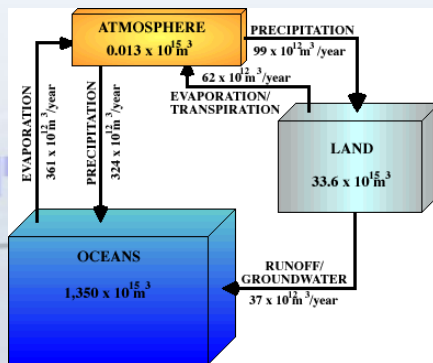
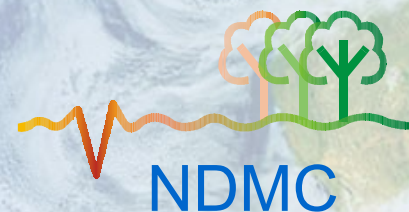
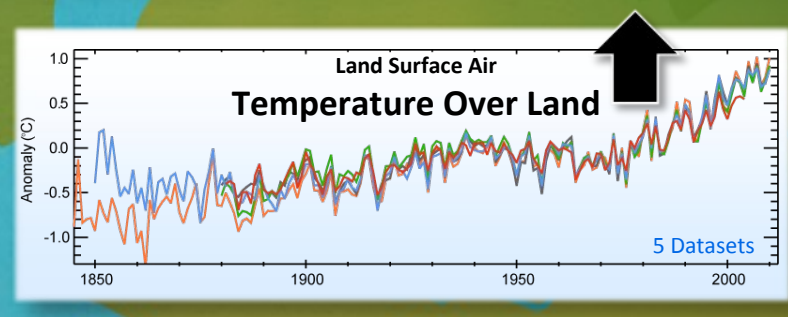
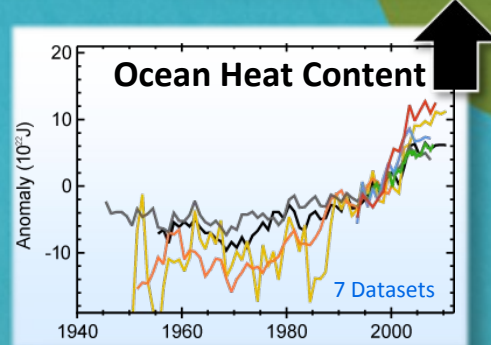
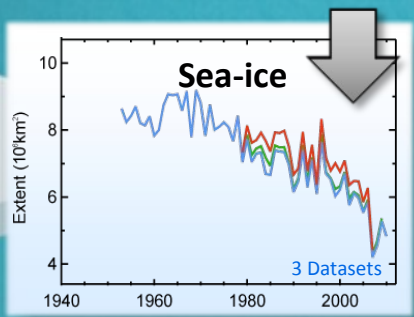
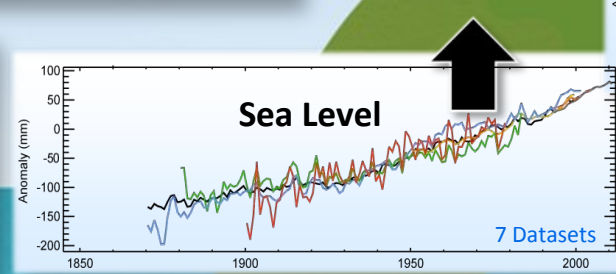
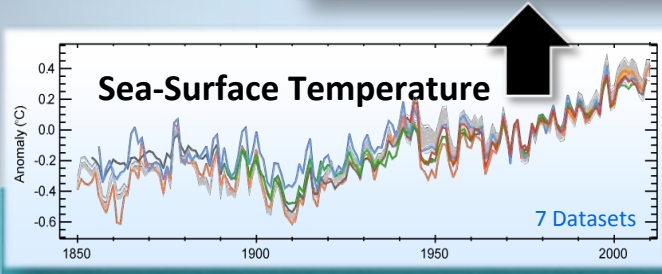
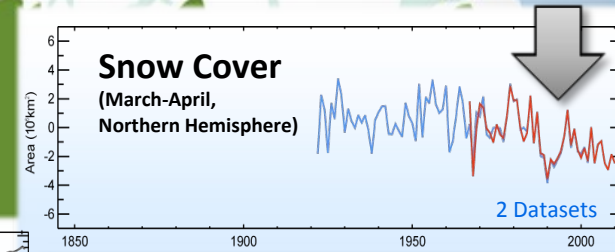
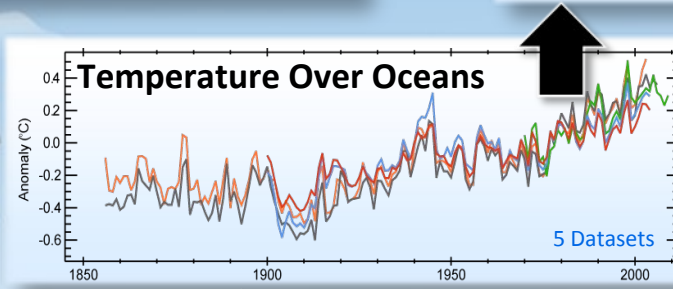
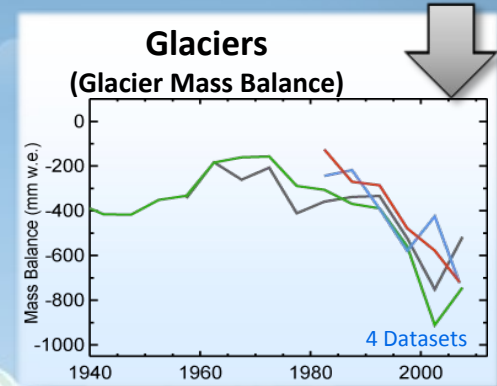
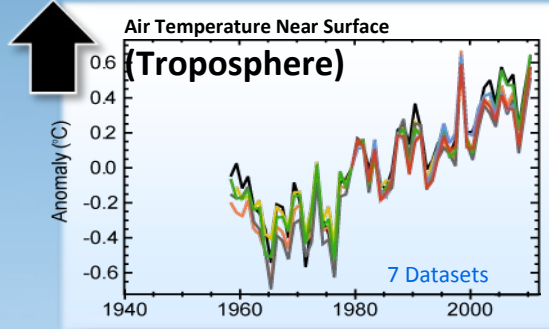
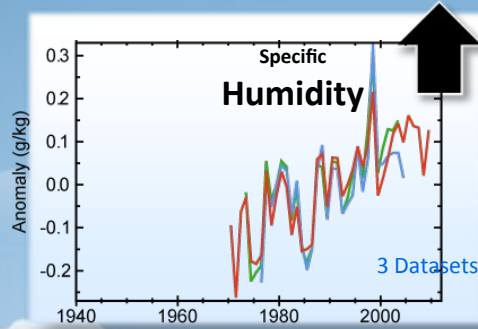


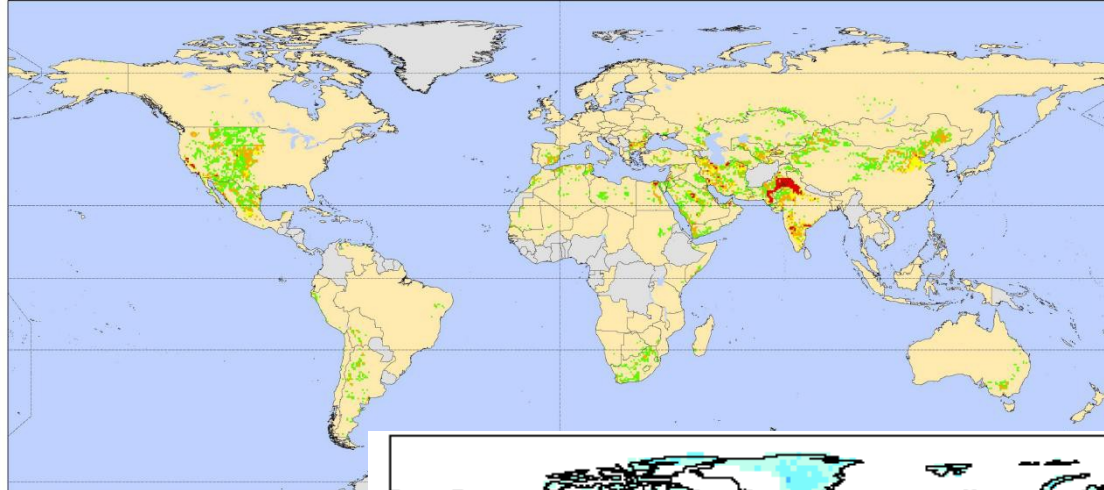
Climate, Drought and Risk in the U.S

Roger S. Pulwarty (and many others!)
Senior Science Advisor (Climate) and
Director, National Integrated Drought Information System
NOAA
Boulder Colorado 80305
roger.pulwarty@noaa.gov



Is the climate changing ? -Observed Trends





Ground water depletion

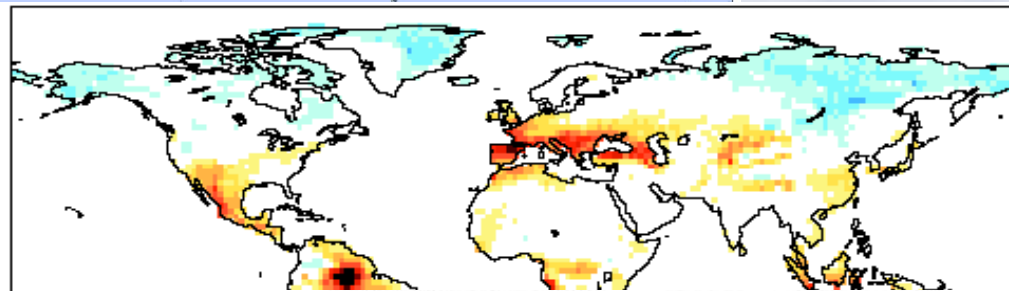
I don't See any Borders



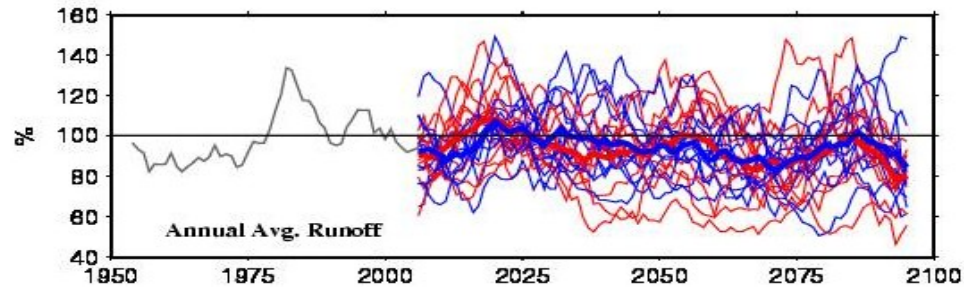
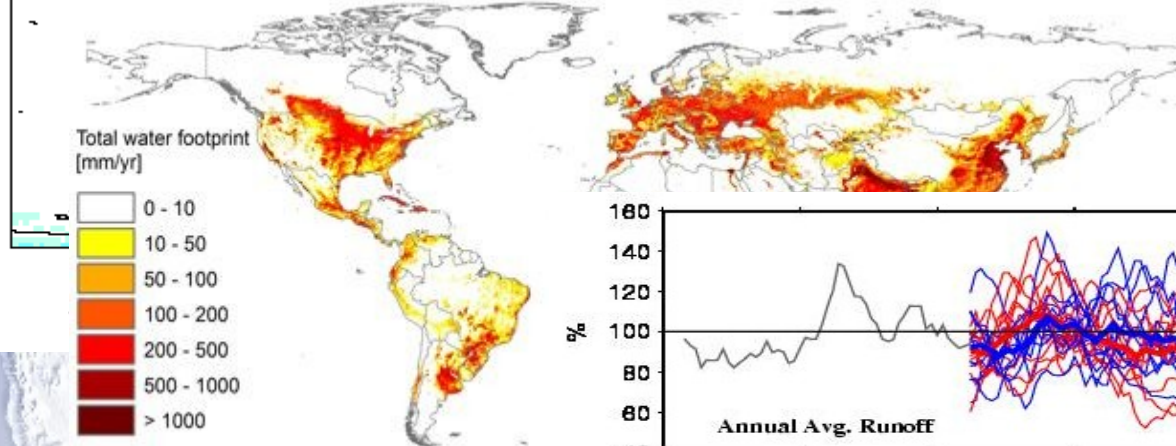
Do you?

(C) No Data 0 - 2

Model agreement (2050)



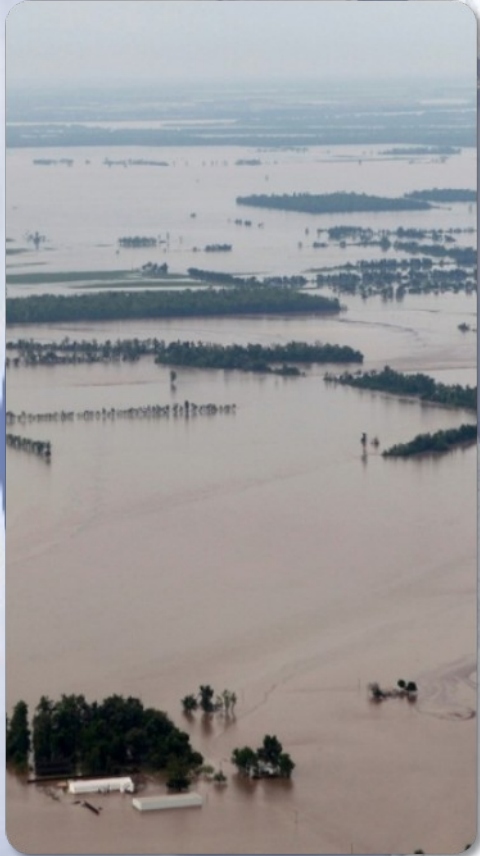
Water footprint



Many potential futures:

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options

A changing climate leads to changes in extreme weather and climate events

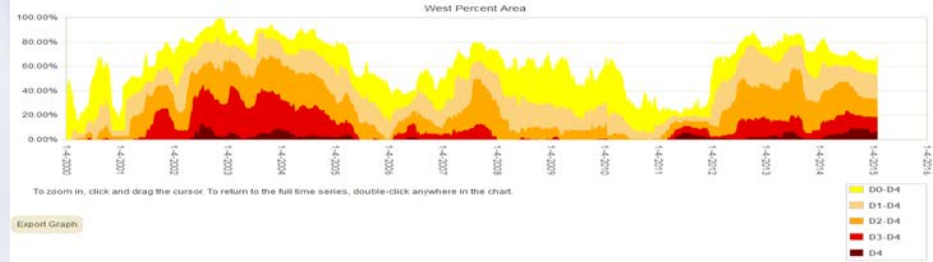


Changing Rain, Snow, and Runoff

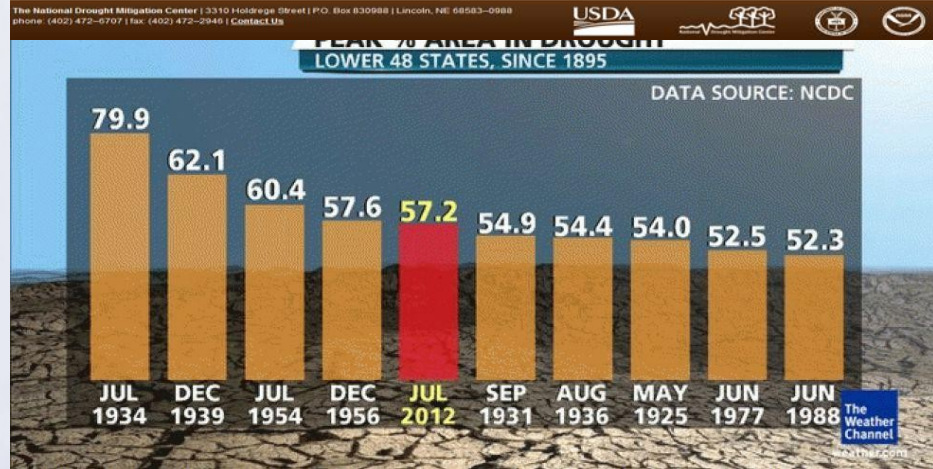
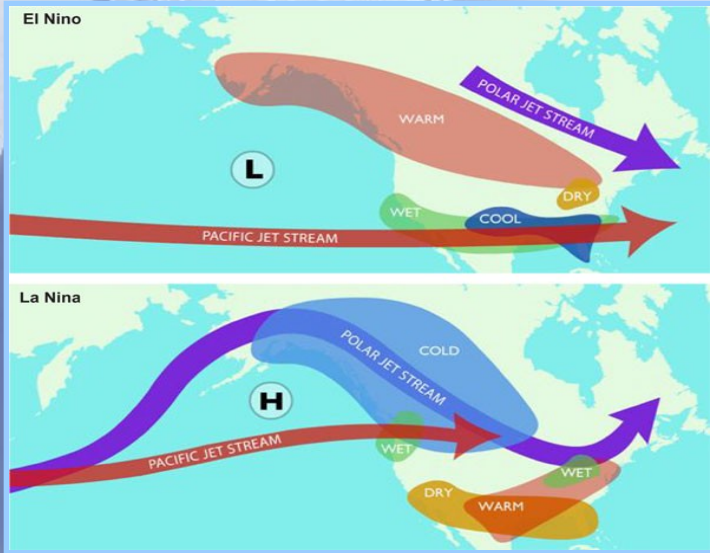
- Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions.
- Very heavy precipitation events have increased nationally and are projected to increase in all regions.
- The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.



Drought: Weather-climate continuum and Adaptation deficits



UNITED DROUGHT INFORMATION SYSTEM



Atmospheric chemistry

Marine Ecosystems

Ice sheets

Ocean surface upper full

Land

Atmosphere region

global



Fronts, convective systems
Cyclones

Blocking

MJO

NAO

ENSO QBO

PDO

AMO

“If we are not careful we will end up where we are going”

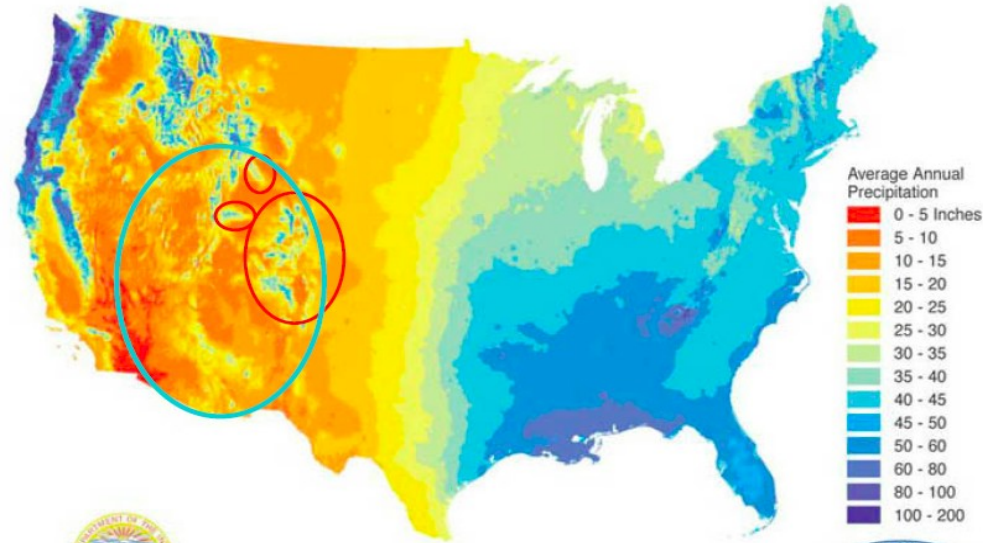


**Central Arizona project
Late-1980's**



**Development in Central
Arizona 20 years later**

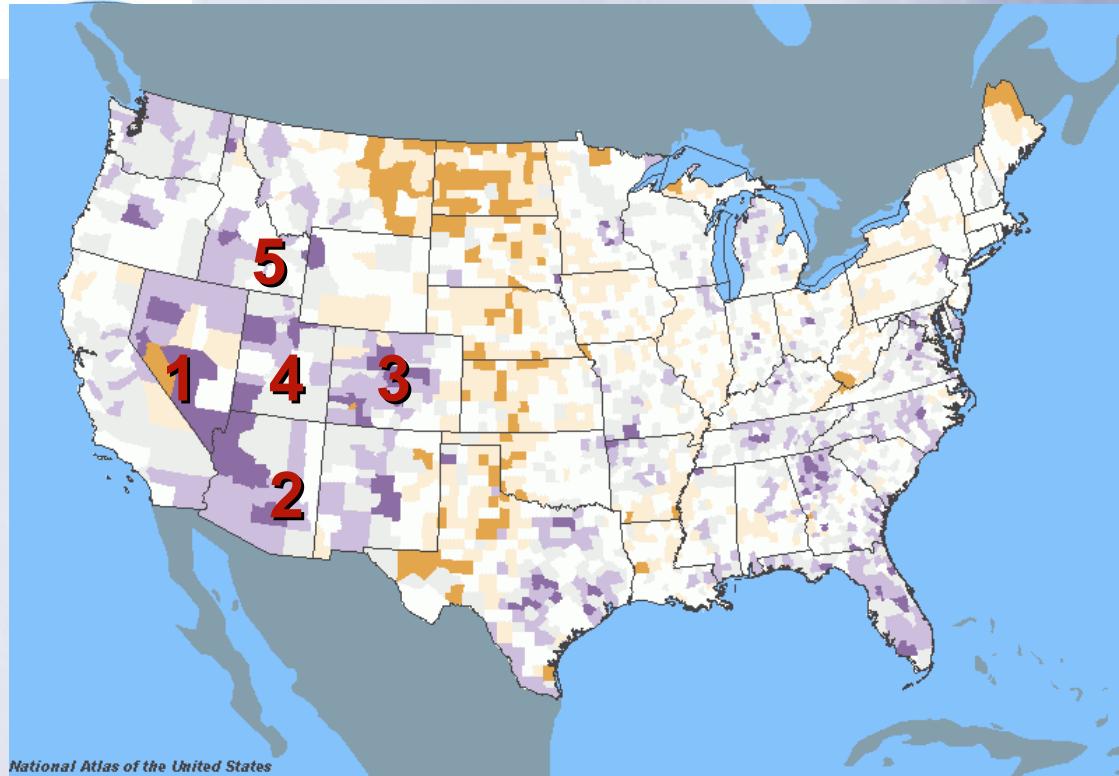
Average Inches of Annual Precipitation
in the United States 1961-1990



**Average
annual
precipitation**



**Population
growth**

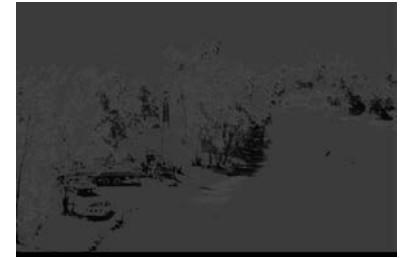


Impacts of a Changing climate

**Climate
Variability &
change**



Higher evaporation.
More farm dams as
surface water
availability reduces?



Increased demand
for groundwater as
surface water
availability reduces?



Greater irrigation
efficiency as surface
water availability
reduces?

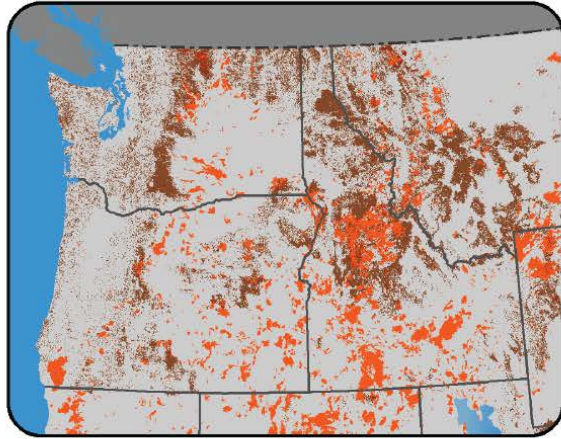


Increased evapo-
transpiration due
to higher temps?



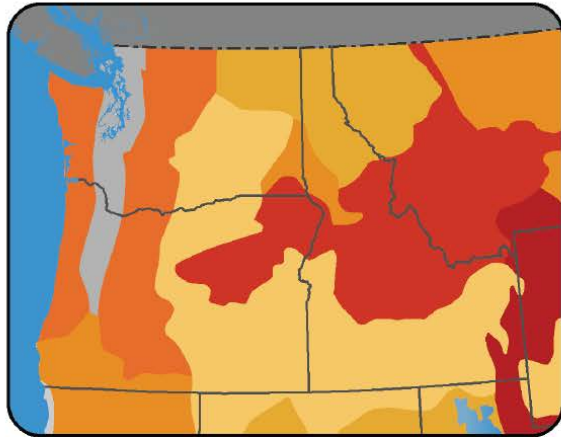
Higher frequency
and intensity of
wildfires due to
higher temps and
droughts?

Insects, Fire in Northwest Forests



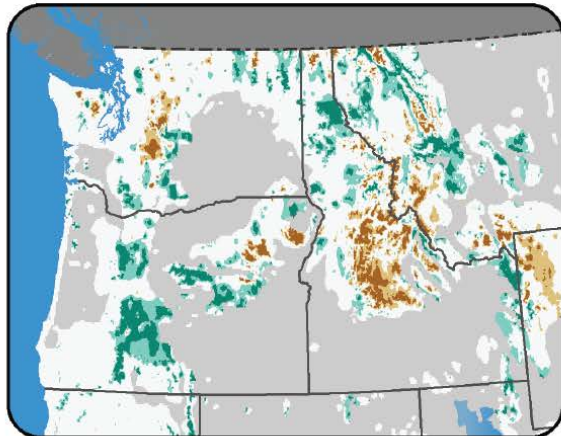
Recent Disturbance

-  Fire area
-  Insect and disease area








Projected Increase in Area Burned

-  600% to 700%
-  500% to 600%
-  400% to 500%
-  300% to 400%
-  200% to 300%
-  100% to 200%
-  Not modeled

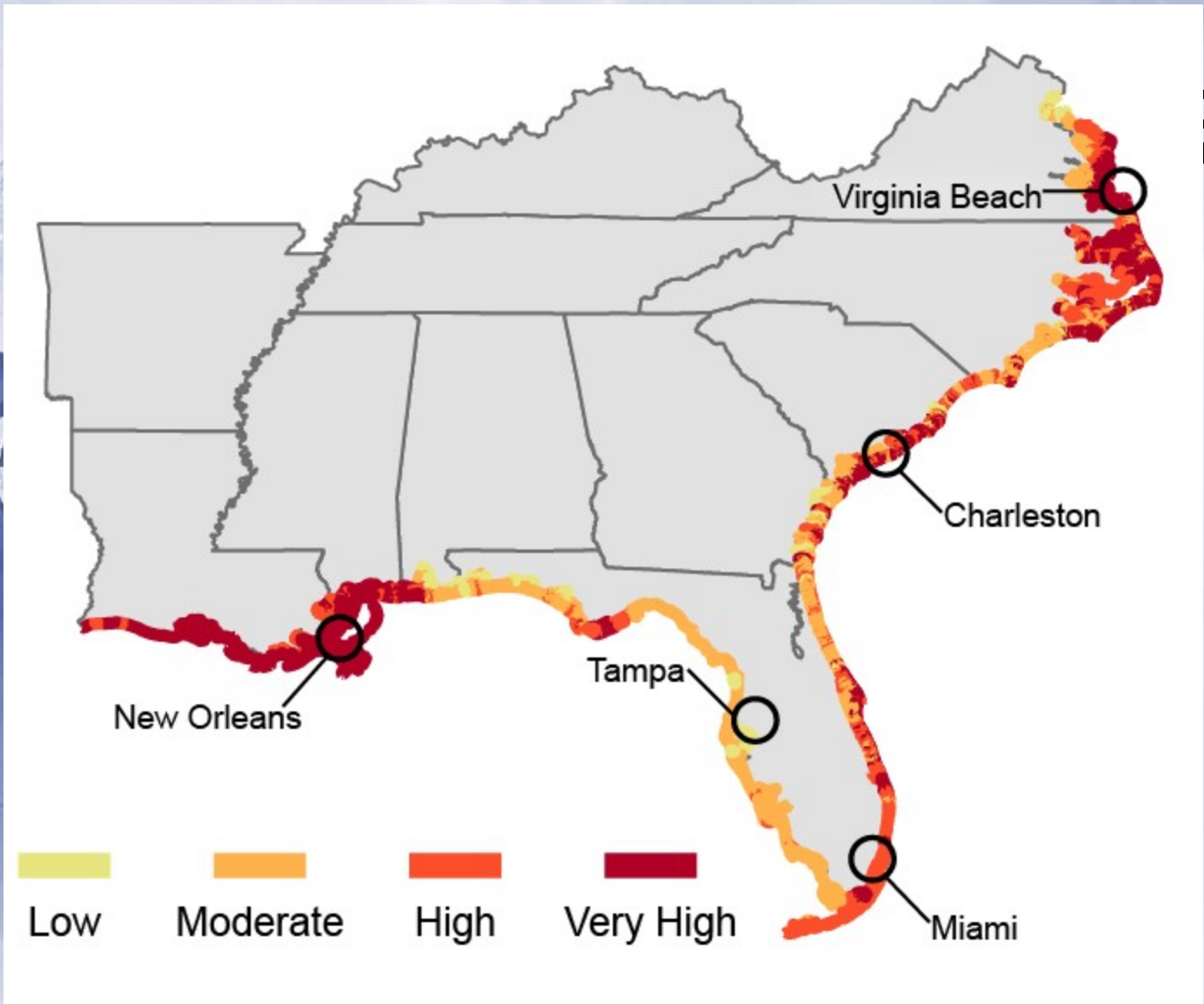


Change in Probability of Mountain Pine Beetle Survival

-  40% to 100%
-  20% to 40%
-  -20% to 20%
-  -40% to -20%
-  -100% to -40%

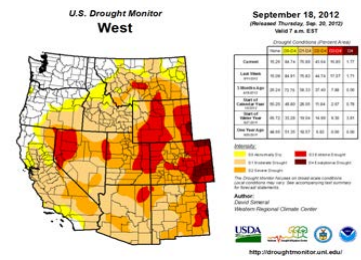
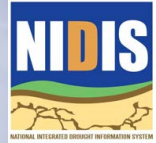


Rise

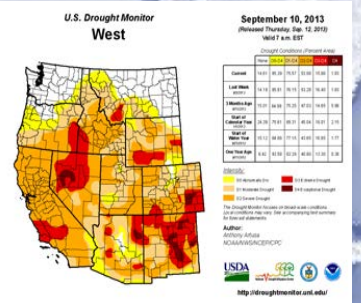


Data from Hammar-Klose and Thieler 2001

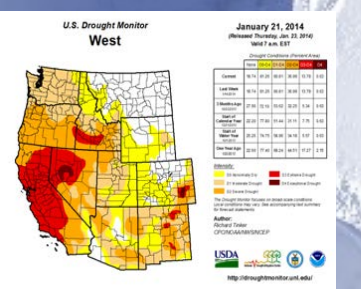
The California Drought Key Questions



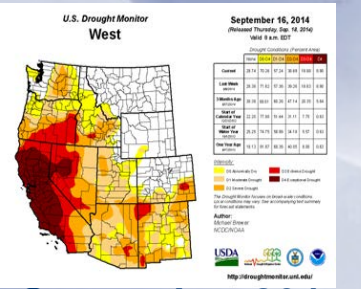
2011



2012

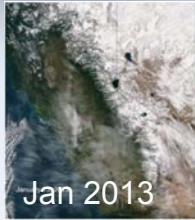


2013



September 2014

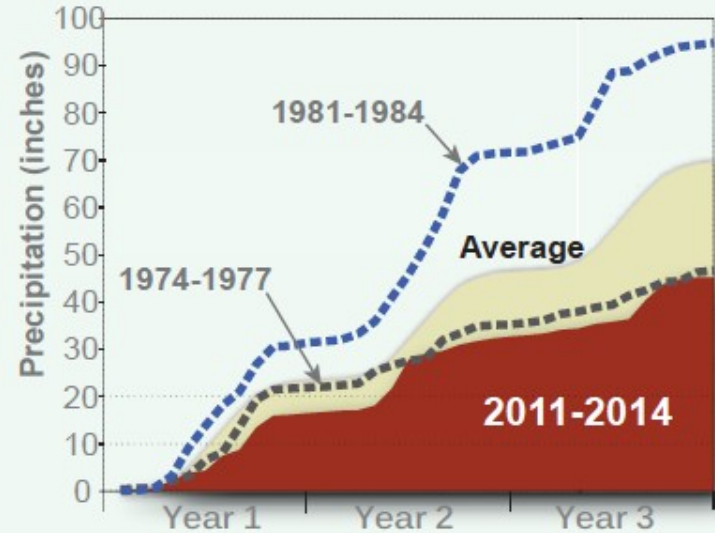
- How did we get here? Status and antecedent conditions
- Why has it been dry/drier than normal? Is this drought like others?
- What are the impacts and where did they occur?
- What information is being provided and by whom?
- How bad might it get and how long will it last?
- How are we planning for this year and for longer-term risks and opportunities?



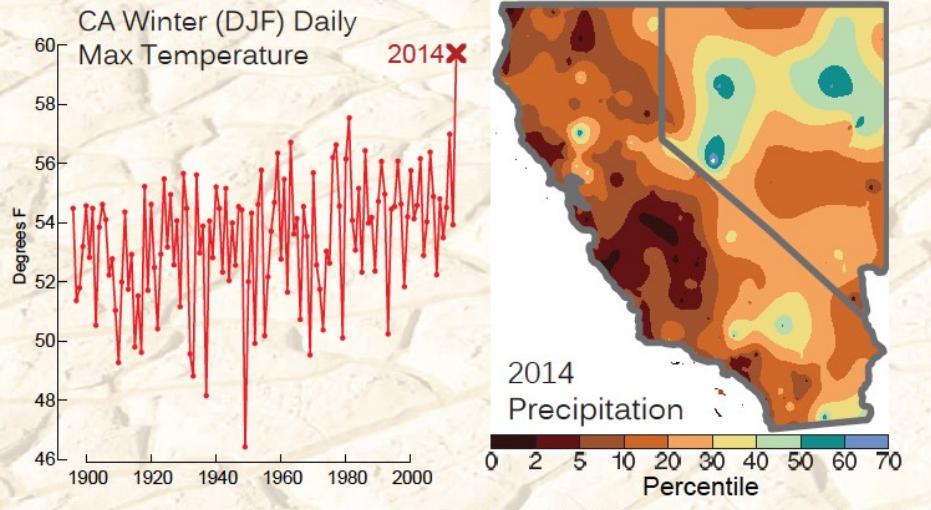
Jan 2013

Jan 2014

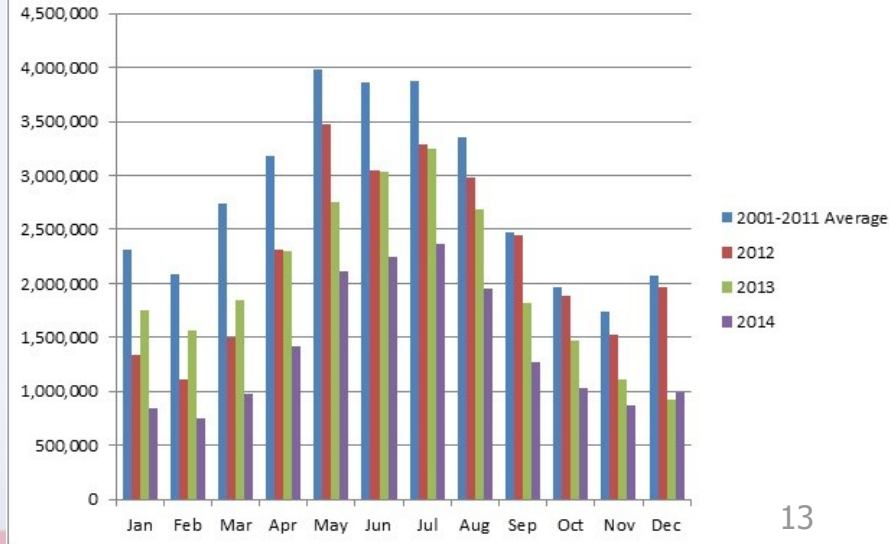
Statewide 3-yr Precip Accumulation



The California Drought of 2014: Record Hot, Record Dry

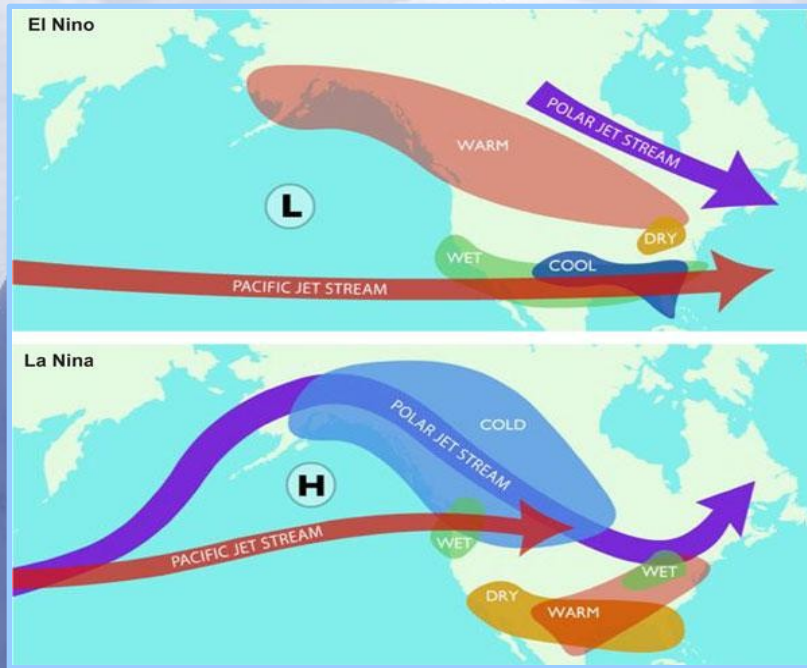


Hydroelectric Power Generation in California by Month (megawatt-hours)

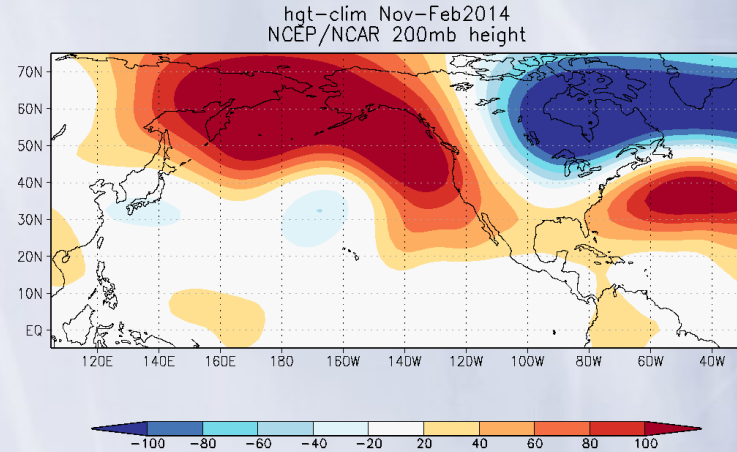


- Could “the” drought have been anticipated? RISA California-Nevada Applications Program

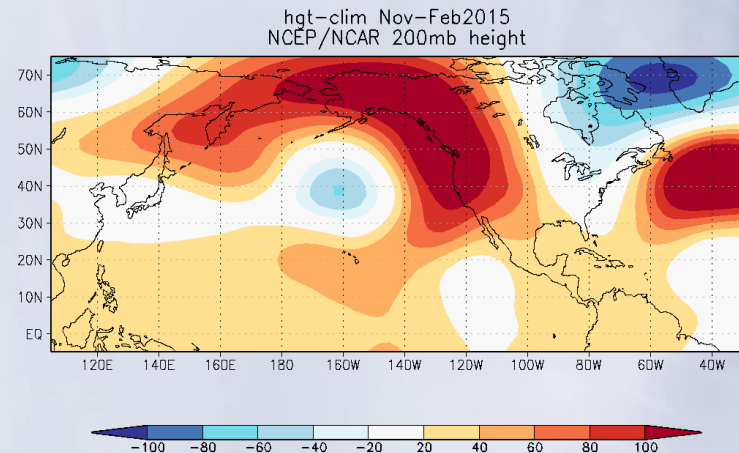
Atmospheric Drivers of Drought Over the West



November 2013-February 2014



November 2014 -February 2015

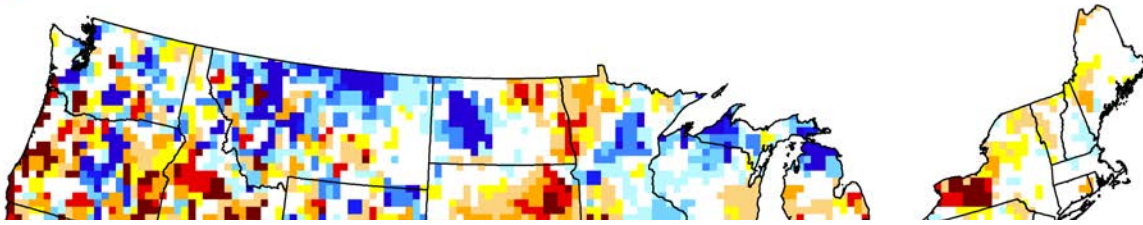


High Pressure conditions



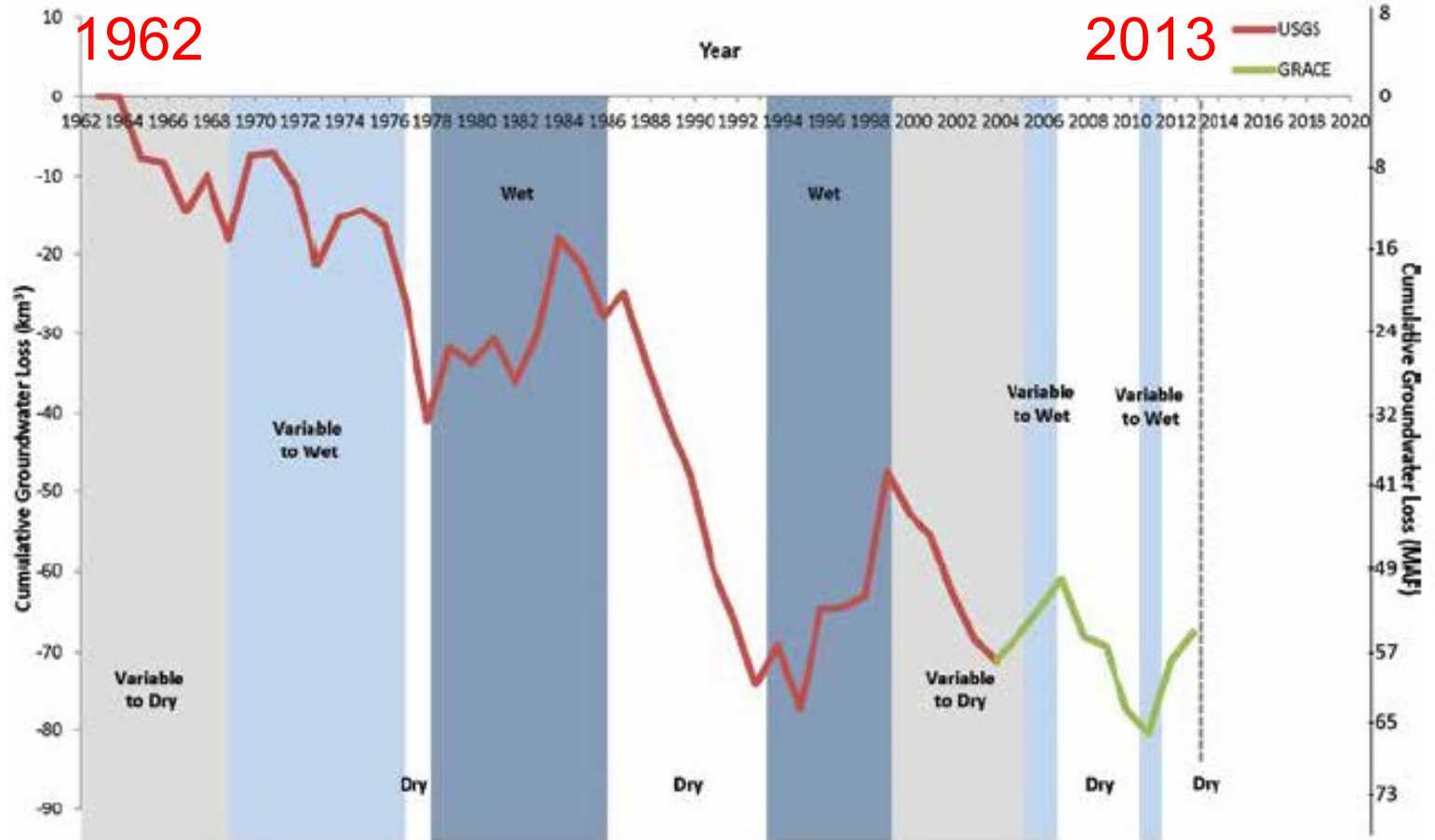
GRACE-Based Root Zone Soil Moisture Drought Indicator

March 30, 2015



Ground water conditions

GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE)



1962

2013

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

2014 January
showing extensive
areas of dryness

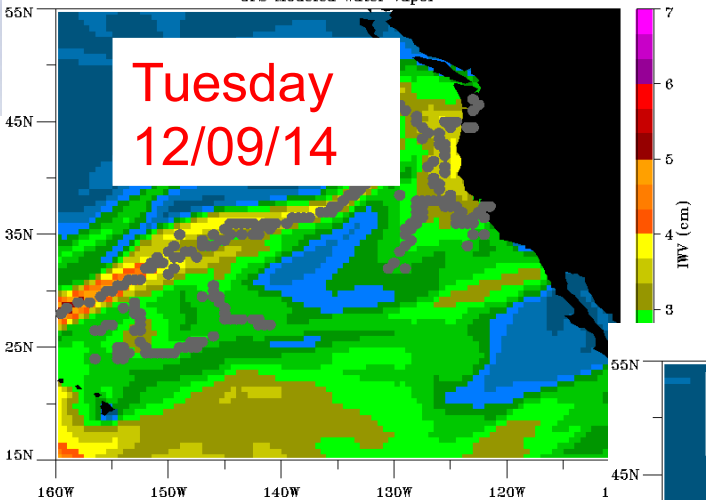
Outside of
Cultivated
Area Mask

2014

Atmospheric Rivers (ARs)

20141204 120 Hour Forecast
GFS Modeled Water Vapor

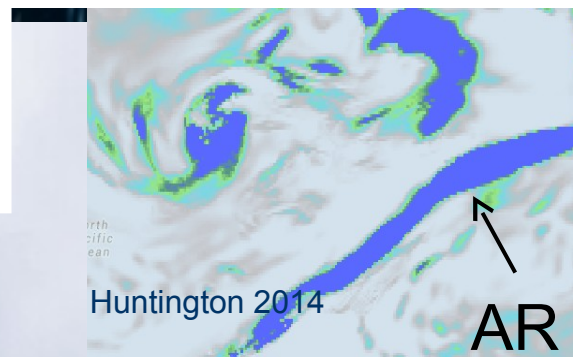
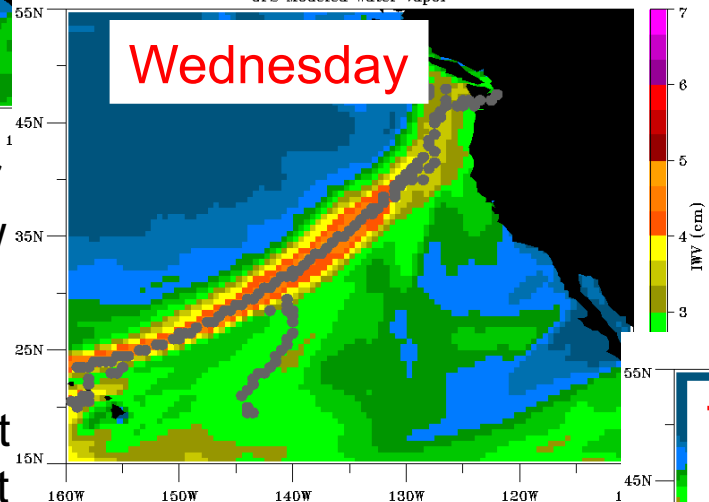
Tuesday
12/09/14



transport of water vapor
at the boundary of a low
pressure system

20141204 144 Hour Forecast
GFS Modeled Water Vapor

Wednesday

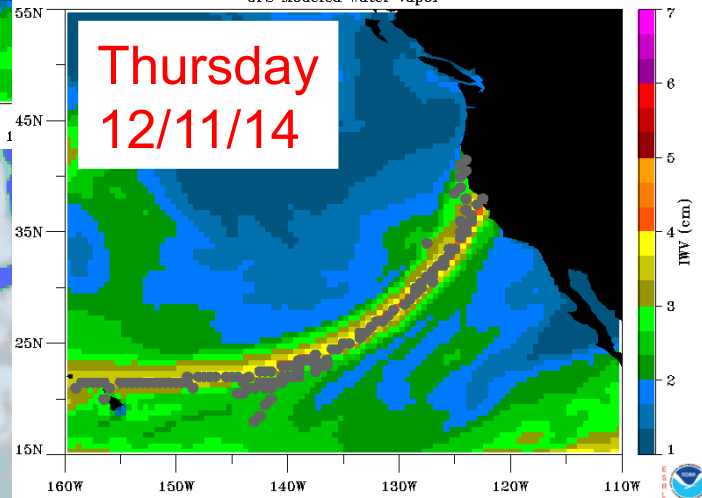


February 8th, 2015

February 8th, 2014

20141204 168 Hour Forecast
GFS Modeled Water Vapor

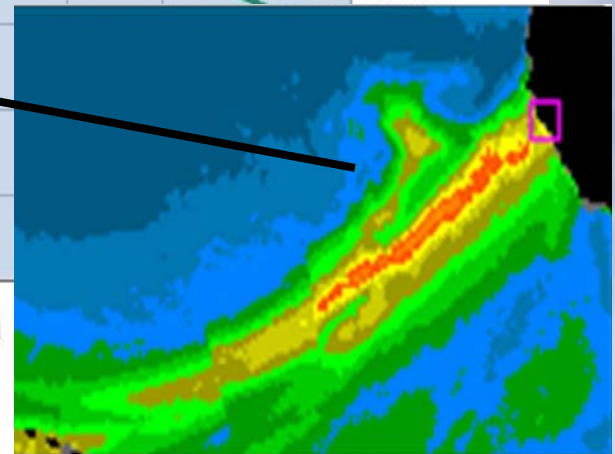
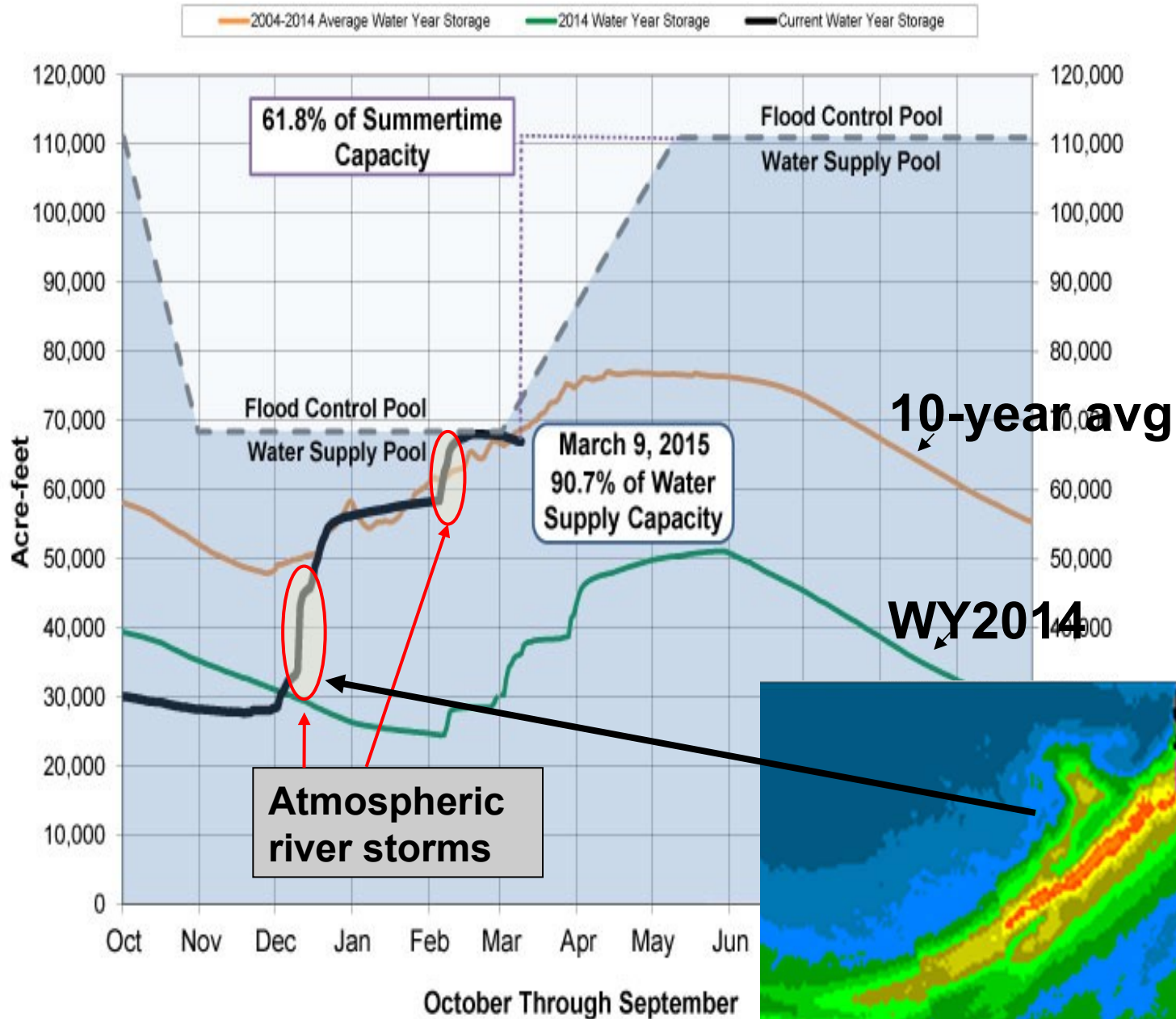
Thursday
12/11/14



- ~ 40-70% of the drought breaks in the west coast since 1950 are due to ARs

- Large & slow moving ARs can cause flooding

Lake Mendocino Water Supply Storage



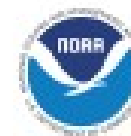
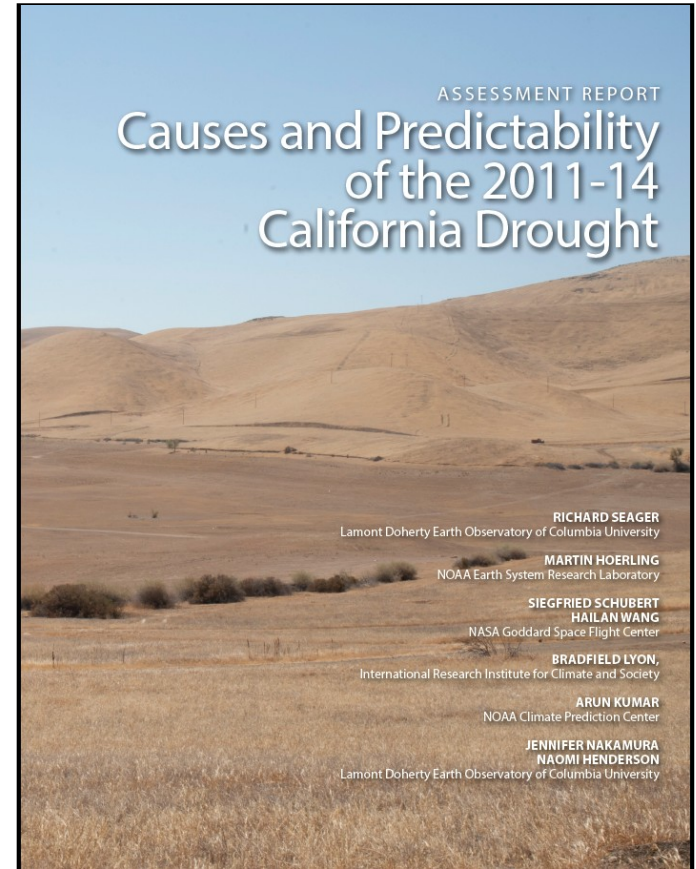
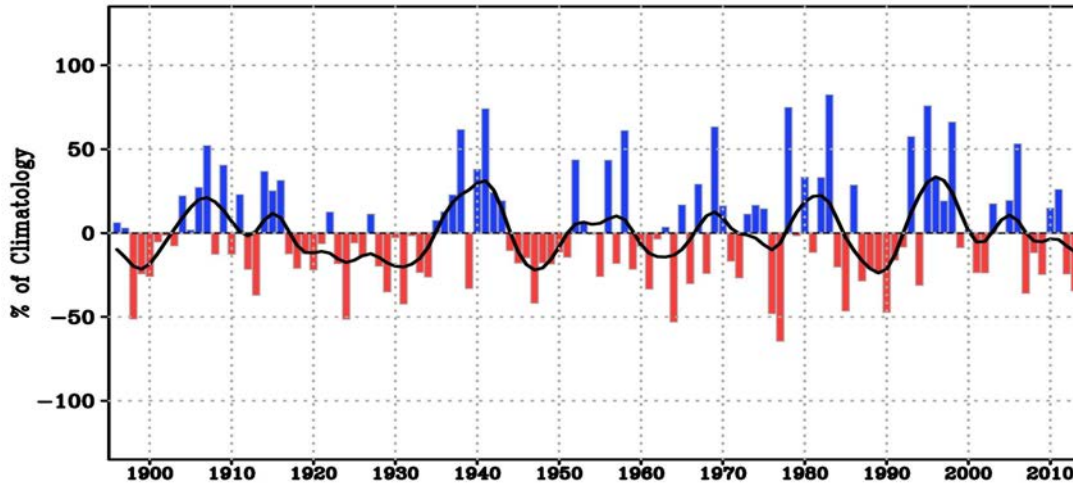


Could this drought have been anticipated?

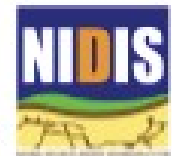


Is this drought due to anthropogenic climate change?

California (PRISM)
Dec–Apr Precipitation Departures: 1896–2013

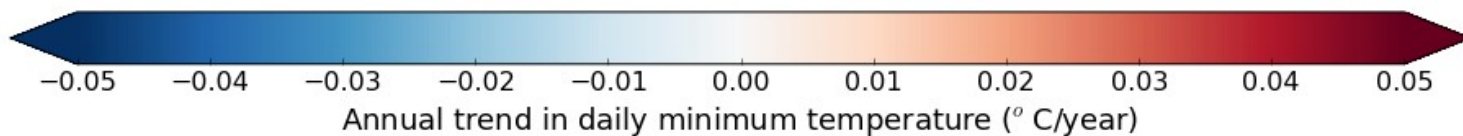
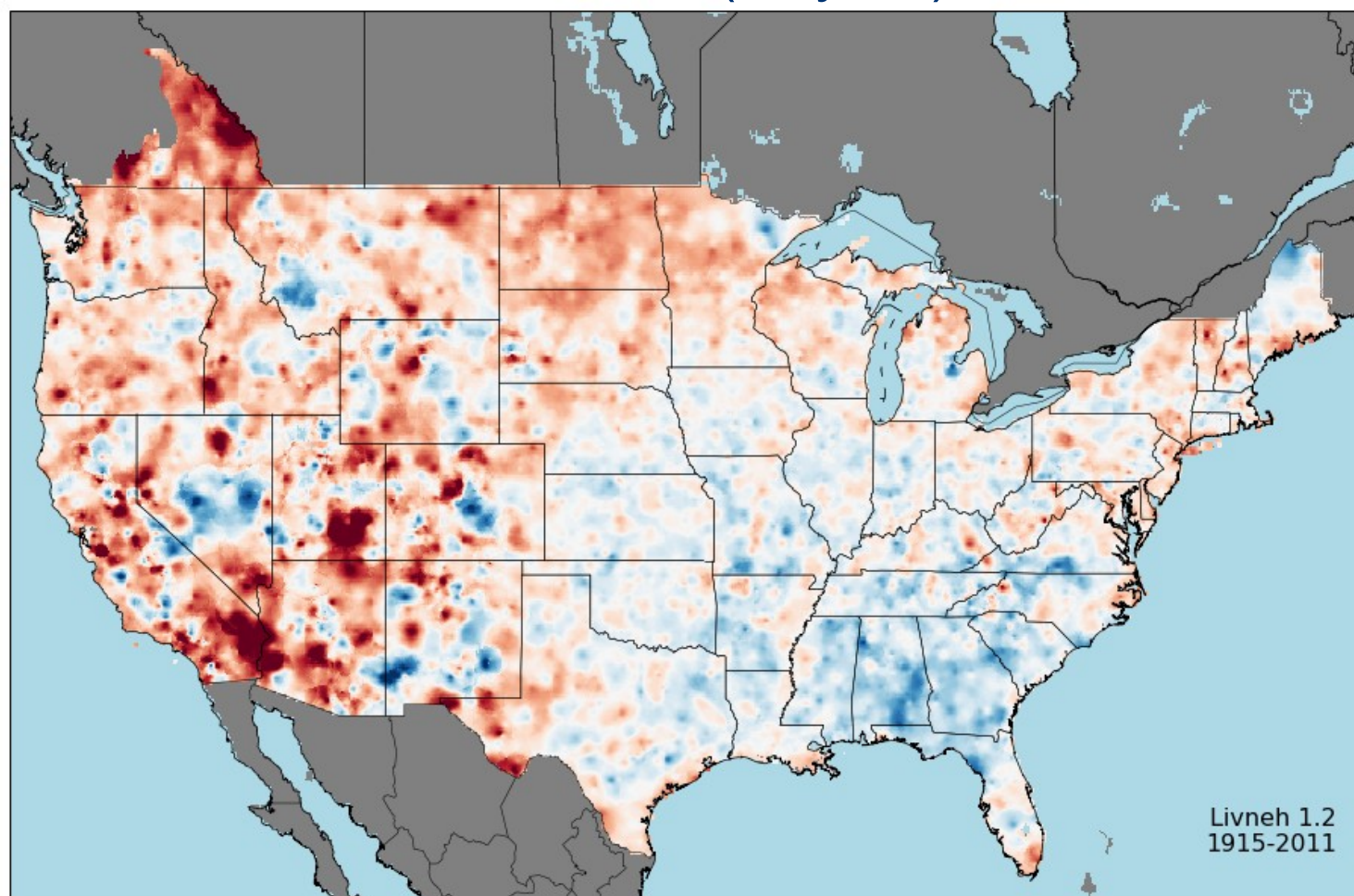


MAPP
Modeling, Analysis,
Predictions, and Projections



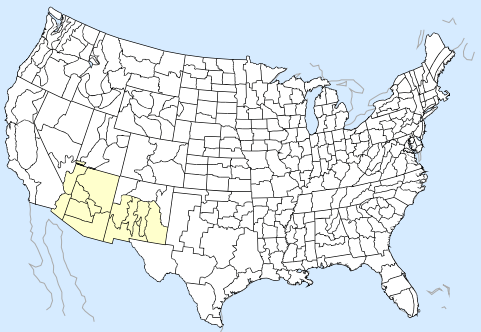
NOAA Drought Task Force

CONUS daily minimum temperature trend 1915-2011 ($^{\circ}\text{C}/\text{year}$)

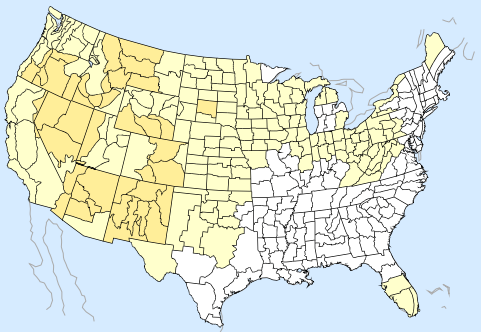


Are Transitions to Semi-Permanent Drought Imminent?

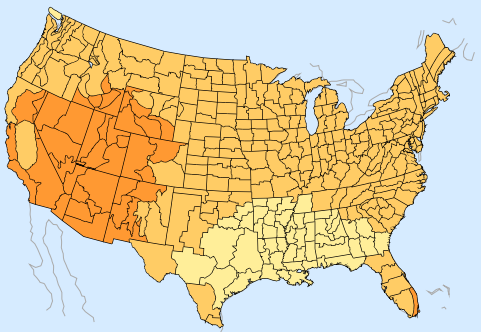
Precipitation



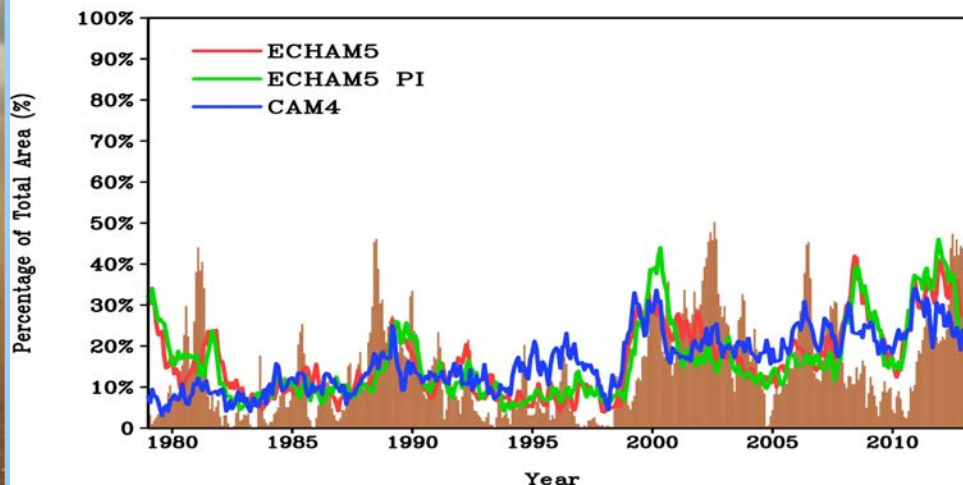
Soil Moisture



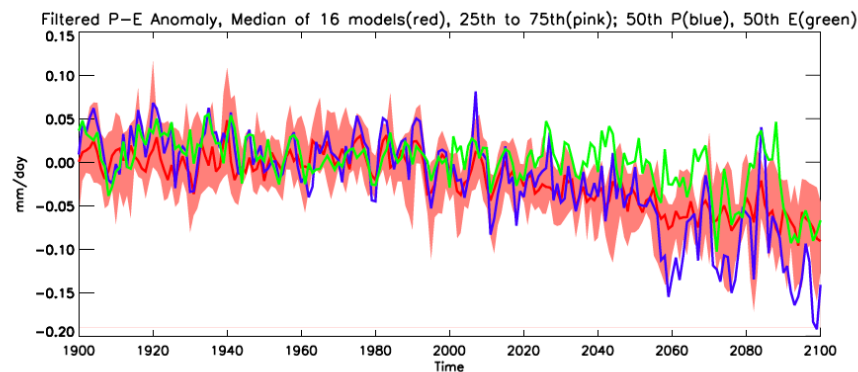
Temperature



Percent Area of the Contiguous U.S. with Soil Moisture $< -1\sigma$



P , E and $P-E$ averaged across all of SW North America in the IPCC AR5 global climate model simulations and projections for 1900 to 2100

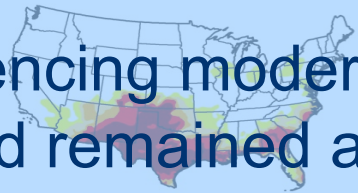
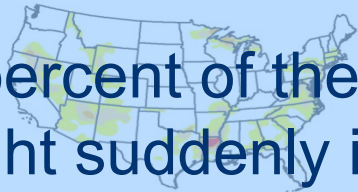


Ongoing transition to a drier climate driven by decreasing precipitation

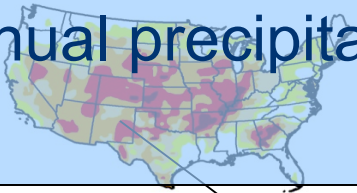
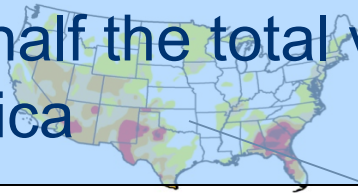
Effect of Long Term Global Ocean Warming

The weather-climate continuum

The percent of the U.S. experiencing moderate to severe drought suddenly increased and remained at elevated levels during the first decade of the 21st Century



Even a perfect SST prediction would “likely” capture much less than half the total variance in annual precipitation over North America



Area (%) of the US (including Alaska, Hawaii and Puerto Rico) categorized as D1, D2, D3 or D4 on the US Drought Monitor

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

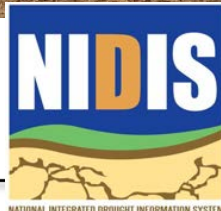
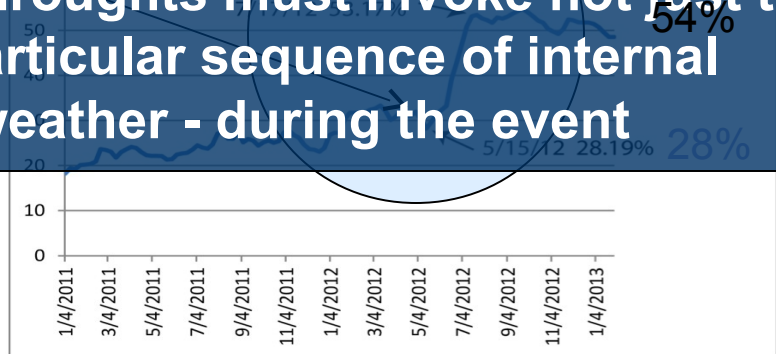


Figure 1. How did we get here? Conditions on dates (Source: NIDIS and US Drought Monitor)

Evaporative Demand Drought Index

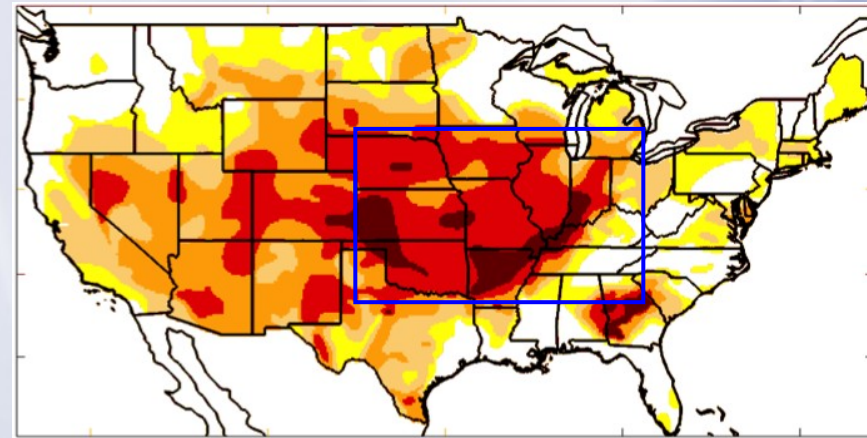
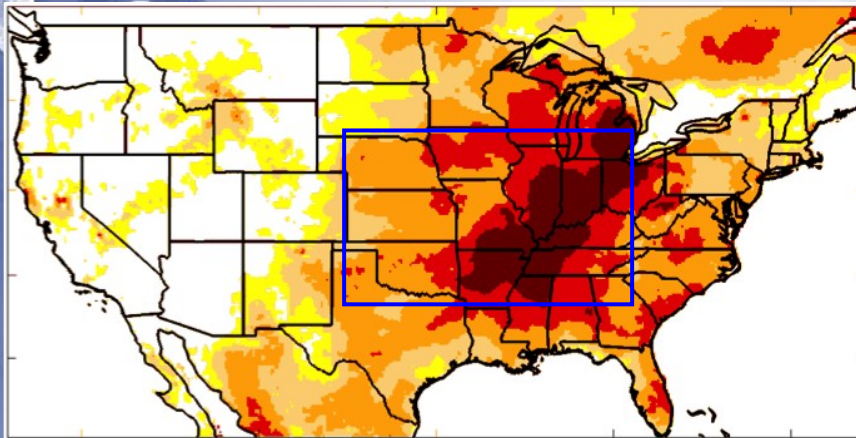
EDDI shows strong early warning potential-2012

August 7

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

2-week *EDDI*

US Drought Monitor



flash droughts in MO, AR, IL, KS region
note little drought in western US

Deep D in HI, ND, NE, D3 to deep much of region;
no drought in NY, PA, AR, OK, NE months after *EDDI*

- Due to land-atmosphere feedbacks, evaporative demand (E_0) reflects surface moisture conditions, *often before ET does*,
 - responds positively to both flash droughts and sustained droughts.

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

Recent Studies

Projected Annual Flow Reductions

Christensen et al., 2004	~18%
Christensen and Lettenmaier, 2007	~6%
Milly et al., 2005	10 to 25%
Hoerling and Eischeid, 2007	~45%
Seager et al., 2007	“an imminent transition to a more arid climate”
McCabe and Wolock, 2008	~17%
Barnett and Pierce, 2008	assumed 10-30%

Response One: These are so different, we can't trust any of them...

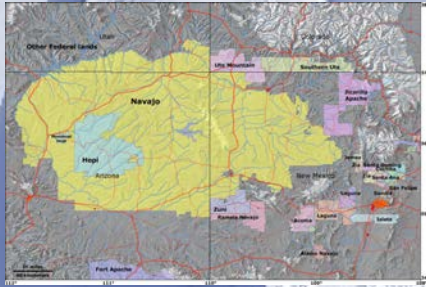
Response Two: We need to resolve these differences! Are the differences due to climate uncertainty or different models and methods?

Response Three: None of these studies show increasing flows. Any decrease is a source of concern.

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

Four Corners Region

Stable Sand Dunes
= $P/PE > 0.31$

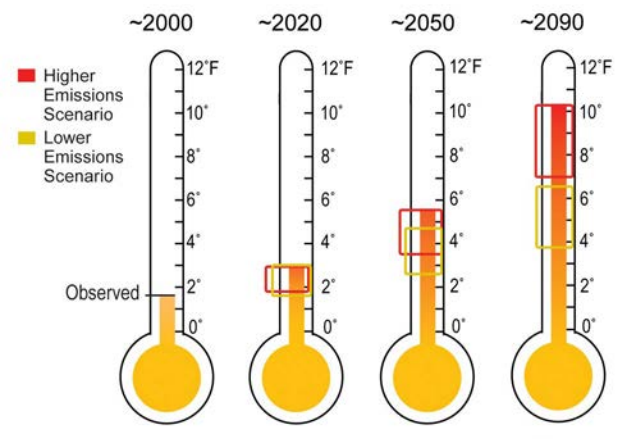


Partly Active Dunes

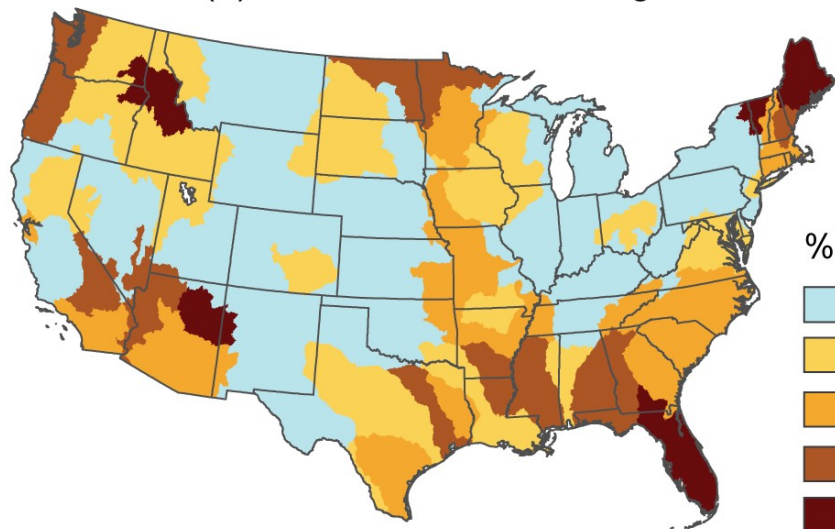
Fully Active Dunes
= $P/PE < 0.125$



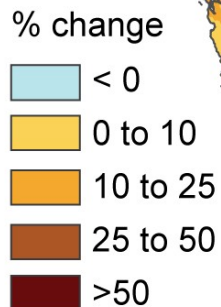
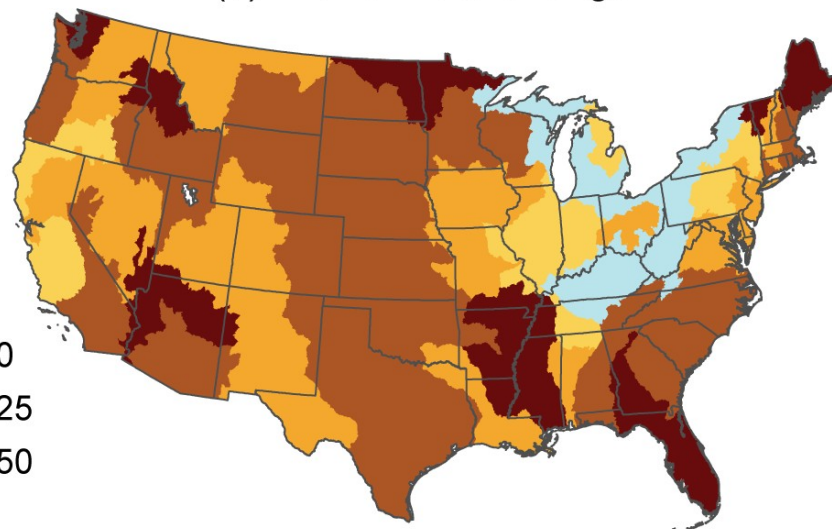
Projected Changes in Water Withdrawals: Growth and demand 2005 to 2060

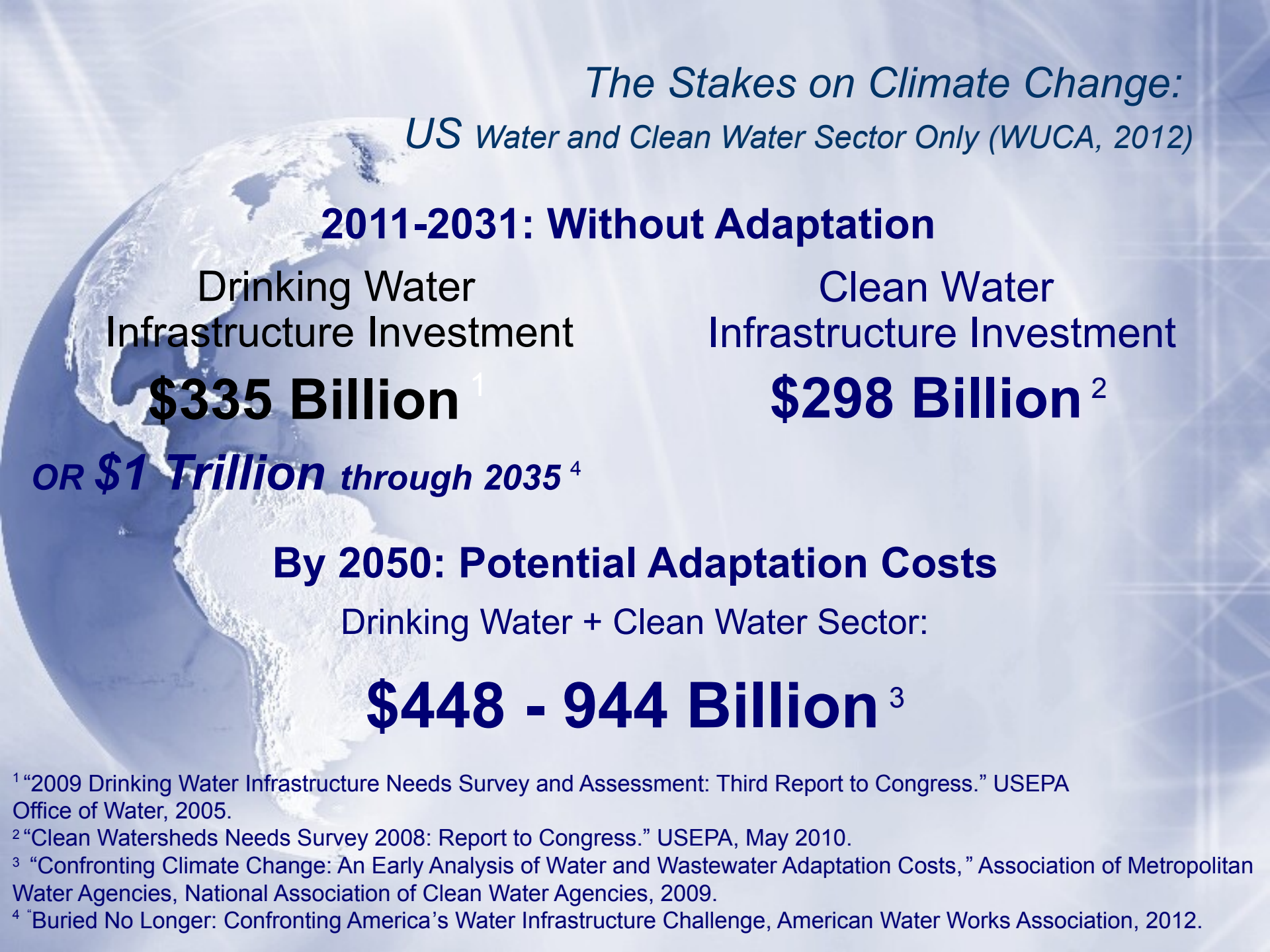


(a) Without Climate Change



(b) With Climate Change





*The Stakes on Climate Change:
US Water and Clean Water Sector Only (WUCA, 2012)*

2011-2031: Without Adaptation

Drinking Water
Infrastructure Investment

\$335 Billion¹

Clean Water
Infrastructure Investment

\$298 Billion²

OR \$1 Trillion through 2035⁴

By 2050: Potential Adaptation Costs

Drinking Water + Clean Water Sector:

\$448 - 944 Billion³

¹ "2009 Drinking Water Infrastructure Needs Survey and Assessment: Third Report to Congress." USEPA Office of Water, 2005.

² "Clean Watersheds Needs Survey 2008: Report to Congress." USEPA, May 2010.

³ "Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs," Association of Metropolitan Water Agencies, National Association of Clean Water Agencies, 2009.

⁴ "Buried No Longer: Confronting America's Water Infrastructure Challenge, American Water Works Association, 2012.

Assess "Build-out": Services provided, Avoided costs



CONFRONTING CLIMATE CHANGE:

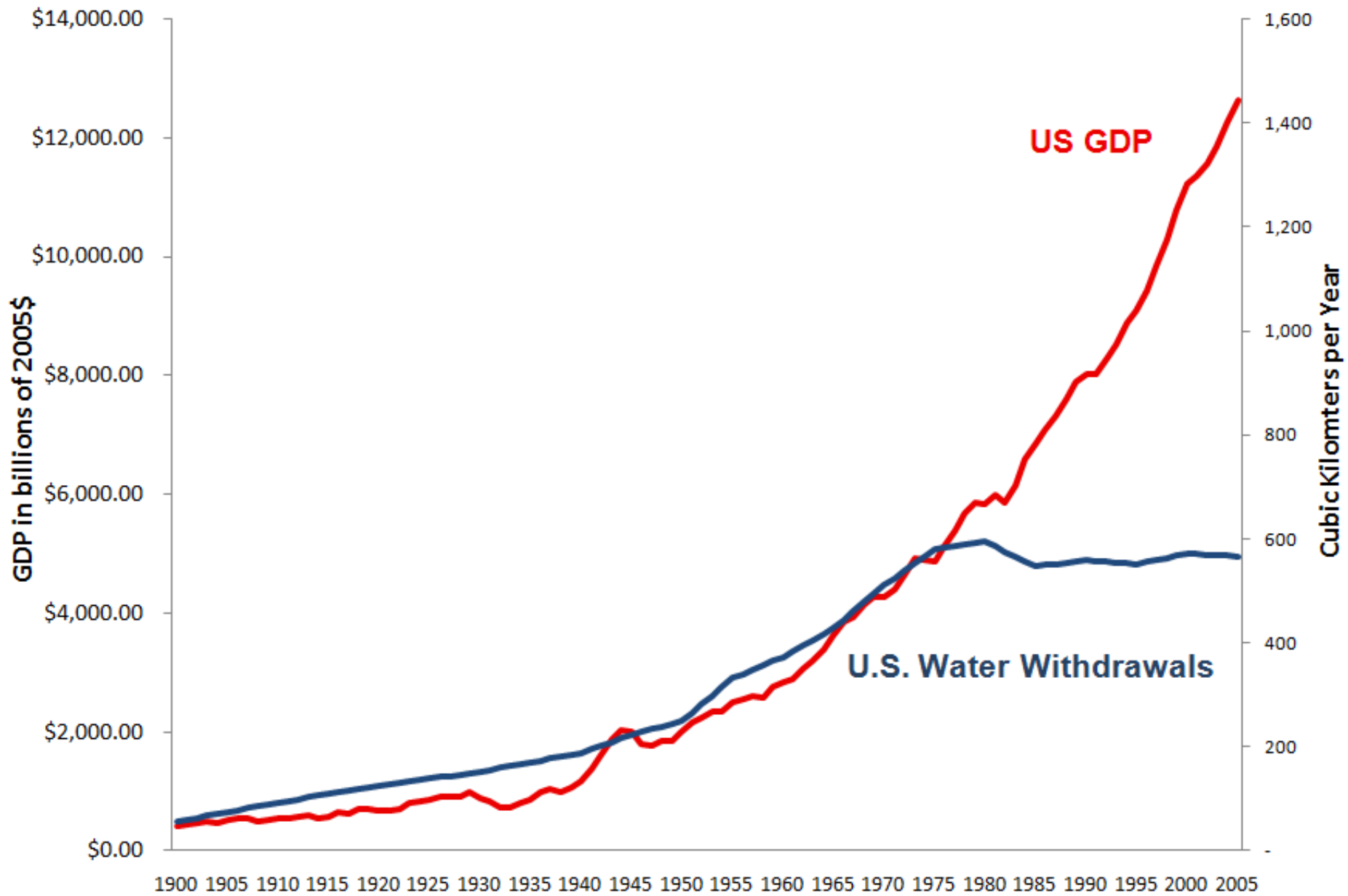
An Early Analysis of Water and Wastewater Adaptation Costs



NACWA, AMWA

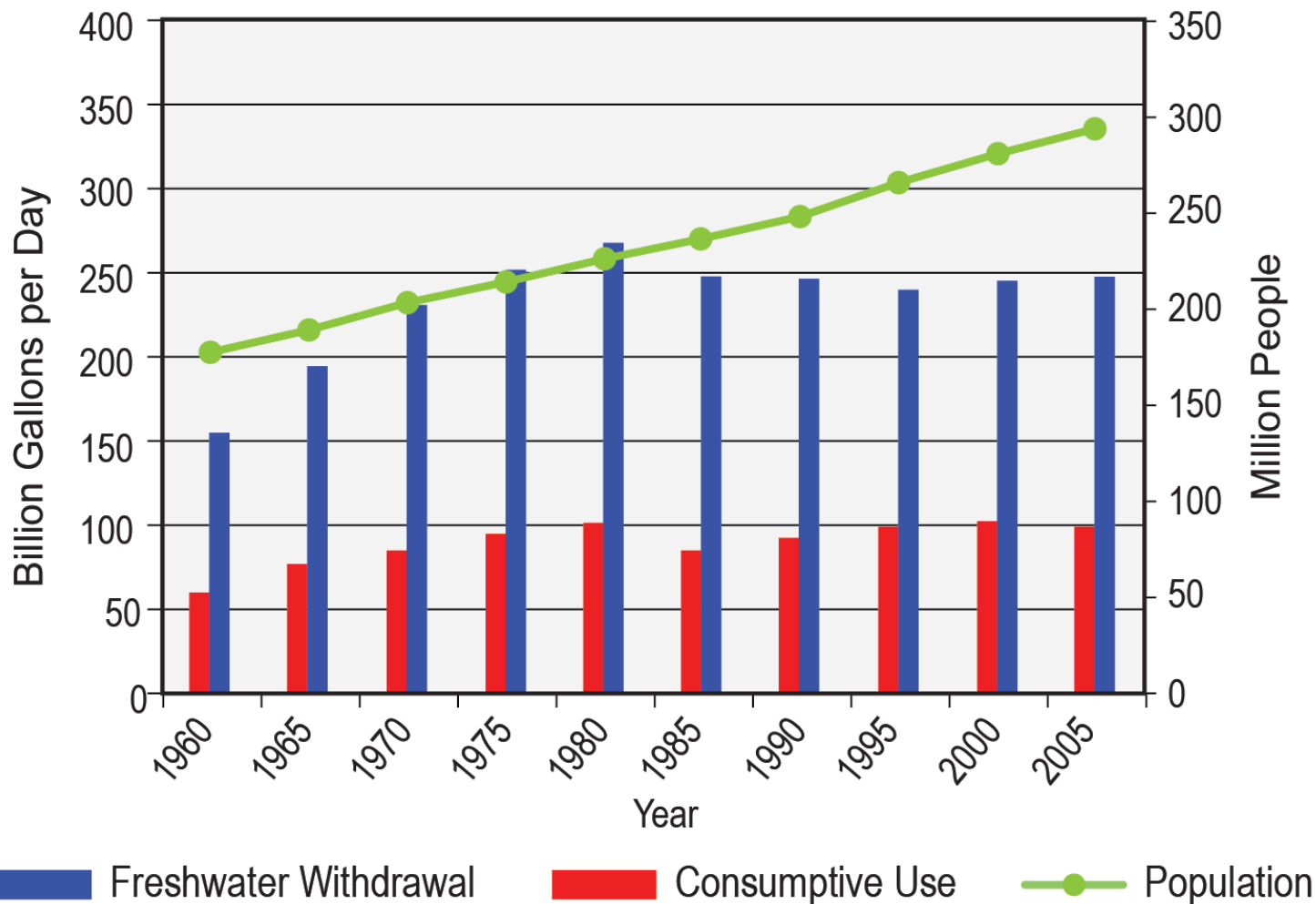
Is it all bad?





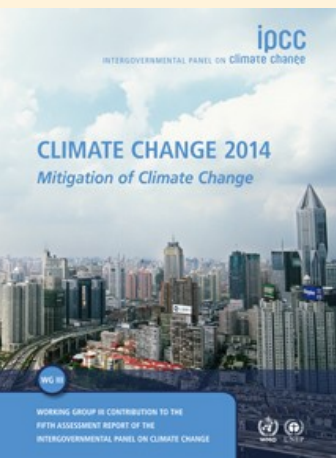
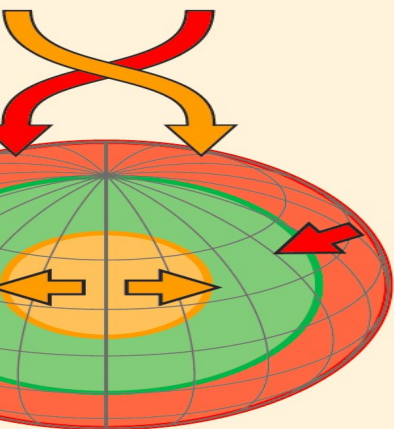
Source: Christian-Smith and Gleick 2012 "A 21st Century US Water Policy." Oxford University Press.

U.S. Freshwater Withdrawal, Consumptive Use, and Population Trends



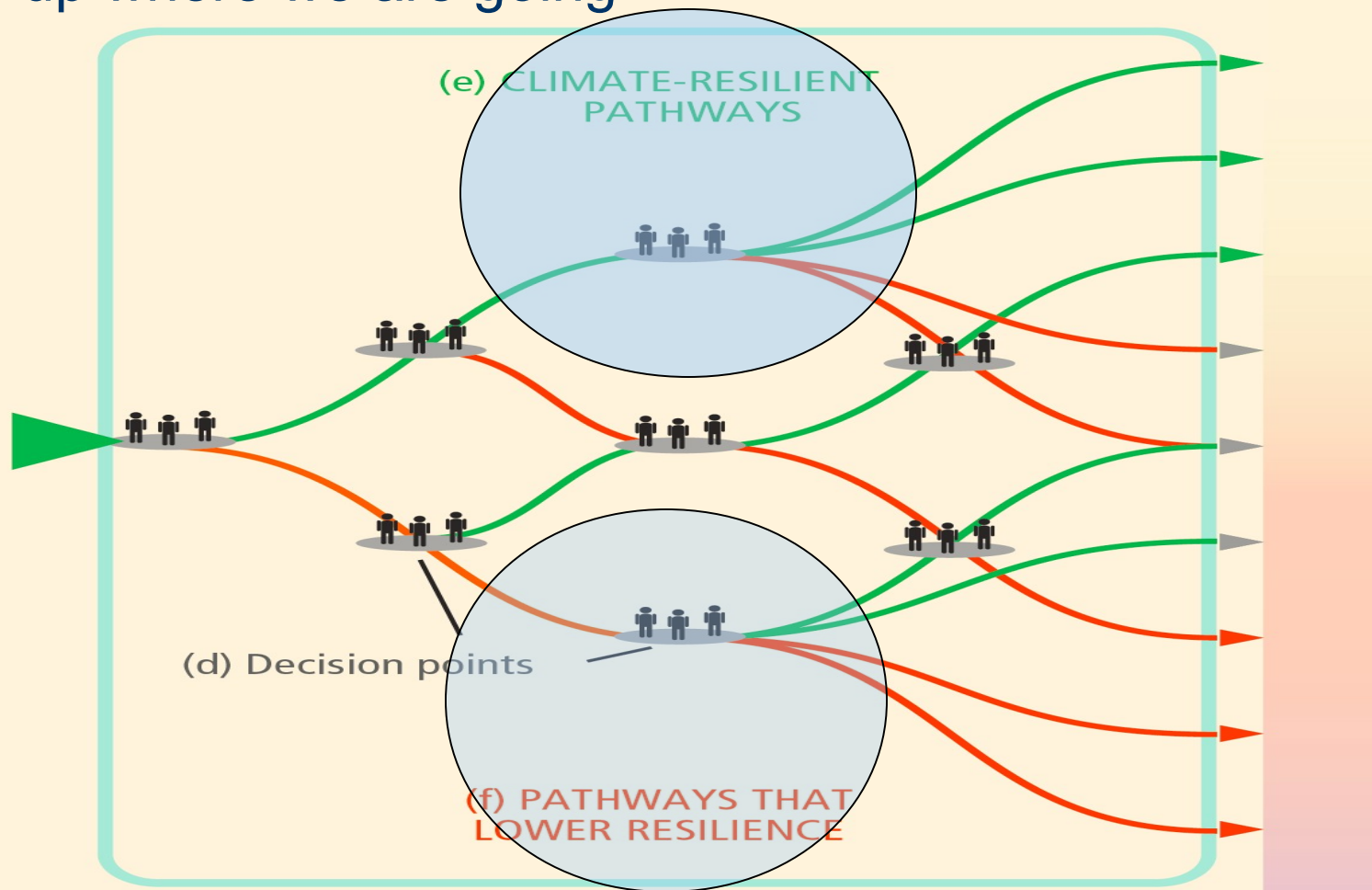
Our world

Multiple stressors including climate change



(b) Opportunity space

“If we are not careful we will end up where we are going”



(d) Decision points

Energy-Water Nexus: Strategic Pillars

Sustainable and Resilient Energy in an Uncertain Water Future

Optimize
freshwater
efficiency
of energy

Optimize
energy
efficiency
of water
management

Enhance
reliability and
resilience of
energy and
water
systems
security

Increase
safe and
productive
use of
nontraditional
water
sources

Promote
responsible
energy
options with
respect to
water

Exploit
productive
synergies
among water
and energy
systems

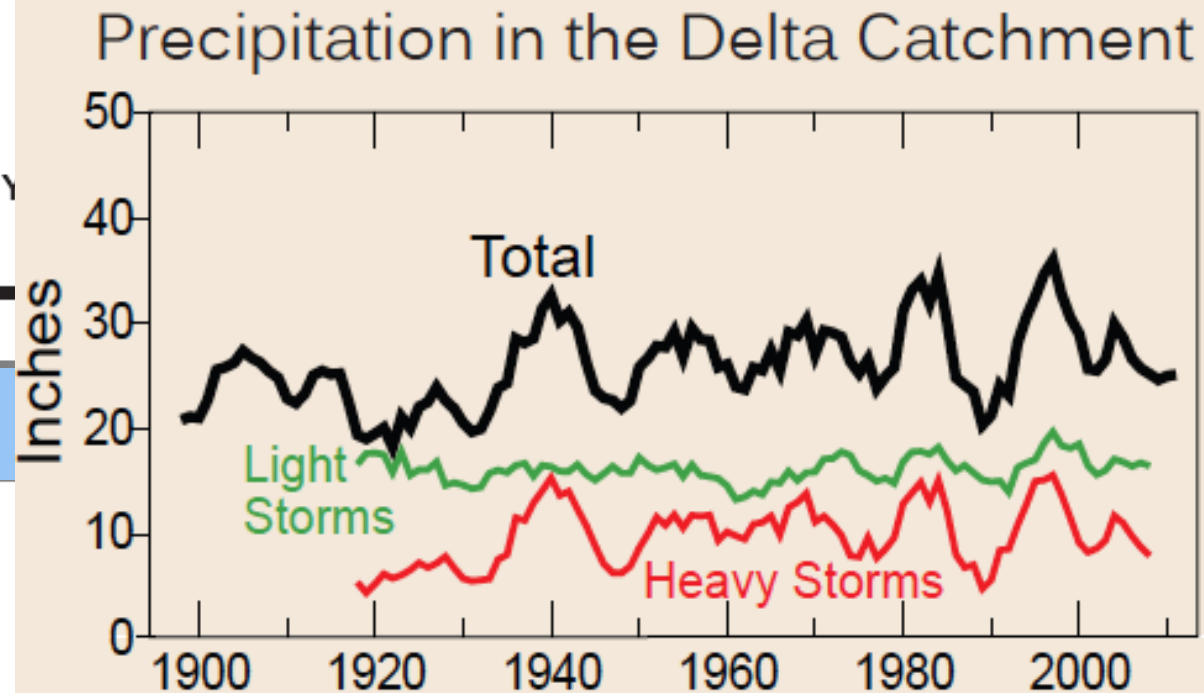
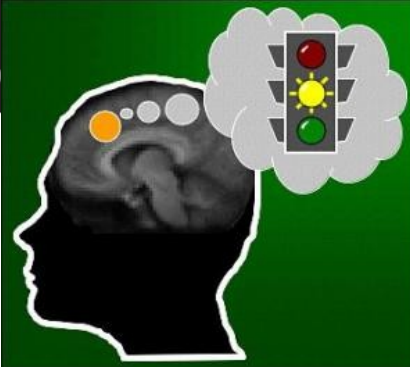
1. Acknowledge the cross-timescale nature of climate and of early warning information

Improved understanding of long-term variations of largest storms- dictate the occurrence of droughts in California

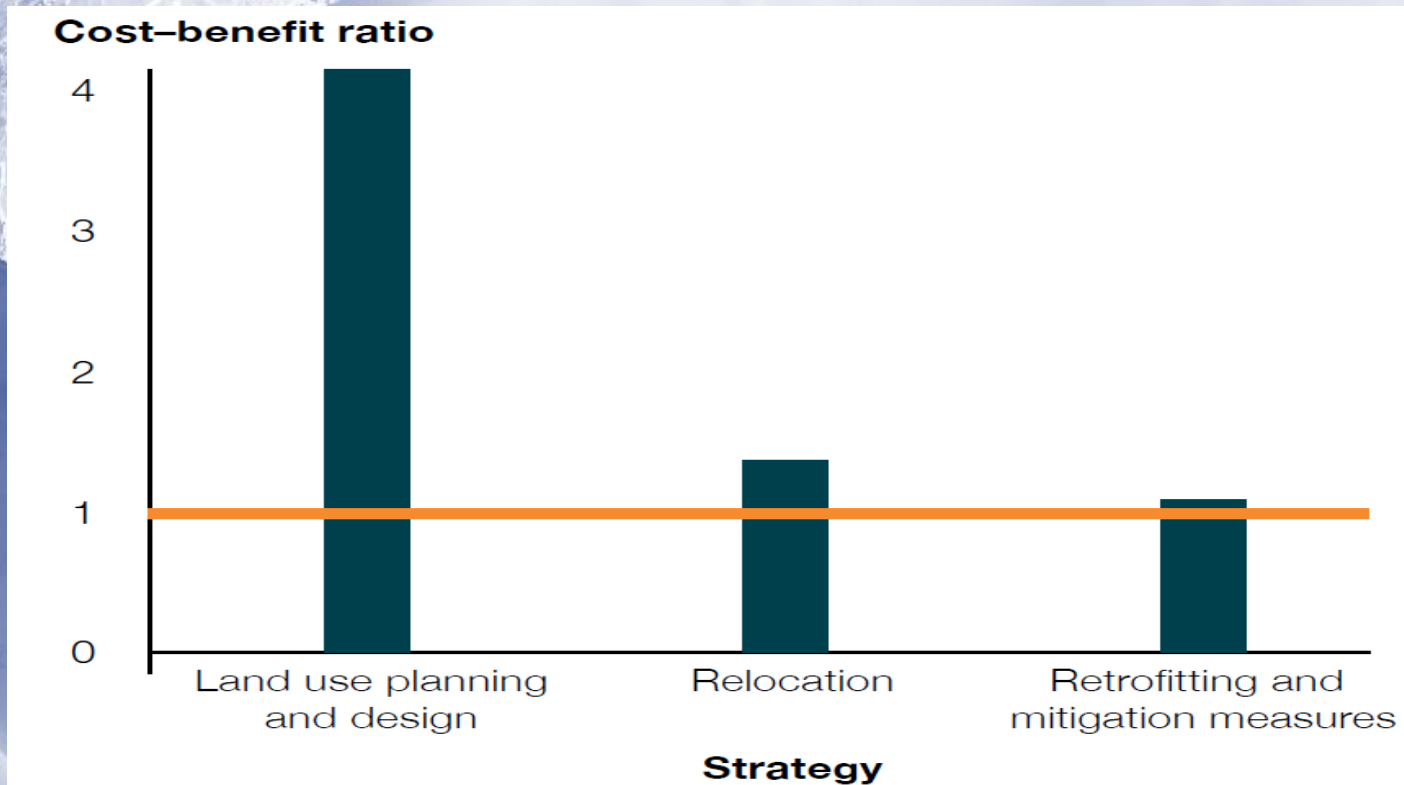
Daily Weather
Forecasts

Seasonal to ~1 Y
Outlooks

Initial
Probl

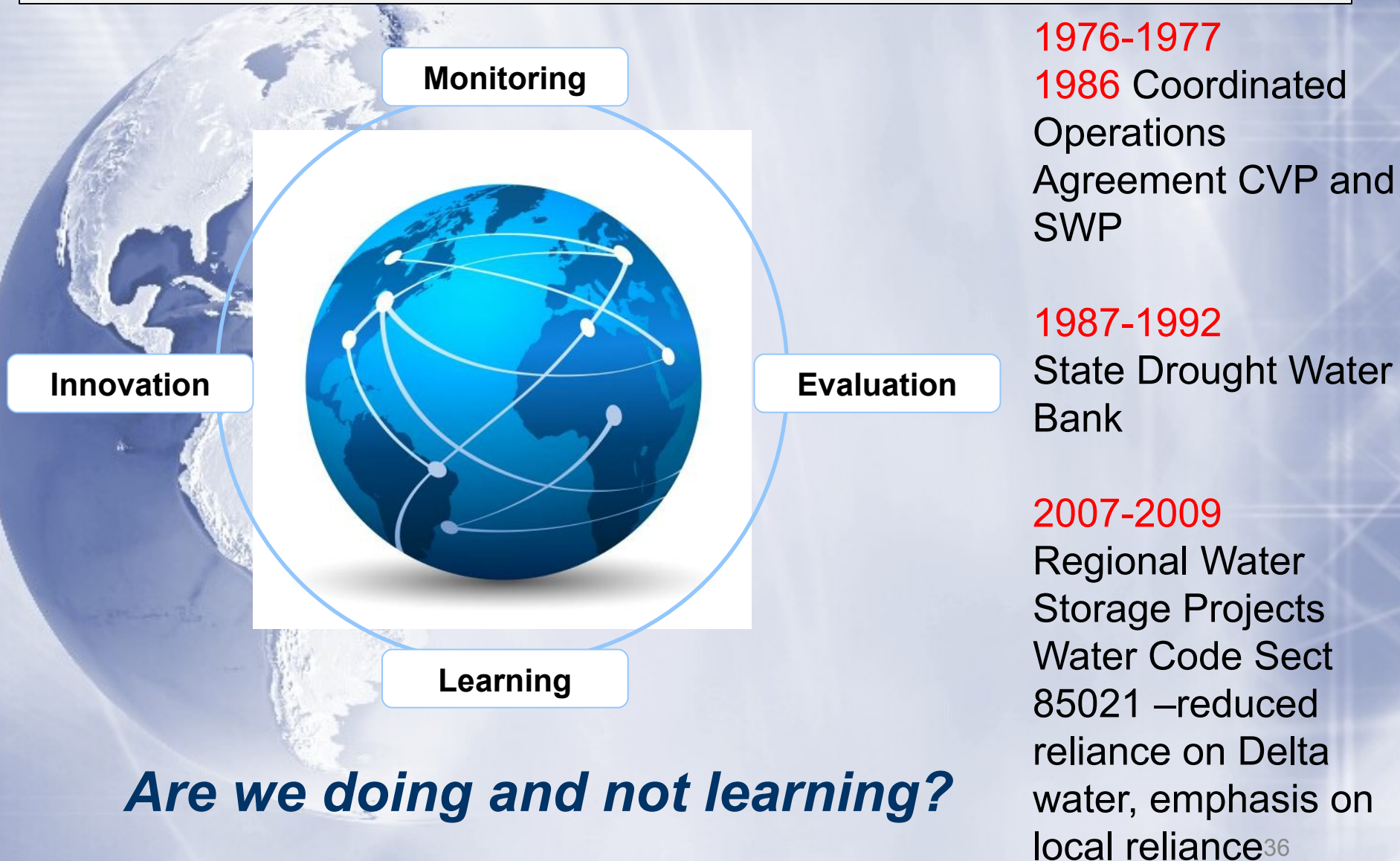


2. Recognize alternative means of addressing water security
Best adaptation practices may be novel configurations of land and water resources- and information to support those decisions

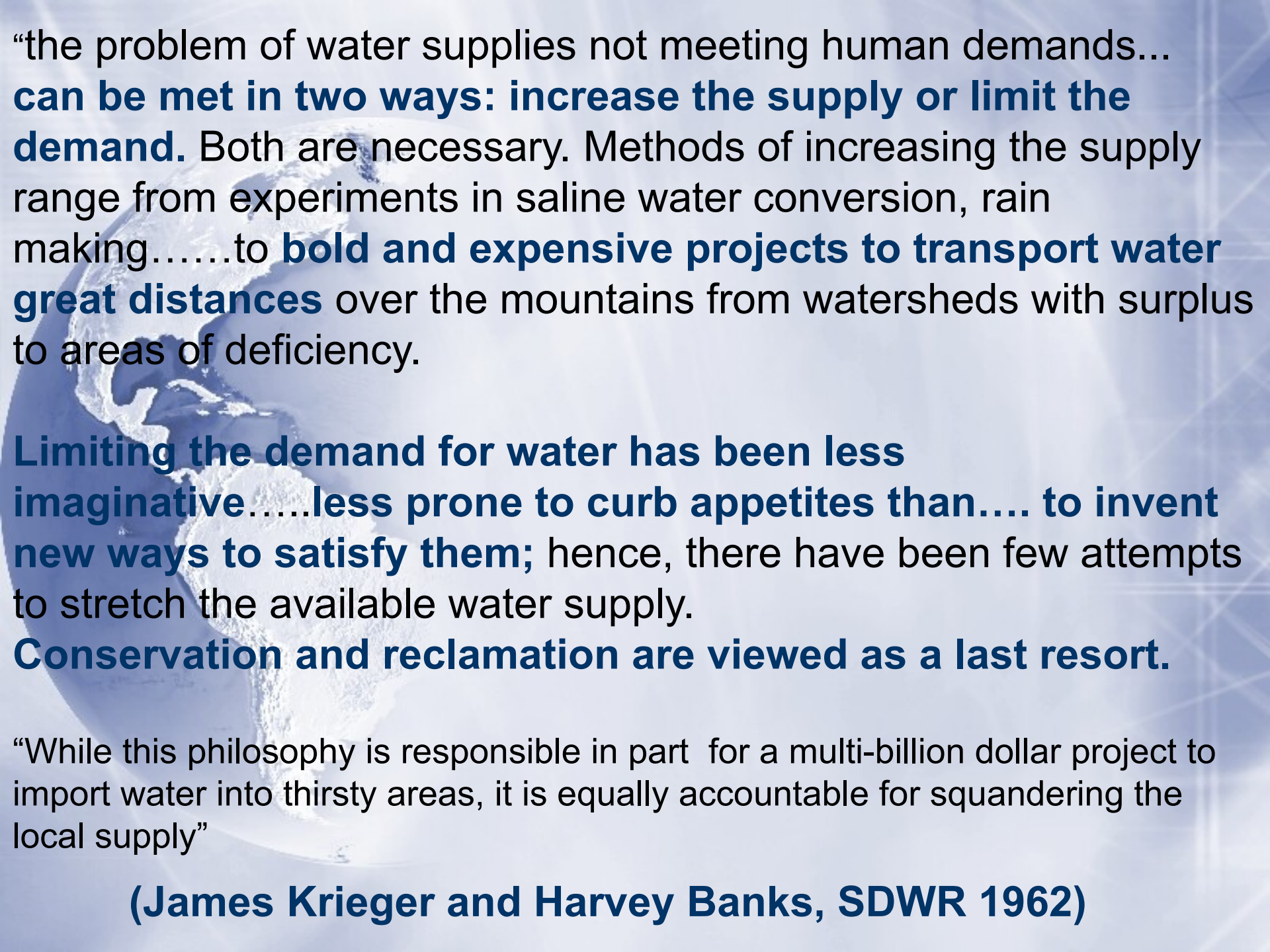


SMART Growth Conservation costs -water obtained by conservation is still the cheapest option per AF for development (Kenney et al 2010)

3. Managing drought-related risks in a changing climate: understanding (and learning) the lessons



Are we doing and not learning?



“the problem of water supplies not meeting human demands... **can be met in two ways: increase the supply or limit the demand.** Both are necessary. Methods of increasing the supply range from experiments in saline water conversion, rain making.....to **bold and expensive projects to transport water great distances** over the mountains from watersheds with surplus to areas of deficiency.

Limiting the demand for water has been less imaginative.....less prone to curb appetites than.... to invent new ways to satisfy them; hence, there have been few attempts to stretch the available water supply.

Conservation and reclamation are viewed as a last resort.

“While this philosophy is responsible in part for a multi-billion dollar project to import water into thirsty areas, it is equally accountable for squandering the local supply”

(James Krieger and Harvey Banks, SDWR 1962)

The fundamental adaptation question:
How often /when should we revise our assumptions?



OVERCONFIDENCE

This is going to end in disaster, and you have no one to blame but yourself.

What can we say about future drought intensity?

Droughts will intensify in the 21st century in some seasons and areas in the West due to reduced precipitation and/or increased evapotranspiration

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

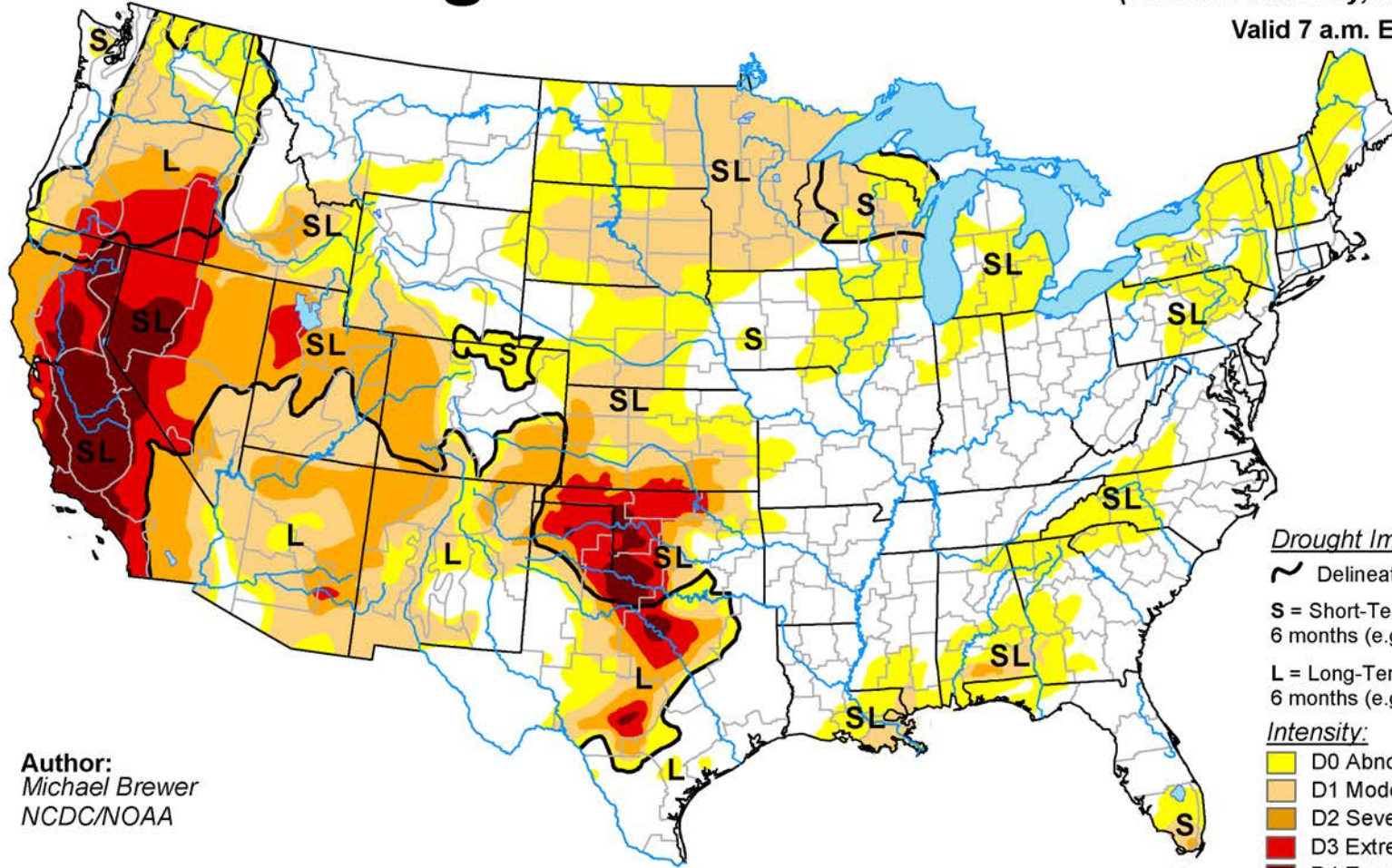
Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality- increases in sediment, nitrogen, and other pollutant loads.

U.S. Drought Monitor

April 14, 2015


(Released Thursday, Apr. 16, 2015)

Valid 7 a.m. EST








Author:
Michael Brewer
NCDC/NOAA

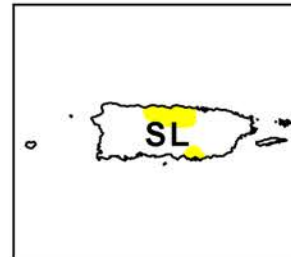
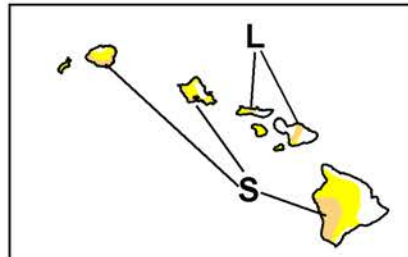
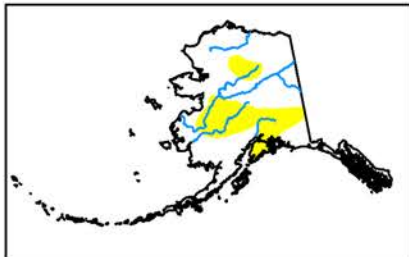
Drought Impact Types:

-  Delineates dominant impacts
- S** = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
- L** = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

Intensity:

-  D0 Abnormally Dry
-  D1 Moderate Drought
-  D2 Severe Drought
-  D3 Extreme Drought
-  D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

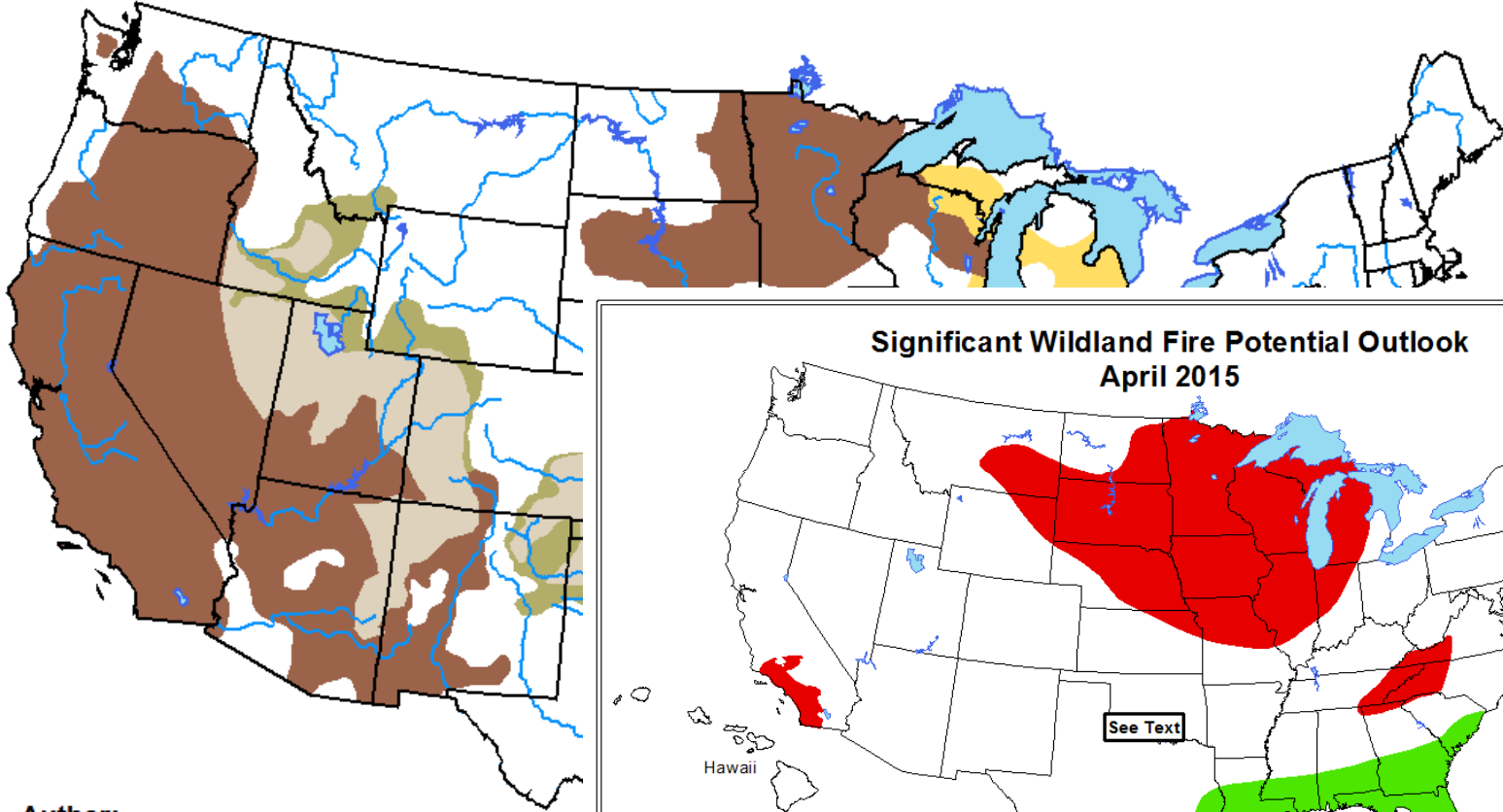


<http://droughtmonitor.unl.edu/>

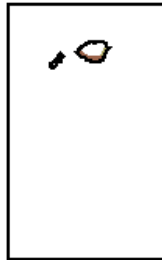
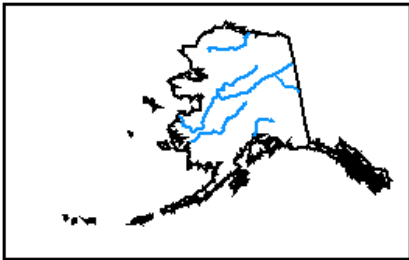
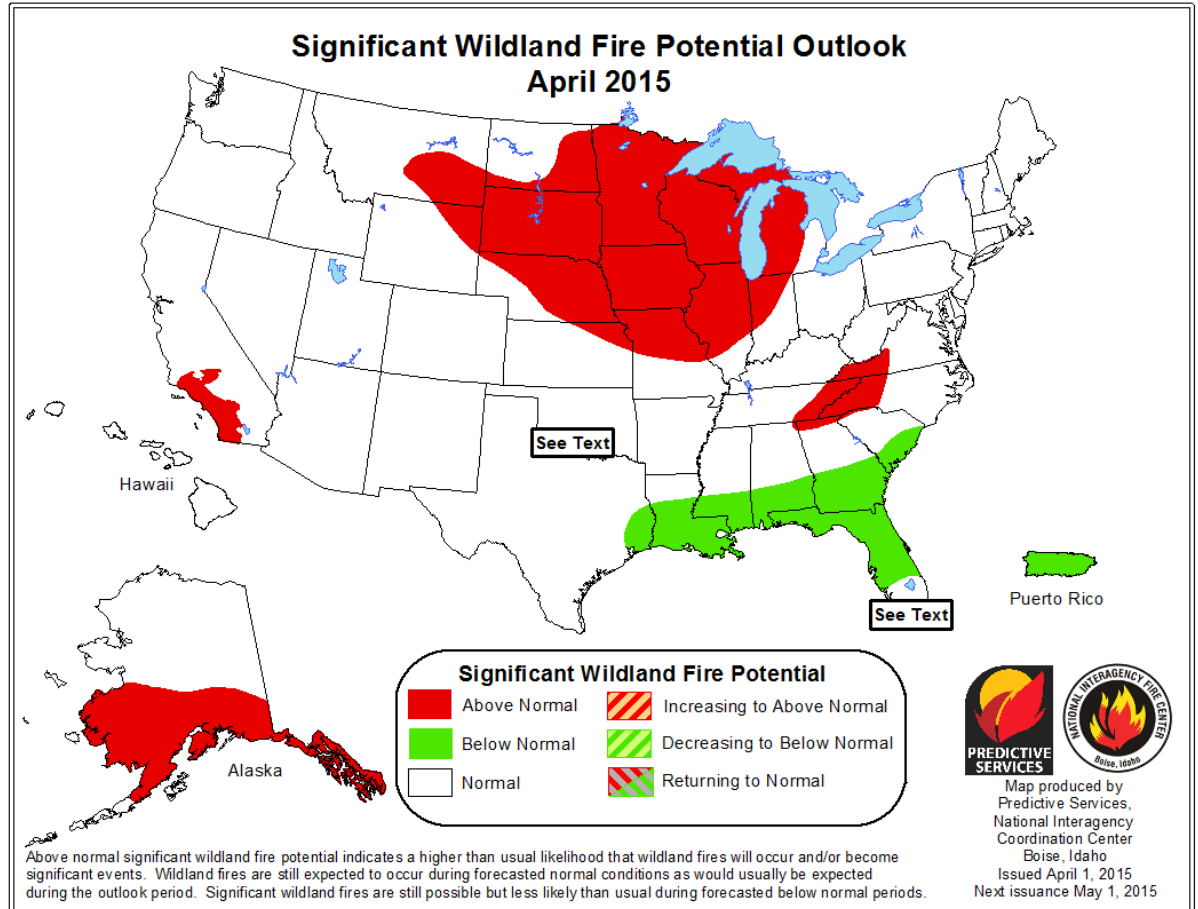
U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid for April 16 - July 31, 2015
Released April 16, 2015



Author:
Rich Tinker
NOAA/NWS/NCEP/Climate Prediction Center



<http://go.usa.gov/hHTe>

Developing Information Systems on Changing Weather and Climate Extremes

- Highlighting the role of rates of change trends, frequency, and magnitude of extremes in the context of planning and preparation



Preparing for Challenges to Water Resources in a Changing Climate

NOAA's Climate Program Office sponsors science and research for a more resilient world.

All regions and economic sectors in the United States depend on adequate and reliable water supplies. Too much or too little water can result in substantial economic and social disruption.

Droughts and floods have cost billions of dollars across the nation. Monetarily, the agricultural sector has been hardest hit, but drought puts significant stress on water use across all sectors.

CPO.NOAA.gov

RESEARCH SPOTLIGHT: CALIFORNIA DROUGHT

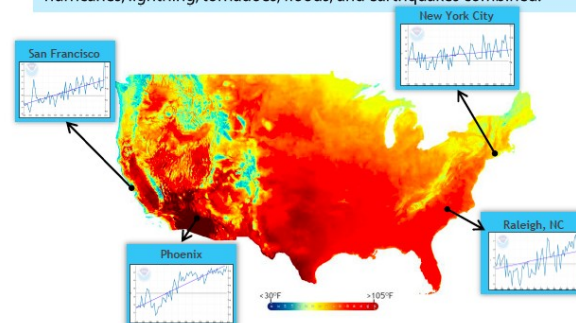


Preparing for Climate and Weather Extremes

Building a National Integrated Heat Health Information System

When an extreme weather or climate event such as heat wave, hurricane, or flood combines with exposure and vulnerability, it can have profound effects on society and the environment, resulting in loss of life, productivity, property, and natural habitat.

From 1979-2003, excessive heat exposure caused 8,015 deaths in the U.S. During that period, more people died from extreme heat than from hurricanes, lightning, tornadoes, floods, and earthquakes combined.



The base map shows projected average minimum temperatures for July 2030 in degrees Fahrenheit under a low emissions scenario (best case scenario). Each call out box shows the city's historical minimum temperature from 1950 to 2015.

Click on Sign to add text and place signatures on a PDF file

CPO.NOAA.gov

INCREASED HEAT WAVES ACROSS THE U.S.



Heat affects urban populations, outdoor and rural workers, and outdoor events and activities.



The latest National Climate Assessment found that extreme

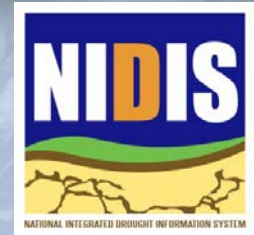
ers have been ia with and ements to preparedness, recovery.

ong NOAA, ia partners are ll predateding it—and focus hand



Thank you

drought.gov



City of Aurora, Colorado

2007

- Wetter
- Demand Management
- Aquifer Mining
- Over-drafting
- Indirect Use
- Ag Leasing /Interruptible Supplies

2010

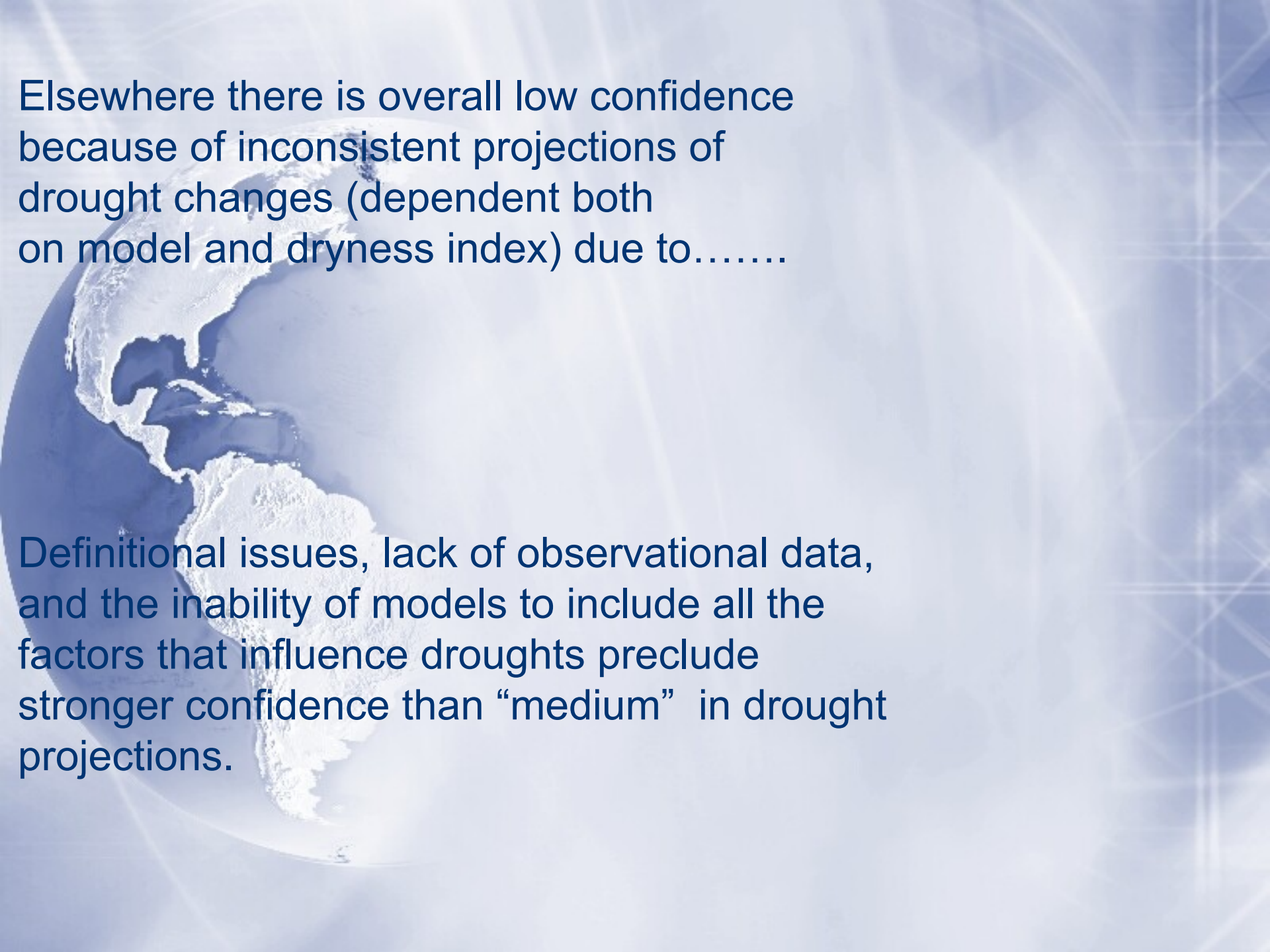
- Wetter
- Demand Management
- Aquifer Mining
- Over-drafting
- Planned Indirect Use /Maximization of Local Water
- Ag Leasing/
Interruptible

2015

- Y2010 +
- Small Trans-basin
- Limited Ag Transfers
- Public Benefit Multi-Purpose

2025

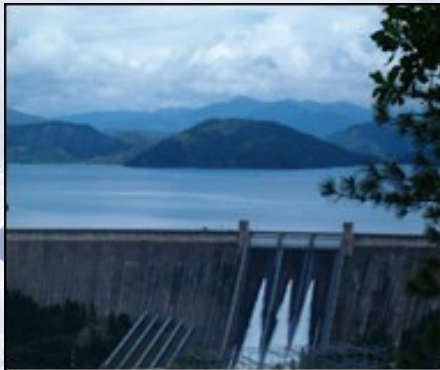
- Y2020 +
- One or Two Regional Trans-basin Projects
- System Integration
- Expanded Re-allocation of Ag Uses
- Planned Indirect Potable Projects



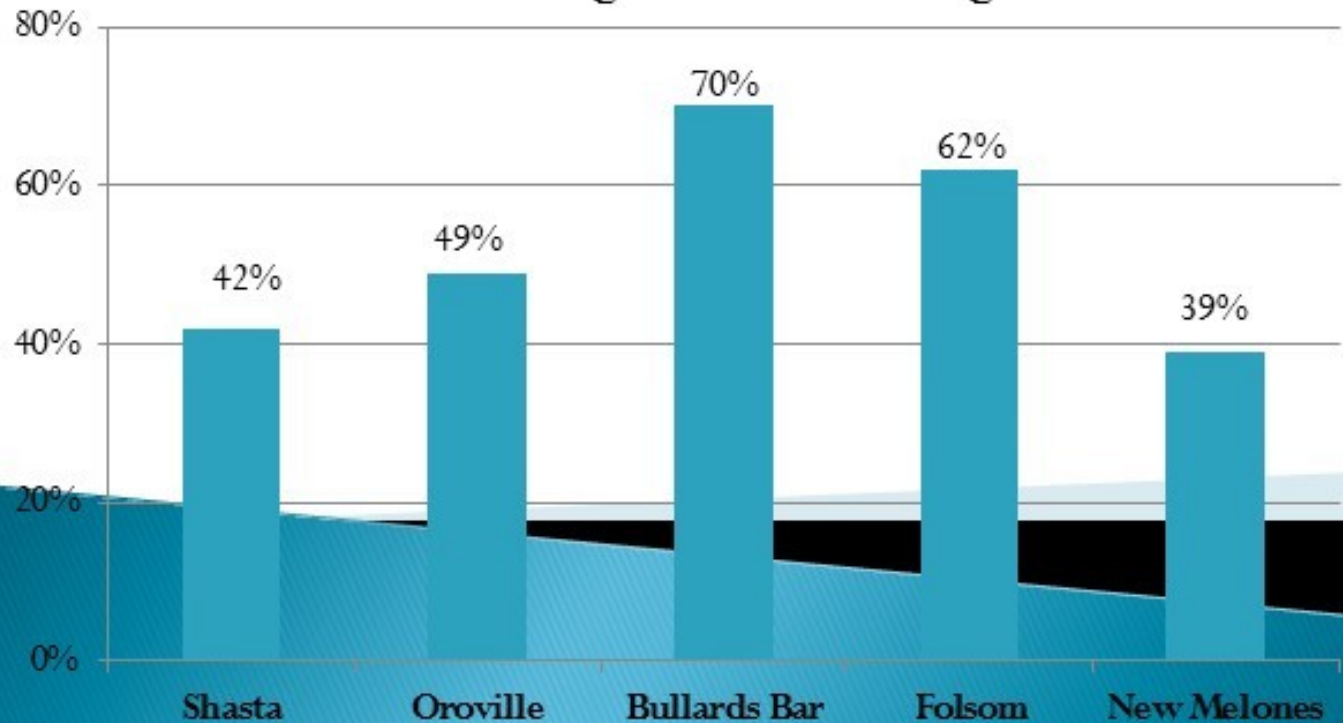
Elsewhere there is overall low confidence because of inconsistent projections of drought changes (dependent both on model and dryness index) due to.....

Definitional issues, lack of observational data, and the inability of models to include all the factors that influence droughts preclude stronger confidence than “medium” in drought projections.

WATER STORAGE



Reservoir Storage Percent of Average for 10/8/2014



Hydrologic Data Courtesy of the California Department of Water Resources



Issued Thursday, Oct 9, 2014 at 10:44 am PDT
National Weather Service - Sacramento, CA



U.S. Drought Monitor
West

How did we get here? Status and antecedent conditions

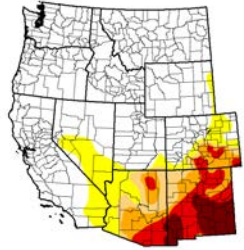
Why has it been dry/drier than normal? Is this drought like others?

What are the impacts and where did they occur?

What information is being provided and by whom?

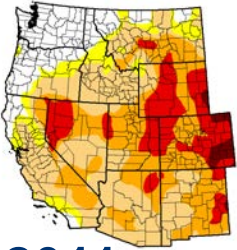
How bad might it get and how long will it last?

How are we planning for this year and for longer-term risks and opportunities?



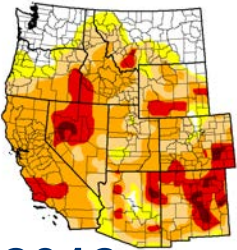
2010

U.S. Drought Monitor
West



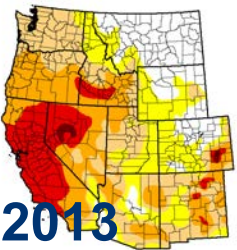
2011

U.S. Drought Monitor
West

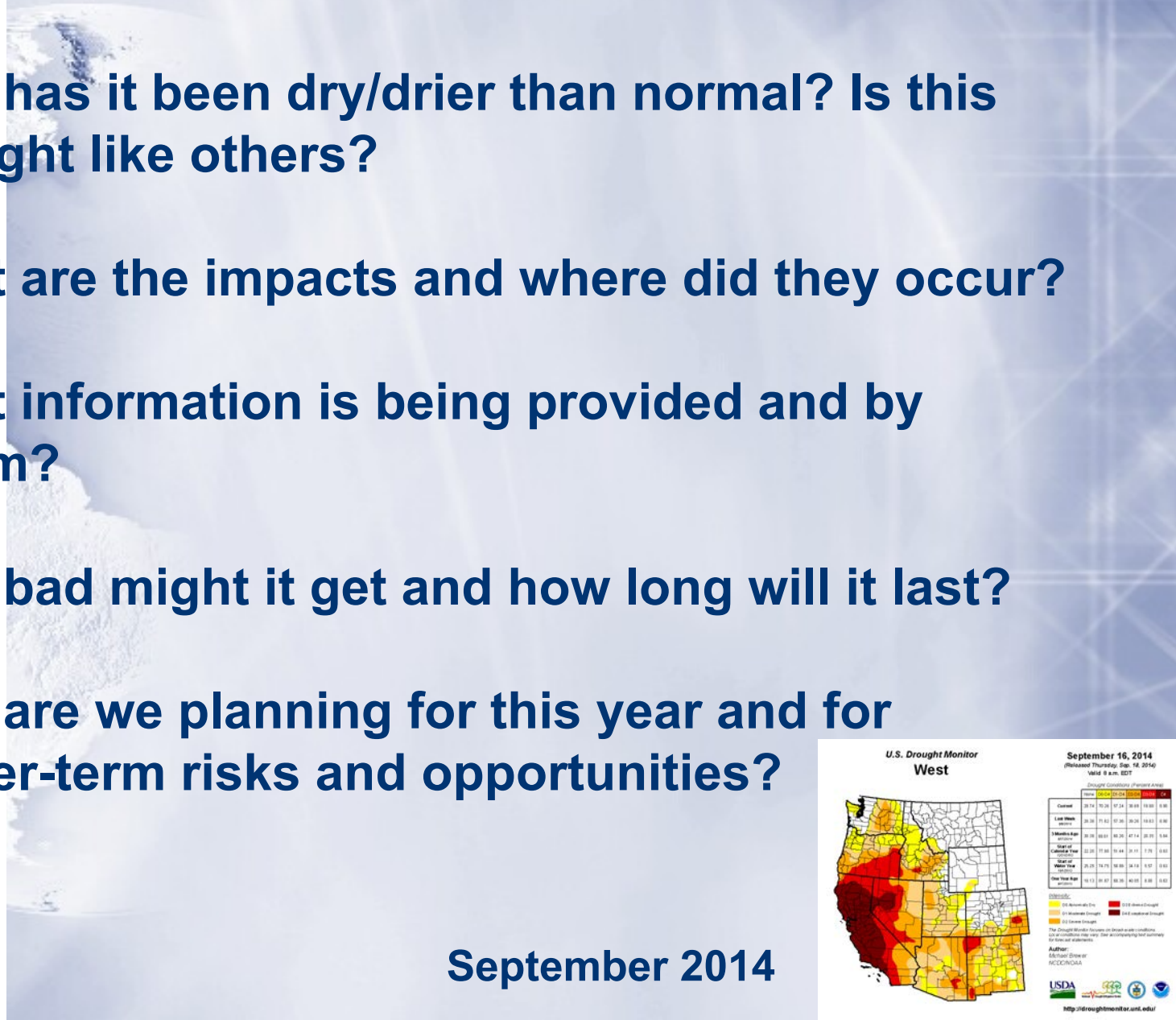


2012

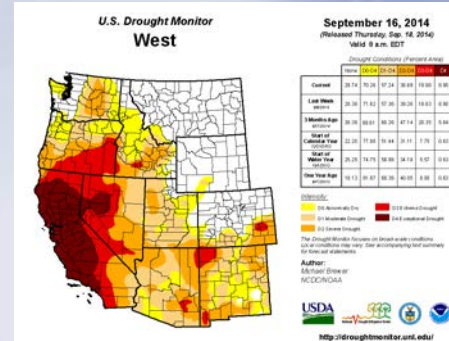
U.S. Drought Monitor
West



2013



September 2014



Climate Division CA Precipitation Anomaly Winter (black) and Lowpass (magenta)

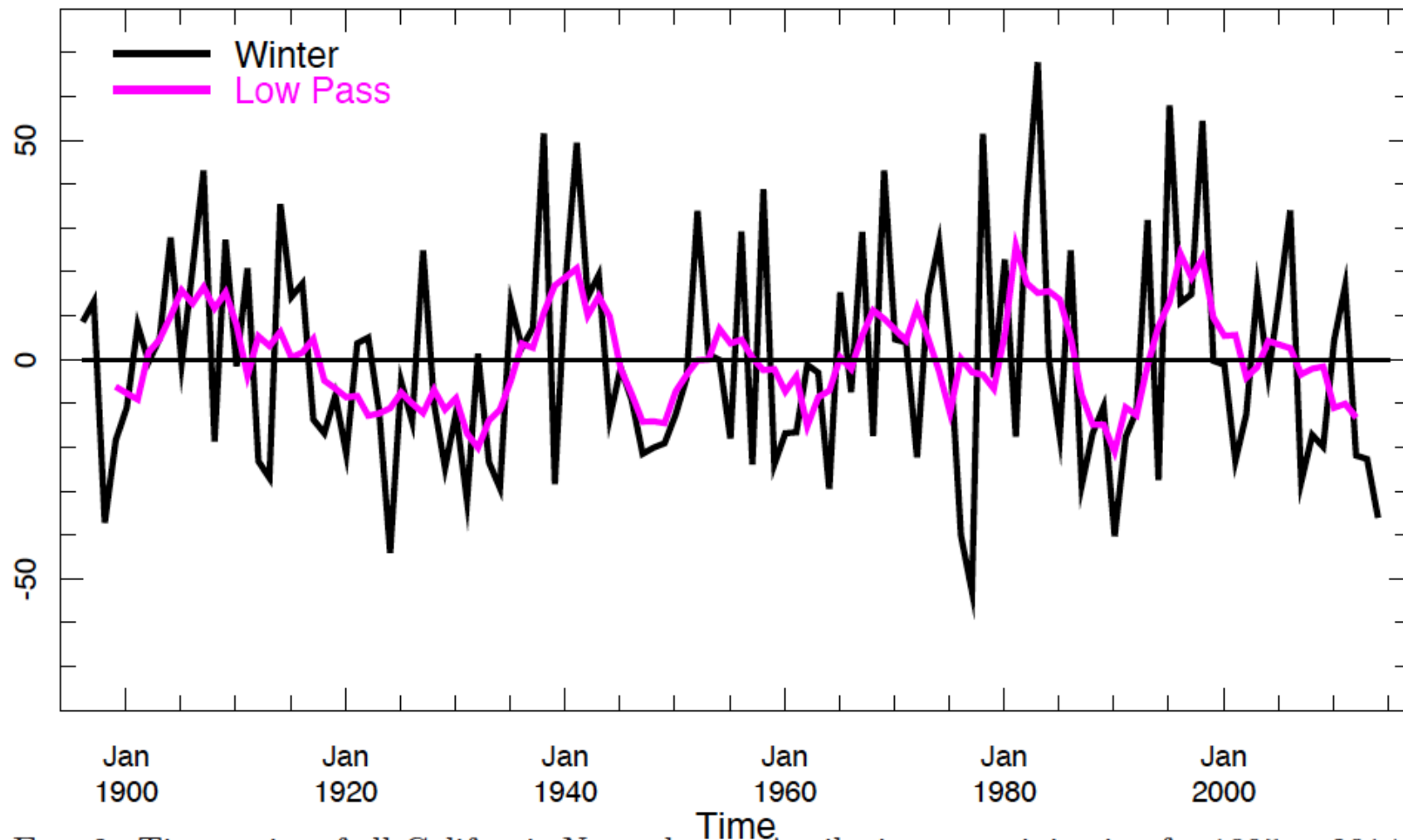


FIG. 2. Time series of all-California November to April winter precipitation for 1895 to 2014 and the same after low-pass filtering with .

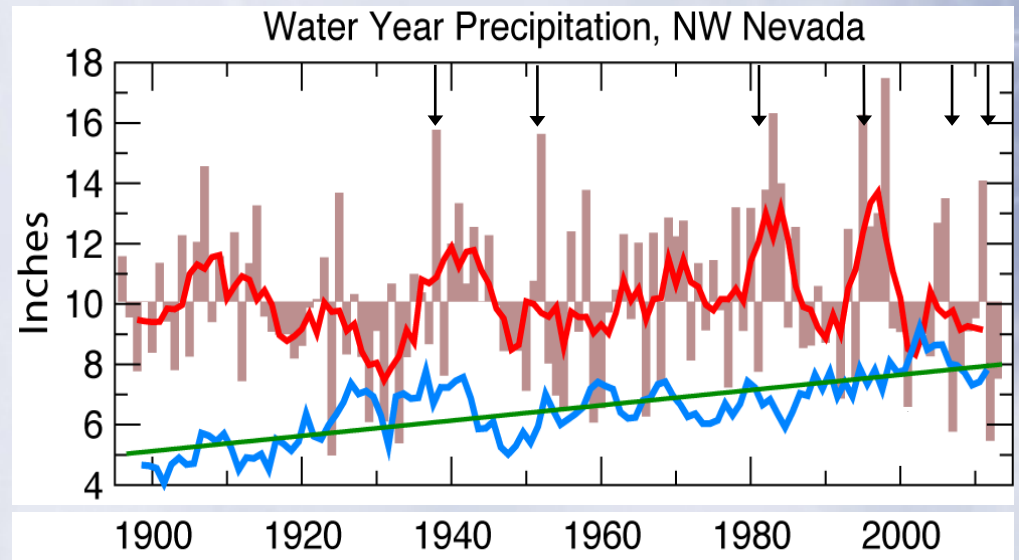
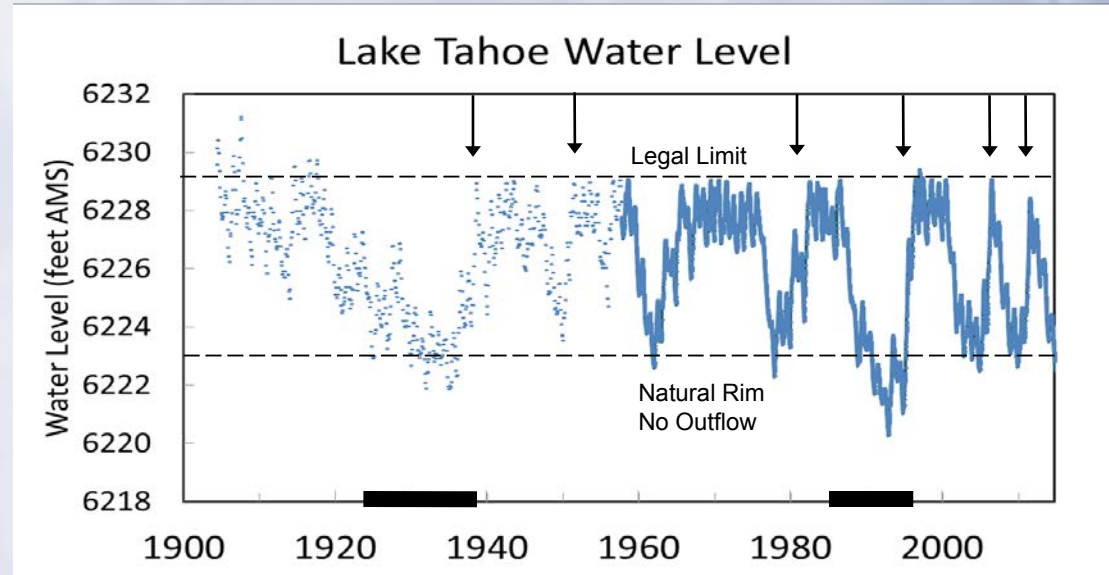
Modern



Medieval

Lake Tahoe Recent Drought History

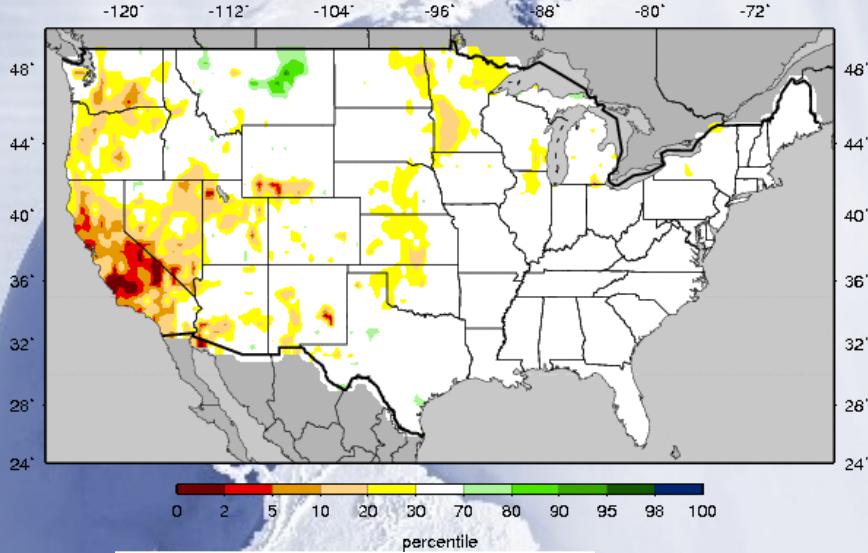
- Water levels in Lake Tahoe are good indicators of persistent hydrologic droughts
- Many years in a row of no outflow into Truckee River (30s & 90s)
- Lower water levels in the 90s than in 30s due to increased demands
- **One very wet winter can break a persistent drought in the region**
 - Need many very wet winters for reservoirs with large storage deficits (i.e. Lake Mead)



Forecasts for May 2015

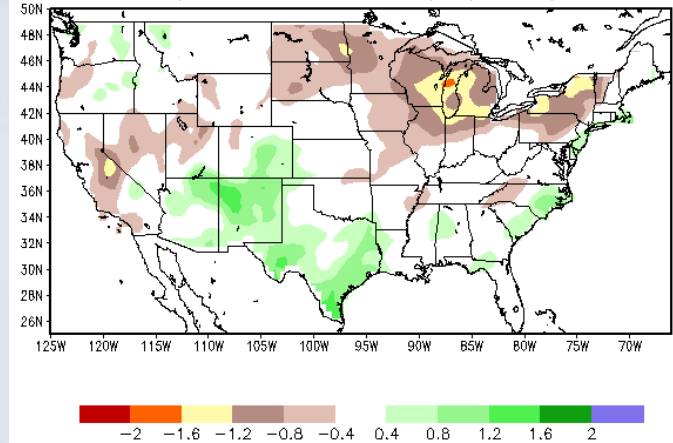
ESP UW

Initialized 20150403 -- 2 month lead



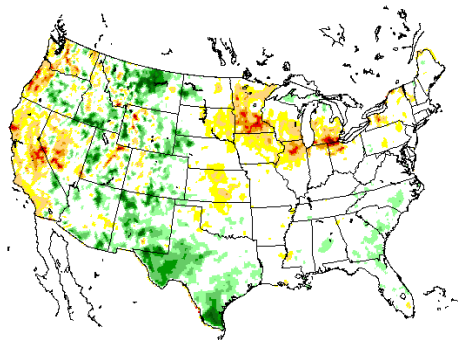
SPI6

c) Ensemble Mean (May2015)



Princeton-MSU-EMC

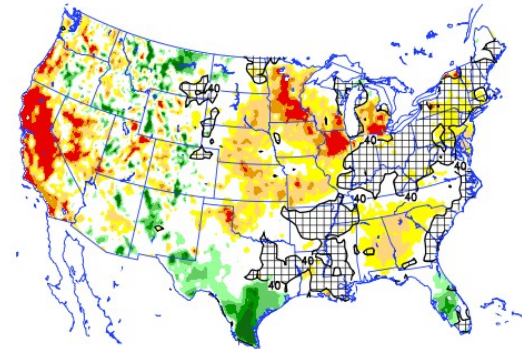
Experimental Drought Estimates based on CFSv2 Forecast
Total Column Soil Moisture Percentiles (Median of Full Ensemble)
MAY2015 (init: 201504)



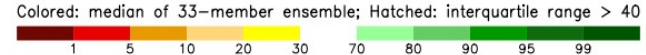
Tue Apr 7 09:31:06 EDT 2015

MSU

Predicted Monthly Soil Moisture Percentile in 201505
(wrt samples in 1979-2011)



CFSv2-VIC-based ensemble forecast initialized on 20150327
Colored: median of 33-member ensemble; Hatched: interquartile range > 40



2015-03-31-18:55

