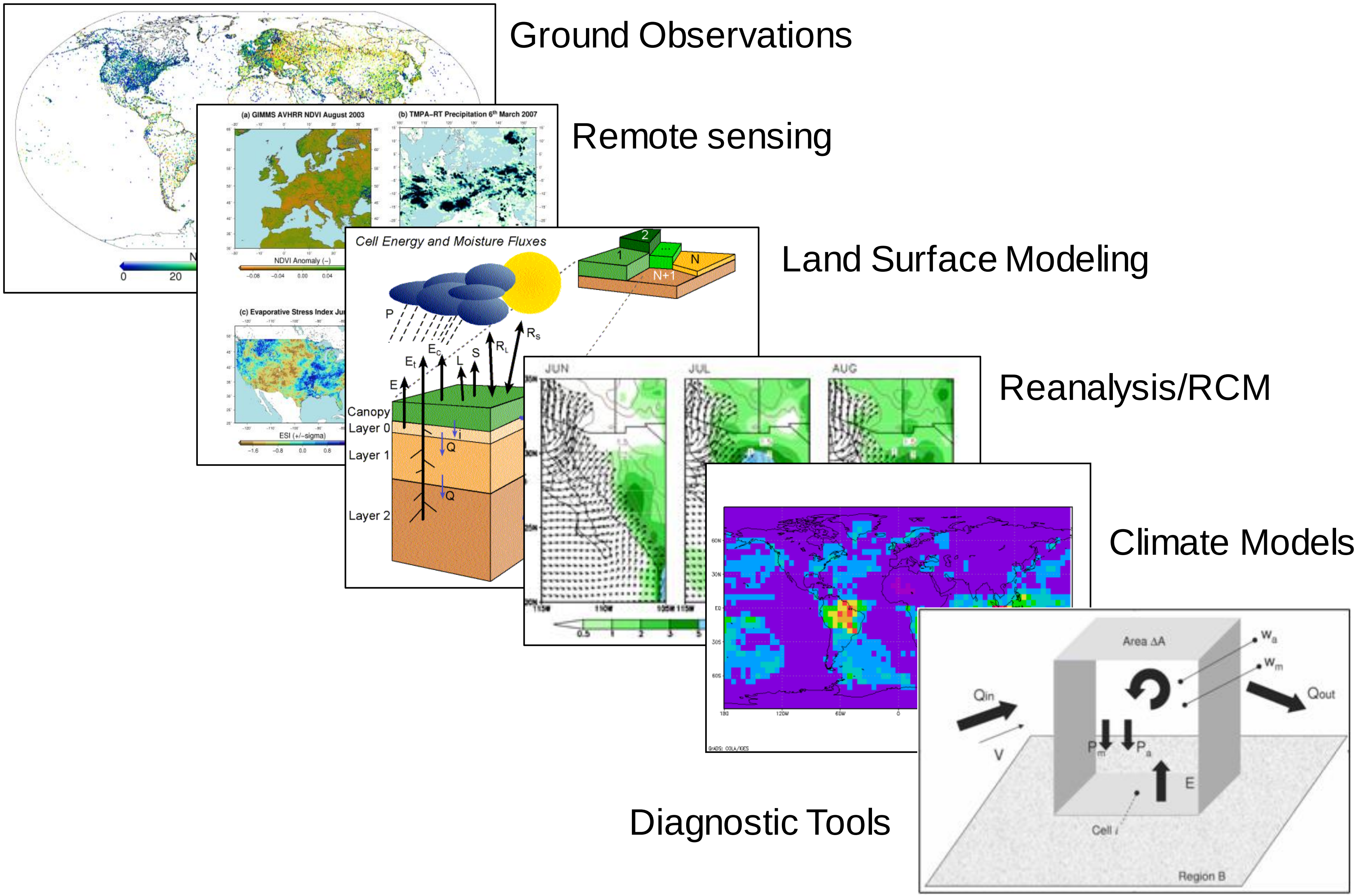
What are the mechanisms of drought development and recovery?

What are the uncertainties in future projections of hydrological change?

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

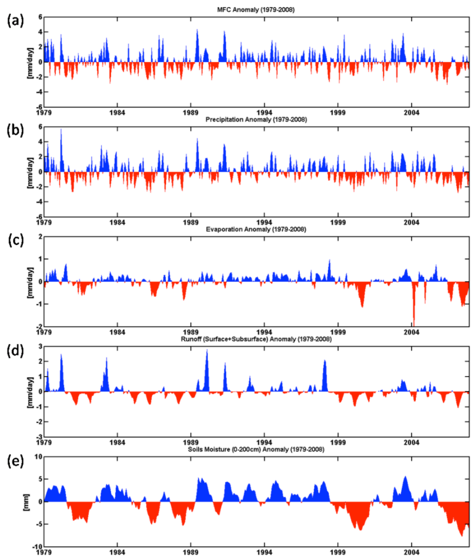
How can we use this research to improve societal resilience to short term climate variability and adaptation to long-term climate change?

Research Tools that We Use

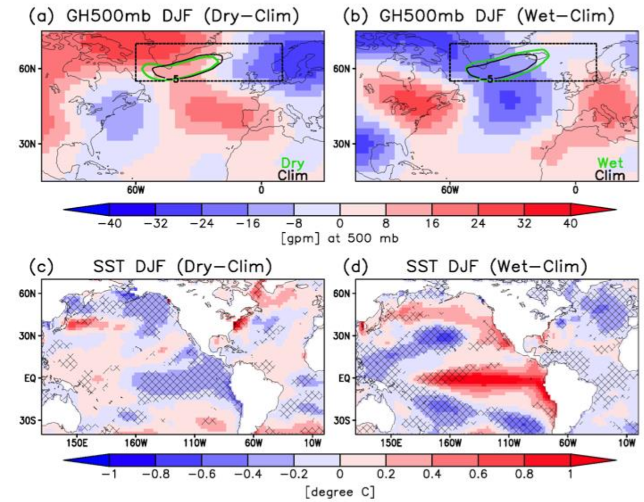


Example 1: Understanding Drought

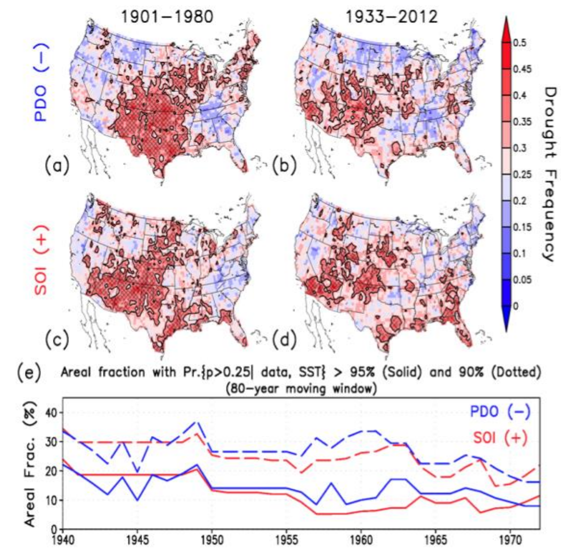
1. Drought Reconstruction



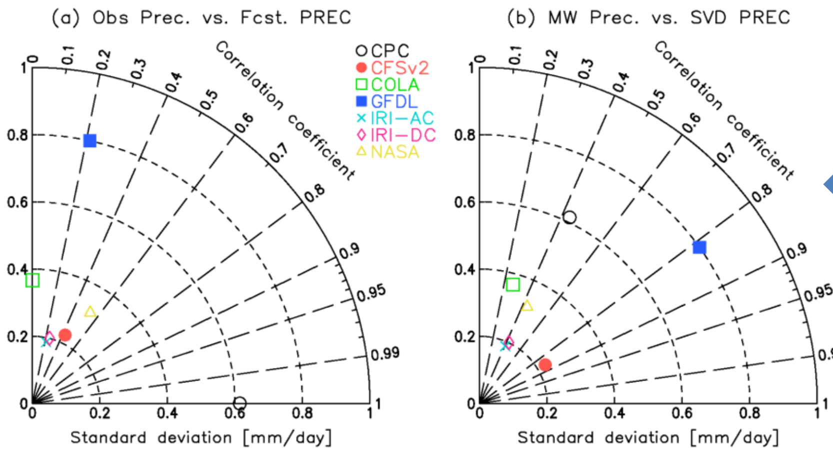
2. Drought Mechanisms



3. Drought Risk



4. Drought Predictability



Drought Reconstruction

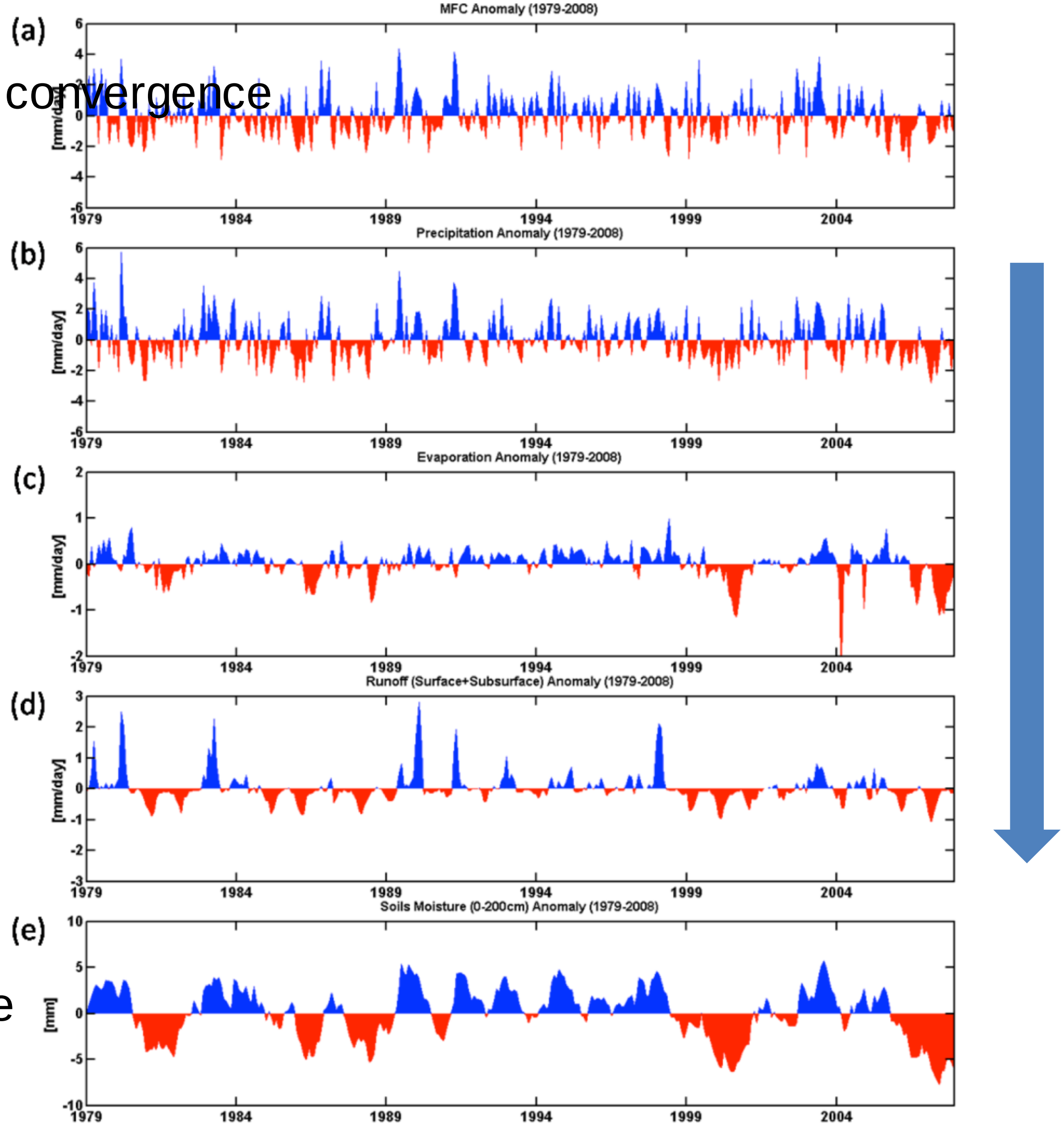
Moisture flux convergence

Precipitation

Evapotranspiration

Runoff

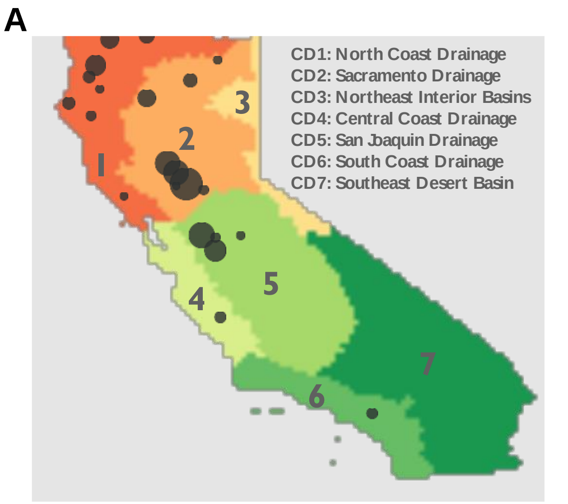
Soil moisture



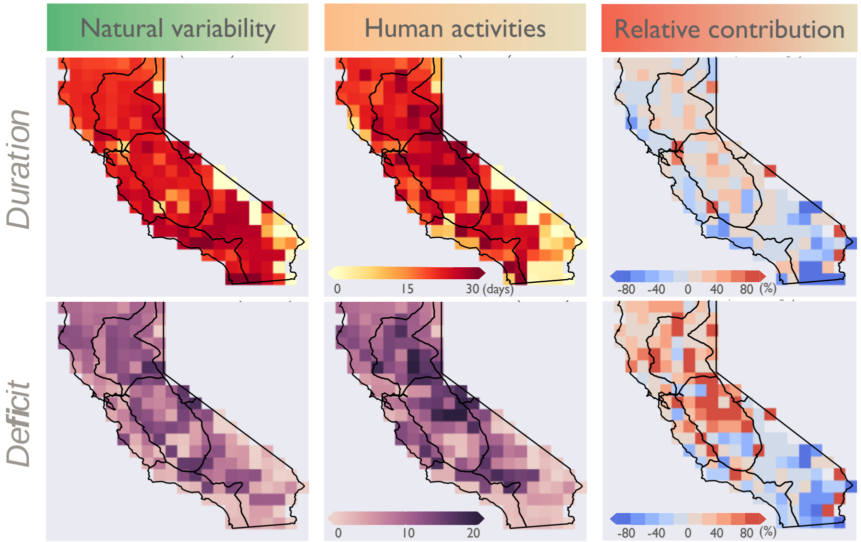
Propagation of drought signal from the atmosphere to the land surface to the sub-surface

Example 2. Impact of Water Use and Management on Drought

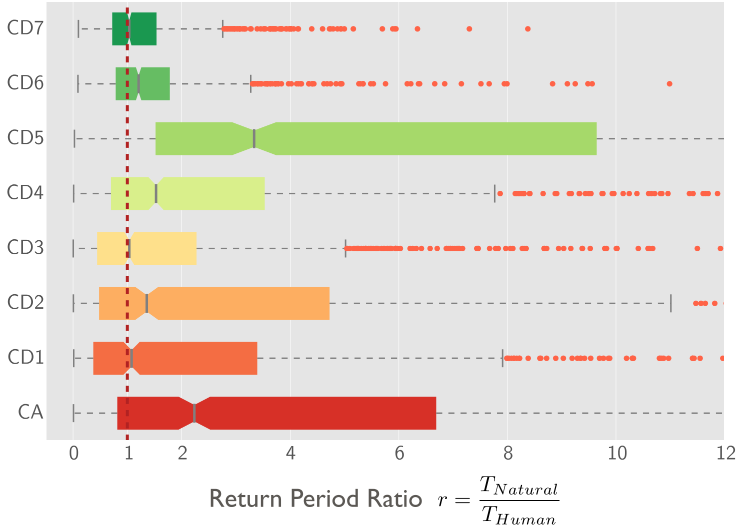
- Impact of management (reservoir operations, irrigation, power generation) can be large but relatively unknown
- Incorporation of management and water use into a hydrological model allows us to attribute human influences on drought



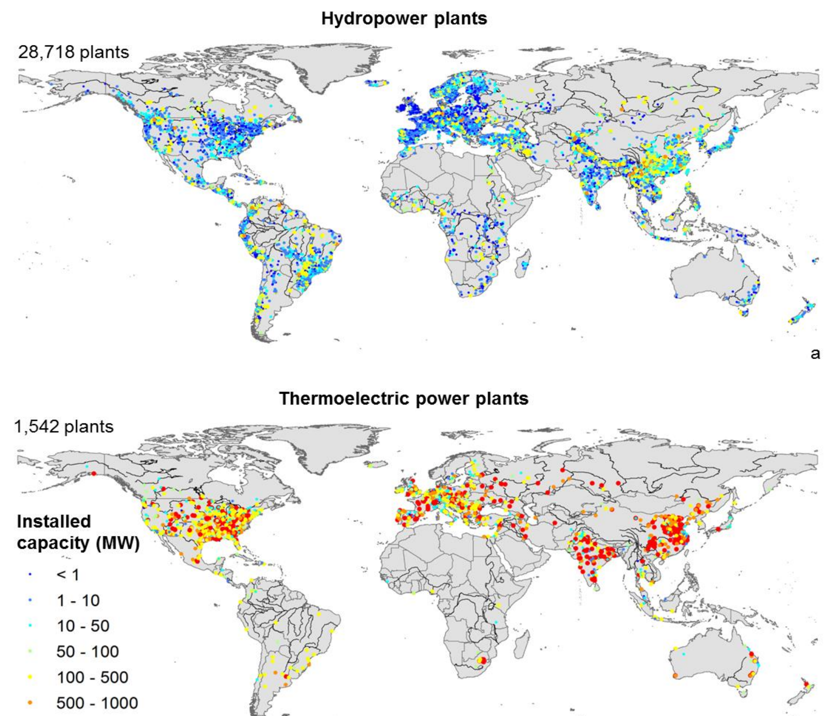
California hydrological drought duration and deficit



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

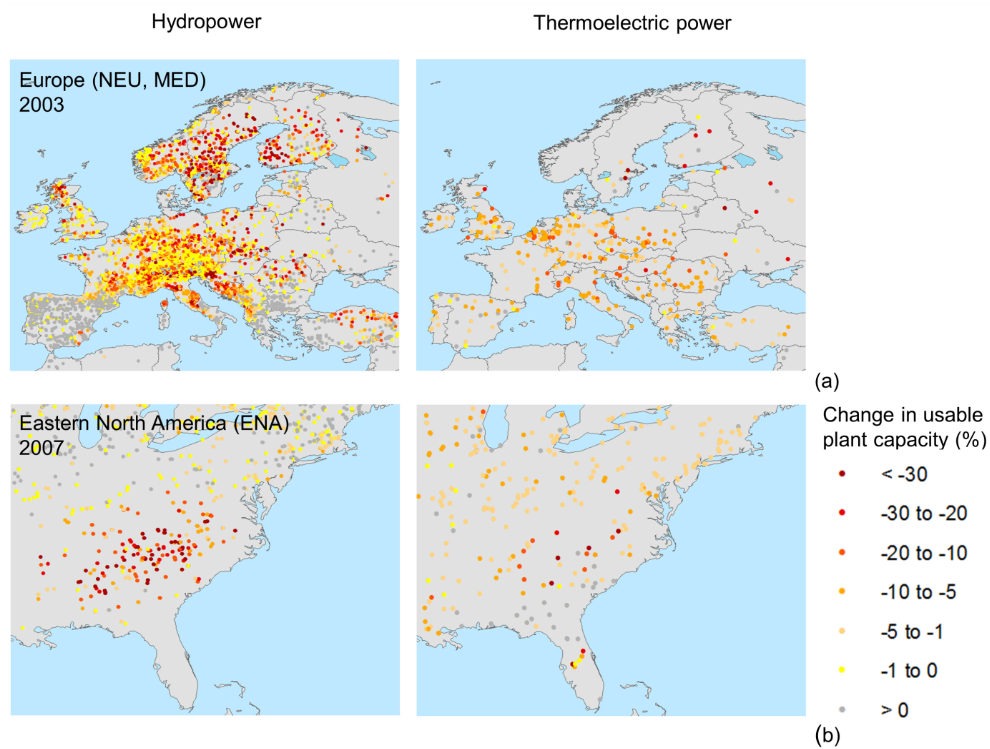


Example 3. Climate-Water Impacts on Energy Production



van Vliet et al., 2016

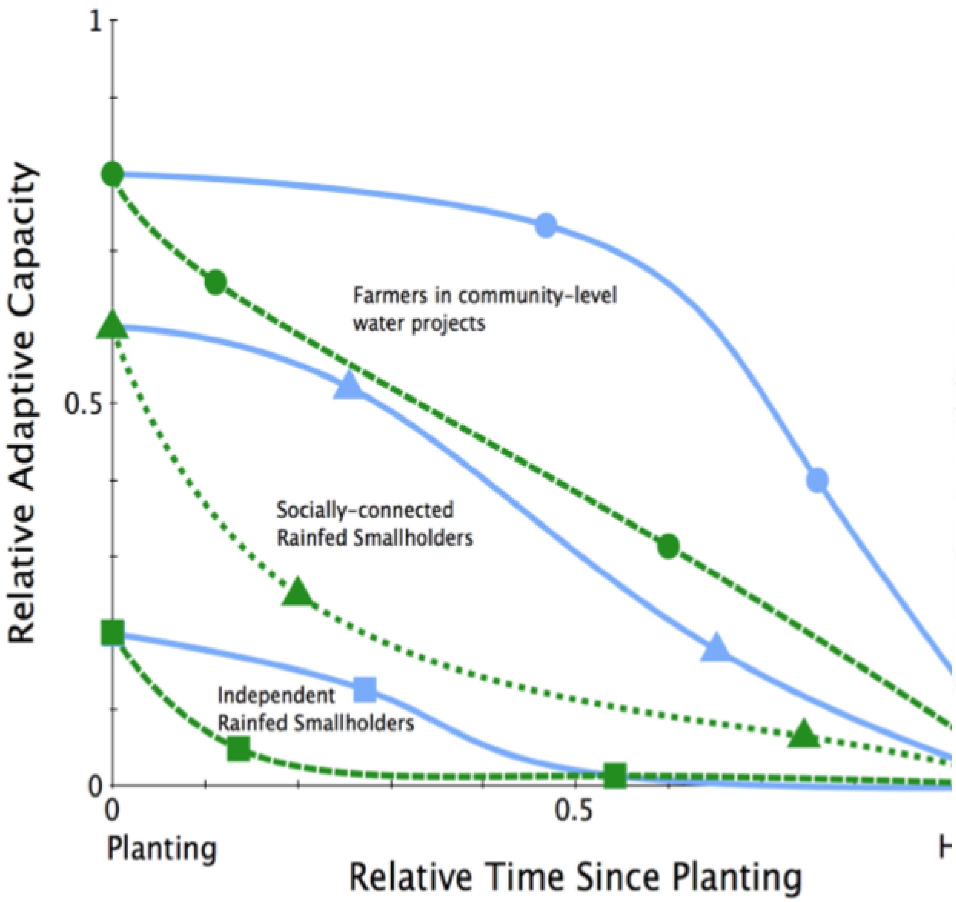
Understanding how drought and heat-waves intersect to affect hydropower and thermoelectric power generation and changes in demand under current and future climates – and the consequences for pollutant and GHG emissions



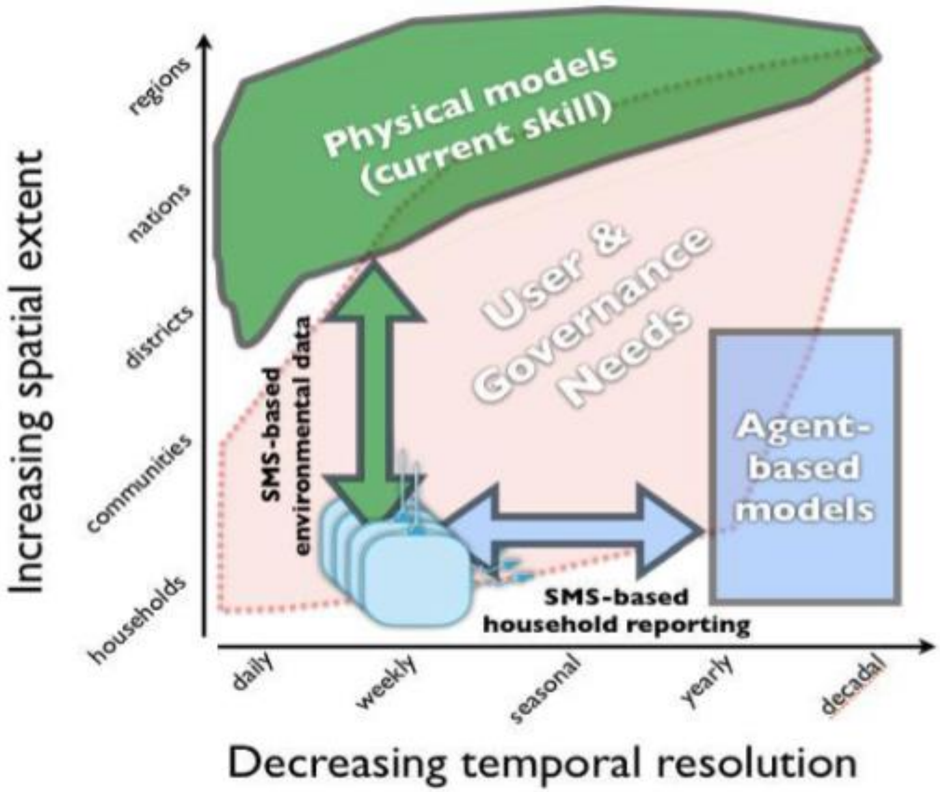
Change in hydropower and thermoelectric power usable capacity for the drought, warm year of 2003 in Europe (a) and 2007 in the Eastern North America (b) relative to the average for 1981-2010.

Example 4. Understanding Resilience of Smallholder Farmers in Kenya and Zambia

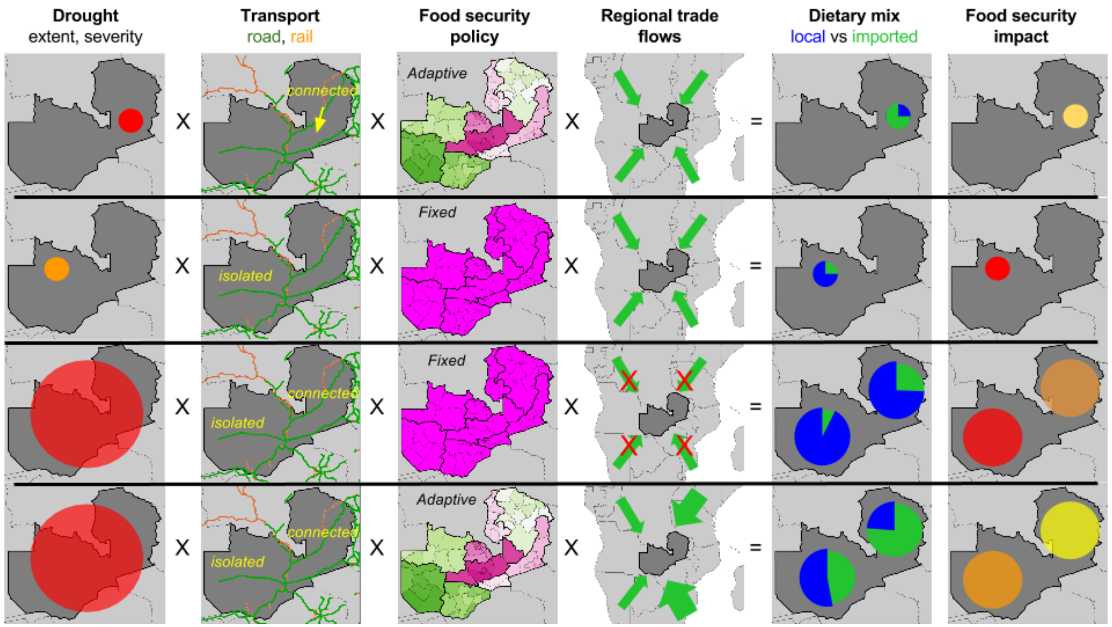
Intra-seasonal adaptive capacity of smallholder farmers differs under different social, institutional and environmental conditions



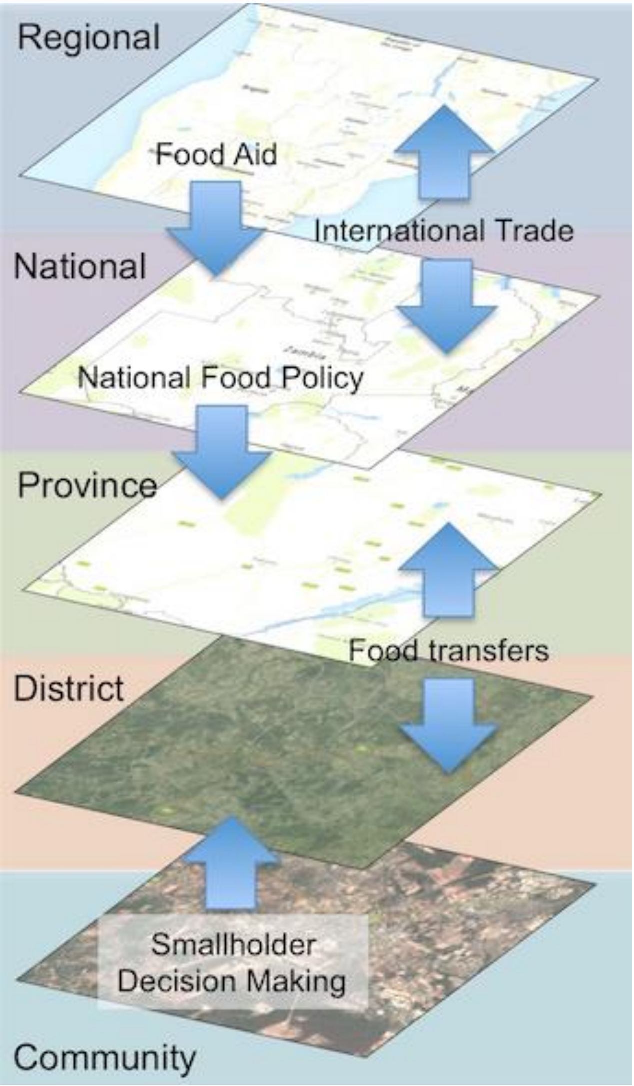
Solving this requires information at the scales of decision making and bringing the skill of models down to this scale



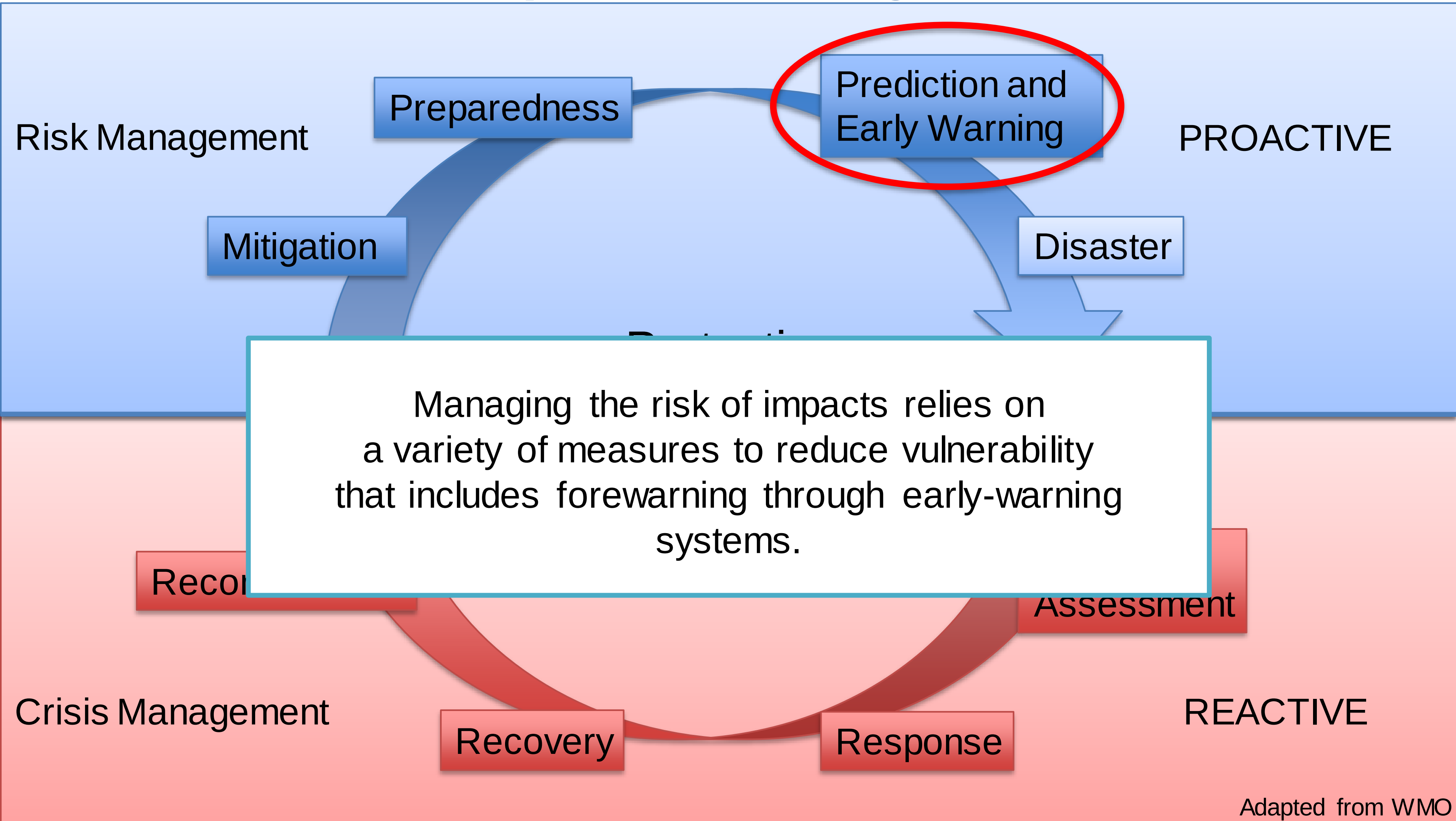
Example 5. Understanding cross-scale interactions on drought impacts on food security in Zambia



(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.

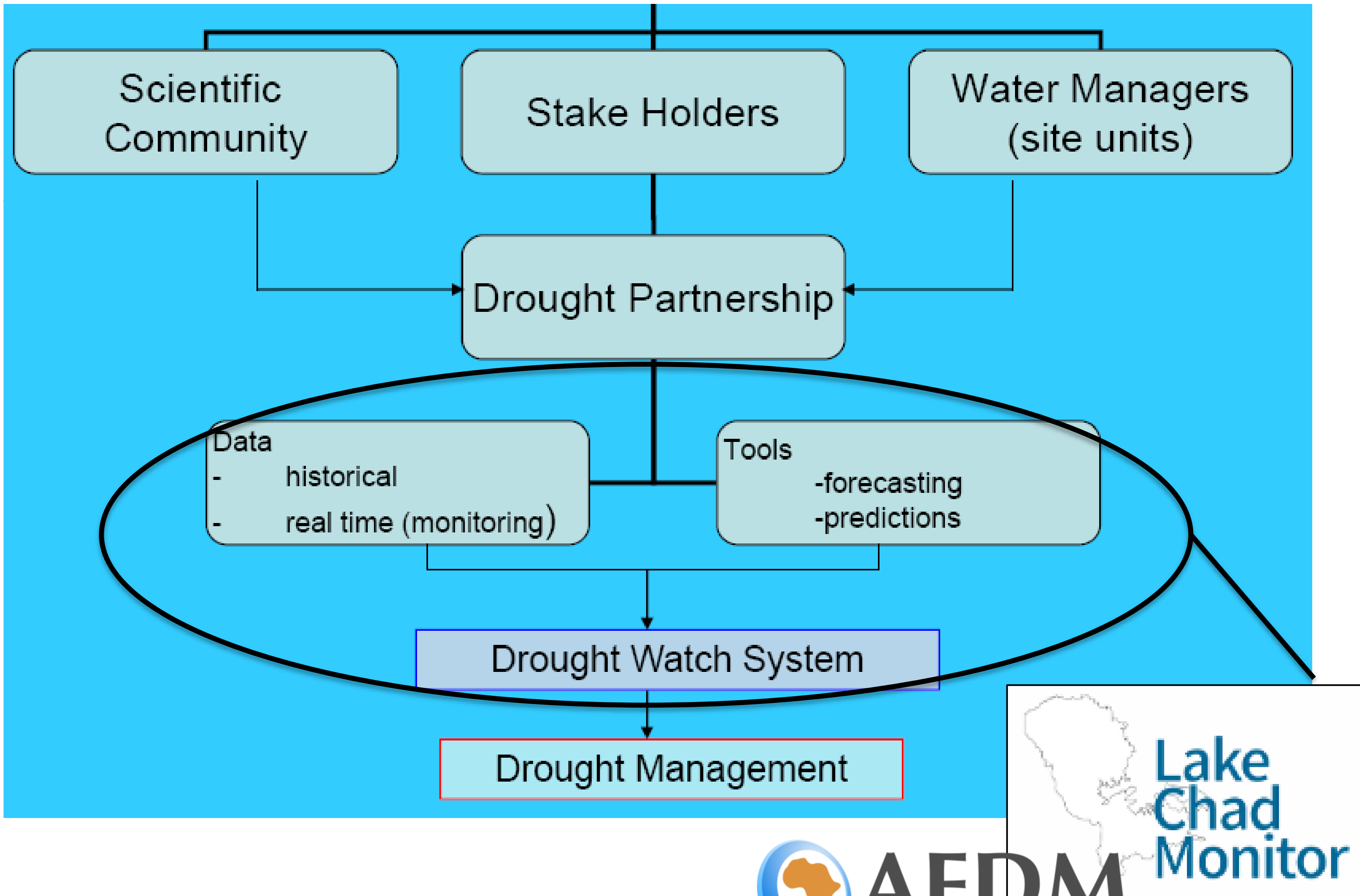


How do we use this research to reduce the impacts of drought?



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.

Drought Early Warning System Components



AFDM
African Flood and Drought Monitor

National/Regional Capability for Drought Monitoring

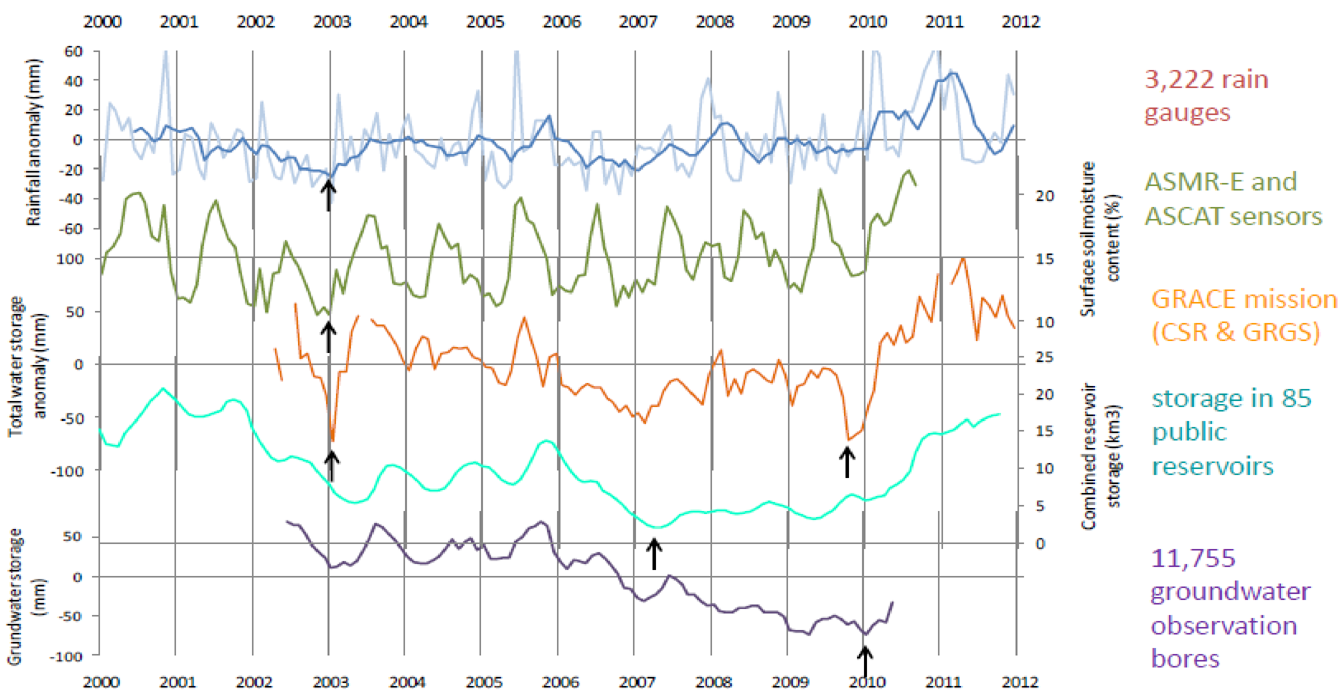
One Conceptual Framework	Level 1 (NADM Model)	Level 2	Level 3
Drought Experts	In-house expertise for monitoring, forecasting, impacts, research, planning, education	Limited in-house expertise	Rely on external expertise
National Climate Observing Network	Extensive data networks, near-real time daily observations	Limited networks (spatial density and/or timeliness)	Rely on national CLIMAT/ WWW reports and external observations (e.g., satellite obs & global models)
National Drought Assessments	National Drought Monitor already routinely produced timely (monthly or more frequently)	National assessments produced to support regional/continental monitoring	Rely on external expertise to produce national assessments
International Data Exchange	Station data exchanged for creation of regional or continental standardized indicators	Limited data exchanged internationally	Only CLIMAT or WWW data exchanged internationally
International Collaboration	National experts collaborate to create regional or continental Drought Monitor	Some national input to regional or continental Drought Monitor	Rely on external experts to produce national assessment for regional/ continental Monitor
IT Infrastructure	ArcGIS, web, email	Limited ArcGIS, web, and/or email access	No IT infrastructure, rely on alternatives

Decreasing capability →

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)



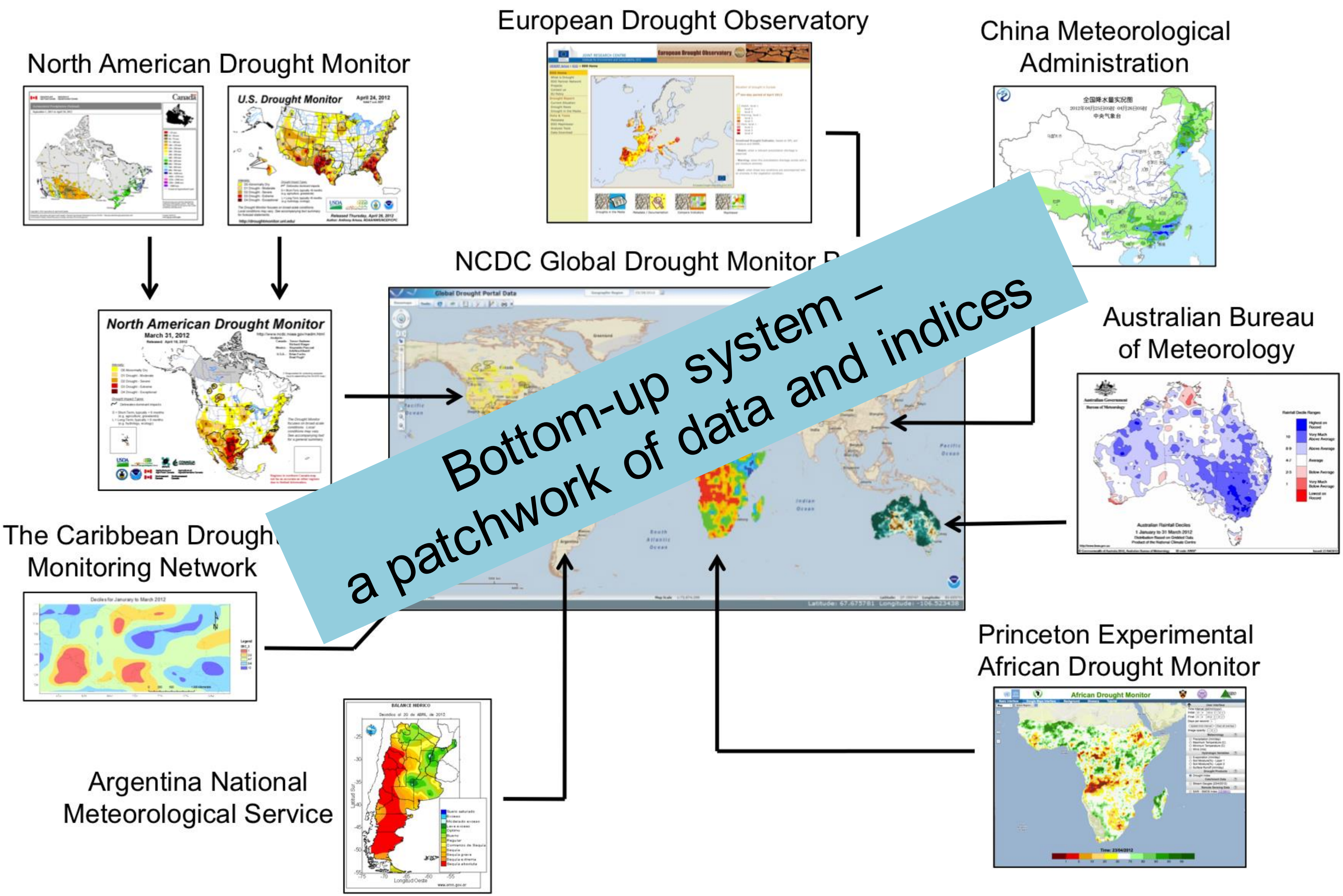
Two Approaches to Regional to Global Drought Early Warning

- 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

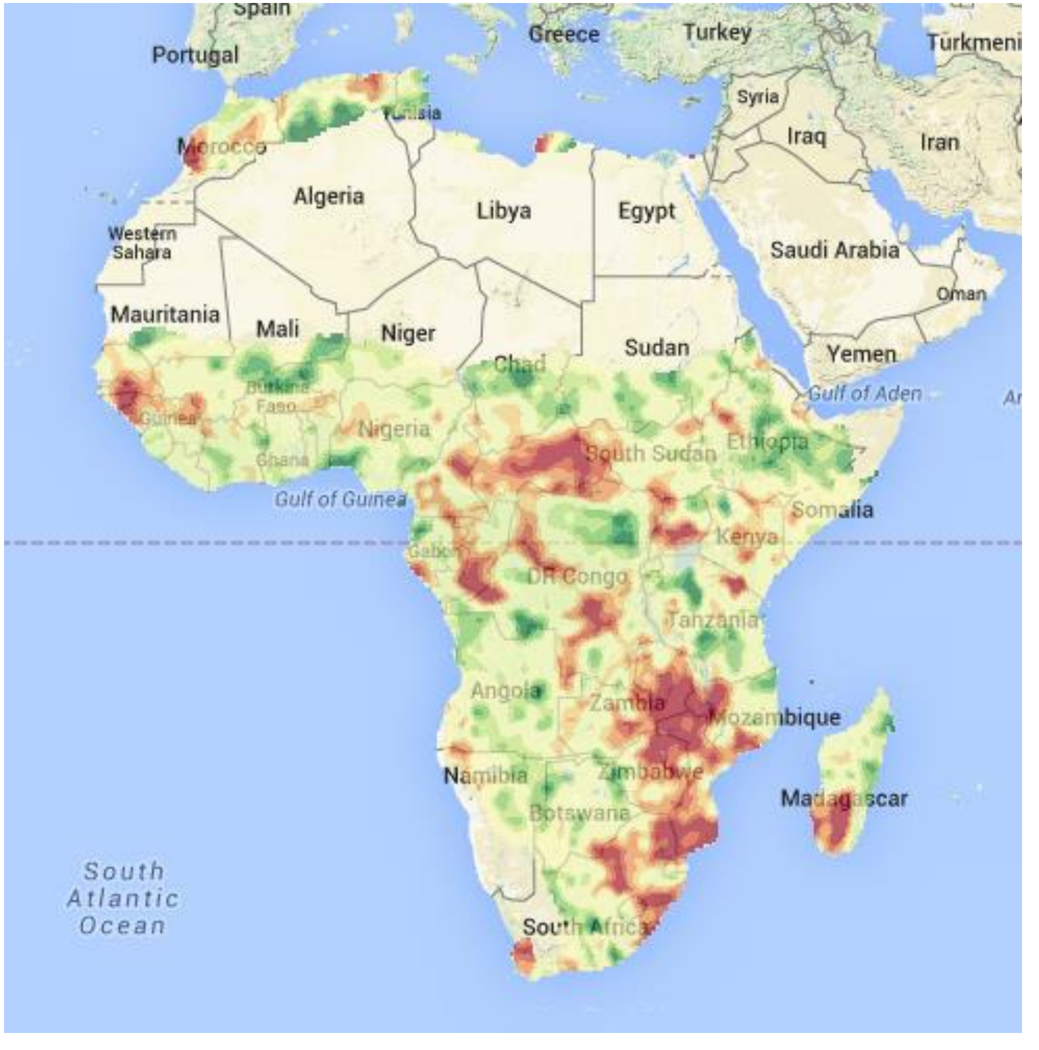
- *Combined* Top Down and Bottom Up System
  - Complementary top down application where drought monitoring capability is lacking or where local information can be merged

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

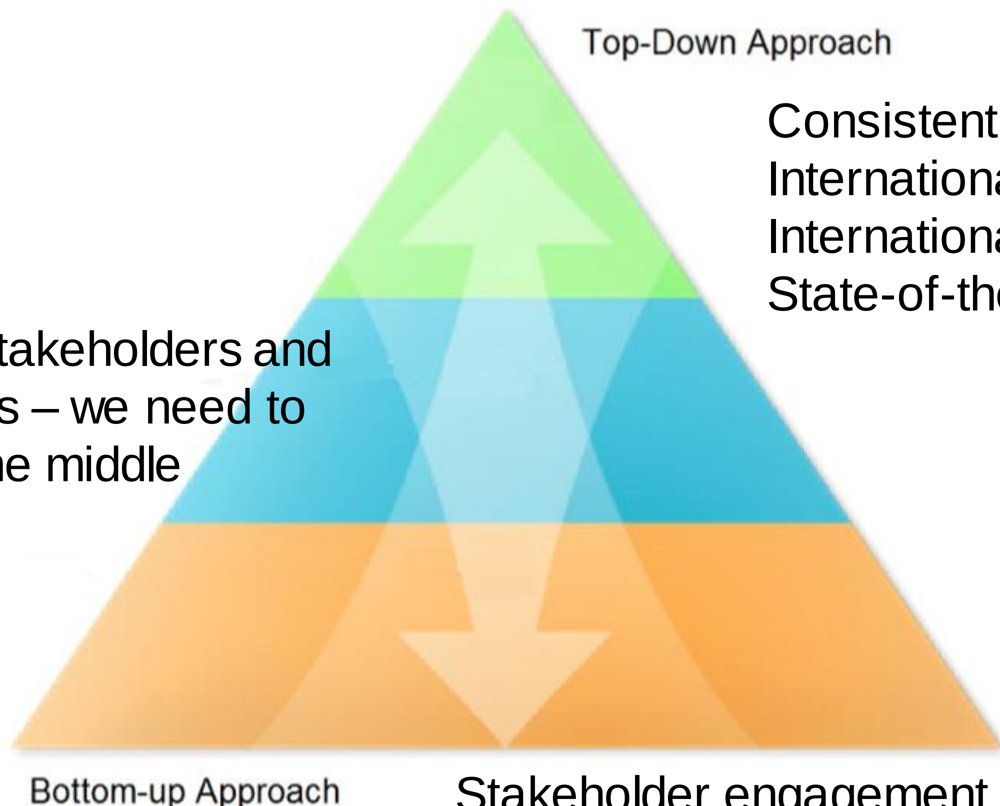


Our Top-Down Approach for Drought Monitoring

Continental hydrological modeling and data assimilation of remote sensing



Meeting in the middle: bottom up meets top down

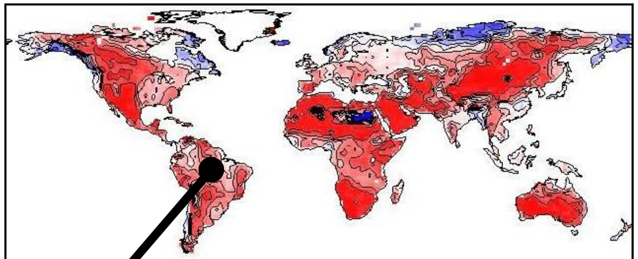


Consistent global data products
International expertise
International collaboration
State-of-the-art technologies

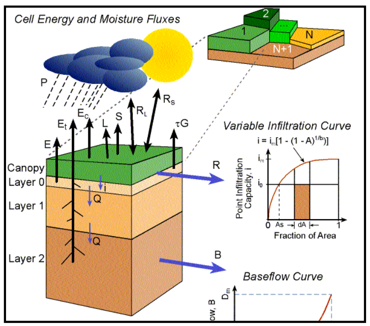
To be useful to stakeholders and decision makers – we need to meet in the middle

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

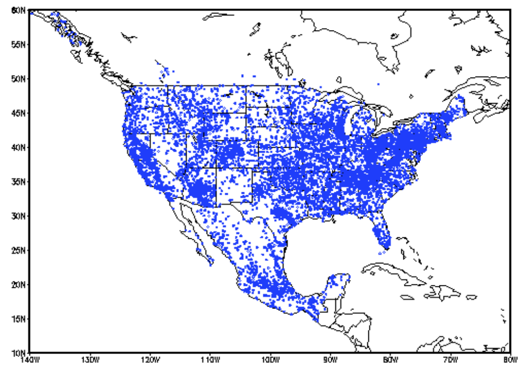
Data and Tools for Drought Monitoring and Prediction



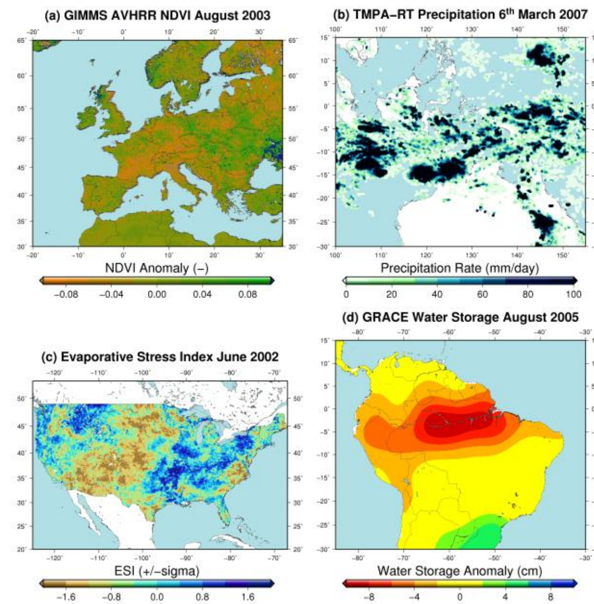
Hydrological Modeling



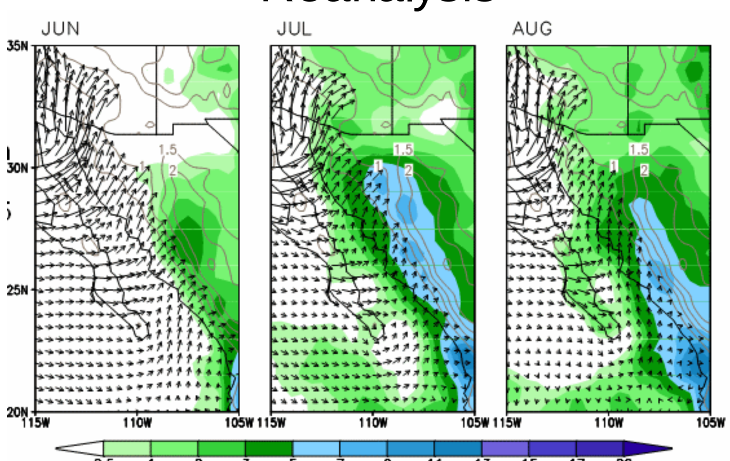
Ground Observations



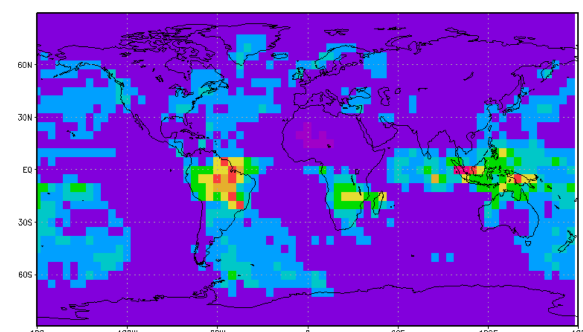
Satellite Remote Sensing



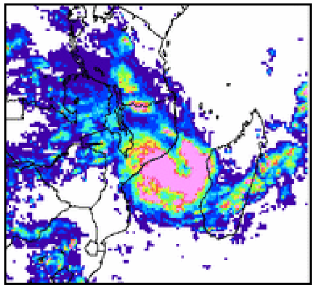
Reanalysis

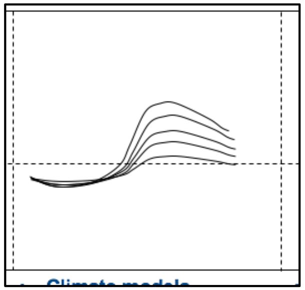


Regional/Global Climate Models, Statistical Prediction

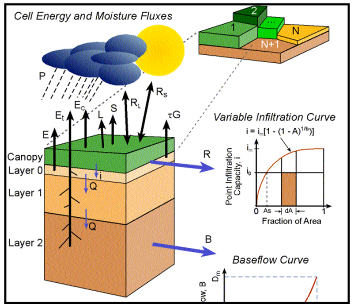


Putting it all together:
Hydrological and Drought Monitoring and Forecasting System



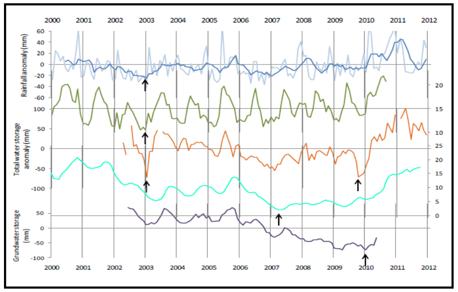


Real-time Weather and Seasonal Forecasts

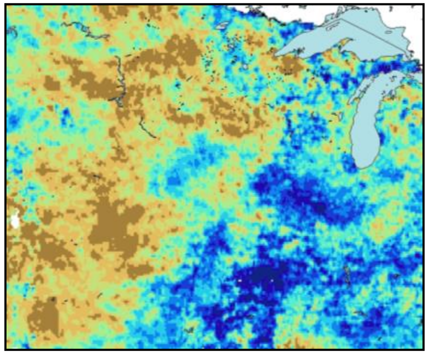


Land surface (hydrology) models

Initial Conditions



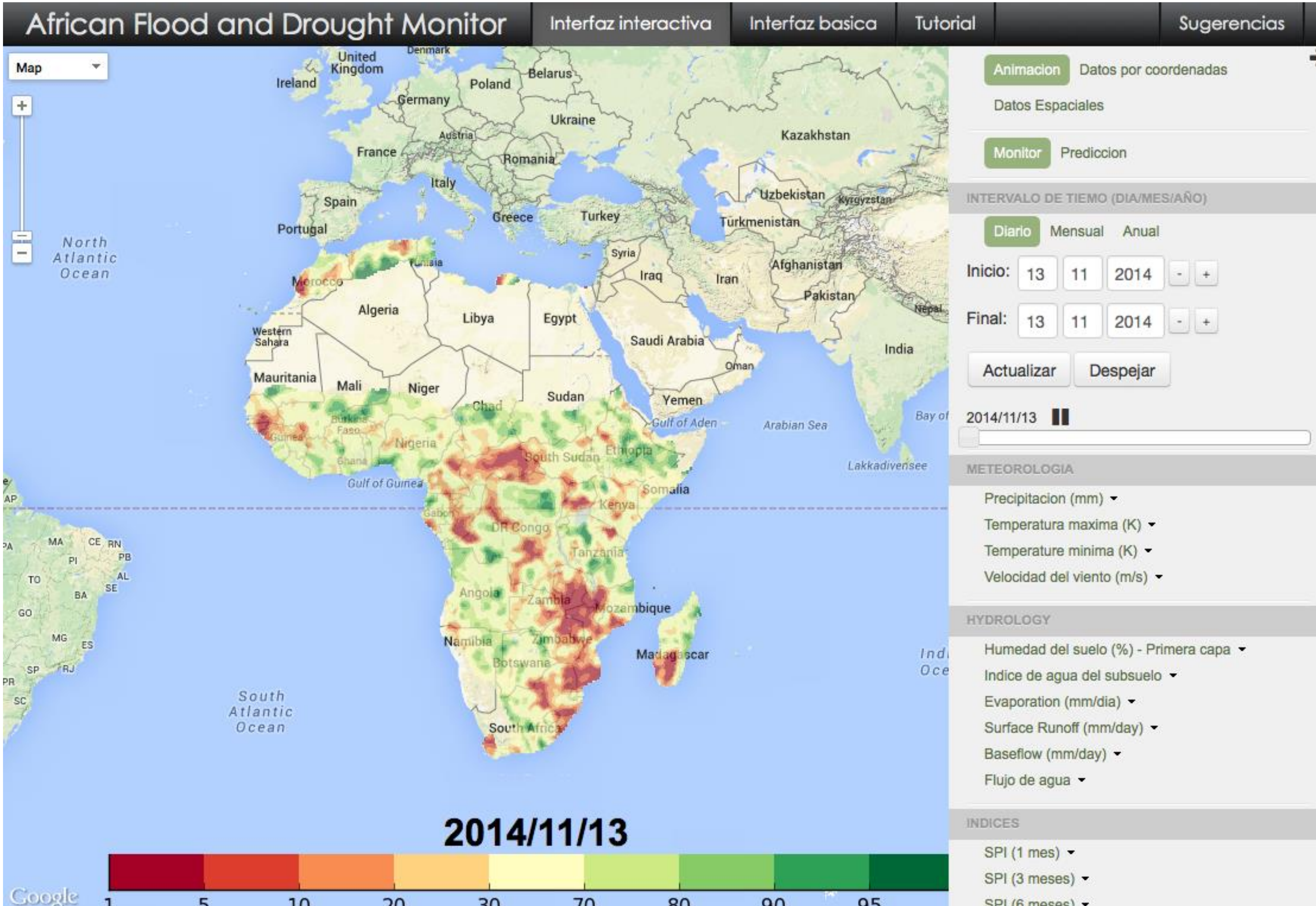
Hydrological Variables, Streamflow, Drought Indices

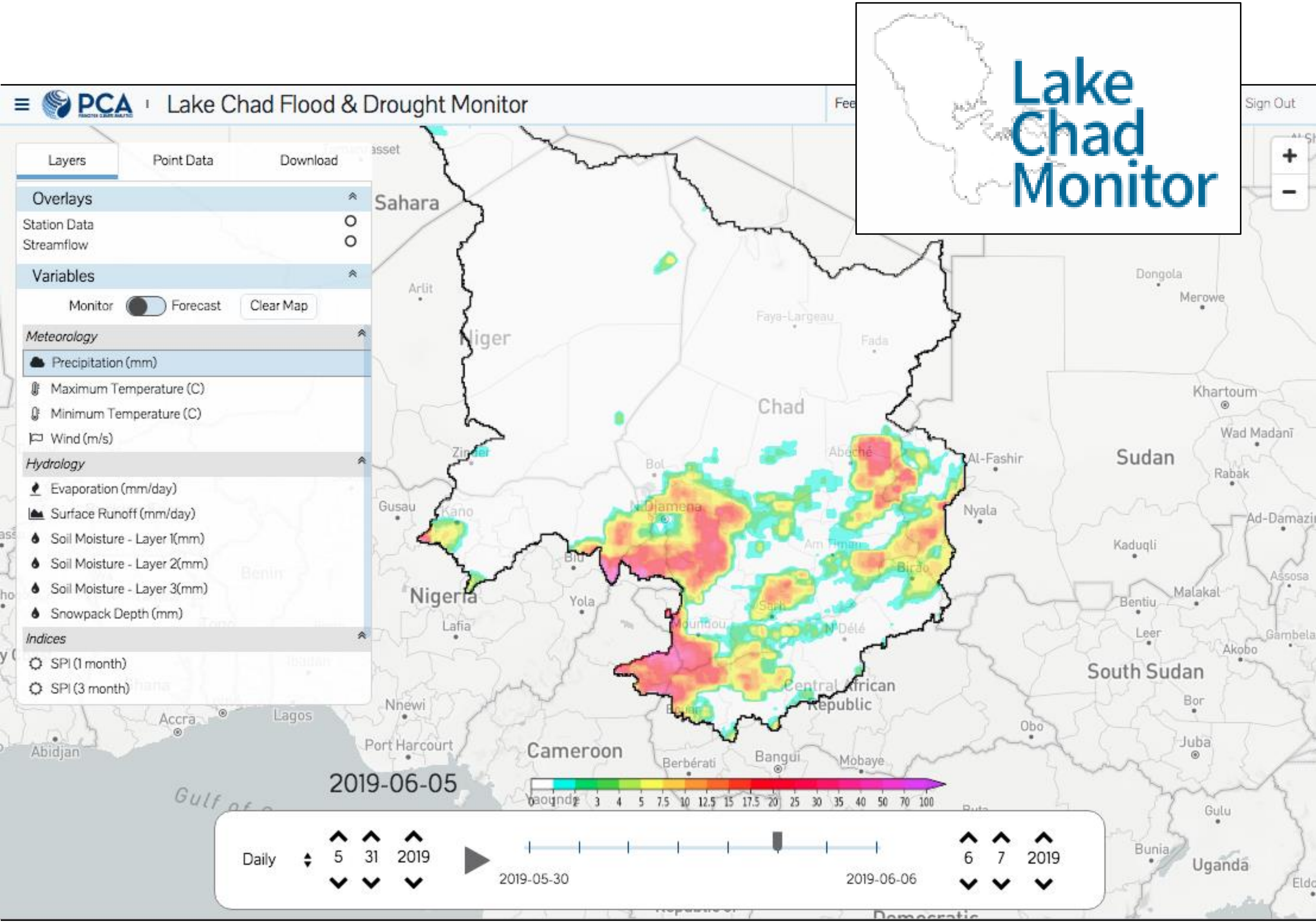


Management/Mitigation

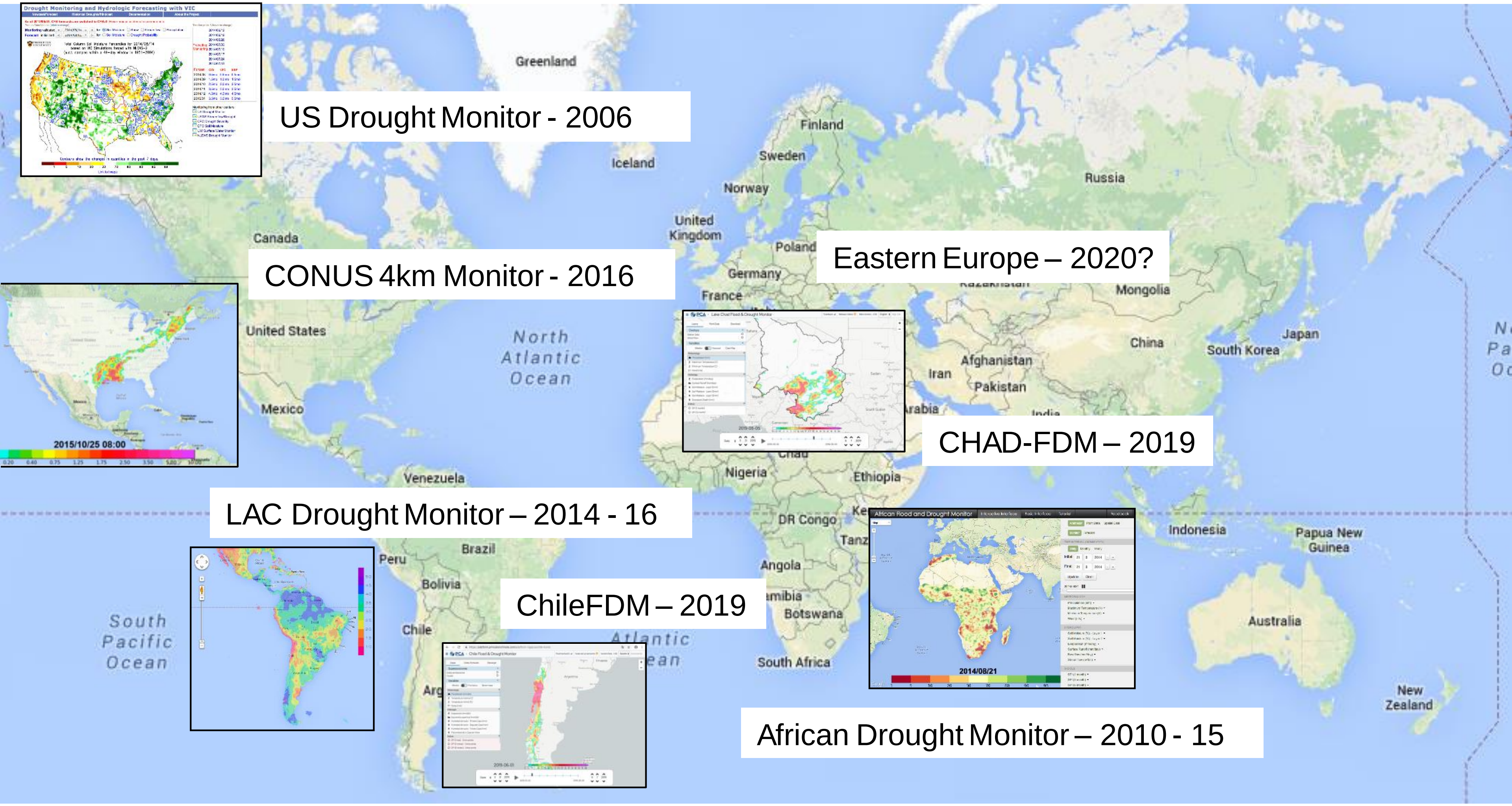
AFDM

African Flood and Drought Monitor




Lake Chad Monitor
PCA
Lake Chad Flood & Drought Monitor
Sign Out
Layers
Point Data
Download
Overlays
Station Data
Streamflow
Variables
Monitor
Forecast
Clear Map
Meteorology
Precipitation (mm)
Maximum Temperature (C)
Minimum Temperature (C)
Wind (m/s)
Hydrology
Evaporation (mm/day)
Surface Runoff (mm/day)
Soil Moisture - Layer 1(mm)
Soil Moisture - Layer 2(mm)
Soil Moisture - Layer 3(mm)
Snowpack Depth (mm)
Indices
SPI (1 month)
SPI (3 month)
2019-06-05
Daily
5
31
2019
2019-05-30
2019-06-06
6
7
2019
Sahara
Niger
Chad
Sudan
Nigeria
Cameroon
Central African Republic
South Sudan
Uganda

Translation of Research into Operational Hydrological Monitoring and Forecasting



Summary and Conclusions

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

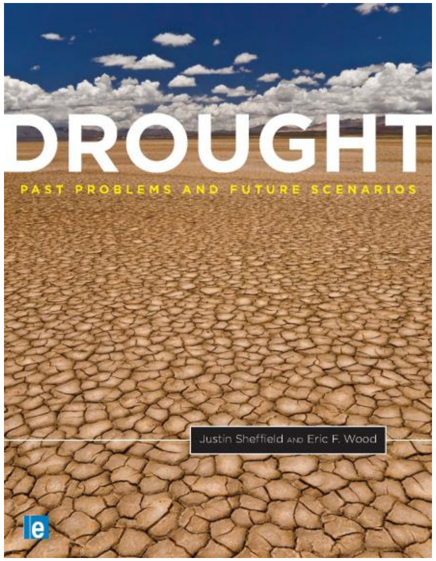
- A key part of addressing drought impacts is provision of early-warning

- 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

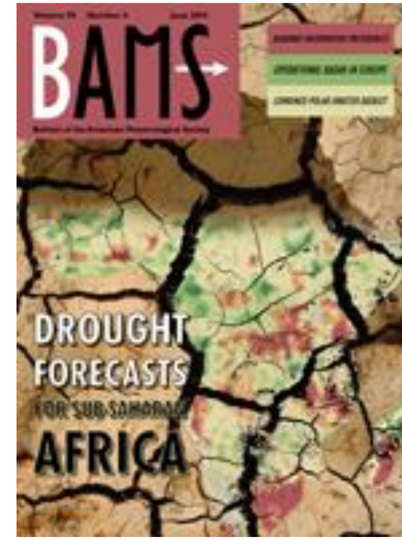
- But large challenges in translating this into useful and useable information, particularly in understanding decision making

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



Drought: Past Problems and Future Scenarios
Justin Sheffield and Eric F. Wood
Earthscan

Sheffield, J., et al., 2014; A drought monitoring and forecasting system for sub-Sahara African water resources and food security. *Bull. Am. Met. Soc.*



Yuan, X., J. K. Roundy, E. F. Wood, J. Sheffield, 2015: Seasonal Forecasting of Global Hydrologic Extremes: System Development and Evaluation over GEWEX Basins. Bull. Amer. Meteor. Soc., 96, 1895–1912. doi: http://dx.doi.org/10.1175/BAMS-D-14-00003.1

Guan, K., E. F. Wood, D. Medvigy, J. Kimball, M. Pan, K. K. Caylor, J. Sheffield, X. Xu, and M. O. Jones, 2014: Terrestrial hydrological controls on land surface phenology of African savannas and woodlands, J. Geophys. Res. Biogeosci., 119, 1652–1669, doi:10.1002/2013JG002572.

Kam, J., J. Sheffield, and E. F. Wood, 2014: Changes in drought risk over the contiguous United States (1901–2012): The influence of the Pacific and Atlantic Oceans, Geophys. Res. Lett., 41, 5897–5903, doi:10.1002/2014GL060973.

Chaney, N., J. Sheffield, G. Villarini, E. F. Wood, 2014: Development of a High Resolution Gridded Daily Meteorological Data Set over Sub-Saharan Africa: Spatial Analysis of Trends in Climate Extremes. J. Climate, 27, 5815–5835. doi: http://dx.doi.org/10.1175/JCLI-D-13-00423.1.

Estes, L., N. Chaney, J. Herrera-Estrada, J. Sheffield, K. Caylor, and E. F. Wood, 2014: Varying trends in water supply and demand during the African maize growing season, 1979-2010. Environ. Res. Letts., 9, 075005.

Nijssen, B., S. Shukla, C. Lin, H. Gao, T. Zhou, J. Sheffield, E. F. Wood, and D. P. Lettenmaier, 2013: A prototype Global Drought Information System based on multiple land surface models, J. Hydrometero., e-View, doi: http://dx.doi.org/10.1175/JHM-D-13-090.1 .