Transitions and transformations—Climate extremes, hotspots, and adaptation, in semi-arid regions

Roger S. Pulwarty, Doug Kluck
Transitions and transformations-
Climate extremes, hotspots, and adaptation,
in semi-arid regions

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NOAA

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2 Central Regional Climate Services Director
(J. Porter, B. Rippey, R. McNider, A. Hoell, J. Verdin, others)
Increasing food production has been one of the major triumphs of the human enterprise over the last century.

Traditionally emphasis has been placed on production, the availability aspect of food security, the elements of accessibility and stability, are under increasing scrutiny.
A changing climate leads to changes in extreme weather and climate events
What do we know?

Ten Indicators of Changing Conditions:
The Romans Ignored The AD 305 IPCC Report (and apparently several National Climate Assessments)!


DEFERRED MAINTENANCE?
“Hotspots”

System, region - unit of analysis (what is vulnerable?), valued attributes of concern (why is it important?), external hazard (to what is the system vulnerable?), a temporal reference (when?)

Developed to target conservation efforts - maps explicitly developed to help aid organizations in priority setting and strategic planning with regards to climate adaptation projects

• High exposure, high sensitivity, rates of change and low adaptive capacity, to suffer significant impacts

• Identify likely climate change impacts and conveying with strong visual elements
Many potential futures: Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.
Landscape changes
Dryland Farming in the Four-Corners Region (USGS, NIDIS)

Sand Dune Mobility = $W/(P/PE)$

Stable Sand Dunes
$= P/PE > 0.31$

Partly Active Dunes

Fully Active Dunes
$= P/PE < 0.125$
The adaptation solution space
Risk Levels-High adaptation versus current approaches

Present -→ 2030-40 -→ 2080-2100 (2°C, 4°C)

POLAR REGIONS
- Risks for Ecosystems
  - High
  - Med
  - Very Low

SMALL ISLANDS
- Compounded Stress on Water Resources
- Reduced Crop Productivity and Livelihood and Food Security
- Vector- and Water-Borne Diseases

AFRICA
- Compound Stress on Water Resources
- Reduced Crop Productivity and Livelihood and Food Security
- Vector- and Water-Borne Diseases

CENTRAL AND SOUTH AMERICA
- Reduced Water Availability and Increased Flooding and Landslides
- Reduced Food Production and Quality
- Vector-Borne Diseases

THE OCEAN
- Reduced Fisheries Catch Potential at Low Latitudes
- Increased Mass Coral Bleaching and Mortality
- Coastal Inundation and Habitat Loss

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

EUROPE
- Increased Flood Losses and Impacts from Extreme Heat Events
- Increased Water Restrictions
- Increased Flood Damage to Infrastructure and Settlements

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

UNprecedented Challenges, Especially from Rate of Change

(IPCC, 2014)
Hotspots:
Soil moisture reductions combined with reduced adaptive capacity:

For Wheat: southeastern U.S., southeastern South America, the northeastern Mediterranean, and parts of central Asia,
For Maize: southeastern South America, parts of southern Africa, and the northeastern Mediterranean
Effective early warning systems and emergency preparedness (very high confidence)

- Integrated water resource management (high confidence)
- Rehabilitation of degraded coastal and terrestrial ecosystems (high confidence)
- Robust building codes and standards reflecting knowledge of current disaster risks (high confidence)
- Ecosystem-based/nature-based investments, including ecosystem conservation measures (high confidence)
- Micro-insurance, including weather-indexed insurance (medium confidence)
- Vulnerability-reducing measures such as pro-poor economic and human development, through for example, improved social services and protection of employment, wealth creation (very high confidence)

Risk Management

Resilience

Practices that enhance resilience to projected changes in disaster risk:

- Integrated coastal zone management integrating projections of sea level risk and weather/climate extremes (medium confidence)
- National water policy frameworks and water supply infrastructures, incorporating future climate extremes and demand projections (medium-high confidence)

Vulnerability reducing measures such as pro-poor economic and human development, through improved social services and protection
Weather-Climate-a Continuum and an adaptation deficit.....

Tornadoes
Snowstorms
Hurricanes
Typhoons

Heat Waves
Storm Track
Variations
Madden-Julian

El Niño-Southern Oscillation

Decadal Variability
Solar Variability
Deep Ocean Circulation

3 YEARS
10 YEARS
30 YEARS
100 YEARS

1 DAY
30 DAYS
1 SEASON
3 YEARS

Early warning....resource allocation.... Infrastructure Design

Atmospheric chemistry

Ocean surface upper full

Atmosphere region global

Land surface

Ice sheets

Marine Ecosystems
Annual Mean Temperature

What should we be trying to predict? (assuming some measure of skill)
Since the AR4, international food prices have reversed historical downward trend. . (Porter et al, 2014 IPCC WGII AR5)
If it’s so easy why is it so hard?

Dreadnaught-class Starship

Meet “The Borg”
“Dry gets drier”
“Wet gets wetter”

Not necessarily

(Greve and Seniveratne 2014)
Recent Studies of Mid-century Climate Change Impacts on Colorado River flows (Lee’s Ferry)

The future is already here. It’s just not very evenly distributed. -- William Gibson

<table>
<thead>
<tr>
<th>Recent Studies</th>
<th>Projected Annual Flow Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christensen et al., 2004</td>
<td>~18%</td>
</tr>
<tr>
<td>Christensen and Lettenmaier, 2007</td>
<td>~6%</td>
</tr>
<tr>
<td>Milly et al., 2005</td>
<td>10 to 25%</td>
</tr>
<tr>
<td>Hoerling and Eischeid, 2007</td>
<td>~45%</td>
</tr>
<tr>
<td>Seager et al., 2007</td>
<td>“an imminent transition to a more arid climate”</td>
</tr>
<tr>
<td>McCabe and Wolock, 2008</td>
<td>~17%</td>
</tr>
<tr>
<td>Barnett and Pierce, 2008</td>
<td>assumed &lt;10 to 30%</td>
</tr>
</tbody>
</table>

Response One: “These are so different, we can’t trust any of them…”

Response Two: “We need to resolve these differences!”
“Are the differences due to climate uncertainty or different models and methods?”

Response Three: “None of these studies show increasing flows”
“Any decrease is a source of concern”
Usually requested…..

• model agreement – convergence (not just at the grid-box scale)
• narrowing the projection range
• higher-resolution spatial and temporal scales, and improved shorter
• time-horizon projections

Influenced by choice of forcing data, calibration scheme, objective function etc.

The state of the practice is improving but in many cases does not fully recognize fundamental uncertainties – many adaptation studies are likely ‘overconfident’
Model agreement/convergence?

Observational agreement
Despite advances to date, predicting the future hydro-climate variables will remain a major challenge:

- Nature is complex and observing and modeling its nonlinear behavior is very challenging. So, “have a will to doubt” the credibility of information generated by models.

- Long-term and sustained observation programs are critical, especially for model verification. Without some degree of verifiability, hard to expect their use.
Midwest yields (and rise of center-pivot irrigation and other technology). Areas like the Southeast gave up on corn.
United States: Winter Wheat

Yellow numbers indicate the percent each state contributed to the total national production. States not numbered contributed less than 1% to the national total.

- Major areas combined account for approximately 75% of the total national production.
- Major and minor areas combined account for approximately 99% of the total national production.
- Major and minor areas and state production percentages are derived from NASS county- and state-level production data from 2006-2010.

Note: The agricultural data used to create the map and crop calendar were obtained from the National Agricultural Statistics Service at: http://www.nass.usda.gov/.

Crop calendar dates are based upon NASS crop progress data from 2006-2010. The field activities and crop development stages illustrated in the crop calendar represent the average time period when national progress advanced from 10 to 90 percent.
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Corn crop calendar for most of the United States

Crop calendar dates are based upon NASS crop progress data from 2006-2010. The field activities and crop development stages illustrated in the crop calendar represent the average time period when national progress advanced from 10 to 90 percent.
U.S. Corn Yield, Bushels Per Acre
1985-2015*

2010-12: First time U.S. corn yield fell three years in a row since 1928-30.

* The projected 2015 U.S. corn yield of 167.2 bushels/acre is adapted from “USDA Agricultural Projections to 2024.”
A complete explanation of these droughts must invoke not just the ocean forcing but also the particular sequence of internal atmospheric variability - weather - during the event.
**Evaporative Demand Drought Index (EDDI)** shows strong early warning potential - 2012

- **EDDI** reflects surface moisture conditions, often before ET does,
  - responds positively to both flash droughts and sustained droughts.

### August 7

$$ EDDI_j = \frac{\sum_{t=i}^{j}(ET_{0t} - \overline{ET}_{0t})}{\sigma_{ET_{0t}}} $$

2-week **EDDI**

- US Drought Monitor

**Legend:**
- drought developing in entire region
- note little drought in western US

**Map:**
- drought developing in IN, IL, MO, AR, KS, OK
- drought expands; does not deepen
- drought in NY, PA, and VA, 2 months after **EDDI**

- Note: drought in MO, AR, KS, IL; no drought in MI, CE, OK, NE.
<table>
<thead>
<tr>
<th>Crop</th>
<th>Unit</th>
<th>USDAO projection/ estimate as of:</th>
<th></th>
<th></th>
<th></th>
<th>Change</th>
<th>Percent change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5/10/2012</td>
<td>1/11/2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>$/bu</td>
<td>4.60</td>
<td>7.40</td>
<td>2.80</td>
<td>60.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>$/bu</td>
<td>13.00</td>
<td>14.25</td>
<td>1.25</td>
<td>9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>$/bu</td>
<td>4.25</td>
<td>7.30</td>
<td>3.05</td>
<td>71.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>$/cwt</td>
<td>15.8</td>
<td>14.9</td>
<td>-0.9</td>
<td>-5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>$/bu</td>
<td>6.10</td>
<td>7.90</td>
<td>1.80</td>
<td>29.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>Cts/lb</td>
<td>75.0</td>
<td>68.5</td>
<td>-6.5</td>
<td>-8.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
El Niño

Anomalous oceanic and atmospheric conditions in the Pacific that influences climate around the world
Forecasting El Niño impacts
October 2015 – March 2016
Drought Impact on Rice Crops: Thailand, northern Philippines, southern Indonesia
Rapid Transition to La Niña?

Historical NINO3.4 Sea Surface Temperature Anomaly

- 1983
- 1998
- 2016?

<table>
<thead>
<tr>
<th>Rank</th>
<th>Year</th>
<th>Abandonment</th>
<th>Climate Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1917</td>
<td>34%</td>
<td>1916-17 Cold Phase</td>
</tr>
<tr>
<td>2.</td>
<td>1933</td>
<td>32%</td>
<td>Neutral</td>
</tr>
<tr>
<td>3.</td>
<td>1935</td>
<td>29%</td>
<td>Neutral</td>
</tr>
<tr>
<td>4.</td>
<td>2002</td>
<td>29%</td>
<td>1998-2001 Cold Phase</td>
</tr>
<tr>
<td>5.</td>
<td>1951</td>
<td>29%</td>
<td>1949-50 Cold Phase</td>
</tr>
<tr>
<td>6.</td>
<td>1989</td>
<td>25%</td>
<td>1988-89 Cold Phase</td>
</tr>
<tr>
<td>7.</td>
<td>1936</td>
<td>24%</td>
<td>Neutral</td>
</tr>
<tr>
<td>8.</td>
<td>1955</td>
<td>24%</td>
<td>1954-57 Cold Phase</td>
</tr>
<tr>
<td>9.</td>
<td>1928</td>
<td>24%</td>
<td>1928-29 Cold Phase</td>
</tr>
<tr>
<td>10.</td>
<td>2001</td>
<td>24%</td>
<td>1998-2001 Cold Phase</td>
</tr>
</tbody>
</table>
• La Niña increases the risk of winter wheat abandonment on the Great Plains (e.g. 1951, 1955, 1989, 2001), often the year following development

• La Niña is not a consistent indicator of low corn yields, but low yields sometimes do occur (e.g. 1954, 1964, 1974, 1988)—often during the year of onset

• Hot, dry Midwestern conditions immediately following a wet El Niño regime (e.g. 1983, 1995) can be devastating to corn because shallow-rooted crops suffer as previously soggy soils are baked into concrete.
Using the forecast

...
“Hotspots”

• Increasing pressure on Federal agencies, donors and development organizations to show that scarce public resources are being used in a responsible manner

• Spatial indicators and hotspots maps hold the promise of transparent, “scientific”, and defensible priority setting

• Many hotspots mapping efforts are affected by the spatial scale and uncertainties in the available global data sets. e.g. inconsistent patterns for water security
• Expanding the evidence base and assessment tools to identify agricultural growth strategies for food security
• Integrate adaptation and potential mitigation
• Building policy frameworks and consensus to support implementation
• Strengthening national and local institutions to enable farmer management of climate risks Adoption of context-suitable agricultural practices, technologies and systems
• Enhancing financing options to support implementation, linking climate and agricultural finance
Oscar Selfie Worth as Much as $1 Billion

Oscar photo of host DeGeneres with Bradley Cooper, Jennifer Lawrence, Julia Roberts, Brad Pitt, Meryl Streep, Kevin Spacey and others
World's highest net worth selfie? $1 trillion in one shot

Walmart's Sustainability Product Expo
Global Framework for Climate Services

Goal:
Enable better management of the risks of climate variability and change and adaptation to climate change at all levels, through development and incorporation of science-based climate information and prediction into planning, policy and practice.
AR5 identified a lack of progress in developing implementation pathways for adaptation: in essence noting the need to move from assessment to adaptation action.
### Characteristics of decision making

<table>
<thead>
<tr>
<th>Characteristics of decision making</th>
<th>Simple Risk</th>
<th>Complicated Risk</th>
<th>Complex Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodology</td>
<td>Linear, cause and effect</td>
<td>Top down and/or bottom up, iterative</td>
<td>Iterative and/or adaptive, ongoing and systemic</td>
</tr>
<tr>
<td>Approach</td>
<td>Analytic and technical</td>
<td>Collaborative process with technical input</td>
<td>Process driven. Frame and model multiple drivers and valued outcomes</td>
</tr>
<tr>
<td>Stakeholder strategy</td>
<td>Communication</td>
<td>Collaboration</td>
<td>Deliberation, creating shared understanding and ownership</td>
</tr>
<tr>
<td>Mental models</td>
<td>Common model</td>
<td>Negotiated and shared</td>
<td>Contested initially and negotiated over project</td>
</tr>
<tr>
<td>Values and outcomes</td>
<td>Widely accepted</td>
<td>Negotiated over project by user perspectives and calculated risk</td>
<td>Contested initially and negotiated over project</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Straightforward</td>
<td>With review and trigger points</td>
<td>As real-time as possible, adaptive with management feedback and trigger points</td>
</tr>
</tbody>
</table>

AR5 also identified a lack of progress in developing implementation pathways for adaptation: in essence noting the need to move from assessment to adaptation action.
“Hydro-Ilogical” Cycle

RAIN

Apathy

DROUGHT

MORE DROUGHT

Panic

Concern
1. Acknowledge the cross-timescale nature of climate and of early warning information

Improved understanding of long-term variations of largest storms dictate the occurrence of droughts in California.
Multi-year droughts are, at present, not addressed by any forecast system, clearly a gap in our capabilities
2. Recognize alternative means of addressing water security. Best adaptation practices may be novel configurations of efficiency and land and water resources.

SMART Growth Conservation costs savings on 22 water city and district water plans in Colorado-water obtained by conservation is still the cheapest option per AF for development (Kenney et al 2010).
LAND MATTERS FOR CLIMATE
REDUCING THE GAP AND APPROACHING THE TARGET
3. Recognize “communication” as critical but not sufficient

Broad societal processes that create dynamic pressures and unsafe conditions are not easy to change, yet are fundamental to human vulnerability

A social process - beyond one and even “two-way” communication

More challenging is an understanding the socialization of lessons learned by particular individuals and organizations through their own, direct trial and error experiences
If we only knew the “tradeoffs” .......

Revenue produced by using an acre-foot of water for:

1. Alfalfa: $920
2. Lettuce: $6,000
3. Intel to manufacture core 2 duo chips: $13 million

(Glennon, 2015)
If only we could assess future risks with greater certainty...
4. Focus on institutions and capacity: risk management governance

Accountability - located with planning/fiscal oversight - political authority and policy coherence across sectors. Emergency management organizations can rarely play that role.

Efficiency - achieved in partnership with at-risk sectors and local communities and organizations that represent them.
“If we are not careful we will end up where we are going”
U.S. Freshwater Withdrawal, Consumptive Use, and Population Trends

Graph showing trends in freshwater withdrawal, consumptive use, and population from 1960 to 2005.
Source: Figure prepared by PH Gleick; data from USGS and USBEA, 2014.
• Drought driven by natural variability (sea surface temperatures, soil moisture conditions), climate change (increases in temperature and regional shifts in precipitation), and increased human water demand

• Temperature increases are projected to be a continuing and increasing factor in the changing hydroclimate

• Significant, valuable research enterprise involving federal agencies, and academic partners to improve understanding, monitoring, predictions, and projections of drought e.g. GEOGLAM, NSMN
The fundamental adaptation question: When/How often should we revise our assumptions?
Improving scientific and institutional knowledge, **agility and alignment:** Regional Research Collaboration Networks

- Food production assessments linked with food security assessments
- Information services to support adaptation in changing environments
- Empirical evidence on the effectiveness of technological interventions and social adaptations at all levels of the food system

**Most critical will be development of sustained networks across institutions to ensure that lessons being learned, as risks and opportunities emerge, become embedded in practice, and inform the choice of pathways for resilience.**
When was the Summer of Love? Watergate?-

The year is 2015
We are closer to 450 ppm and 9 000 000 000 000 people than to either of these
Thank you

You cannot solve the problem with the same kind of thinking that created the problem

Albert Einstein
• Summer of 2012 had the most extreme combination of negative PDO and positive AMO in over a century
• This spelled continued drought conditions for CA—was a successful forecast

Wolter, 2015
USING IT IS THE HARDEST PART.

BIG DATA
Cropland Greenness in January

A 35% (400,000 acre) increase in fallowing was observed in 2014 relative to 2011, a year of normal water availability-state resources for county food banks.

2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

January Greenness Deviation from 13 year Average

-3 σ
-2 σ
-1 σ
+1 σ
+2 σ
+3 σ

Less Green

+1σ +2σ +3σ

More Green

-2σ-3σ

Outside of Cultivated Area Mask

2014 January showing extensive areas of dryness

NIDIS, NASA, USDA, USGS, NOAA and the California Department of Water Resources,
The length of time required to detect and attribute a climate trend caused by human activities is determined by:

- Natural variability
- The magnitude of human driven climate change
- The accuracy of the observing and modeling systems

The year in which we become 90% certain depends on our Earth observations, their accuracy, and their completeness.

The economic value of advanced climate observing systems is dramatically larger than their cost (Wielicki, Cooke et al, 2013)

We lack a comprehensive climate observing system capable of testing climate predictions with sufficient accuracy or completeness.
Improving cultivar tolerance to high temperature is a frequently identified adaptation for almost all crops and environments worldwide as high temperatures are known to reduce both yield and quality noting that a new cultivar usually takes between 8 and 20 years to deliver.

- Breeding additional drought-tolerant crop varieties for enhanced storage and access to irrigation water, more efficient water delivery systems, improved irrigation technologies such as deficit irrigation, more effective water harvesting, agronomy that increases soil water retention through practices such as minimum tillage and canopy management,
- agroforestry, increase in soil carbon, and more effective decision support.

There is medium confidence (limited evidence, high agreement) that crop adaptations can lead to moderate yield benefits (mean of 10 to 20%) under persistently drier conditions and that irrigation optimization for changed climate can increase yields by a median of 3.2% as well as having a range of other beneficial effects.
Observations and Monitoring: the current availability and quality of climate observations and impacts data to support adaptation appear inadequate for large parts of the globe.

- Ocean
  - Global coverage
- Satellites
  - Weather and Climate
- Atmospheric
  - Global and domestic
- Capacity Building
  - WMO/IOC JCOMM
    - Global Climate Observing System (GCOS)
Improving scientific and institutional knowledge, agility and alignment: Regional Research Collaboration Networks

• Integrate into existing knowledge networks

• Quality: climate observations, research and information services that match user requirements

• Assess impediments to the flow of knowledge among existing components

• Policies and practices that can limit or facilitate research-partner networks working as a system

• Opportunities for learning and institutional innovation and identifying priorities back up the research chain-gaming scenarios
IF YOU ONLY FOCUS ON THE PROBLEM

YOU MIGHT MISS THE EASY SOLUTION
Most estimates of disaster losses exclude indirect losses – livelihoods, informal economies, intangible losses including ecosystem services, quality of life and cultural impacts.

In some areas drying due to climate change will be overlain on the periodic events/droughts those areas have always experienced.

Short-term actions do not always provide long term risk reduction—can reduce or increase longer-term risks.

For exposed and vulnerable communities, even non-extreme weather and climate events can have extreme impacts.