Weather, climate, and society: operational, research, and development concerns and capabilities of USACE, ERDC, CRREL, and partners

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USACE CLIMATE PREPAREDNESS AND RESILIENCE

U.S. ARMY

US Army Corps of Engineers

ERDC Engineer Research and Development Center

Why are we *all* interested?

- In this context, “everything is connected”
  - food
  - water
  - energy
  - socioeconomics (including stability)
  - logistics
  - supply chain
  - civil works/infrastructure
  - military planning and operations

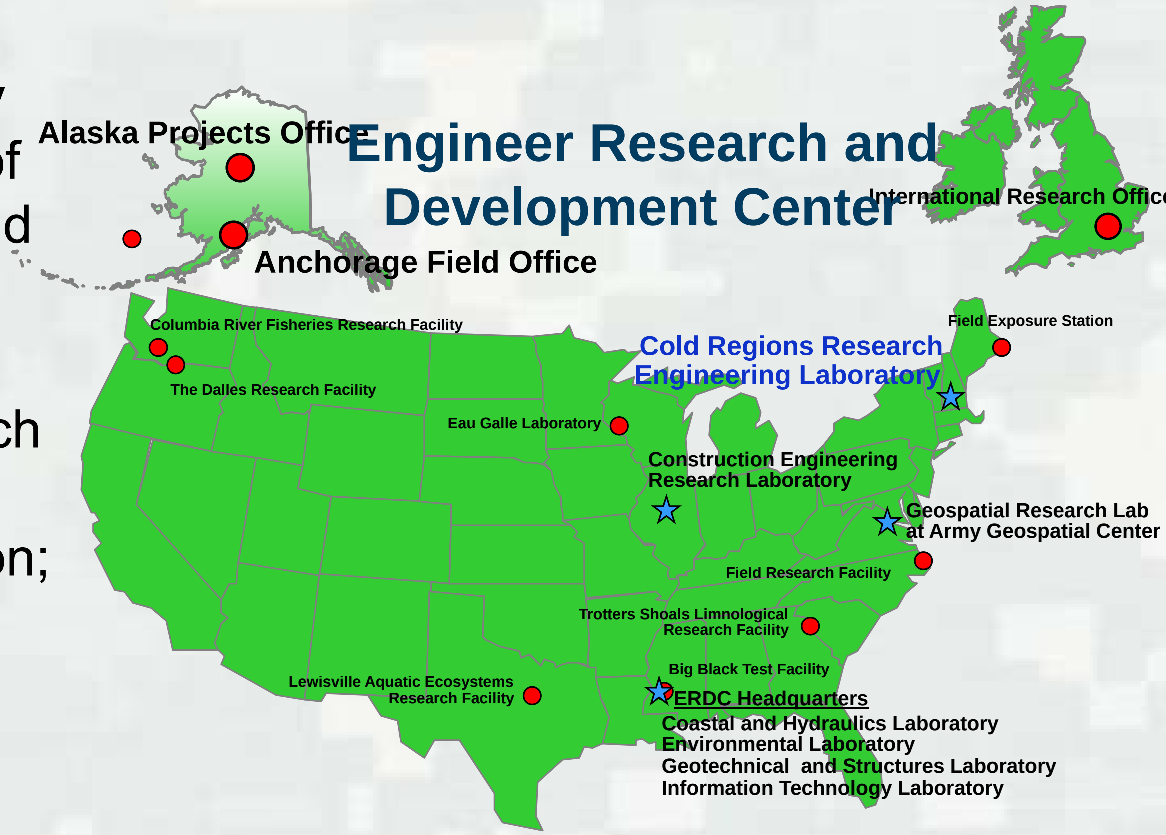
- All interwoven from the smallest to the largest of scales with respect to global environmental change
  - Costs/economics weave one common thread/context…

Addressing Cold Regions and Related Concerns Is Complex, Involving Lots of Data and Models → Collaboration and Coordination Are Key

Consider how your work can help inform what we present – and vice versa.

USACE, ERDC, CRREL

- USACE (United States Army Corps of Engineers) is one of world's largest civil works and project management organizations
- ERDC (Engineering Research and Development Center) is the USACE R&D organization; comprised of 7 labs
- CRREL (Cold Regions Research and Engineering Laboratory) is a facility recognized as a national center of expertise in RS/GIS and cold regions



CCAWWG

Climate Change and Water Working Group

ERDC

In Significant Part a Civil Engineering Organization, With Supporting Basic and Applied Sciences

The American Society of Civil Engineers (ASCE) adopted Policy Statement 360 on the Impact of Climate Change:

Civil engineers are responsible for design and maintenance of infrastructure projects. Climate change may result in significant impacts to this infrastructure. Civil engineers and government policy makers must work together to anticipate and plan for these impacts (modified after ASCE, 2012).

Our engineered facilities, systems, models, algorithms, tactical decision aids, and more could stand to adapt to – and anticipate – changing climate, weather and extreme events…….but climate science has inherent uncertainty and does not necessarily provide an adequate basis for engineering design practice. *Climate science and engineering practice not necessarily mutually exclusive - can even inform one another.*

Meanwhile….

Infrastructure, transport, adaptation, etc costs propagate through society and beyond, interacting with water resource and food concerns.

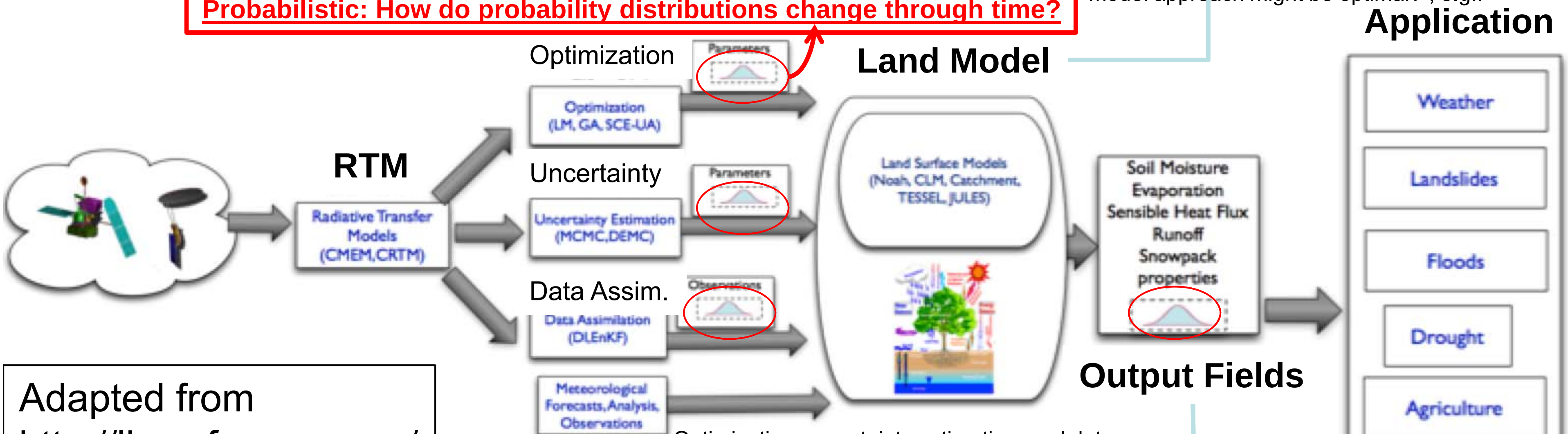
Example: Colorado River Compact based last century in part on an anomalously wet hydrologic record; meanwhile, Western drought recently associated with Arctic change... ("Evidence Linking Rapid Arctic Warming to Mid-latitude Weather Patterns," June 1 Philosophical Transactions of the Royal Society)

Infrastructure, water, energy, and food – <u>interwoven cornerstones</u>.

Example of Importance of Nonstationarity in Land Modeling, and Operational Weather (Often Coupled Processes)

Application and model approach can be intimately cross informative – "Which land model approach might be optimal?", e.g..

Probabilistic: How do probability distributions change through time?



Adapted from http://lis.gsfc.nasa.gov/

Optimization, uncertainty estimation, and data assimilation can involve cycles of comparing output with measurement statistics

Land modeling, weather

- **LIS/AGRMET**
  - E.g., Air Force operational agricultural and meteorological near surface analyses – various customers, including USDA
- **NWP (Numerical Weather Prediction)**
- **KNOWING STATISTICAL DYNAMICS CAN HELP BETTER CONTEND WITH NONSTATIONARITY OF PROBABILITY DISTRIBUTION FUNCTIONS → BETTER MODEL OUTPUT → BETTER INFORMED DECISION MAKING**

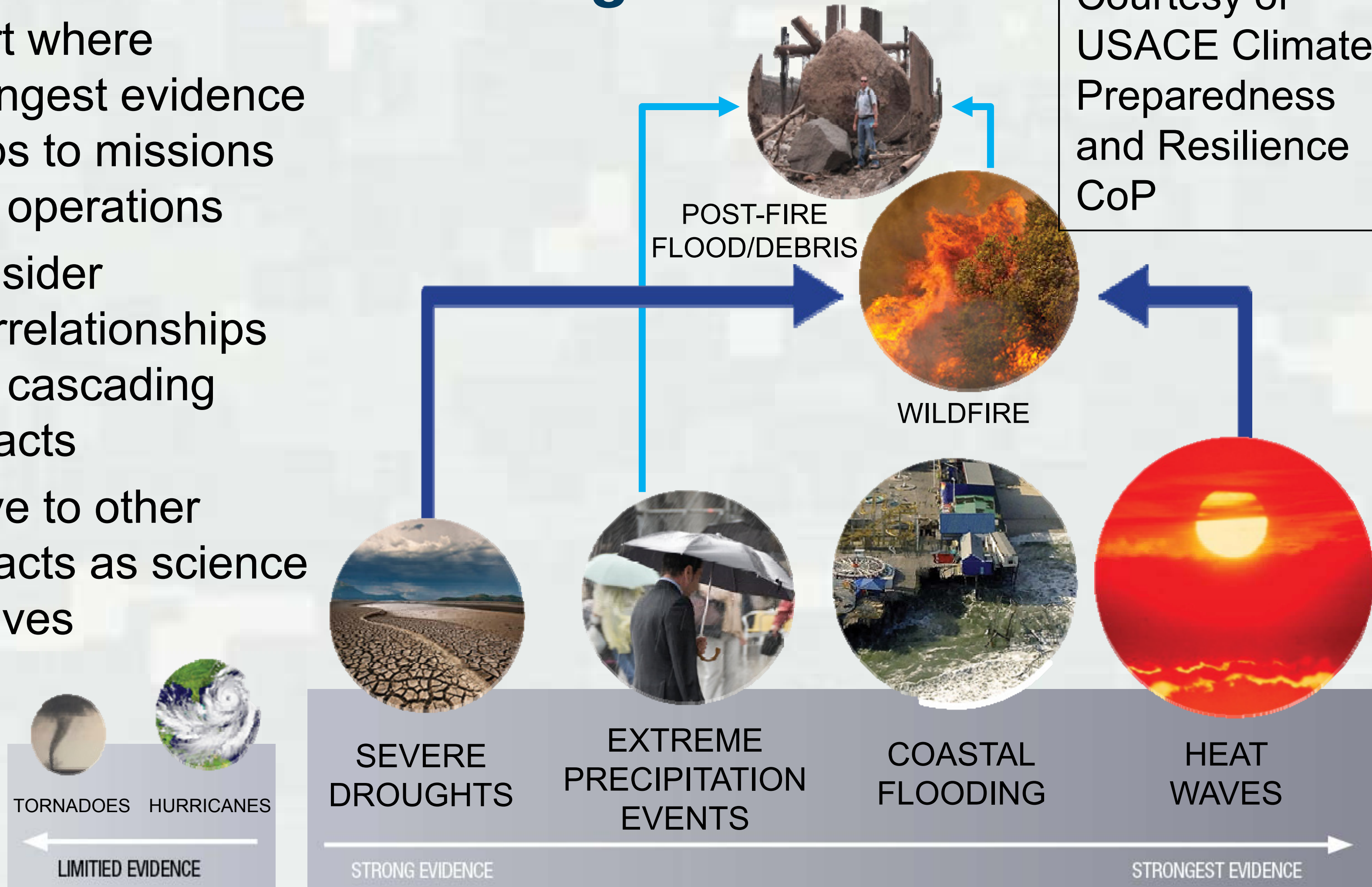
Nonstationarity impacts

- Data assimilation (e.g., CDF matching, "bias correction")
- Optimization and uncertainty estimation
- Precipitation bias correction (e.g., CDF matching)
- Down- and up- scaling between resolutions
- Validation and verification
- Applications/decision aids… ETC ETC

USACE Climate Preparedness and Resilience: Translating Science

1. Start where strongest evidence maps to missions and operations
2. Consider interrelationships and cascading impacts
3. Move to other impacts as science evolves

Courtesy of USACE Climate Preparedness and Resilience CoP



Consider modeling framework (previous slide) and how it might inform – and be informed by – these concerns

USACE Resilience Definition

- "resilience means the ability to **anticipate, prepare for,** and **adapt** to **changing conditions** and **withstand,** respond to, and recover rapidly from **disruptions**."

Presidential Executive Order 13653, Preparing the U.S. for Impacts of Climate Change (NOV 2013)

Courtesy of USACE Climate Preparedness and Resilience CoP

The Importance of Climate Change to *DoD*

Quadrennial Defense Review, 2010

Climate change will reshape the operating environment and impact our facilities and mission

Climate change will stress already stressed systems

Some ecosystems/regions are more vulnerable than others

Conduct assessment of installations to determine the potential impacts of climate on mission and how to adapt

Strategic Sustainability Performance Plan, 2010

Sustain operation into the future without decline of mission or environment

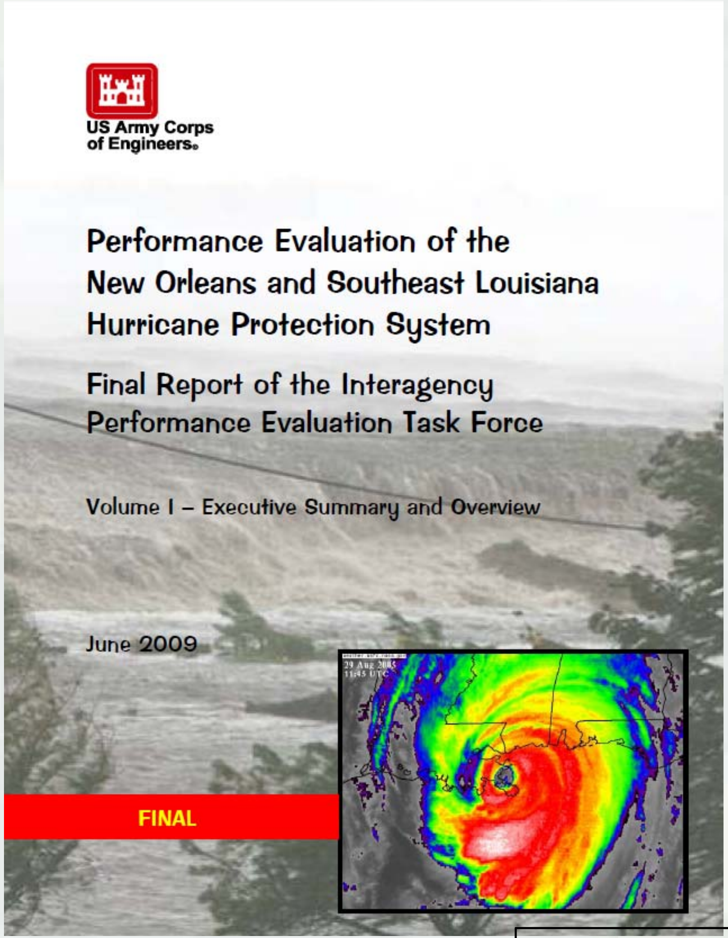
Maintain readiness in the face of climate change

Through Atmospheric, Oceanic, and other Waterway Processes, Many Potential Interwoven Impacts of Global Change

- From long term climatological to seasonal to synoptic, mesoscale, microscale …

- *Lessons learned from equatorward (lower) latitudes….*

Katrina: Incorporate New and Changing Information



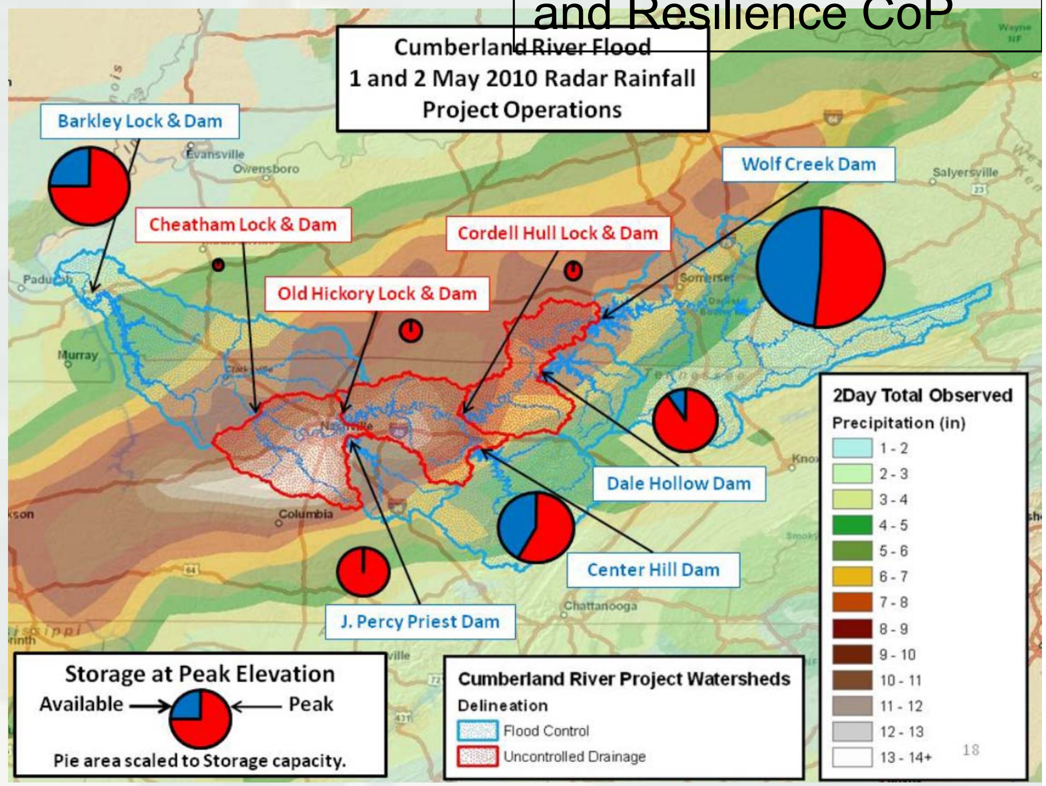
- ***Systems approach*** *should include dynamic conditions* and life-cycle performance including resilience, redundancy, and unanticipated failure modes
- Social impacts often fall disproportionately on the most vulnerable

Courtesy of USACE Climate Preparedness and Resilience CoP

Nashville (2010): You Can't Be Everywhere

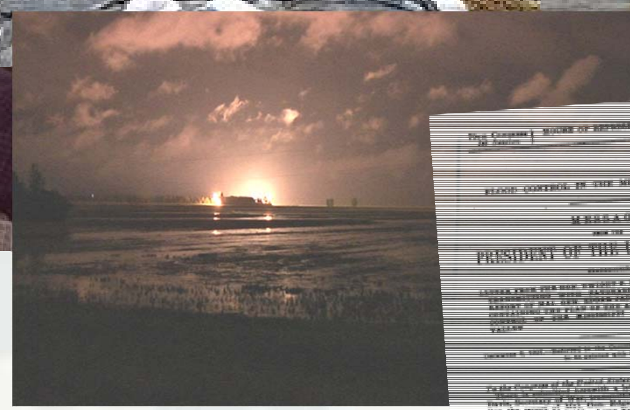
Courtesy of USACE Climate Preparedness and Resilience CoP

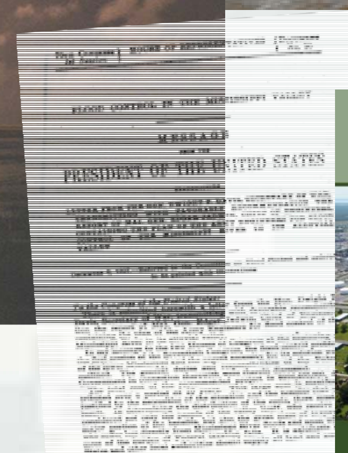
- Four primary factors
  - unseasonably strong late-spring storm system
  - stationary upper-air pattern
  - persistent tropical moisture feed
  - timing of impulses moving through the jet stream
- Controlled basins have the primary purpose of flood storage: Wolf Creek Dam, Dale Hollow Dam, Center Hill Dam, and J. Percy Priest Dam
- Uncontrolled basins have the primary purpose of maintaining navigation depths: Cordell Hull L&D, Old Hickory L&D, and Cheatham L&D

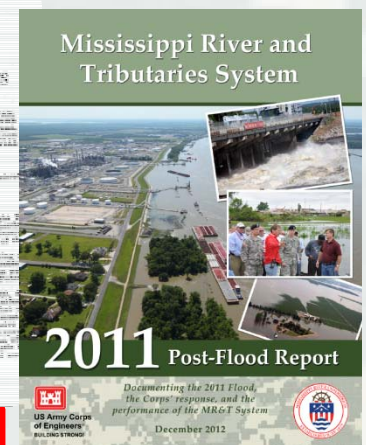


Floods of 2011: Post-1927 Design for intentional flooding (fuse plug spillway) => Resilient Design

Courtesy of USACE Climate Preparedness and Resilience CoP







Like the Army, water resources engineers are accustomed to making decisions under deep uncertainty

Prescience in 1927 resulted in ultimately necessary contingency features (capacity to detonate levee and contain spillage in 2011)

Flood (2011) to Drought (2012): Increased Variability as a New Norm to Contend With?

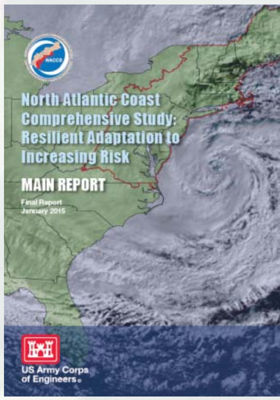
Courtesy of USACE Climate Preparedness and Resilience CoP

2nd highest stage on record (flood stage 34 ft)

Record low water (mean monthly low is 2.8 ft in September)

Sandy (2012):
More Tough *Socioeconomic* Choices Ahead

***...with cascading consequences*?**



Preface

TOUGH CHOICES

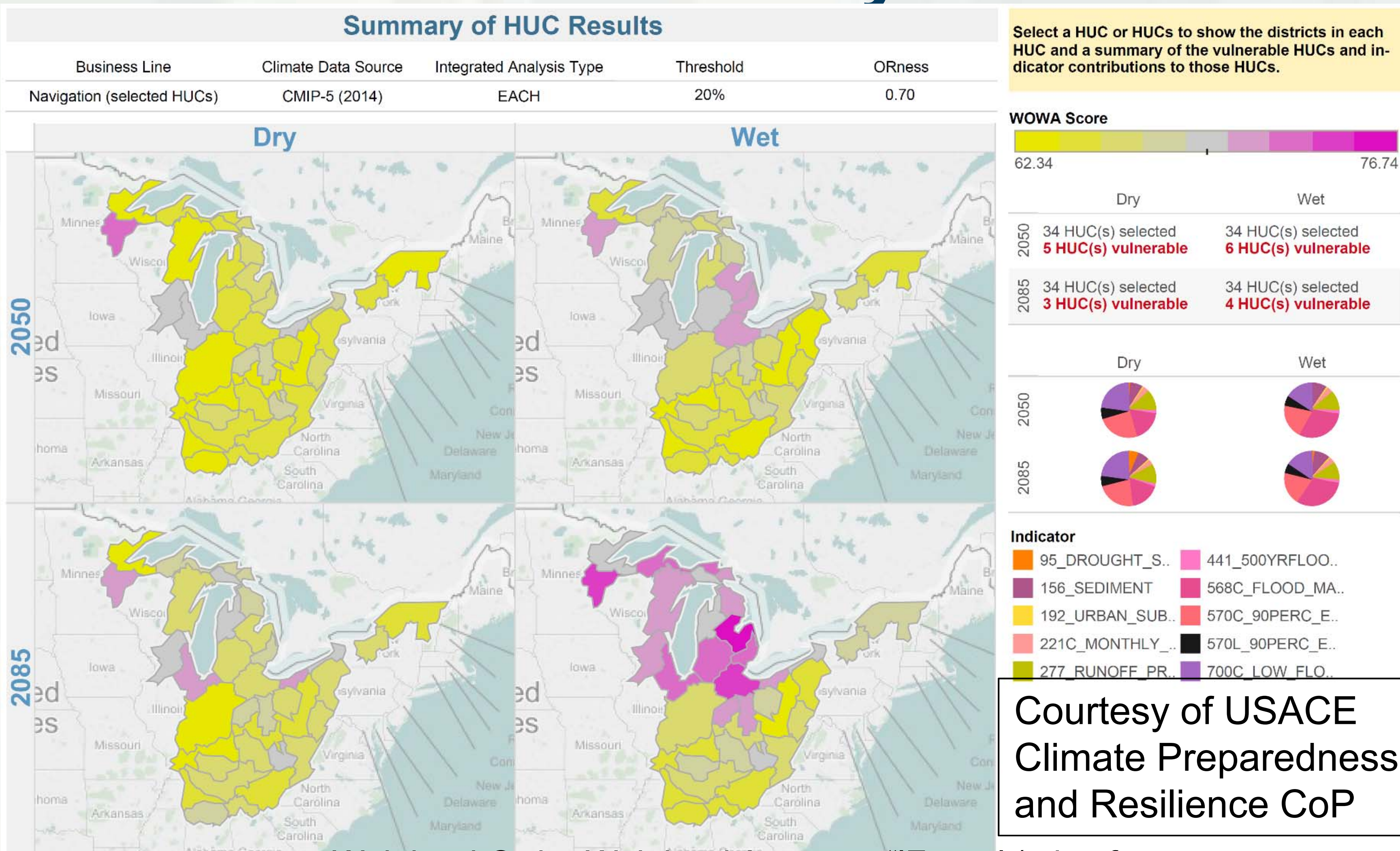
The North Atlantic Coast is a dynamic environment that supports densely populated areas encompassing trillions of dollars of largely fixed public, private, and commercial investment. Hurricane Sandy made us acutely aware of our vulnerability to coastal storms and the potential for future, more devastating events due to changing sea levels and climate change. Changing sea levels represent an inexorable process causing numerous, significant water resource problems such as: increased, wide-spread flooding along the coast; changes in salinity gradients in estuarine areas that impact ecosystems; increased inundation at high tide; decreased capacity for stormwater drainage; and declining reliability of critical infrastructure services such as transportation, power, and communications. Addressing these problems requires a paradigm shift in how we work, live, travel, and play in a sustainable manner as the extent of the area at very high risk of coastal storm damage expands.

This report provides some optimism about the short-term future through the collaborative and multifaceted adaptation measures proposed. However, a realistic view of the long-term challenges facing the area makes it clear that integrated solutions that promote sustainable communities and ecosystems will be needed. Civic and business leaders and citizens must innovate and create solutions that reduce the loss of life, the economic impacts, and the personal devastation that results from coastal storms, while still supporting continued economic growth and opportunities for all. We have begun to take clues from communities and ecosystems which have successfully adapted over time to changing conditions, by expanding from traditional structural risk reduction measures to include more emphasis on nonstructural, natural, and nature-based systems. Given current and projected sea level and climate change trends, some of our built environment will become unsustainable for the human systems presently located there. Coastal communities face tough choices as they adapt local land use patterns while striving to preserve community values and economic vitality. In some cases, this may mean that, just as ecosystems migrate and change functions, human systems may have to relocate in a responsible manner to sustain their economic viability and social resilience. Absent improvements to our current planning and development patterns that account for future conditions, the next devastating storm event will result in similar or worse impacts.

Courtesy of USACE Climate Preparedness and Resilience CoP

http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_main_report.pdf

Watershed Vulnerability Assessment

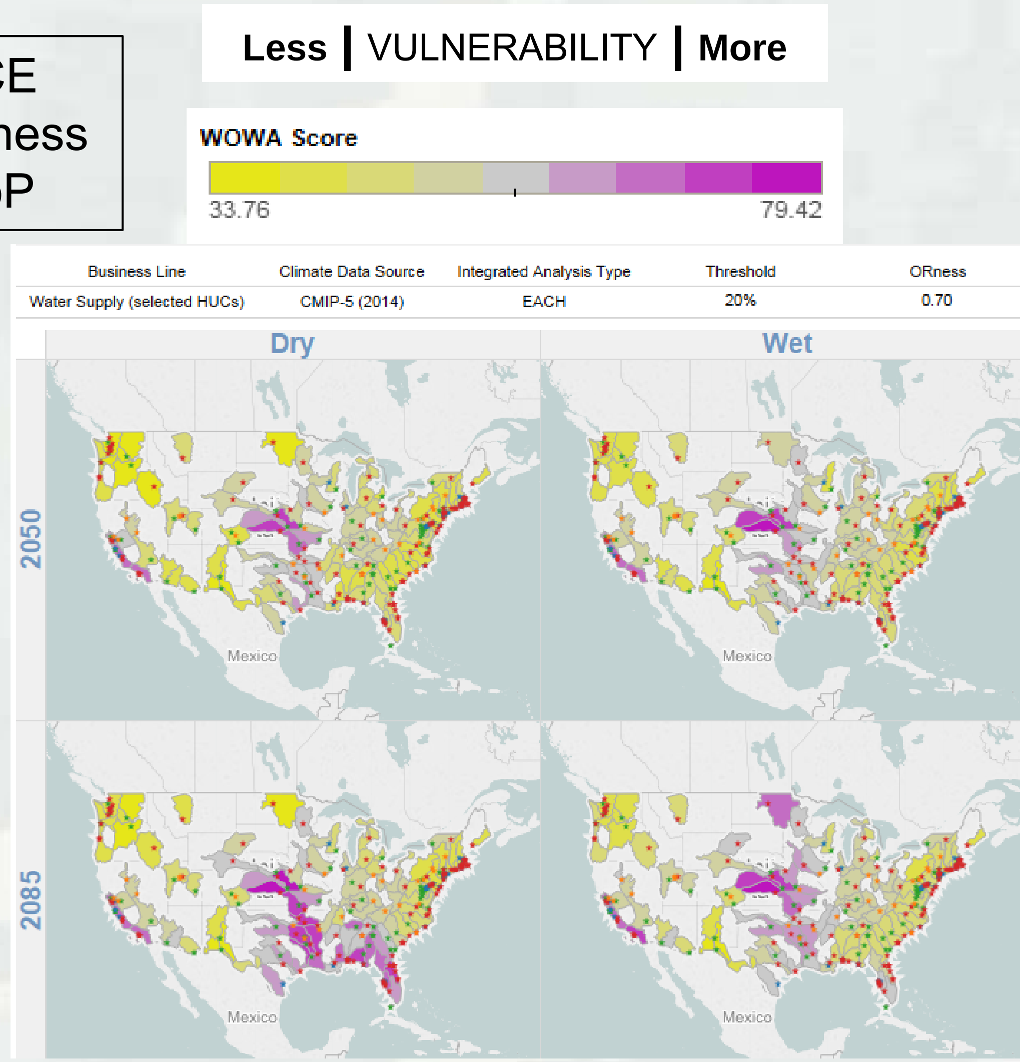


Courtesy of USACE Climate Preparedness and Resilience CoP

- **WOWA**: Weighted Order Weighted Average; "'Fuzzy' (mix of subjective and objective) Prioritization → Vulnerability Score"
- **HUC**: Hydrologic Unit Code; "Basin"

Resilient Army Installations

Courtesy of USACE Climate Preparedness and Resilience CoP

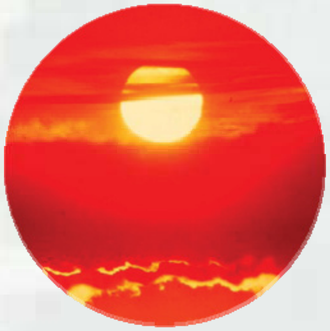


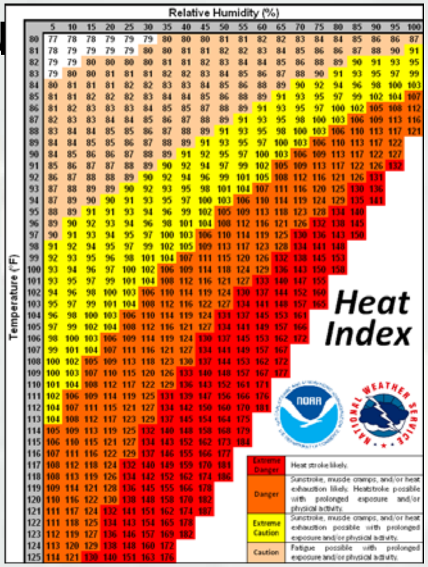
Screening-Level Vulnerability Assessments

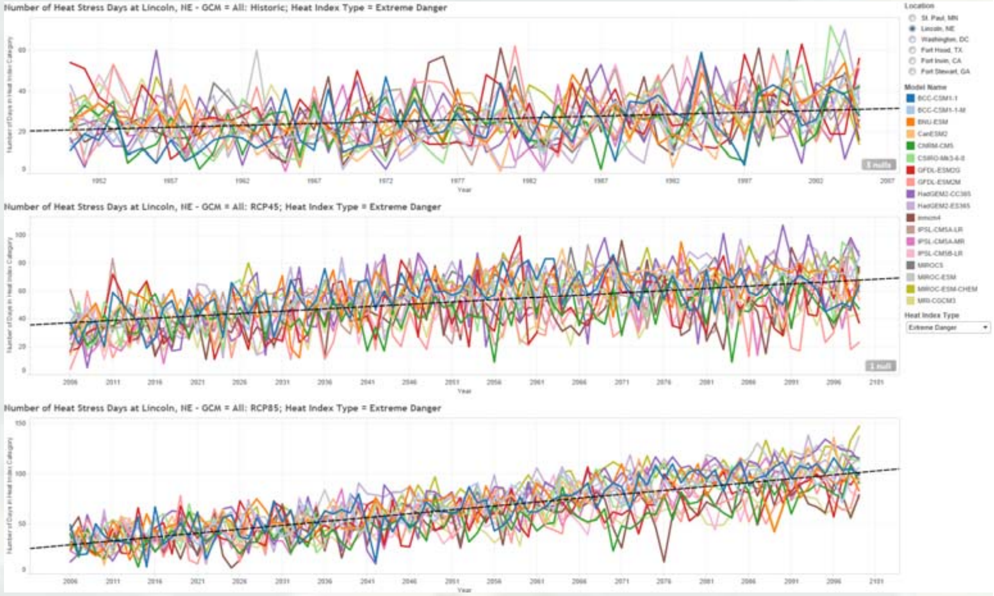
- **ID vulnerabilities**
- **Direct the most vulnerable or those with highest consequences to more detailed assessments**
- **Plan for adaptive measures**
- **Guide implementation priority**

Heat Stress…

- Heat stress combines both heat and humidity
- Affects health and worker safety
- May affect ***construction*** hours and schedu

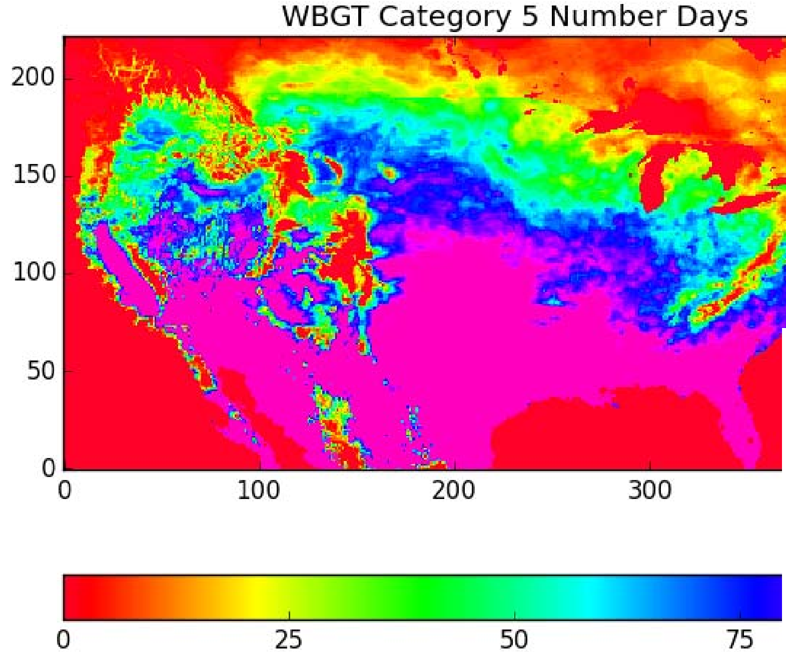




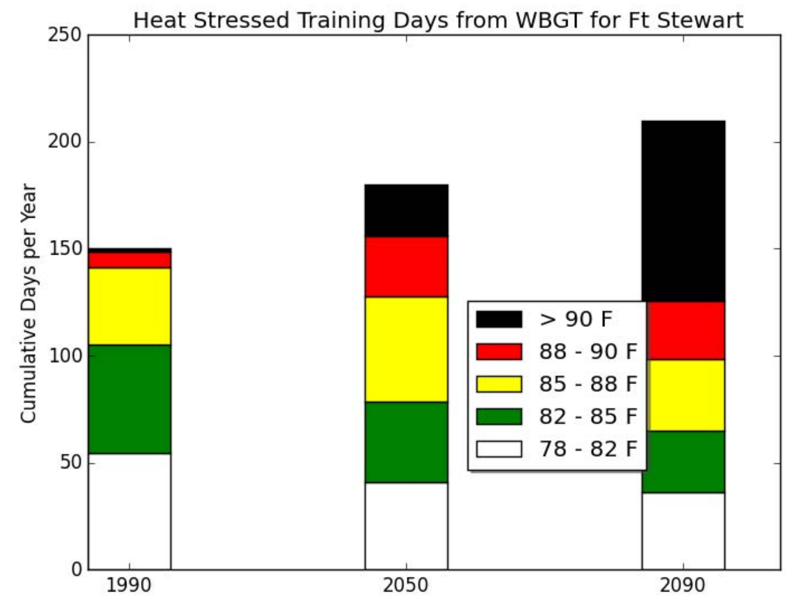


ERDC/CRREL Tools in Development

US-Wide Maps: Heat-stress days, Heating/Cooling
2090 vs 1990 over 18 GCMs



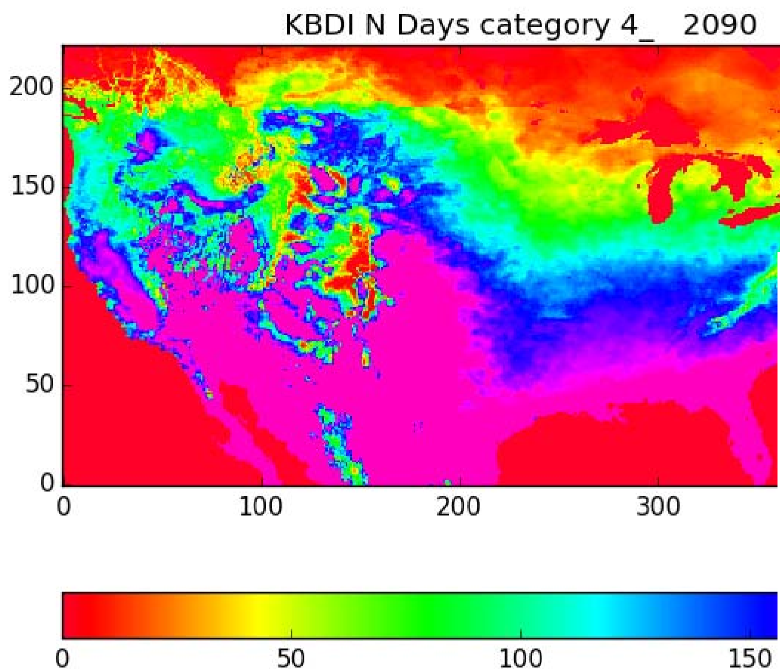
Courtesy of John Weatherly, PhD, CRREL



GCM: Global Climate Model
WBGT: Wet Bulb Globe Temperature (accounts for humidity through wet bulb globe instrument)

ERDC/CRREL Tools in Development

US-Wide Maps: Drought-Index days, Heating/Cooling
2090 vs 1990 over 18 GCMs



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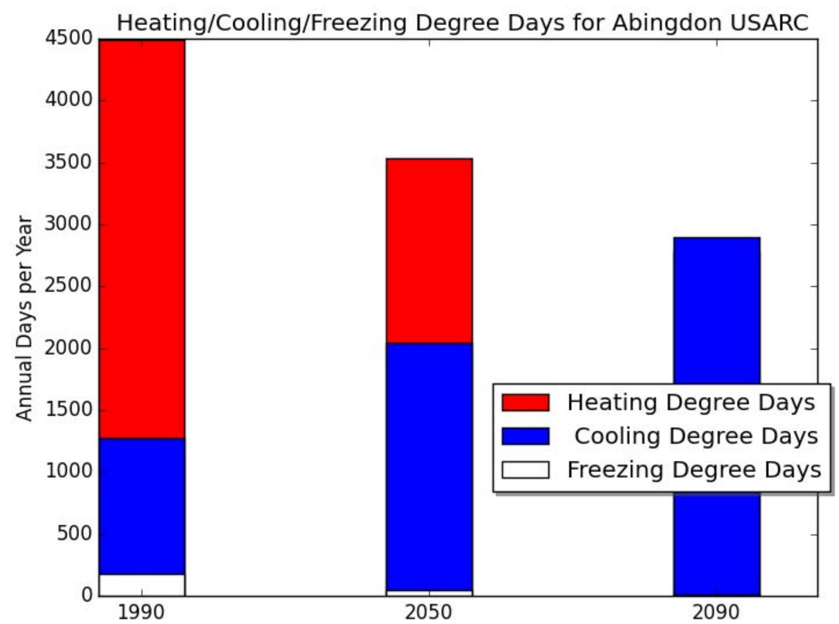
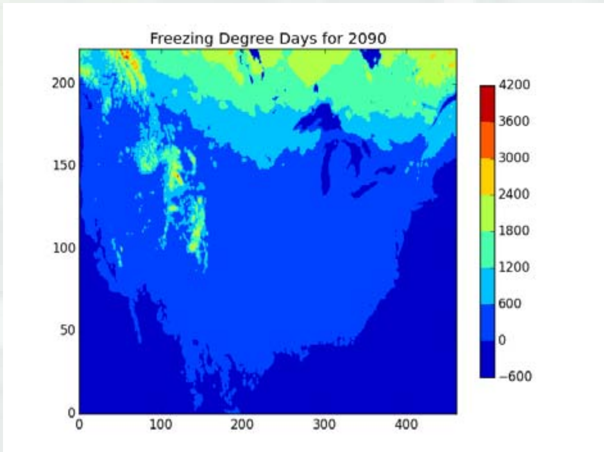
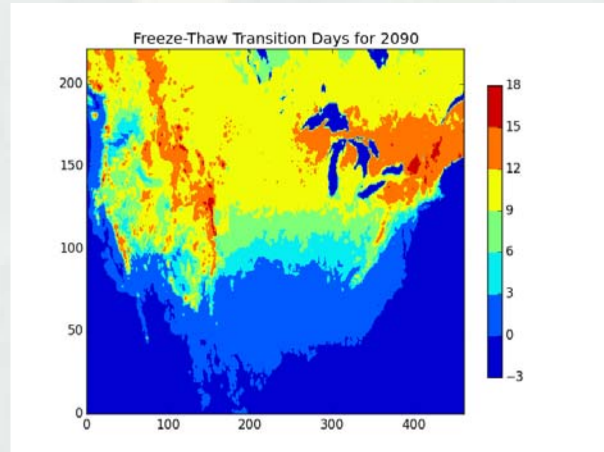


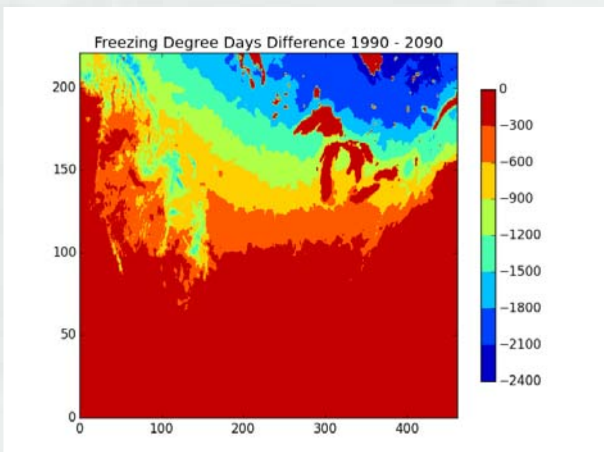
KBDI: Keetch-Byrum Drought Index (fire potential index effectively indicating flamability of organic matter derived from evaporation, precipitation)

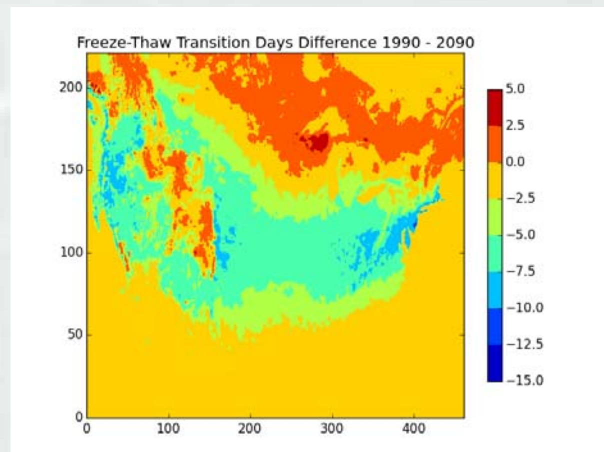
ERDC/CRREL Tools in Development

US-Wide Maps: Freezing Degree-Days and Freeze-Thaw transitions
2090 vs 1990 over 18 GCMs





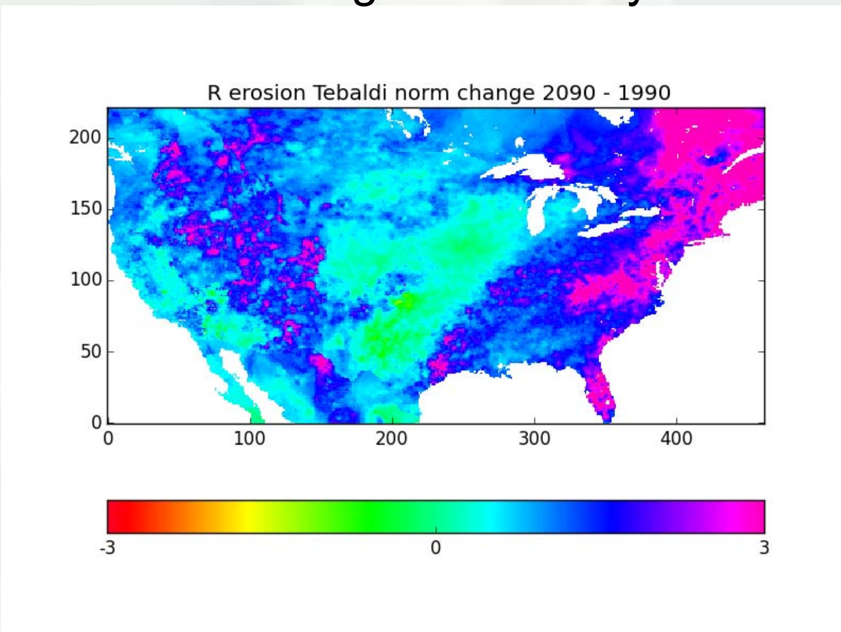


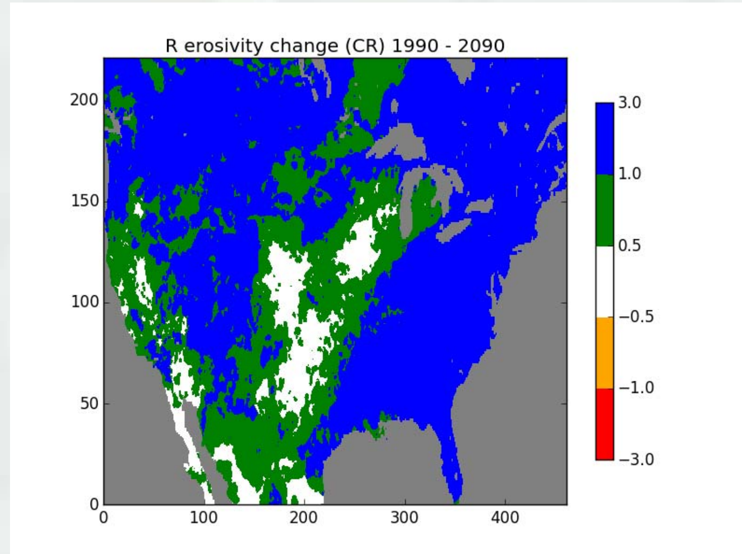


Courtesy of John Weatherly, PhD, CRREL

ERDC/CRREL Tools in Development

Change in Erosivity Potential R from Precipitation Intensity





Courtesy of John Weatherly, PhD, CRREL

Possibilities:

- permafrost degradation,
- inland and coastal erosion,
- wave/storm impacts under IPCC and other climate scenarios (RCPs), etc…

Transportation
Opening of the Northwest Passage

Decreasing ice thickness and cover in Arctic waters is expected to result in the opening of the Arctic to commercial and other human activities.

Increase activity: shipping
oil & gas
fishing
tourism
implications economically elsewhere….. (food, water, energy….)

River Ice Regimes

- Climate variability is resulting in fundamentally different ice conditions than have been experienced in the past.
- Observed changes and concerns about River Ice
  - timing of ice events: later formation date, earlier ice out date, shorted duration of ice cover – extend the navigation season
  - For accurate prediction of many ice characteristics, such as composition, thickness, strength and even duration, however, the complicating effects of snow cover need to be considered
  - Large-scale patterns of warming might affect thermal gradients along large northward-flowing rivers - expected to affect the incidence and magnitude of ice-induced flooding
  - Increased potential for midwinter break ups, which are more unpredictable than spring events but can be just as severe
  - Movement of temperate zone North means regions used to a single seasonal breakup ice event will begin to experience mid-winter breakup
- Decreased predictability of river ice and increases the risk and uncertainty associated with ice jam response and mitigation.
- More flexible, adaptive approach to ice jam
- References: White et al 2007, Prowse et al 2007
- **Inland waterway shipping - More than 60 percent of farm exports move on inland waterways, ~ $100s billion/yr cargo, total: Mississippi - $10s billion/yr commodities shipped; ~$100s million/dy lost economic activity via interuption**

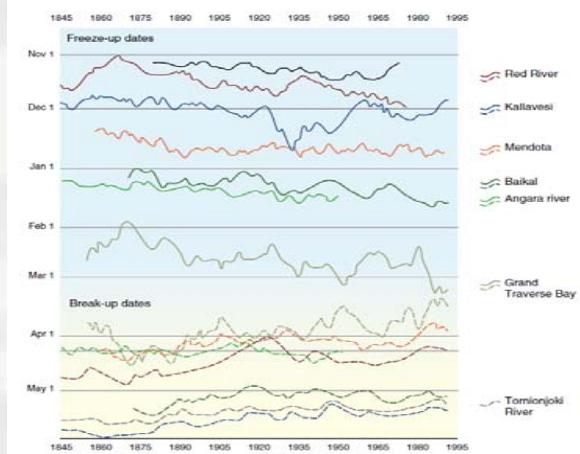


Figure 8.1: Time series of freeze-up and break-up dates from selected Northern Hemisphere lakes and rivers (1846–1995). Data were smoothed with a 10-year moving average.

Source: Based on Magnuson and others 2000

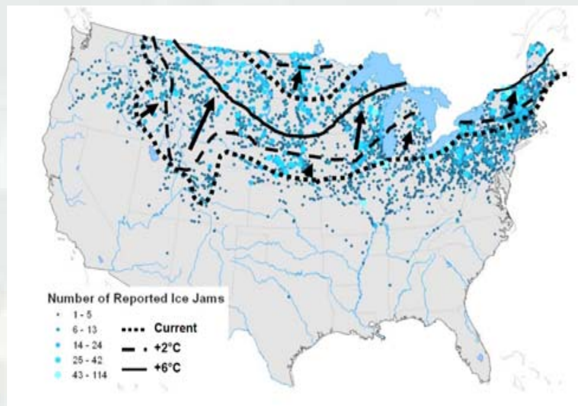
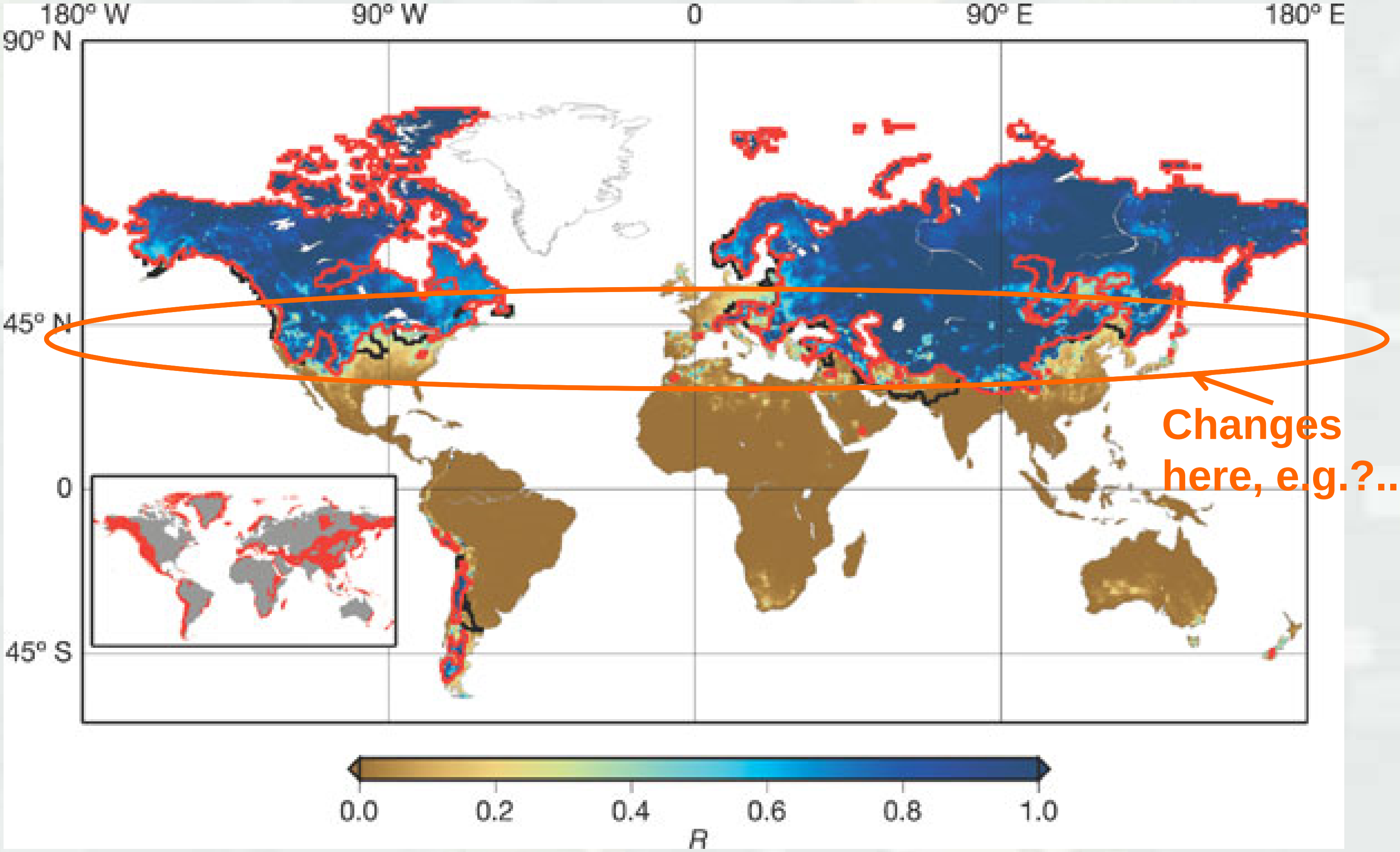


Figure 3. Projected shift in temperate region according to Prowse *et al* (2002) compared to locations of ice jams reported in CRREL IJDB (June 2007).

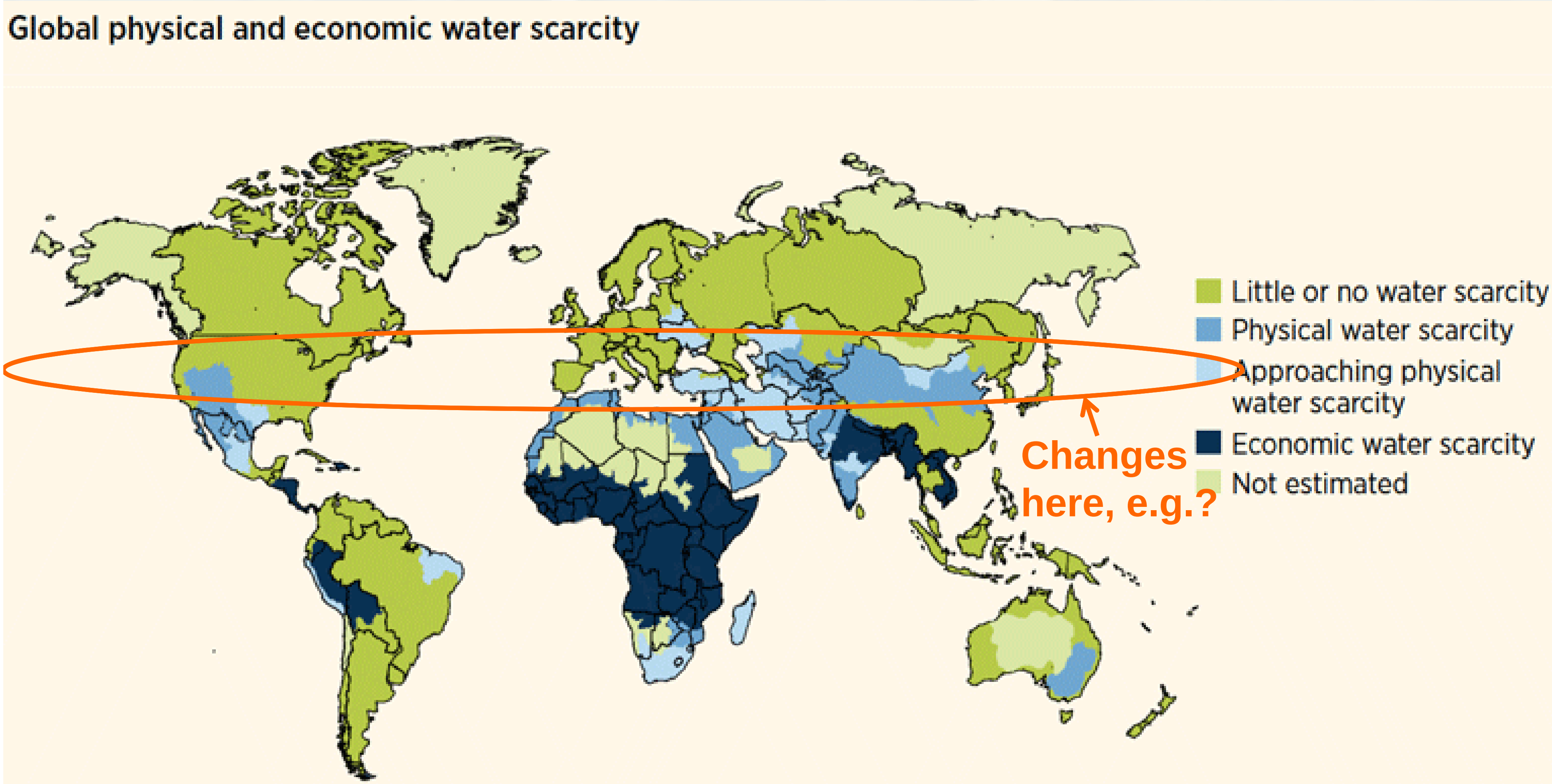
Courtesy of Carrie Vuyovich, CRREL

Where Streamflow is Snowmelt-dominated…



Barnett et al., *2005, Nature*

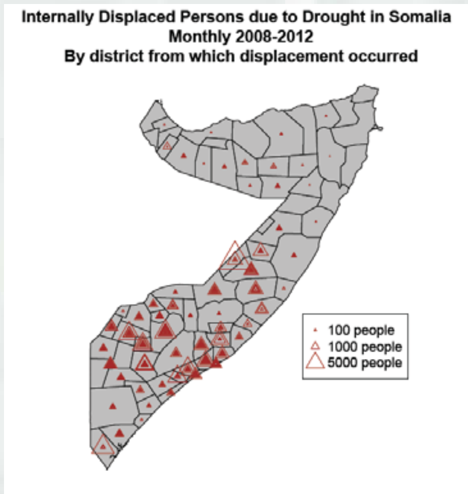
…Global Water Changes



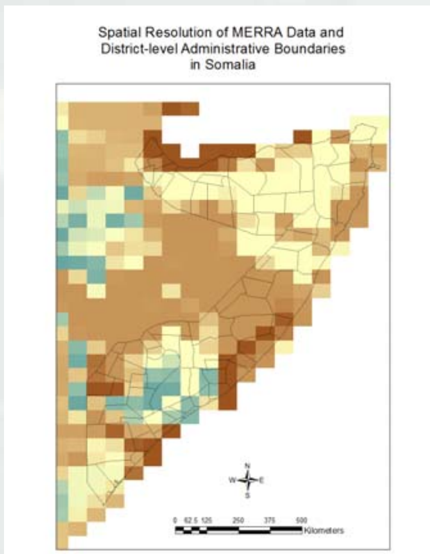
Source: UN World Water Development Report 4, *March 2012*

Drought Effects on Human Population Movements Somalia 2008-2012

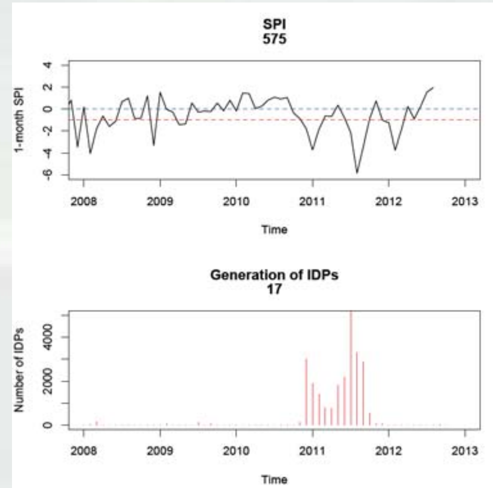
1. Use UNHCR data on drought-caused internally displaced persons in Somalia



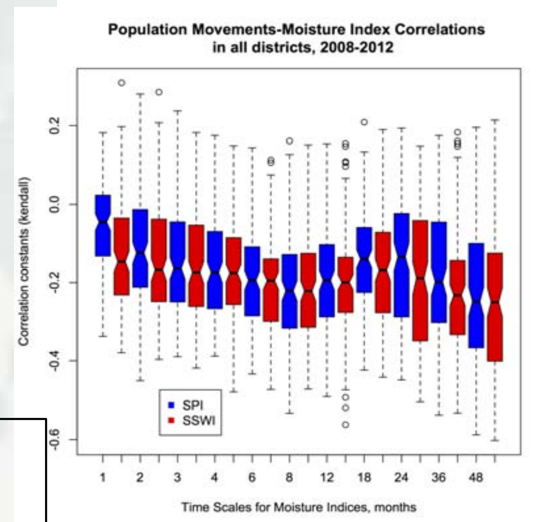
2. Calculate multiple drought indices (SPI, SSWI, various time scales)



3. Assign districts to one or more grid cells and measure associations between moisture indices and population movements

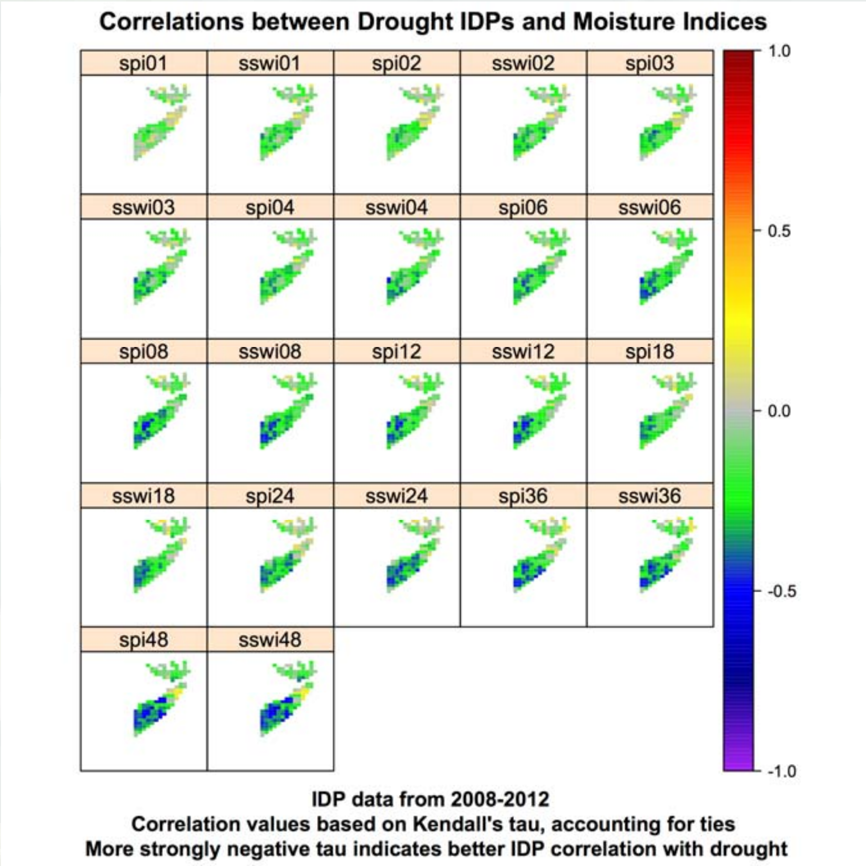


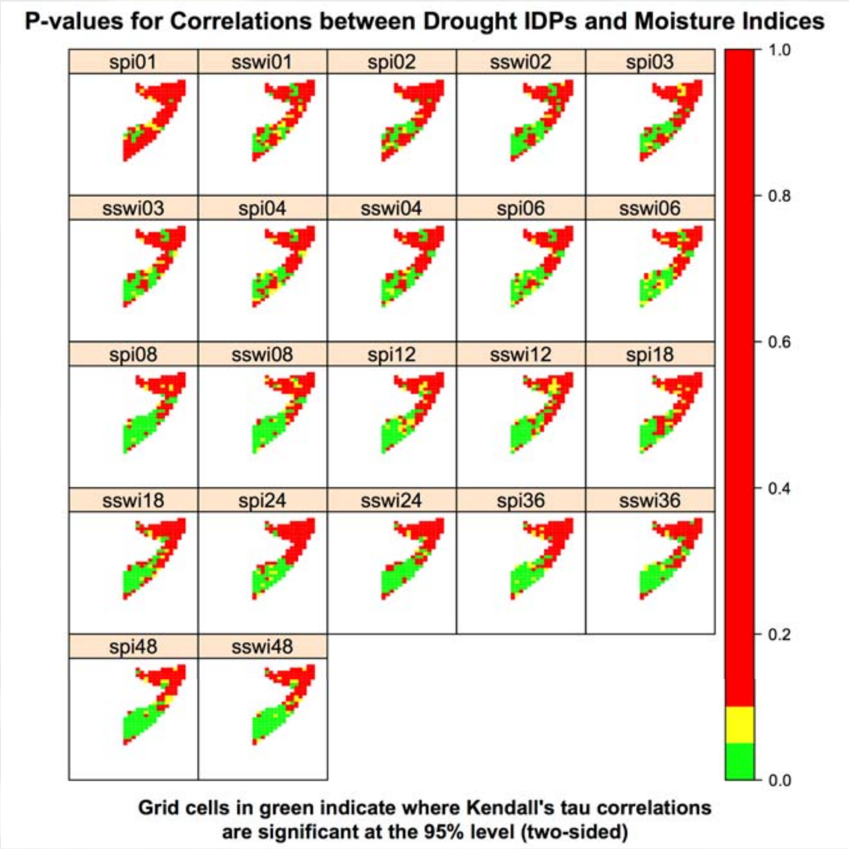
4. Determine which time scales and indices are most correlated with population movements



Courtesy of Jeanne Roningen, CRREL

Identification of useful drought indices that best correlate with population movements

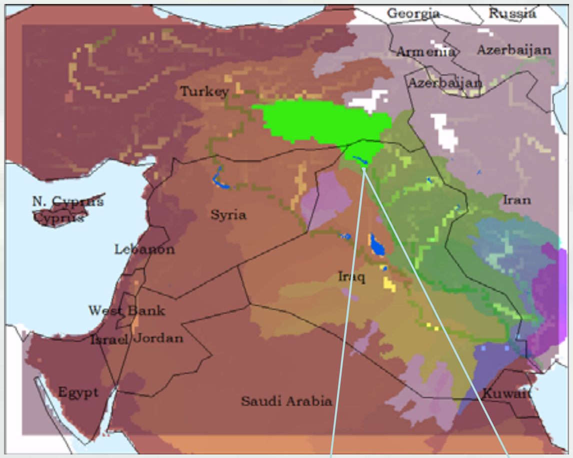


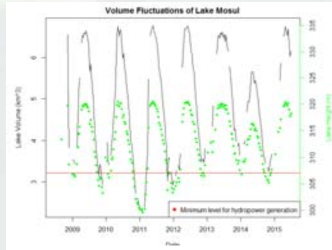


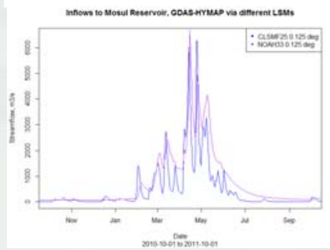
Courtesy of Jeanne Roningen, CRREL

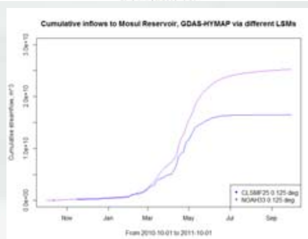
Sensitivity of river flows to LSM configuration in LIS:

Retrospective modeling to understand reasons for hydropower shortages in Upper Tigris







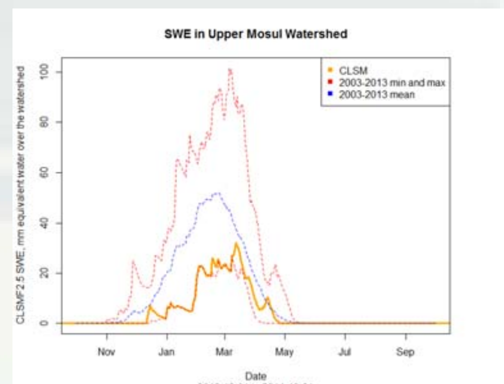


- Able to identify LSM configurations that best bracket inflows to the Mosul Reservoir using OSTM reservoir level data and outflow assumptions during certain times of year; however
- The bracket widens significantly in the last third of the water year. Differences in cumulative outflows range from approximately 5 to 10 km^3 over 2004-2012, which is enough to supply the entire typical dynamic range of the reservoir 1-2 times over.
- Reservoir operations at this location are a relatively small part of understanding the overall flows available to communities downstream of the reservoir, which at the seasonal scale will be largely controlled by the flows that pass through the reservoir in winter and spring.

Political implications:

Does this help us understand whether upstream countries might have been diverting or withholding water, as implied by news report of Iraqi water minister's press release on reasons for prolonged period of offline hydropower in January of 2011?

- Jan 2011 and previous months were unusually dry, modeled by CLSMf2.5 with a late and small snowpack in the upper Mosul watershed. The model does not provide any reason to believe that water was being diverted or withheld by upstream users. Late-season precip made up for the deficit in the early part of the water year and levels were rapidly recovered and at normal levels by early May.



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