Thriving During Climate and Water Change: Strategies for the 21st Century

Defining the New Normal
33rd Annual Executive Briefing
Water Education Foundation
March 17, 2016
Sacramento, CA

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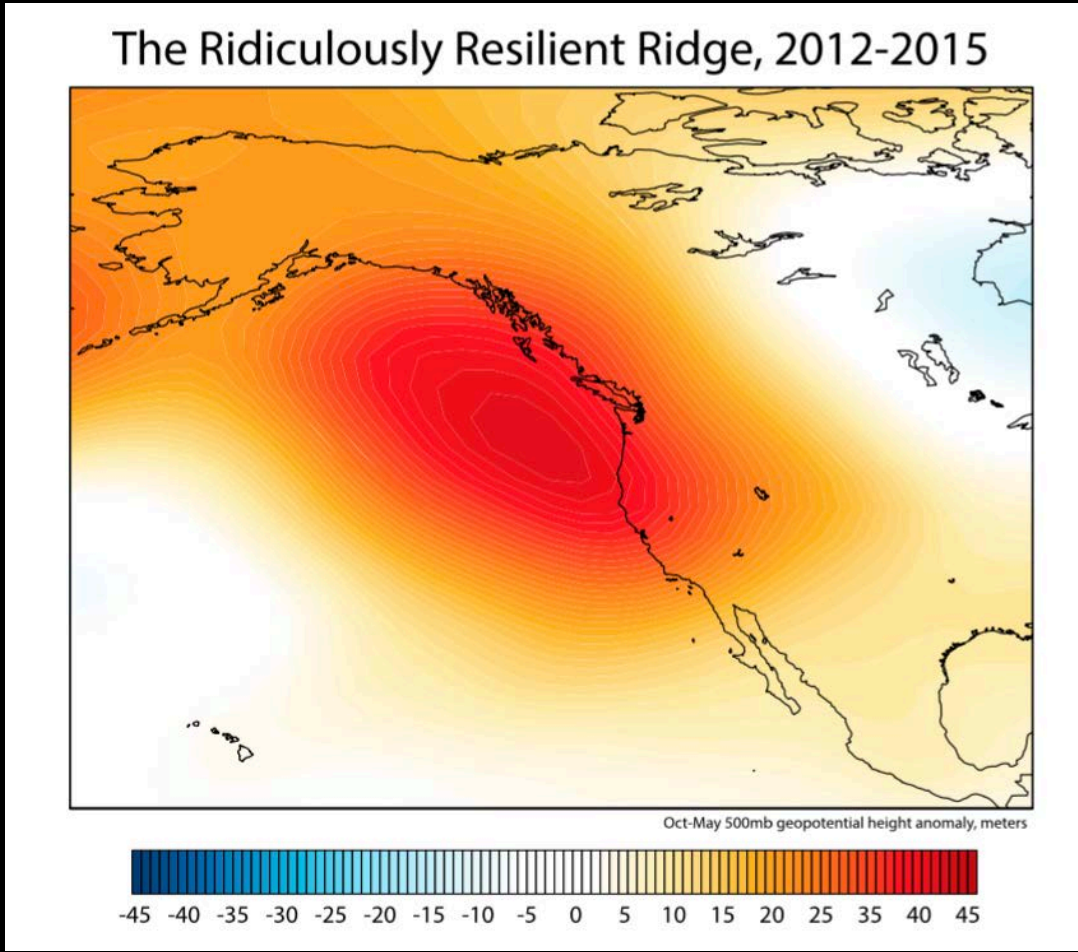
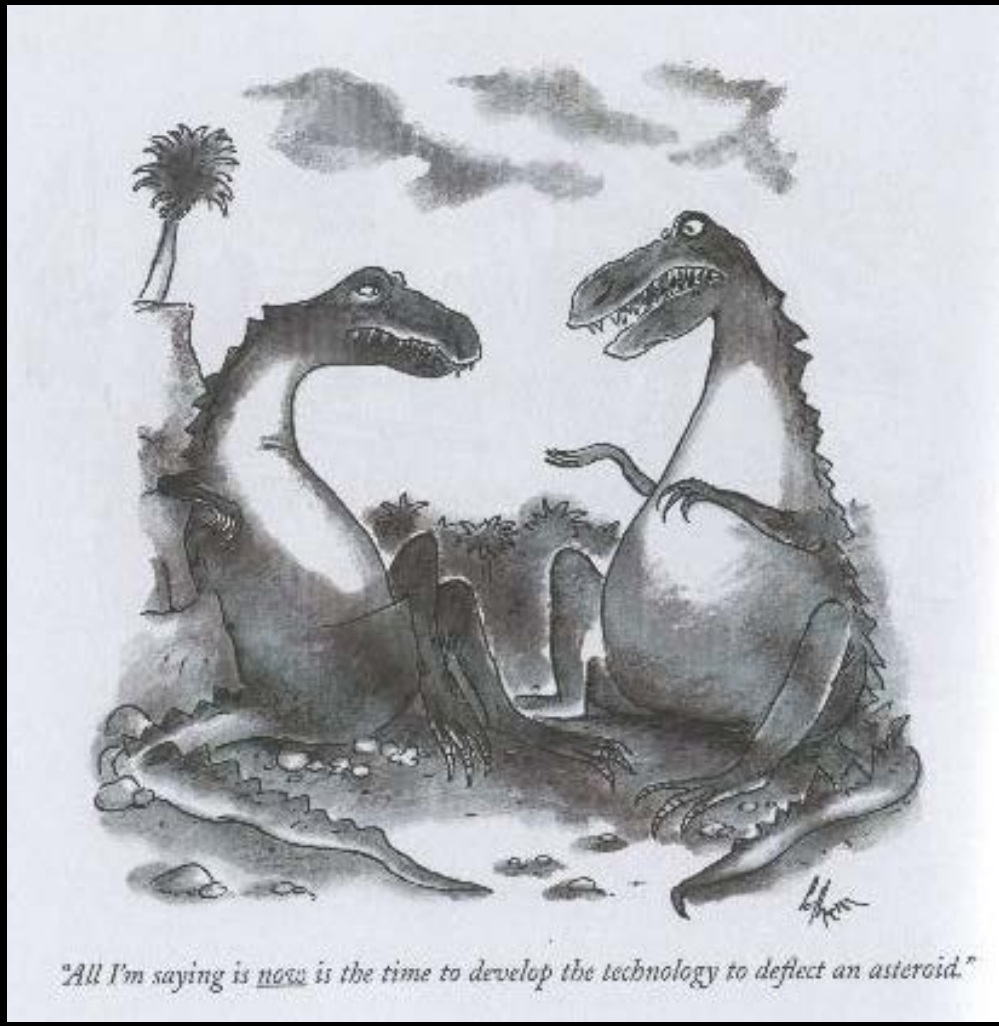


*Outline

- Climate Change Science
  - Climate Change is Water Change
- Recent Climatology
- California, Colorado Droughts
  - Temperature Linkage
  - Megadroughts
- Reasons for Optimism
  - Paris
  - US
  - Technology, Economics
- Some Strategies



"All I'm saying is now is the time to develop the technology to deflect an asteroid."

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

(Manuscript received 6 June 1974, in revised form 8 August 1974)

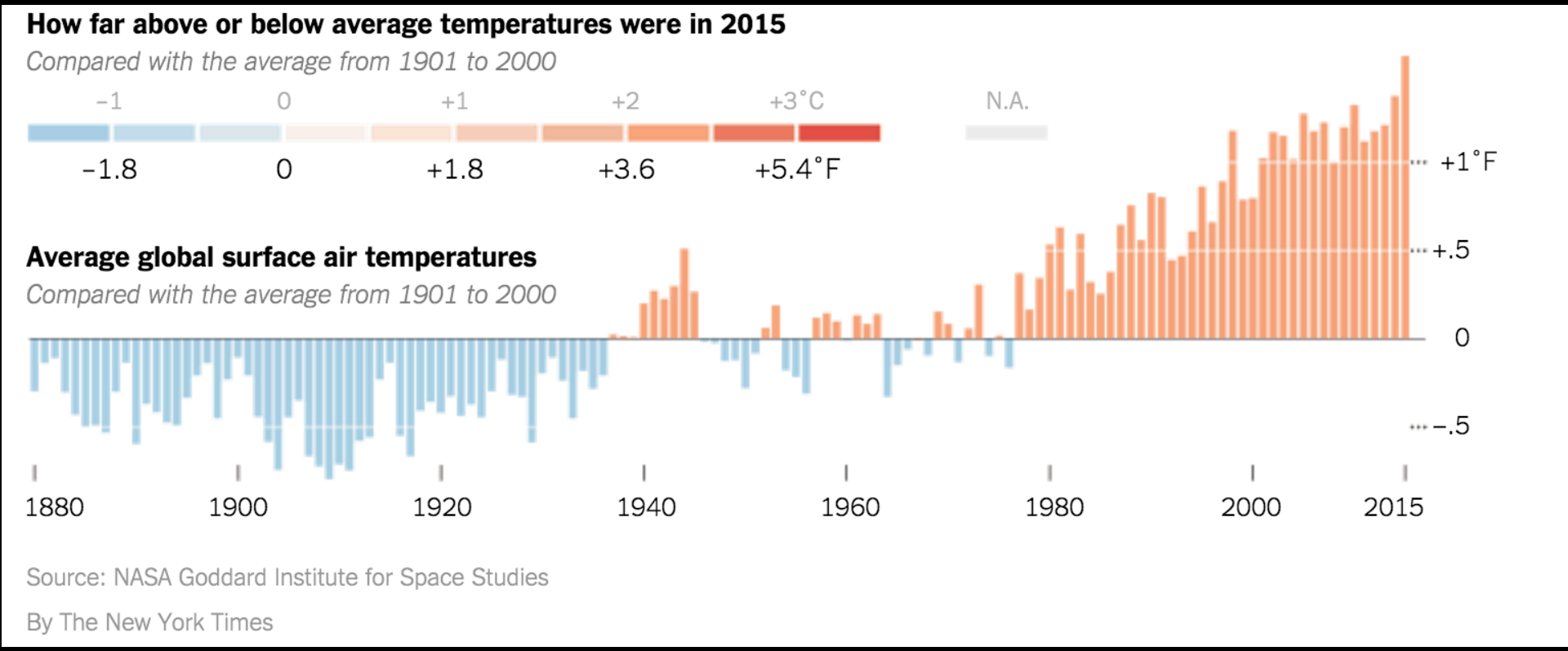
ABSTRACT

An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

SCIENCE

2015 Was Hottest Year in Historical Record, Scientists Say

By JUSTIN GILLIS JAN. 20, 2016



- Back to Back Records 2014, now 2015
- No ‘Pause’ or ‘Hiatus’
- Accelerating Trend?

American Geophysical Union Fall Meeting – San Francisco

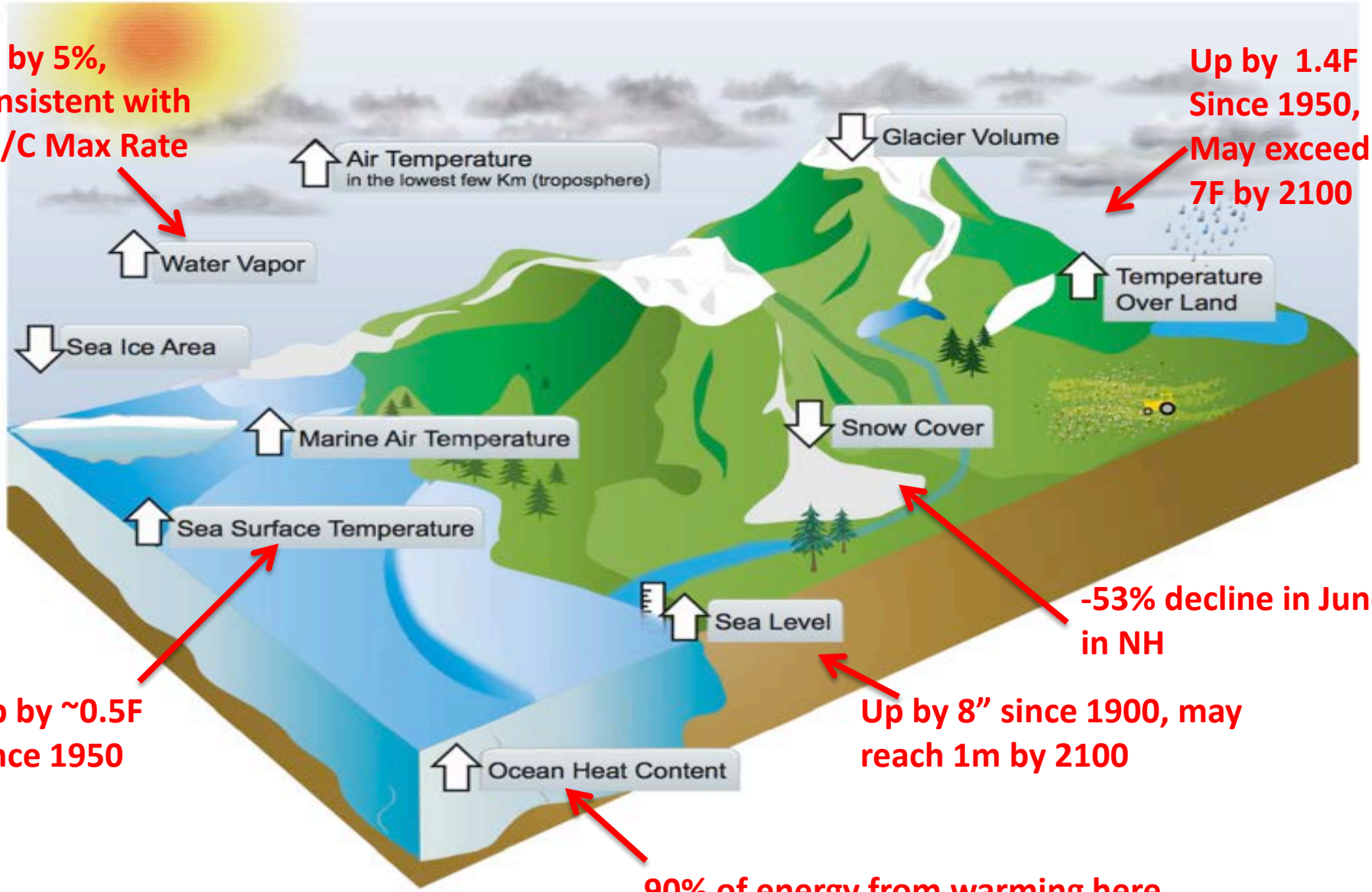
- December every Year
- 24,000 Earth Scientists
- Fully Accepted Science
  - Earth is Warming
  - Humans are the Cause
  - Very Risky to Burn
  - Carbon unabated
  - Water Cycle will be
  - Impacted
- Theory vs “Belief”

Climate Change is Water Change

- Heat Drives the Water Cycle –
  1000 km3 evaporates daily from the oceans

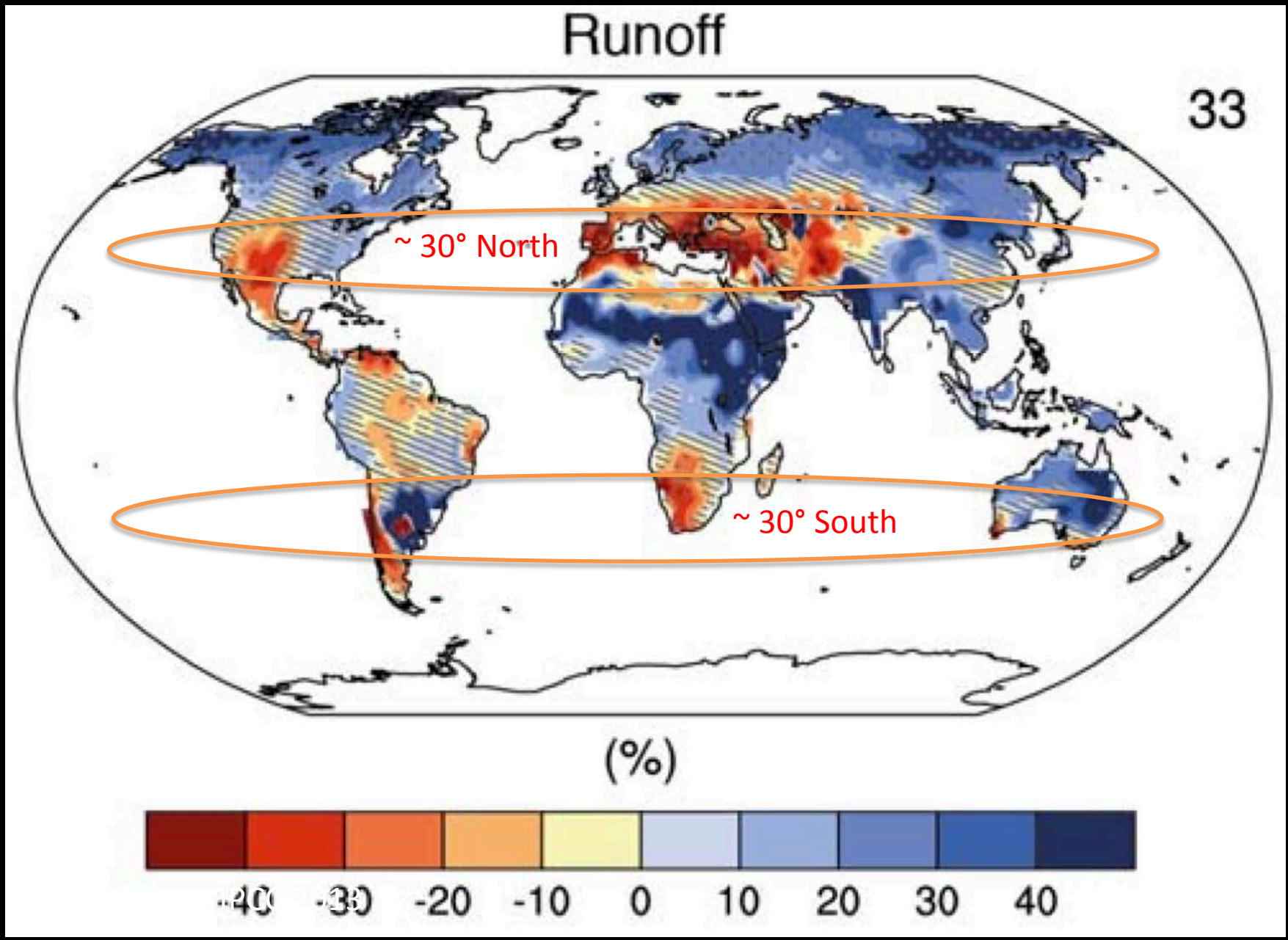
- The Water Cycle mixes heat from areas of too much to too little
- As the Atmosphere Warms it Holds More Moisture:
  ~5F warming is 20% increase
- Heating Up the Earth (and uneven heating) results in Water Cycle changes
  - More Evaporation, More Precipitation, More Moisture
  - Changes in weather patterns
  - Wet Wetter, Dry Drier Standard Rule
  - More Intense Floods and Droughts
- All Kinds of Water Changes Already Noted
  - More rain/less snow, Earlier Runoff, Higher Water Temps, More Intense Rain

IPCC: All Kinds of Observations are Consistent with Climate Change Expectations. 7 out of 10 are water cycle related here…

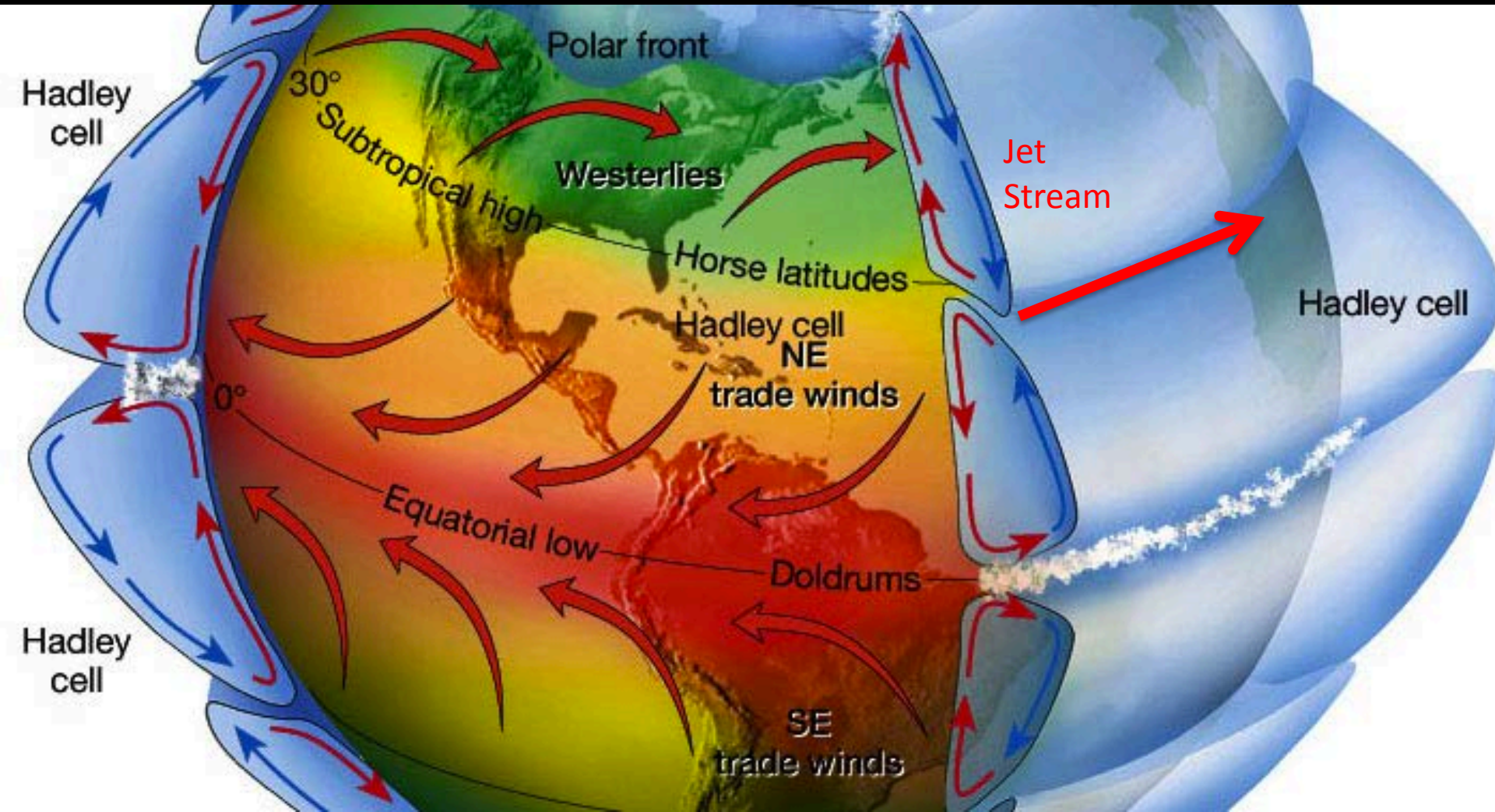


Projections for 2081 to 2100

Precipitation is not runoff!



Hadley Cells



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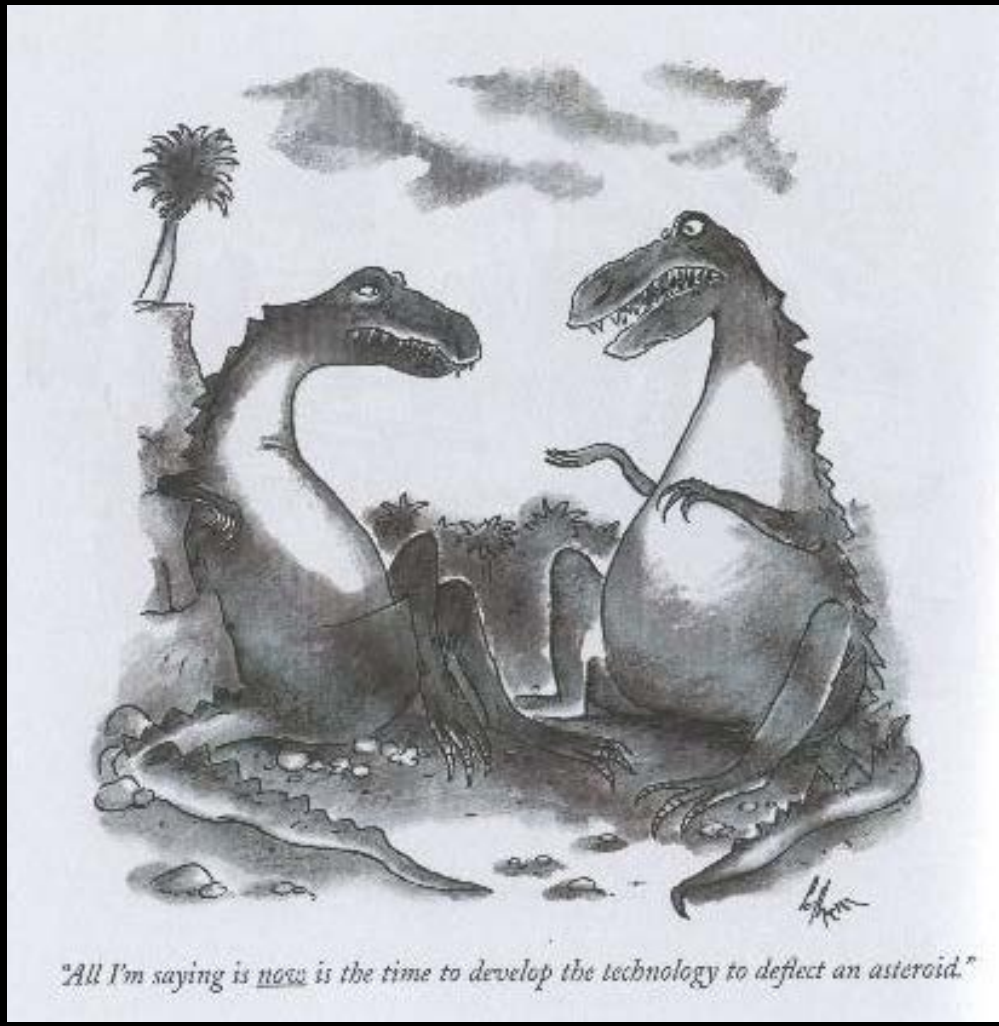
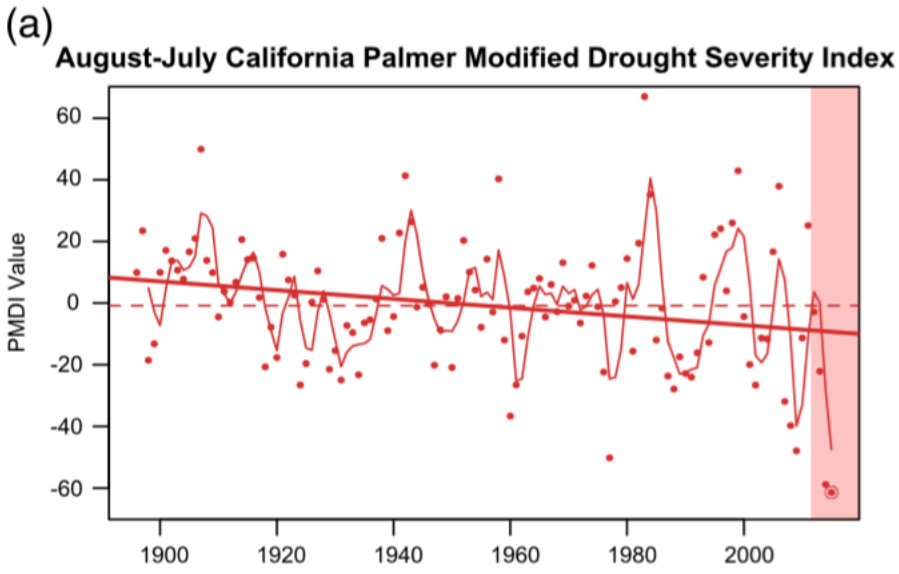
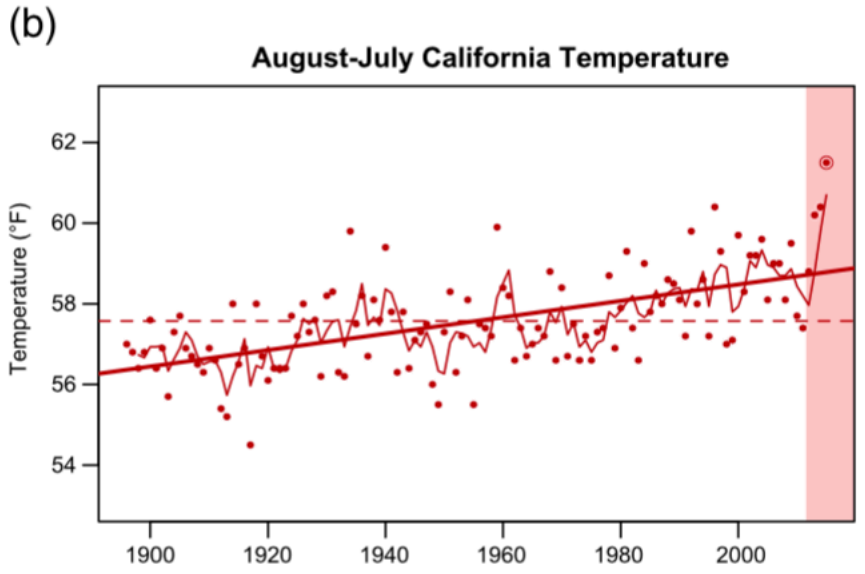
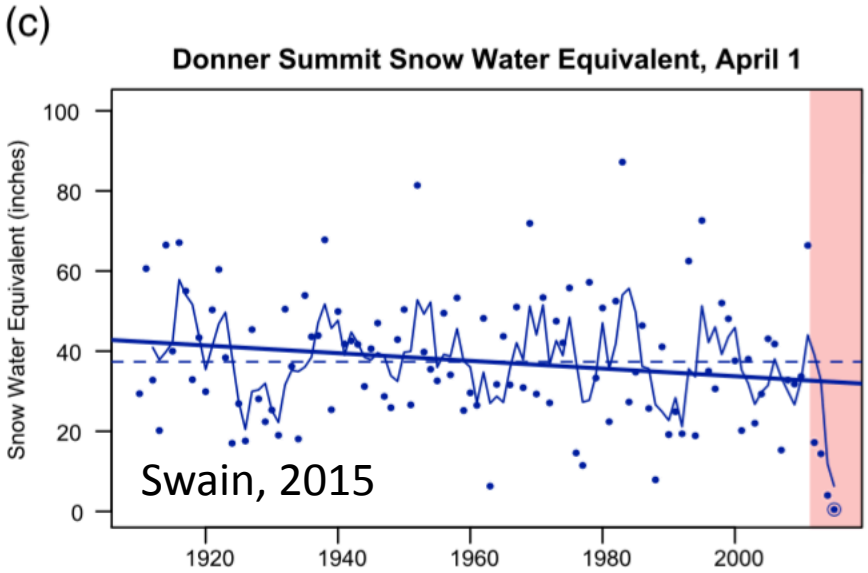


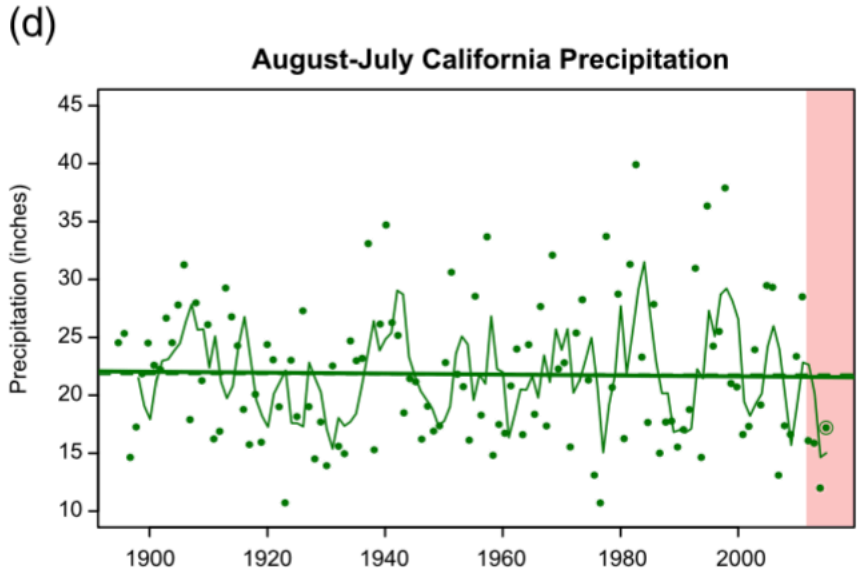
"All I'm saying is now is the time to develop the technology to deflect an asteroid."

California Climate Indicators 1896-2014



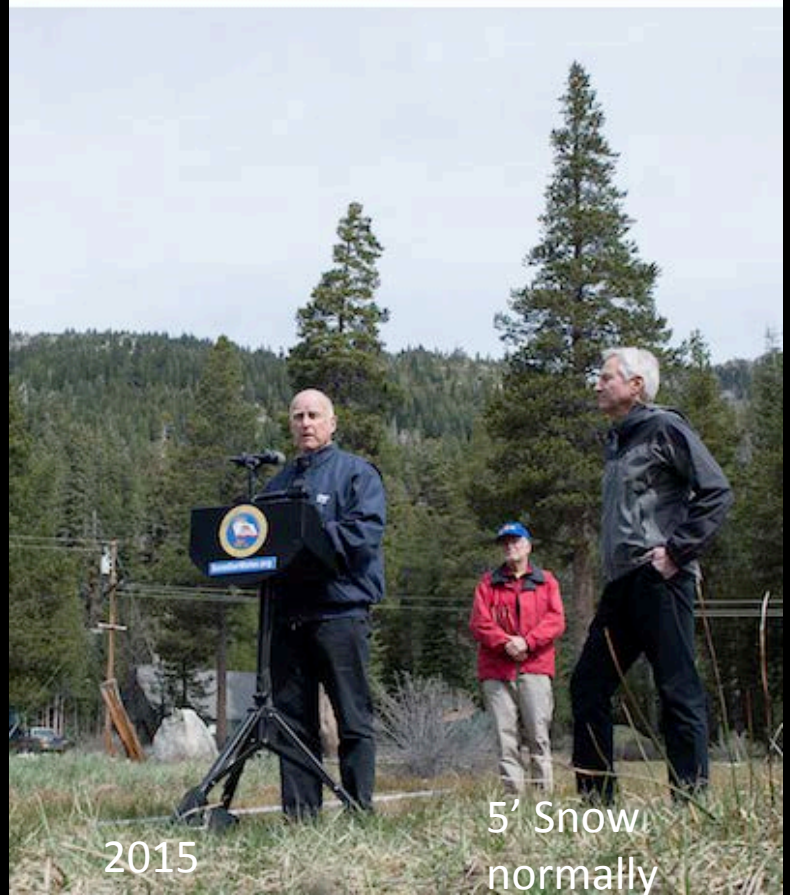




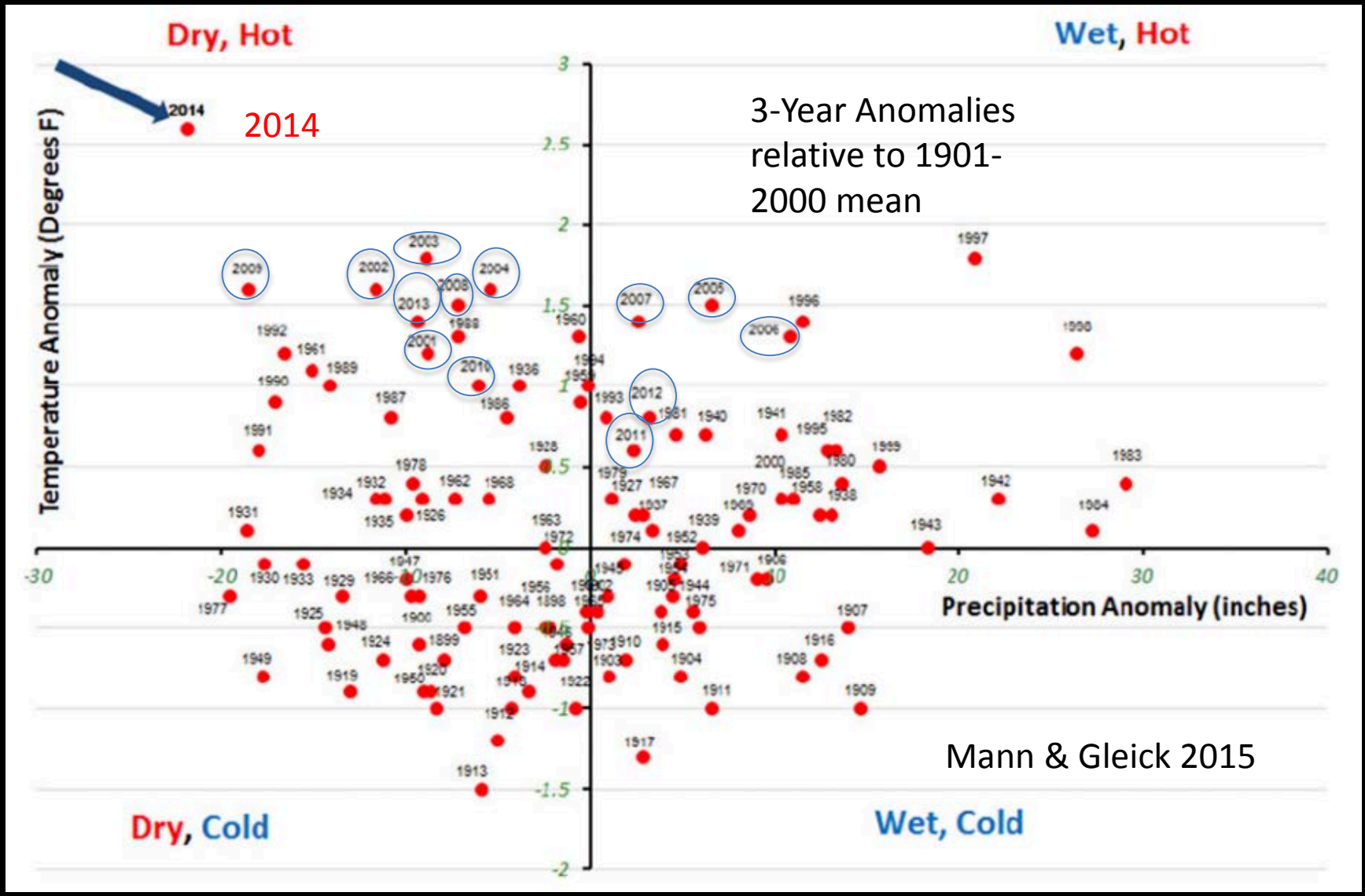


California 2014-2015 Drought

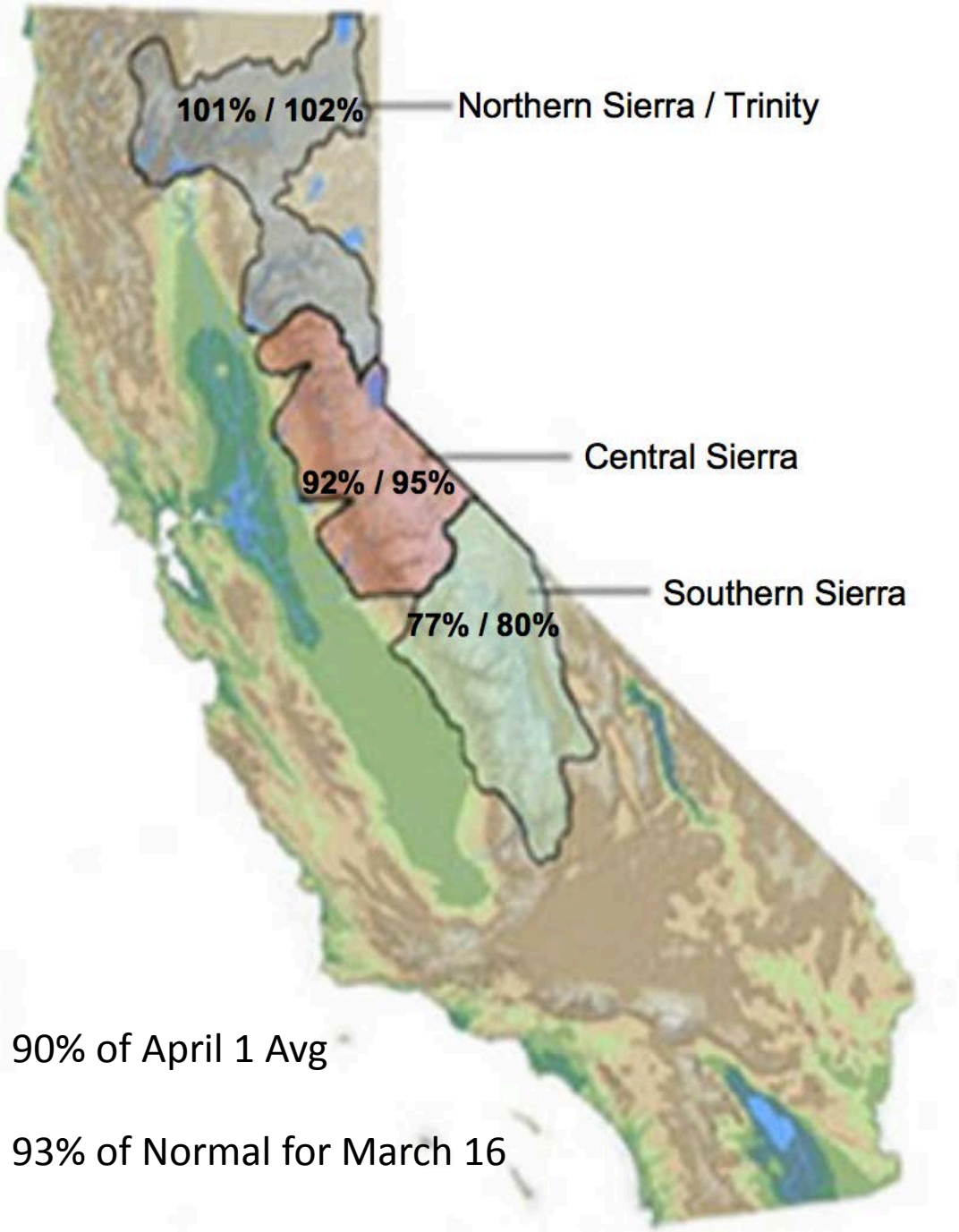
- Winter Temperatures
  - Sierra Winter Above 32 F,
  - (1st time >32F in 120 years)
- Sierra Precipitation
  - Rain, not Snow
  - Not the driest!
  - (40% to 90% of normal)
- Snowpack
  - Lowest Ever - 5% on April 1
  - (1977 at 25%)
  - 500-Year (?) Return Period
- Drought
  - Worst in 1200 (?) Years
- Water Deliveries
  - Record Low to CVP Contractors



CA Precipitation and Temperature



California Snowpack as of March 16, 2016



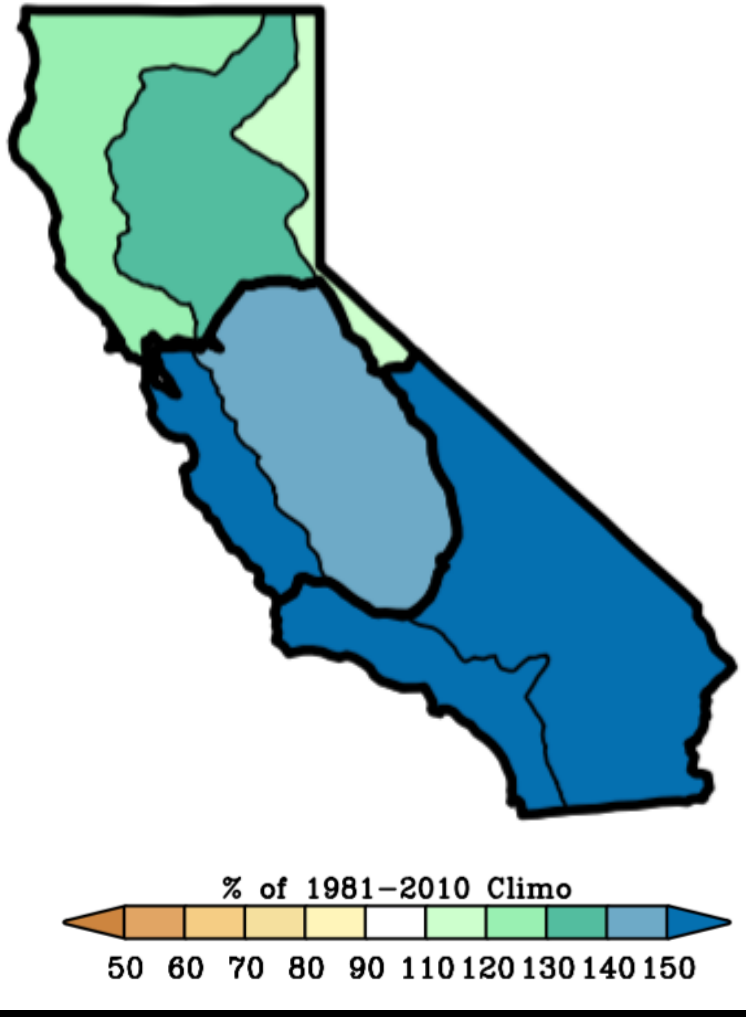
90% of April 1 Avg

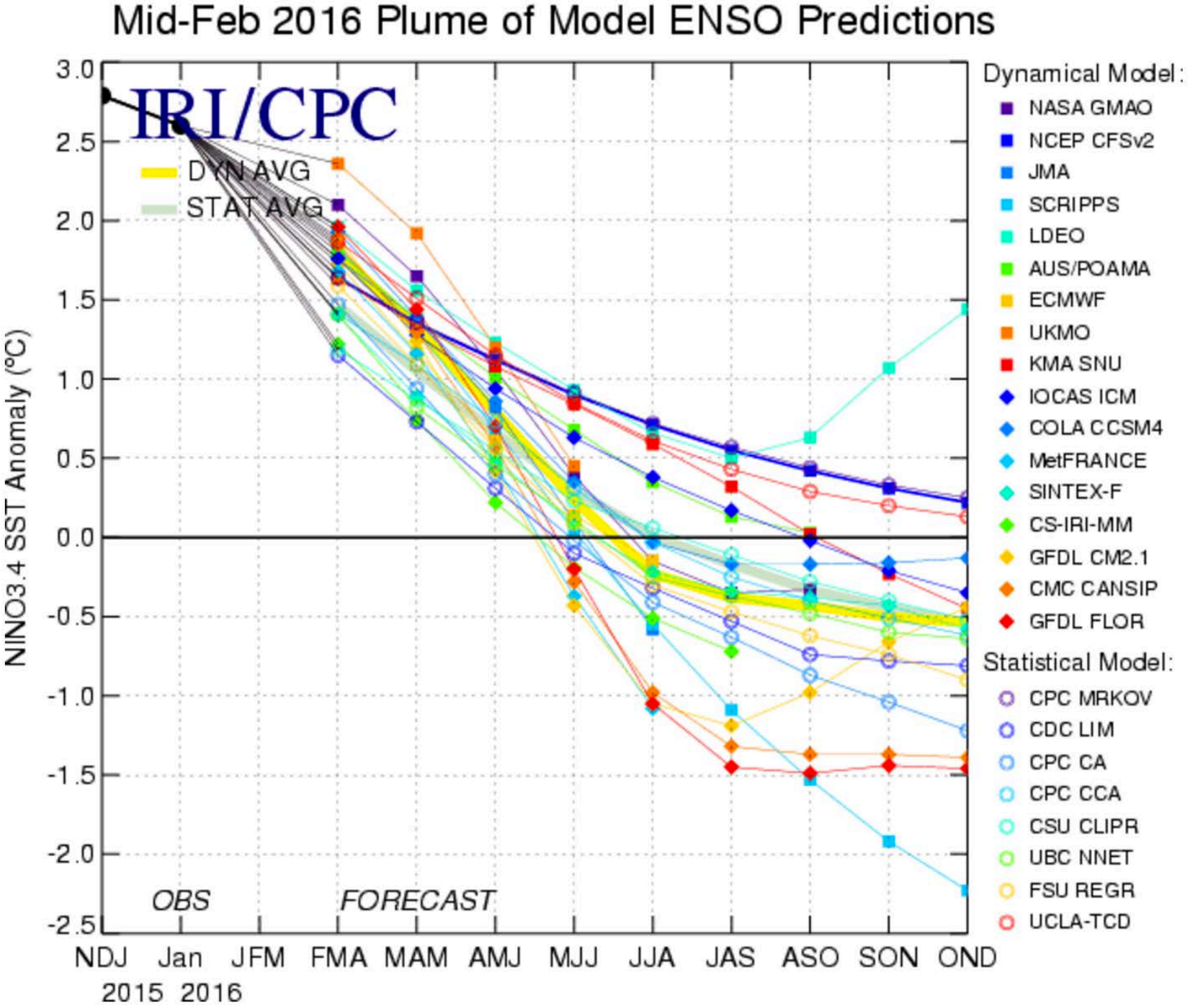
93% of Normal for March 16

"But this year ,the Hadley cell has actually strengthened a bit more than expected."

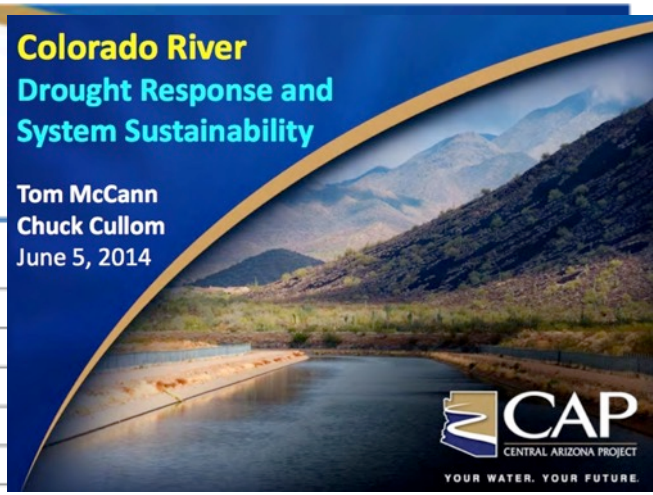
~ Dan Swain, Feb 1, 2016

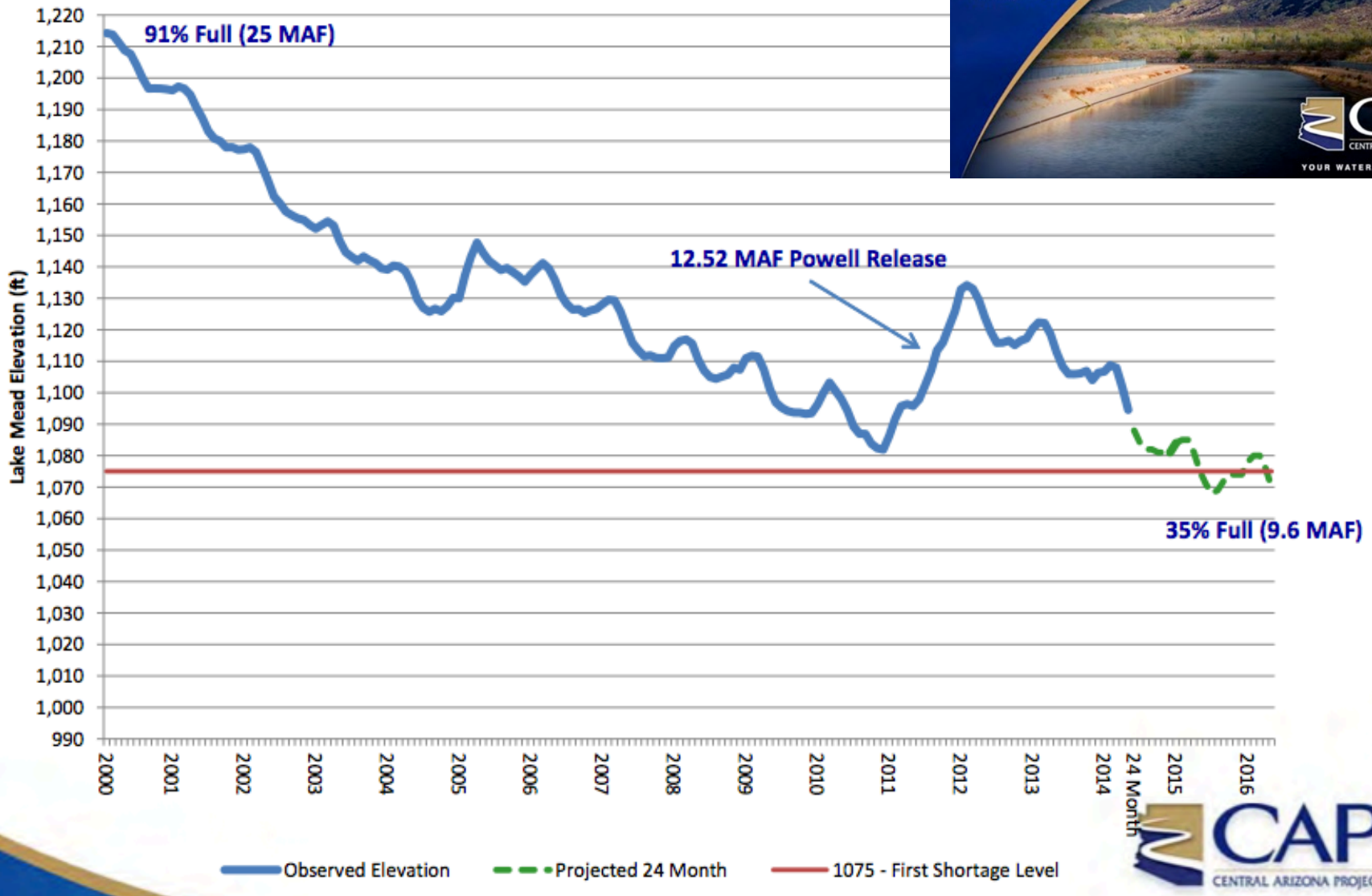
Strong El Nino Precipitation Pattern




Mid-Feb 2016 Plume of Model ENSO Predictions
IRI/CPC
DYN AVG
STAT AVG
NINO3.4 SST Anomaly (ºC)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
OBS
FORECAST
NDJ
Jan
JFM
FMA
MAM
AMJ
MJJ
JJA
JAS
ASO
SON
OND
2015
2016
Dynamical Model:
NASA GMAO
NCEP CFSv2
JMA
SCRIPPS
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
IOCAS ICM
COLA CCSM4
MetFRANCE
SINTEX-F
CS-IRI-MM
GFDL CM2.1
CMC CANSIP
GFDL FLOR
Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD

Lake Mead Since 2000

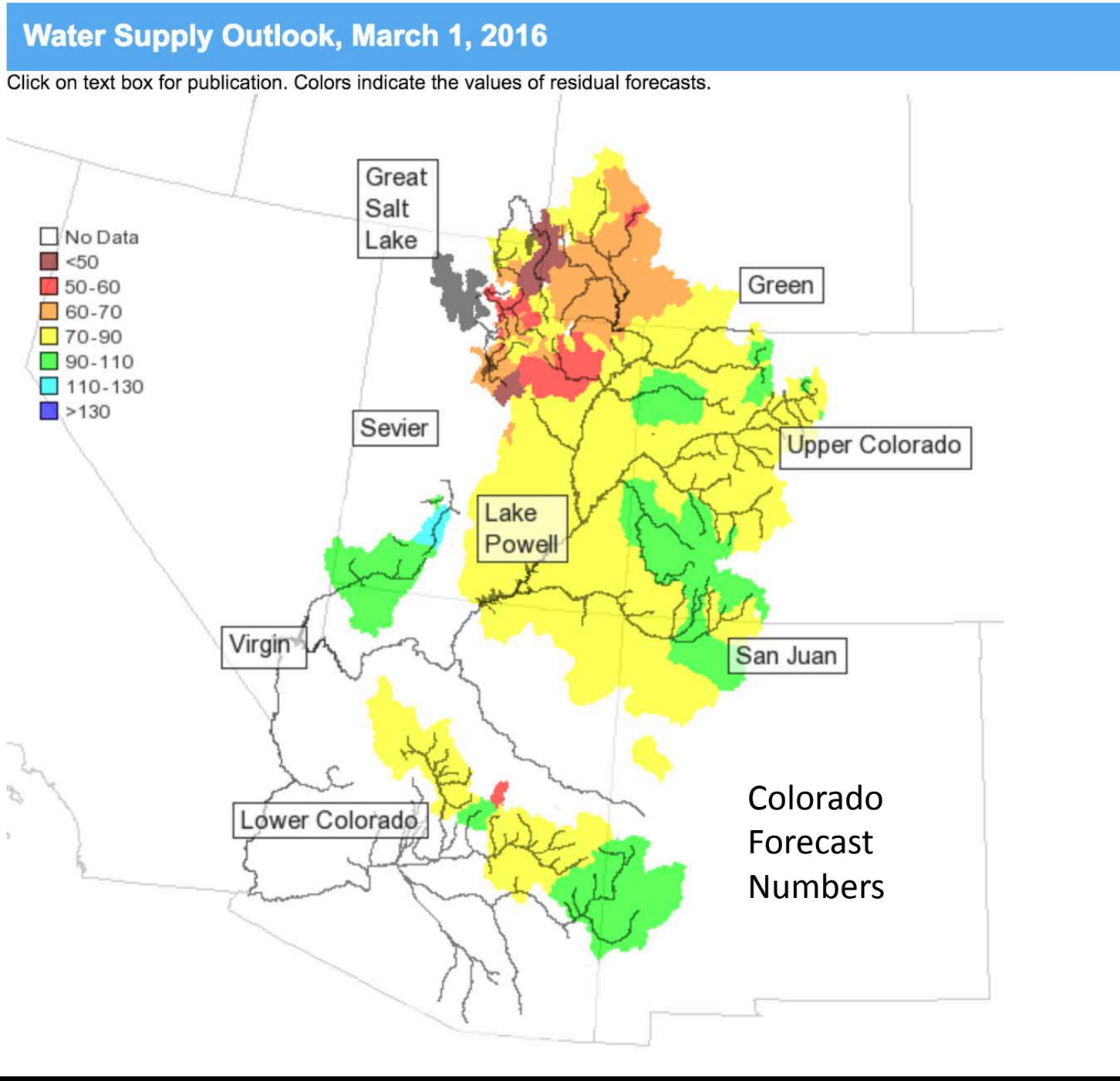




CAP
CENTRAL ARIZONA PROJECT

Colorado River Runoff Projections, March 1, 2016

3/16/16 Lake Powell Forecast is 73% of Average

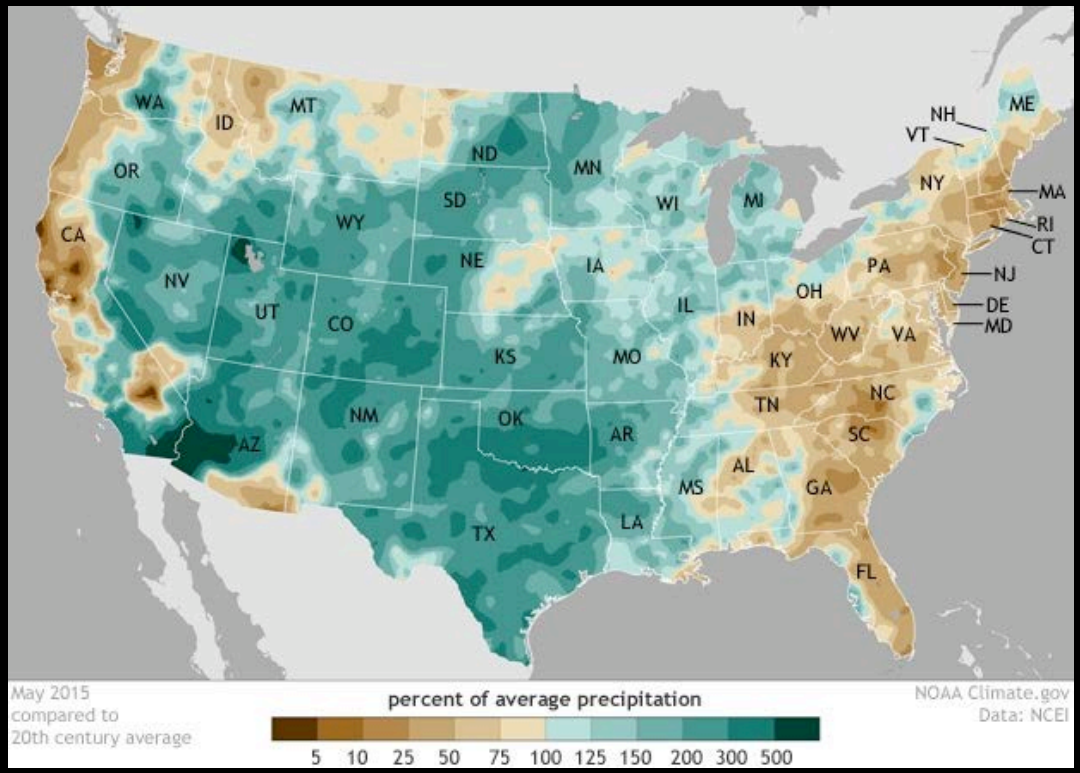


May 2015 was wettest month ever recorded in U.S.

Friday, June 12, 2015

May 2015 was the country's wettest May since records began 121 years ago.

In fact, it was the wettest month ever recorded!



https://www.climate.gov/news-features/featured-images/may-2015-was-wettest-month-ever-recorded-us

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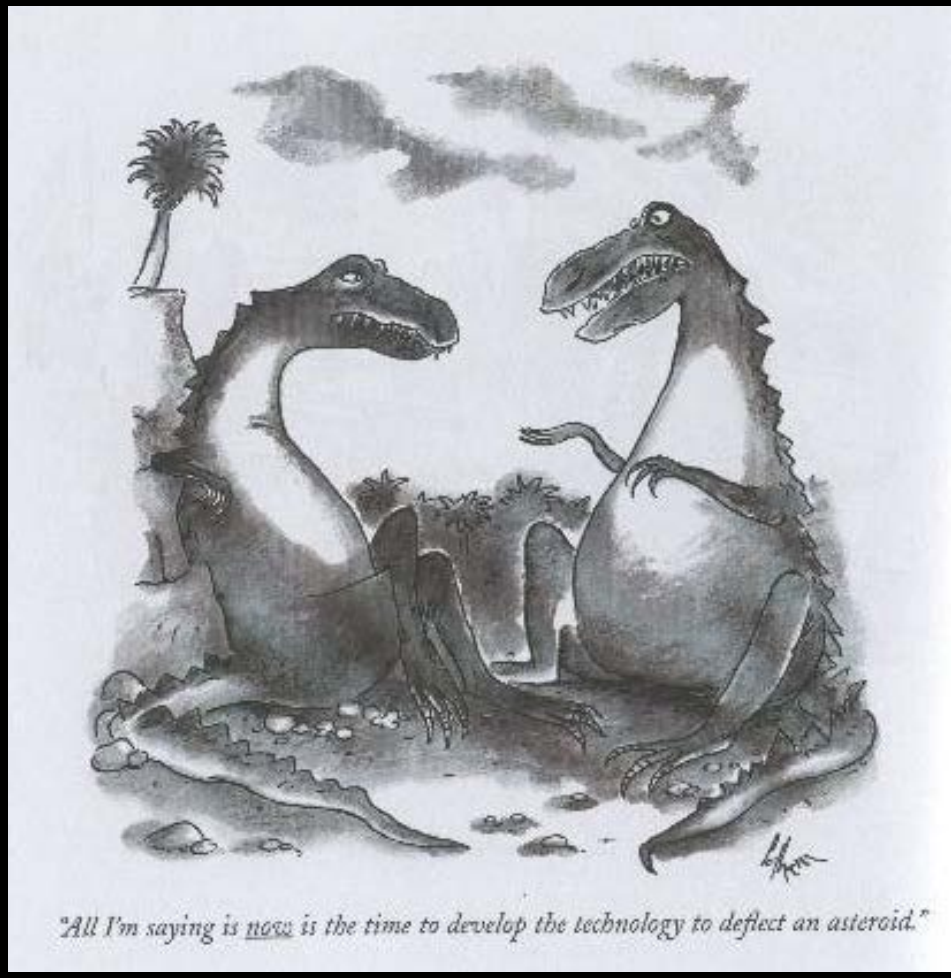
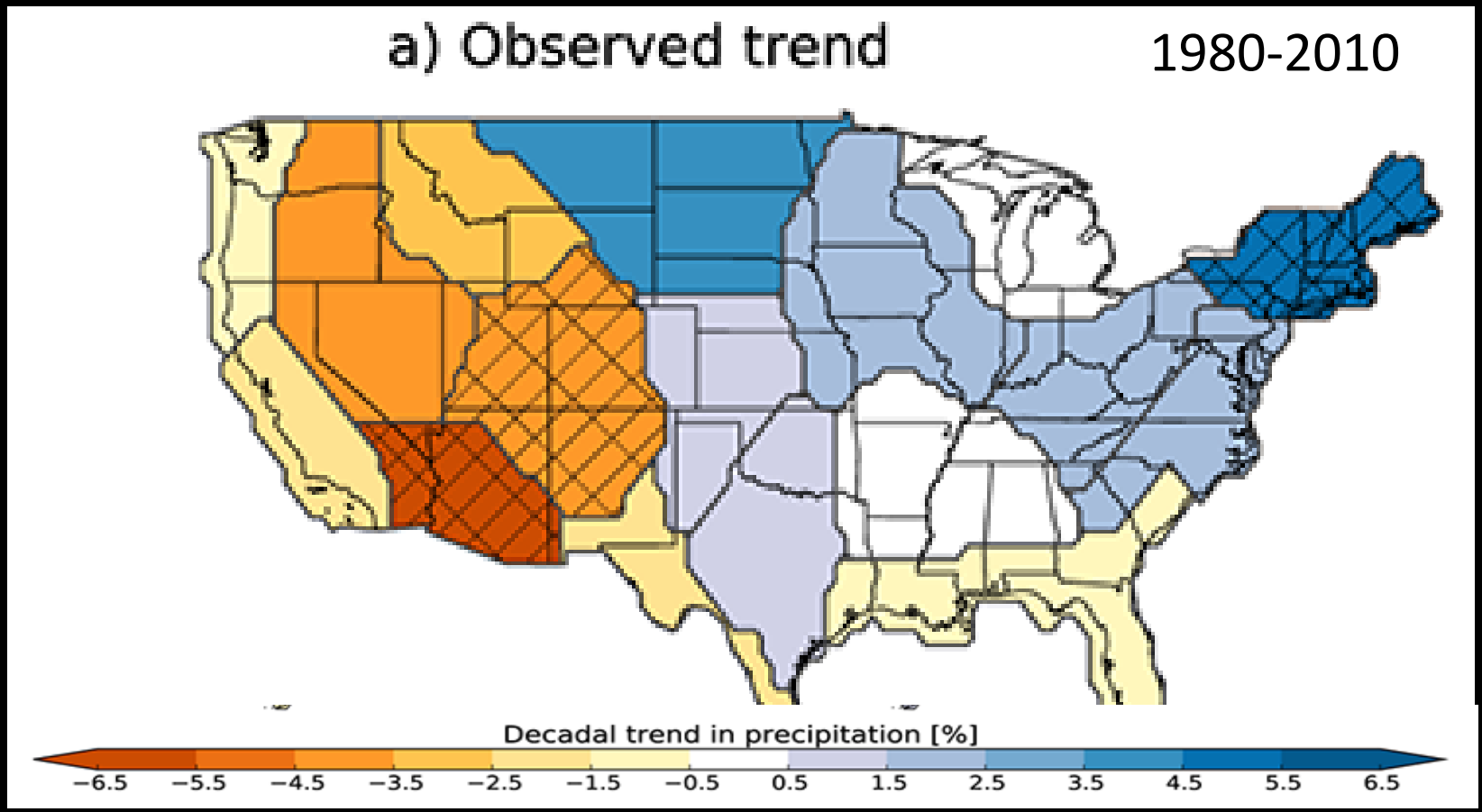


"All I'm saying is now is the time to develop the technology to deflect an asteroid."

Running dry: The U.S. Southwest's drift into a drier climate state

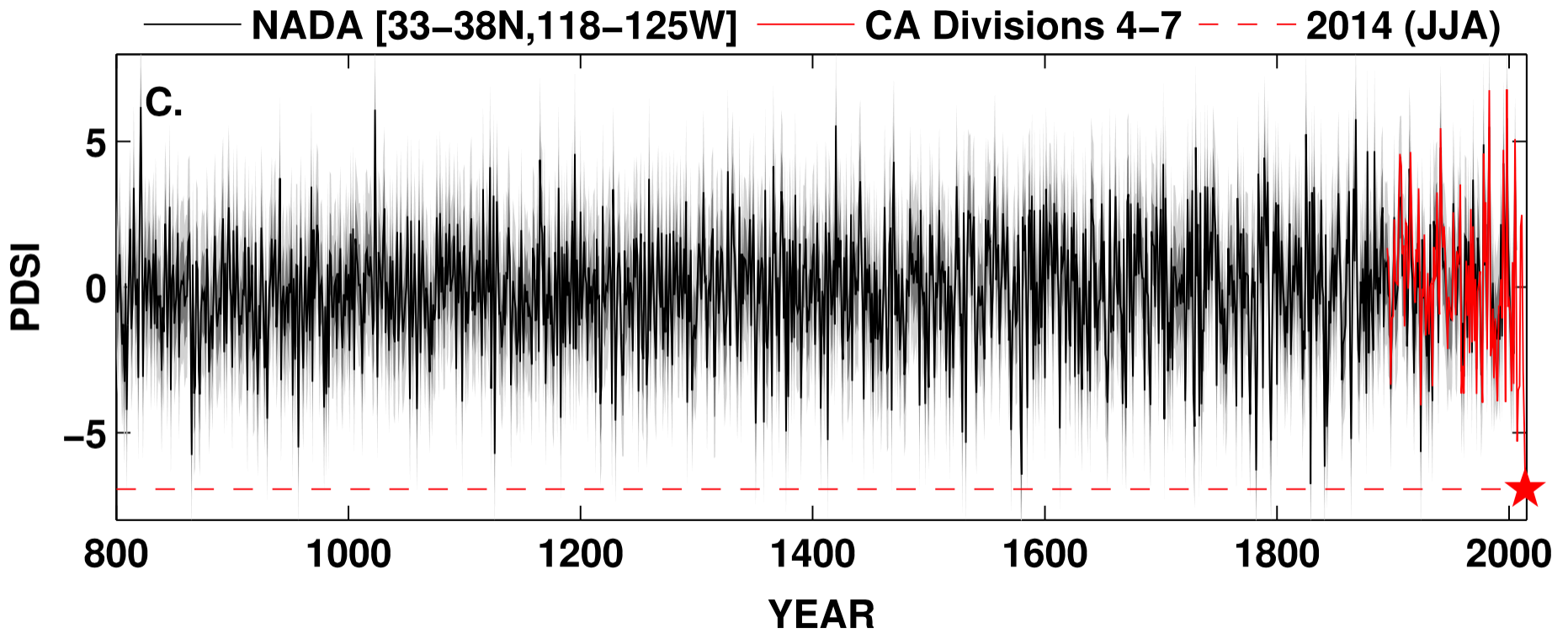


Weather Patterns that provide winter precipitation are becoming less frequent due to Hadley Cell Expansion. Southwest Precipitation has declined by 25%.

Prein et al, 2016

How unusual is the 2012–2014 California drought?

Daniel Griffin[1,2] and Kevin J. Anchukaitis[2]



"The current event is the most severe drought in the last 1200 years, with single year (2014) and accumulated moisture deficits worse than any previous continuous span of dry years."

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL062308

Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought

Amir AghaKouchak[1], Linyin Cheng[1], Omid Mazdiyasni[1], and Alireza Farahmand[1]

[1]Center for Hydrometeorology and Remote Sensing, University of California, Irvine, California, USA

Abstract Global warming and the associated rise in extreme temperatures substantially increase the chance of concurrent droughts and heat waves. The 2014 California drought is an archetype of an event characterized by not only low precipitation but also extreme high temperatures. From the raging wildfires, to record low storage levels and snowpack conditions, the impacts of this event can be felt throughout California. Wintertime water shortages worry decision-makers the most because it is the season to build up water supplies for the rest of the year. Here we show that the traditional univariate risk assessment methods based on precipitation condition may substantially underestimate the risk of extreme events such as the 2014 California drought because of ignoring the effects of temperature. We argue that a multivariate viewpoint is necessary for assessing risk of extreme events, especially in a warming climate. This study discusses a methodology for assessing the risk of concurrent extremes such as droughts and extreme temperatures.

Anthropogenic warming has increased drought risk in California

Noah S. Diffenbaugh[a,b,1], Daniel L. Swain[a], and Danielle Touma[a]

[a]Department of Environmental Earth System Science and [b]Woods Institute for the Environment, Stanford University, Stanford, CA 94305

Edited by Jane Lubchenco, Oregon State University, Corvallis, OR, and approved January 30, 2015 (received for review November 22, 2014)

- No change in precipitation over last few decades
- But the occurrence of drought has increased in last two decades over previous century
- The probability that precipitation deficits occur with warm temperatures has increased
- The probability that precipitation deficits produce drought has increased
- "We therefore conclude that anthropogenic warming is increasing the probability of co-occurring warm–dry conditions like those that have created the acute human and ecosystem impacts associated with the 'exceptional' 2012–2014 drought in California."

AGU PUBLICATIONS

Geophysical Research Letters

Revisiting the recent California drought as an extreme value

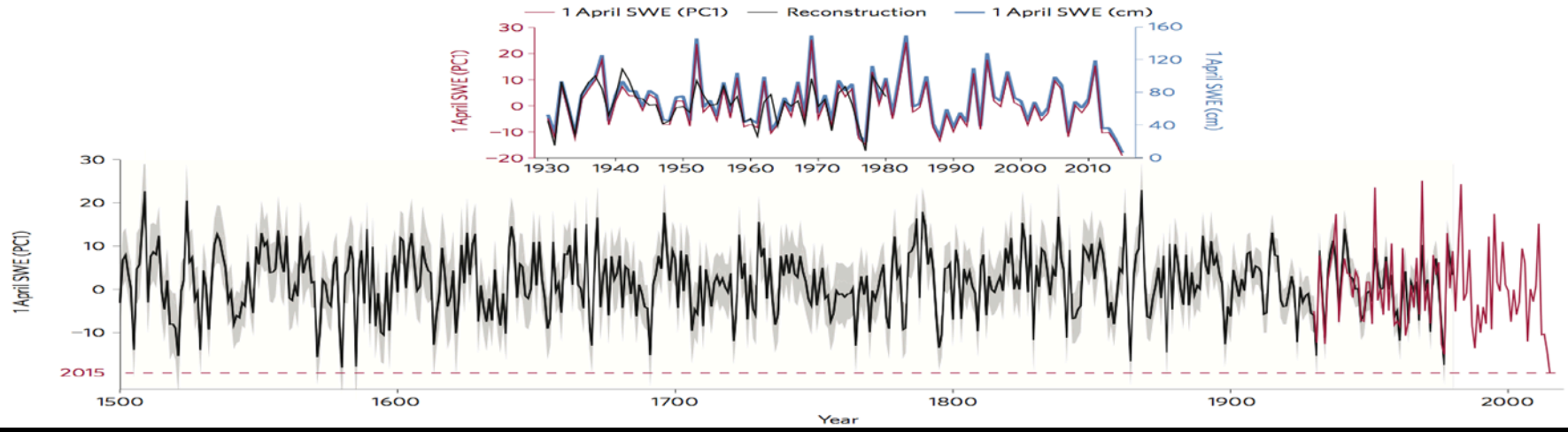
Scott M. Robeson[1]

[1]Department of Geography and Department of Statistics, Indiana University, Bloomington, Bloomington, Indiana, USA

Abstract Spatially weighted averages of Palmer Drought Severity Index (PDSI) over central and southern California show that the 1 year 2014 drought was not as severe as previously reported, but it still is the most severe in the 1895–2014 instrumental record. Using the typical adjustment procedure that matches the mean and standard deviation of tree ring PDSI values to those of instrumental data shows over 10 droughts from 800 to 2006 that were more severe than the 1 year 2014 drought, with the 2014 drought having a return period of 140–180 years. Quantile mapping allows for a closer correspondence between instrumental and tree ring PDSI probability distributions and produces return periods of 700–900 years for the 1 year 2014 drought. Associated cumulative 3 and 4 year droughts, however, are estimated to be much more severe. The 2012–2014 drought is nearly a 10,000 year event, while the 2012–2015 drought has an almost incalculable return period and is completely without precedent.

CORRESPONDENCE:

Multi-century evaluation of Sierra Nevada snowpack



"2015 is unprecedented in the context of the last 500 years"

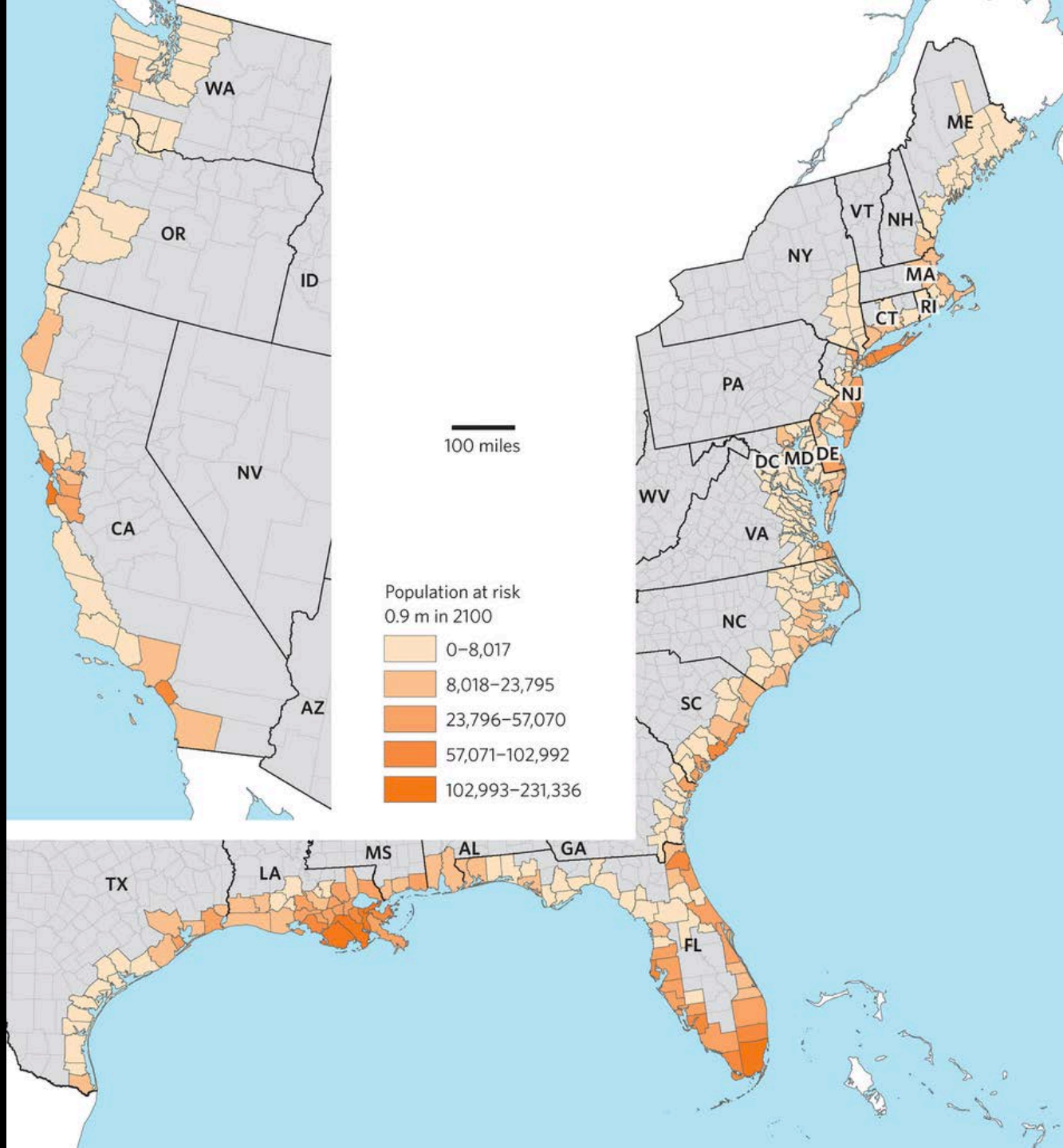
Source: Belmecheri et al., Nature Climate Change, September 14, 2015

California has 3rd largest population at risk in 2100 to Sea Level Rise

@0.8m = 500k

@1.8m = 1m

Hauer et al, 2016

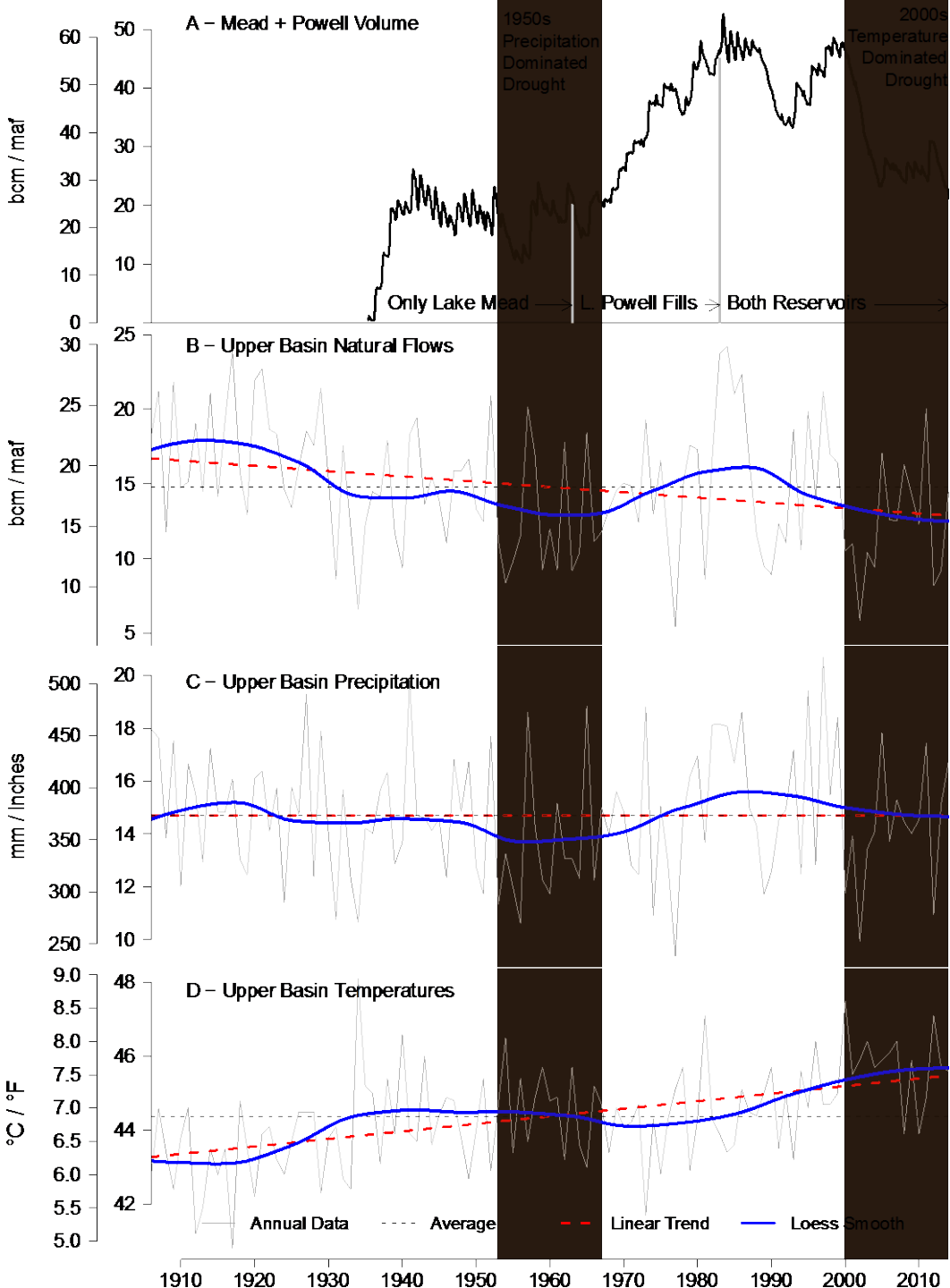


Current 15-Year Colorado River Drought only has 40% of the Precipitation Decline associated with similar 1950s drought.

You have to invoke temperatures to explain current drought.

Up to 50% of current decline due to high temperatures.

Source: Udall & Overpeck 2016, in review

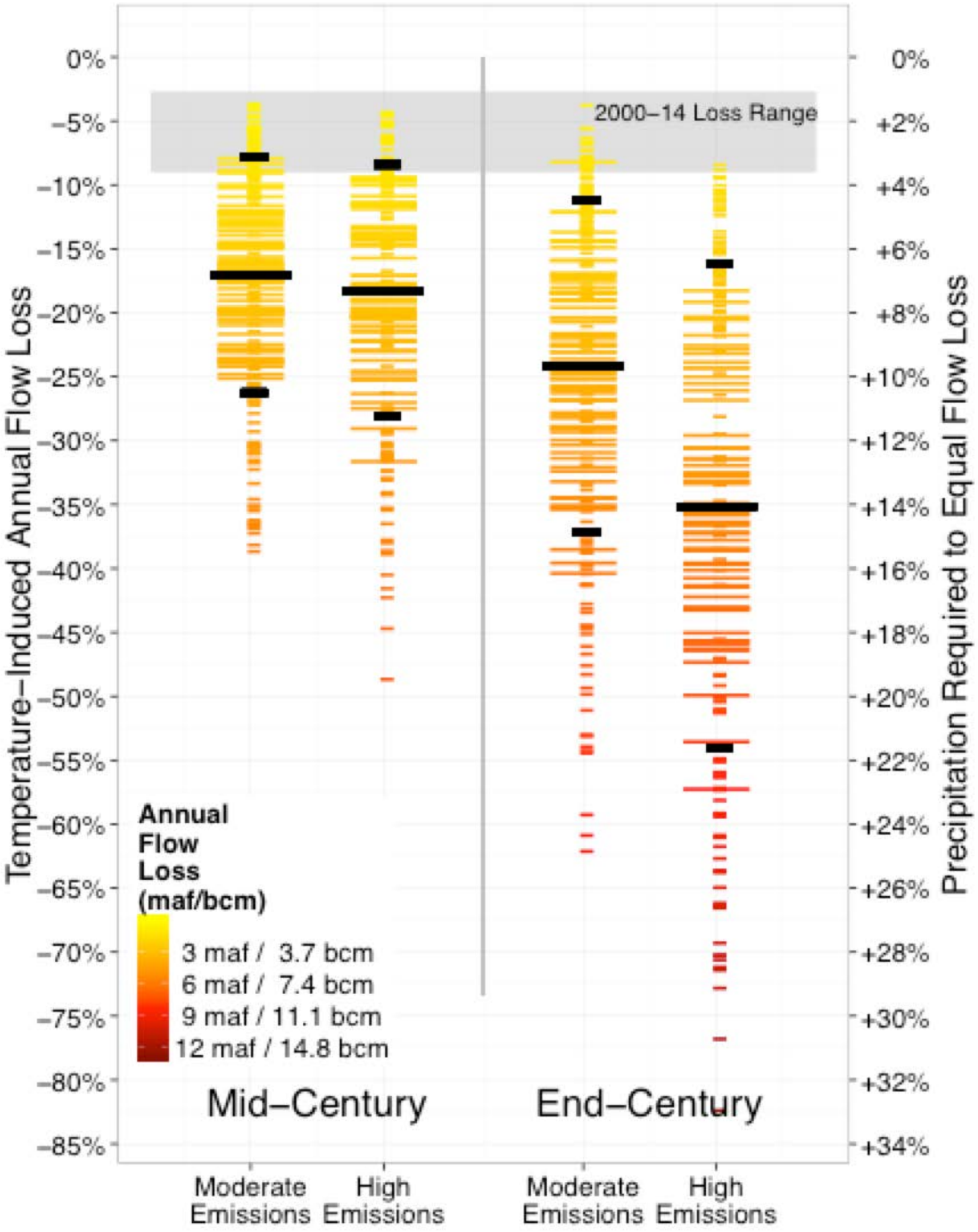


Colorado River Future Flow Losses

Climate Change a combination of …

1. For-Sure Temperature Rise -> Flow Losses

2. Not-Sure Precipitation Change -> Flow Gains?



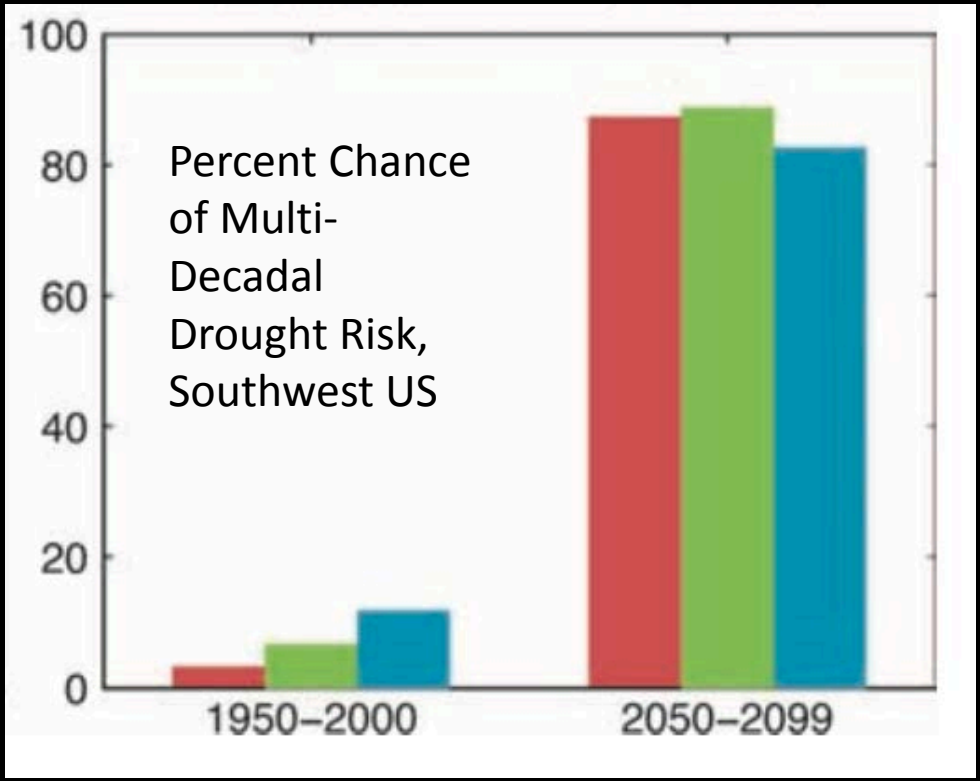
CLIMATOLOGY

Unprecedented 21st century drought risk in the American Southwest and Central Plains

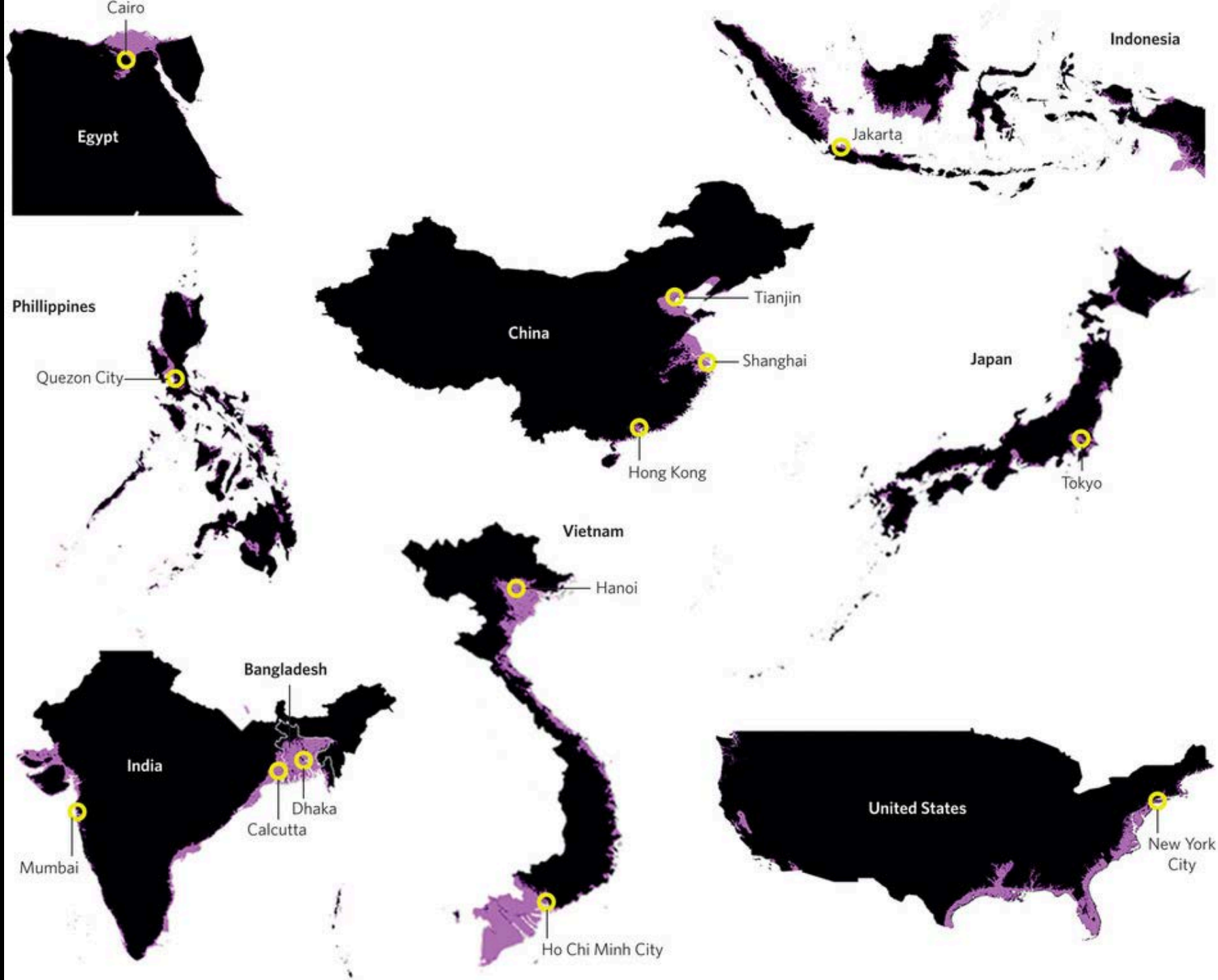
Benjamin I. Cook,[1,2]* Toby R. Ault,[3] Jason E. Smerdon[2]

In both Central Plains and Southwest, Multi-decadal Drought Risk* exceeds 80% in 21st Century

* Defined as Drought lasting 35 or more years



- Increasing influence of air temperature on upper Colorado River streamflow
  - Woodhouse et al, 2016
- Understanding Uncertainties in Future Colorado River Streamflow
  - Vano, et al, 2014
- Projections of declining surface-water availability for the southwestern United States
  - Seager et al, 2012
- The Unusual Nature of Recent Snowpack Declines in the North American Cordillera
  - Pederson, et al, 2011
- Future dryness in the southwest US and the hydrology of the early 21st century drought
  - Cayan, et al, 2010
- Dry Times Ahead
  - Overpeck and Udall, 2010
- Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America
  - Seager et al, 2009
- Water supply risk on the Colorado River: Can management mitigate?
  - Rajagopalan et al, 2009
- When Will Lake Mead Go Dry?
  - Barnett and Pierce, 2008
- Attribution of Declining Western U.S. Snowpack to Human Effects
  - Pierce, et al, 2008
- Warming may create substantial water supply shortages in the Colorado River basin
  - McCabe and Wolock, 2007


Cairo
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Hanoi
Bangladesh
India
Dhaka
Calcutta
Mumbai
Ho Chi Minh City
United States
New York City

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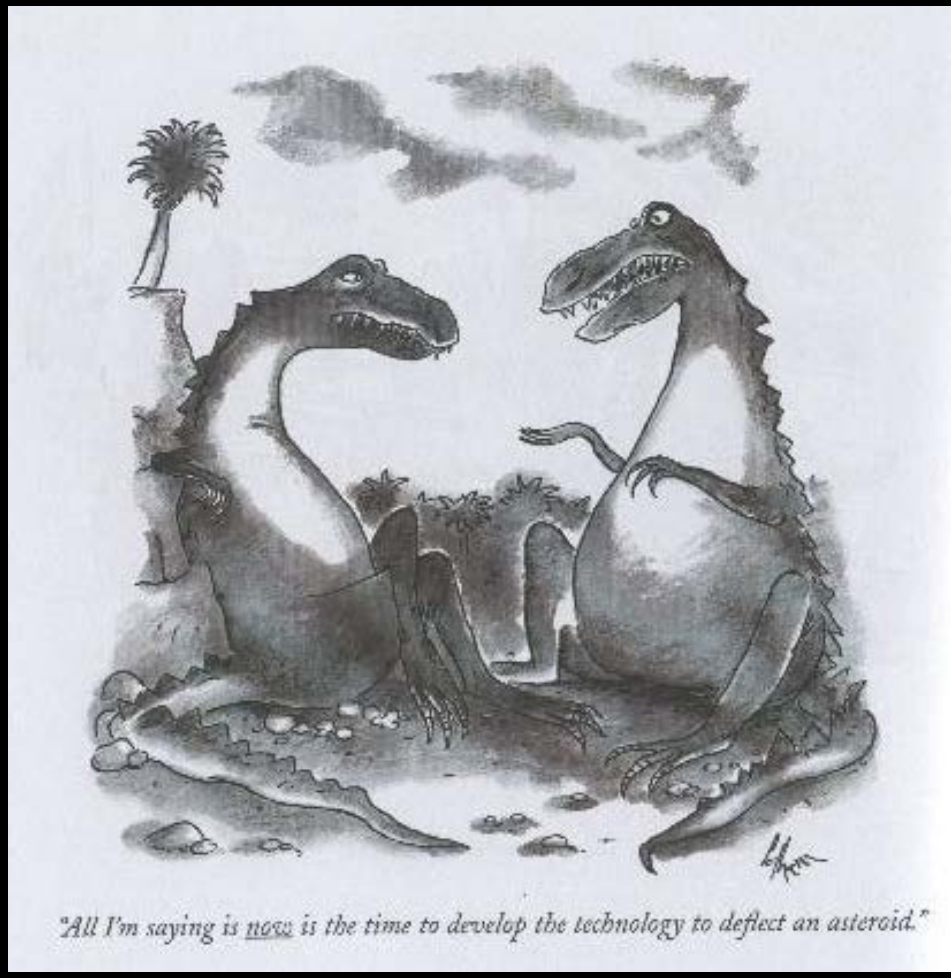
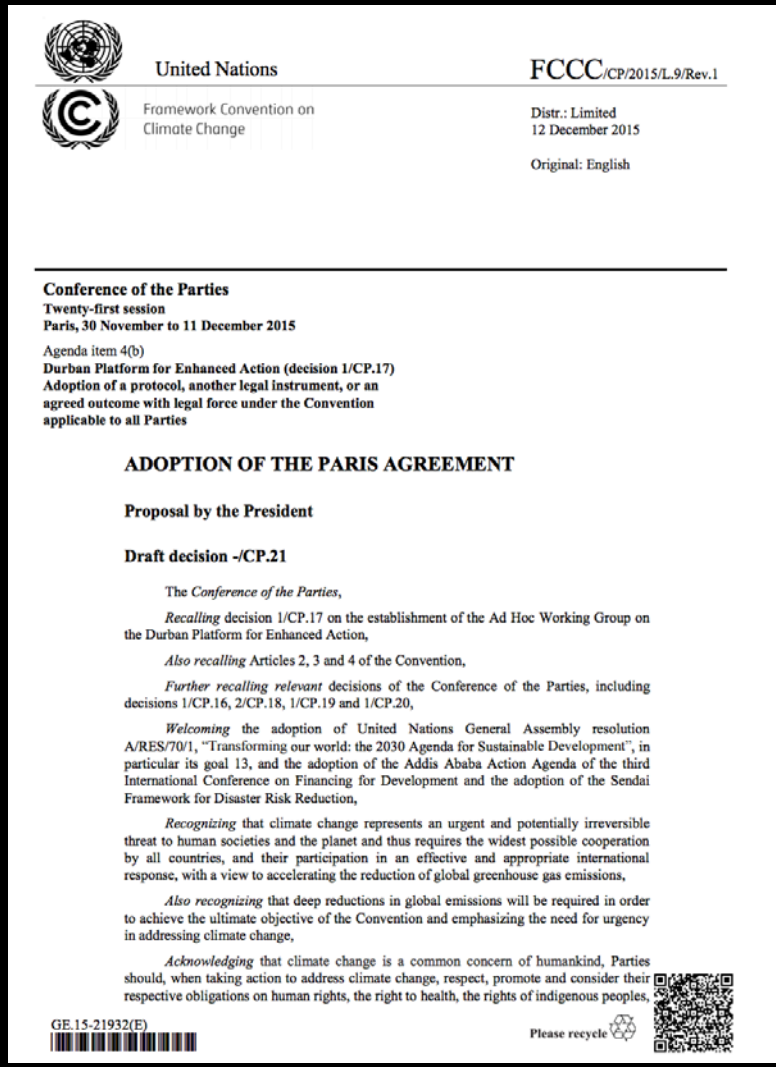


Paris, France
195 Nations
December 12, 2015

UN Framework Convention on Climate Change - "UNFCCC"

- 1988 – IPCC Created
  - 5 Scientific Assessments since 1990
- 1992 – UNFCCC
  - "avoid dangerous" climate change
- 1997 – Kyoto Protocol
  - Excluded Developing Countries
  - DOA in US Senate
  - No goals beyond 2020
- 2015 – Paris Agreement
  - 195 Countries
  - "INDC"s
  - Revisit Commitments every 5 Years
  - Goal : "well-below" 2C
    - Also pursue 1.5C



United Nations

Framework Convention on Climate Change

FCCC/CP/2015/L.9/Rev.1

Distr.: Limited
12 December 2015

Original: English

Conference of the Parties
Twenty-first session
Paris, 30 November to 11 December 2015

Agenda item 4(b)
Durban Platform for Enhanced Action (decision 1/CP.17)
Adoption of a protocol, another legal instrument, or an agreed outcome with legal force under the Convention applicable to all Parties

ADOPTION OF THE PARIS AGREEMENT

Proposal by the President

Draft decision -/CP.21

The *Conference of the Parties*,

Recalling decision 1/CP.17 on the establishment of the Ad Hoc Working Group on the Durban Platform for Enhanced Action,

Also recalling Articles 2, 3 and 4 of the Convention,

Further recalling relevant decisions of the Conference of the Parties, including decisions 1/CP.16, 2/CP.18, 1/CP.19 and 1/CP.20,

Welcoming the adoption of United Nations General Assembly resolution A/RES/70/1, "Transforming our world: the 2030 Agenda for Sustainable Development", in particular its goal 13, and the adoption of the Addis Ababa Action Agenda of the third International Conference on Financing for Development and the adoption of the Sendai Framework for Disaster Risk Reduction,

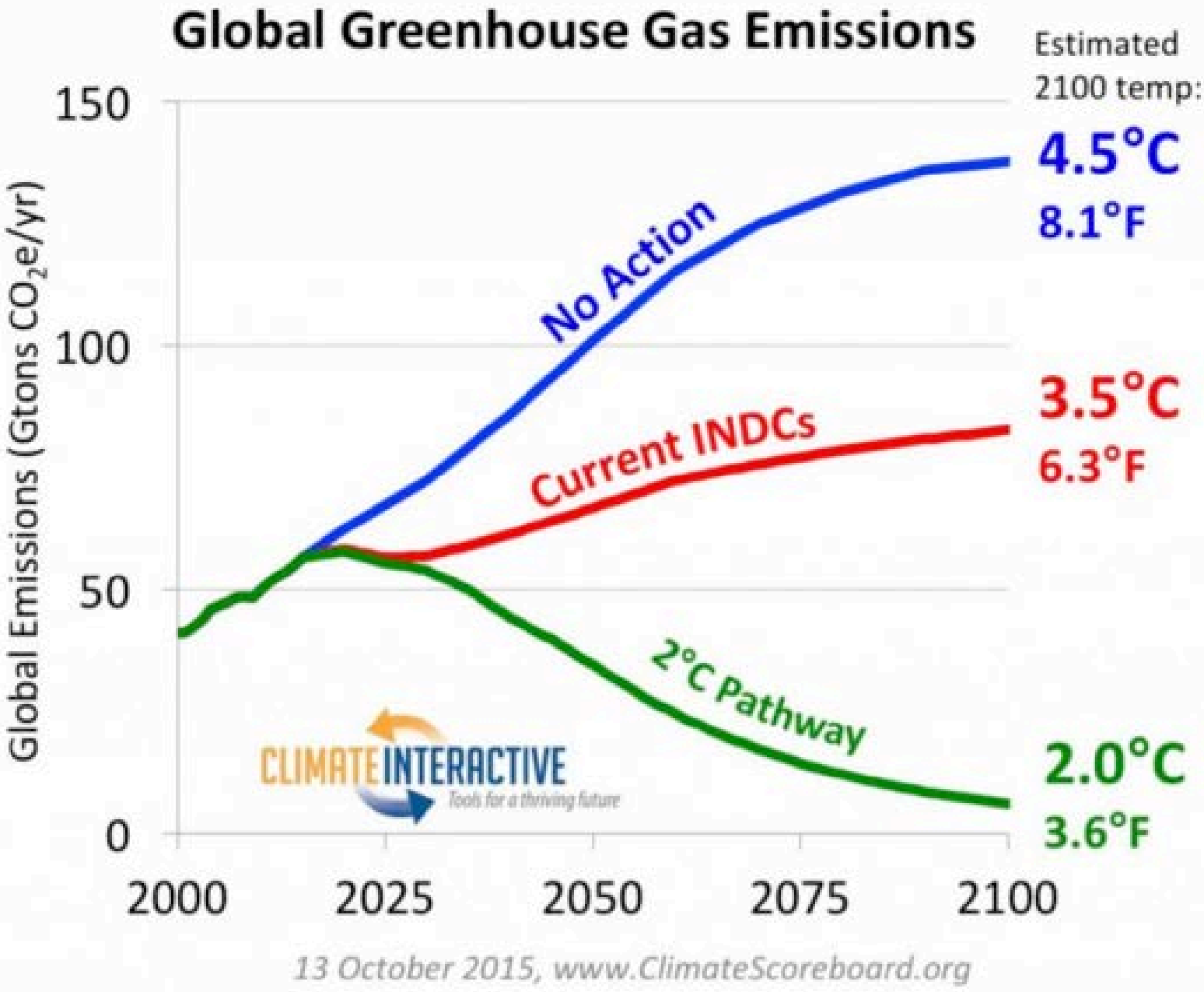
Recognizing that climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions,

Also recognizing that deep reductions in global emissions will be required in order to achieve the ultimate objective of the Convention and emphasizing the need for urgency in addressing climate change,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples,

GE.15-21932(E)

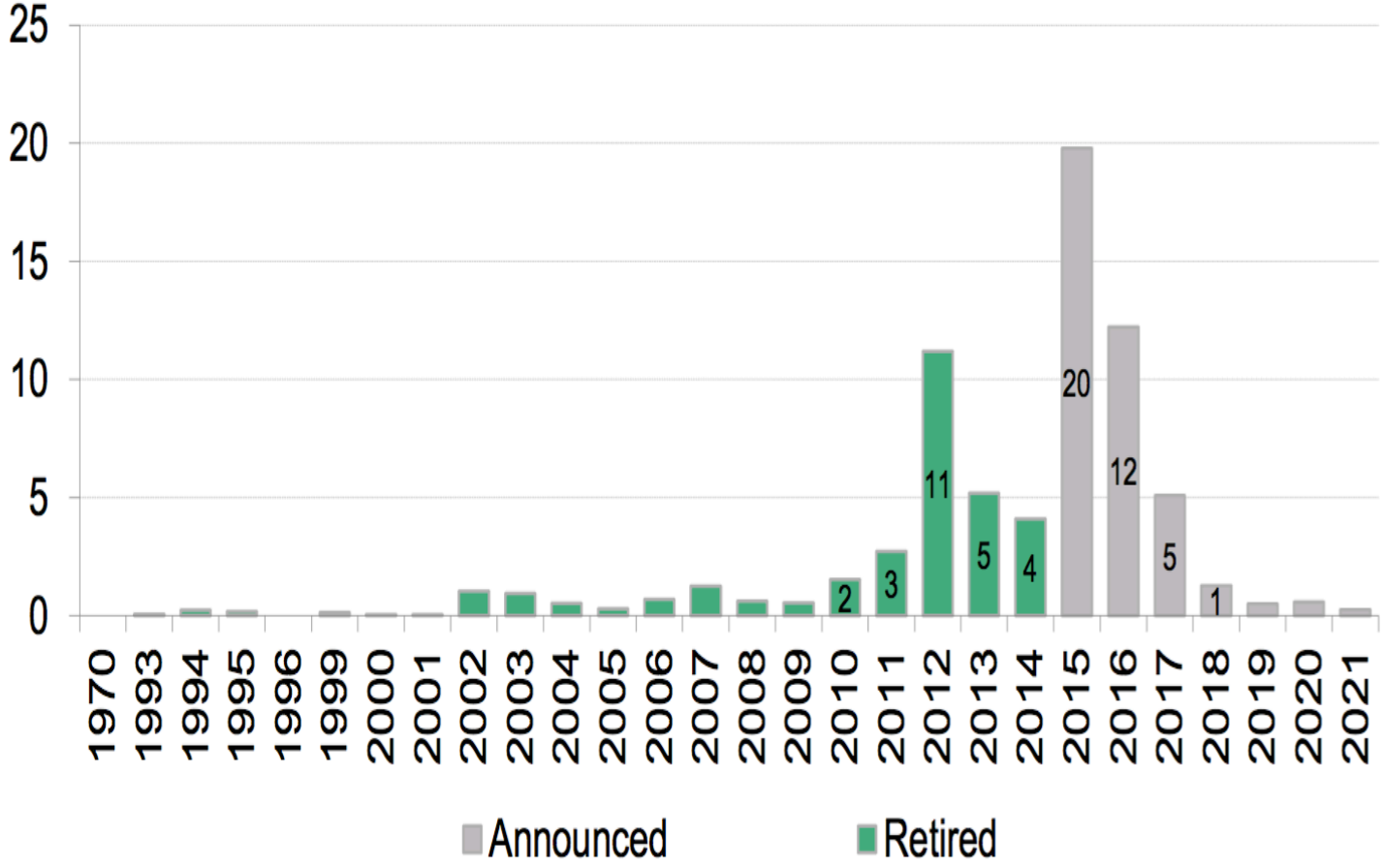
Please recycle


Global Greenhouse Gas Emissions
Estimated 2100 temp:
4.5°C
8.1°F
3.5°C
6.3°F
2.0°C
3.6°F
No Action
Current INDCs
2°C Pathway
Global Emissions (Gtons CO_2e/yr)
150
100
50
0
2000
2025
2050
2075
2100
CLIMATE INTERACTIVE
Tools for a thriving future
13 October 2015, www.ClimateScoreboard.org

Policy: US coal power plant retirements completed and announced by year (GW)

Bloomberg NEW ENERGY FINANCE

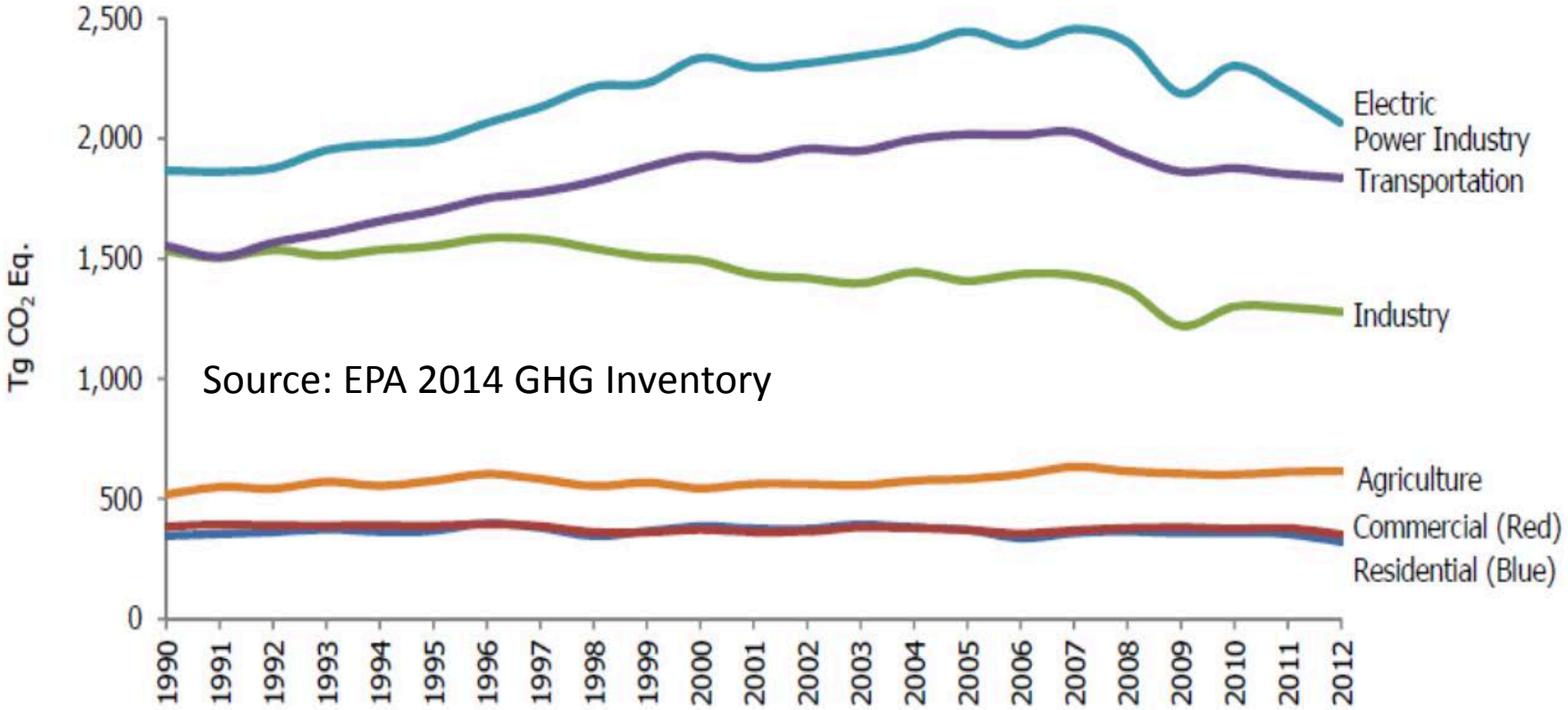
200 Coal Plant Retirements since 2009



Book: Struggling for Air

US Emissions Peaked 2007
Emissions by Sector

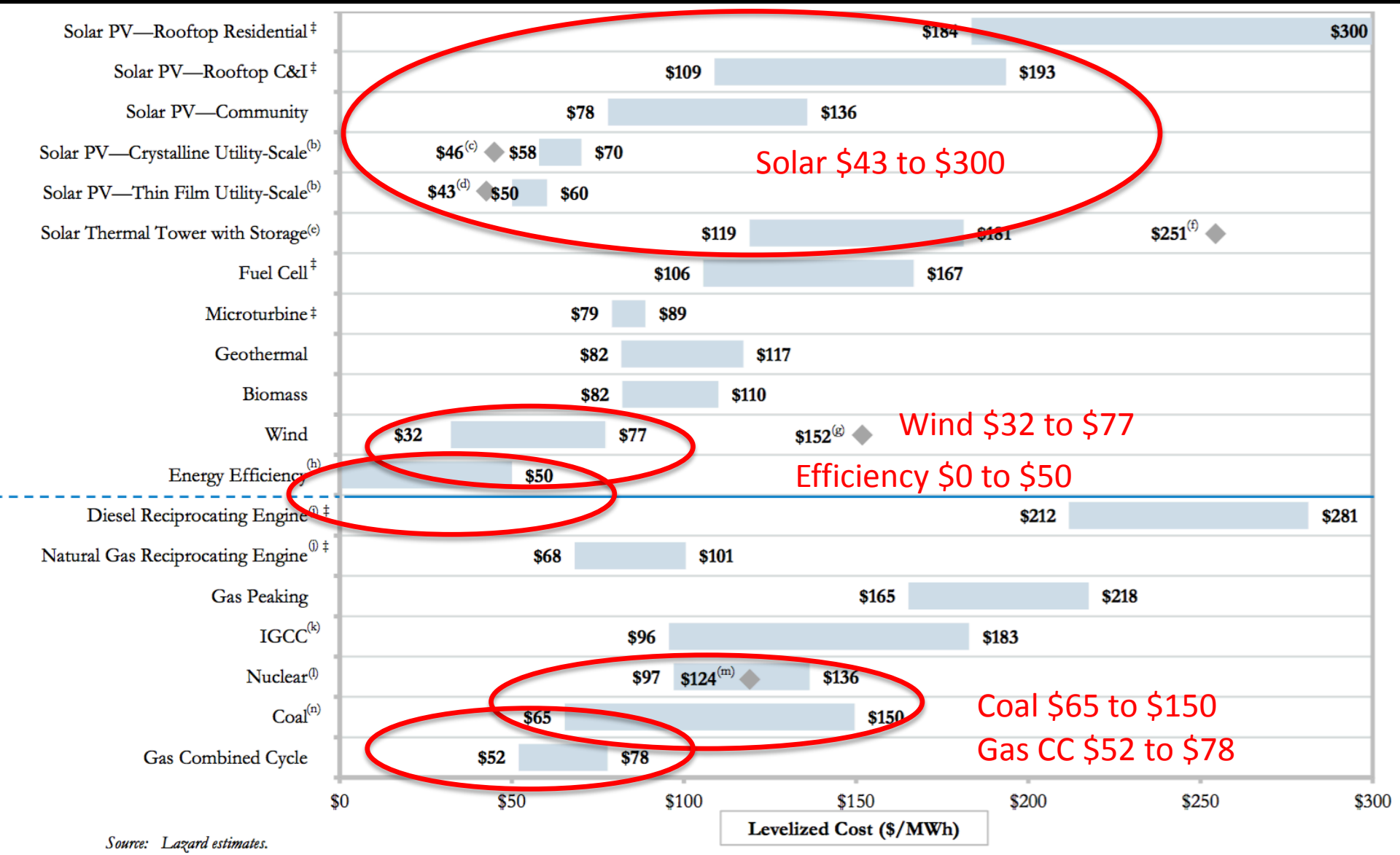
Figure ES-13: Emissions Allocated to Economic Sectors



Source: EPA 2014 GHG Inventory

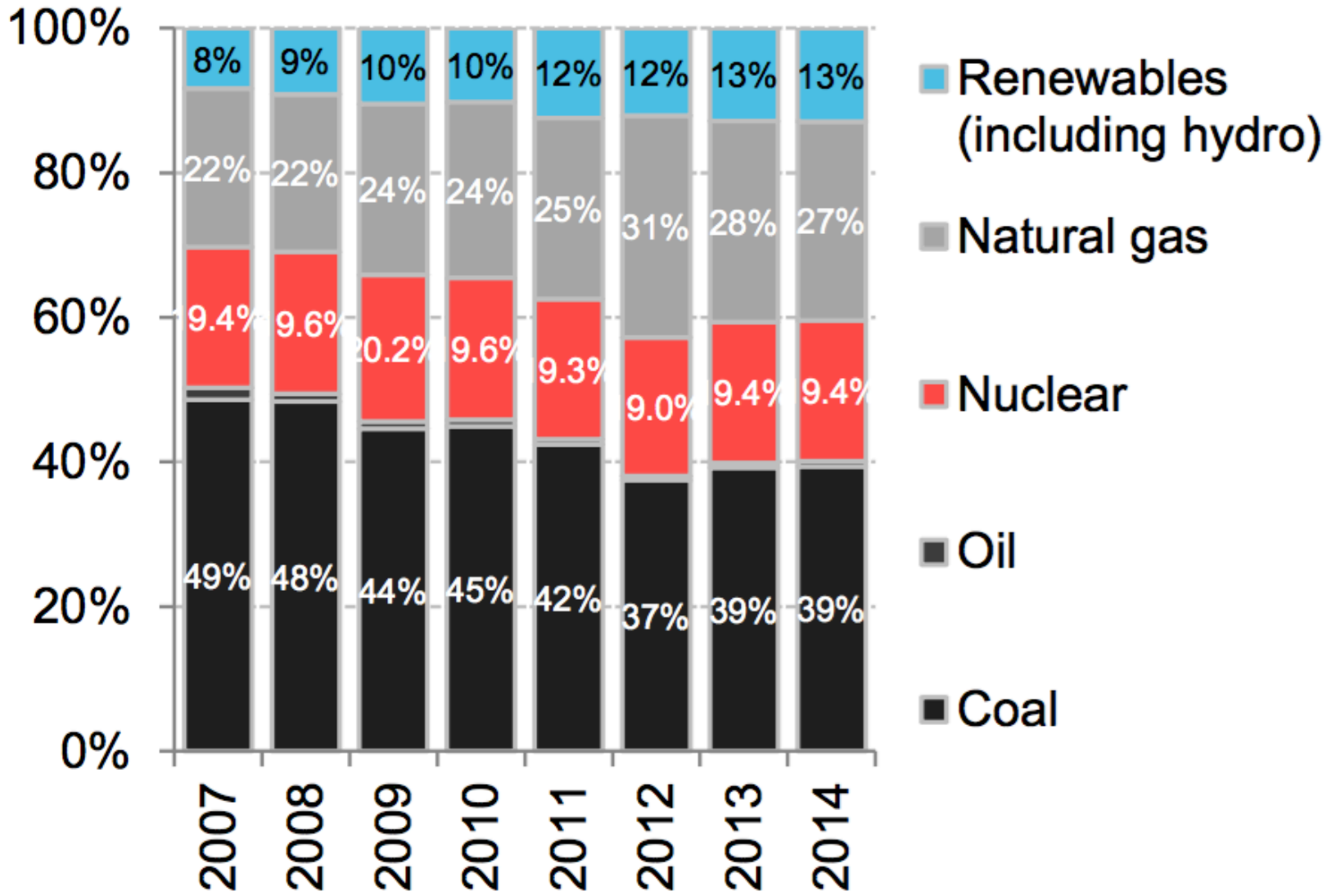
LAZARD

Levelized Cost of Energy



Source: Lazard estimates.

US electricity generation by fuel type (%)



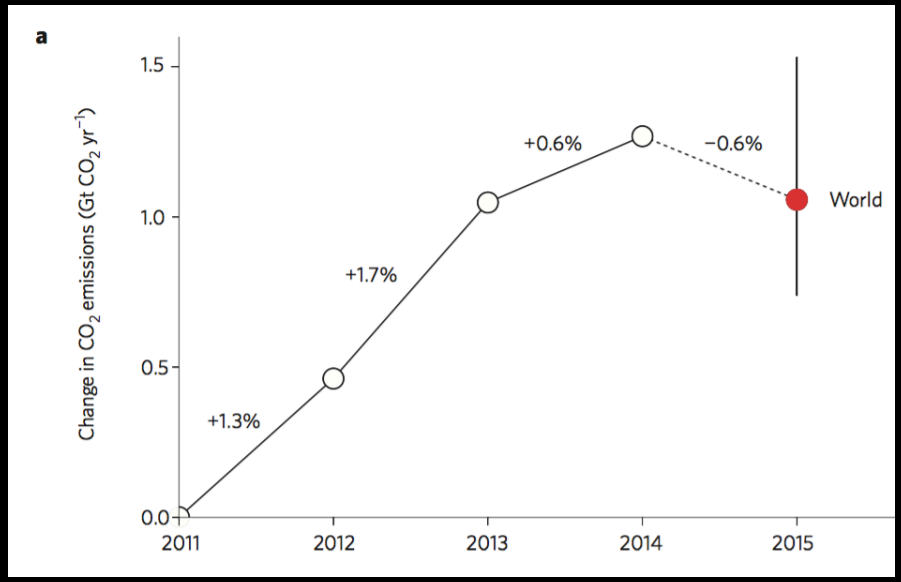
COMMENTARY:

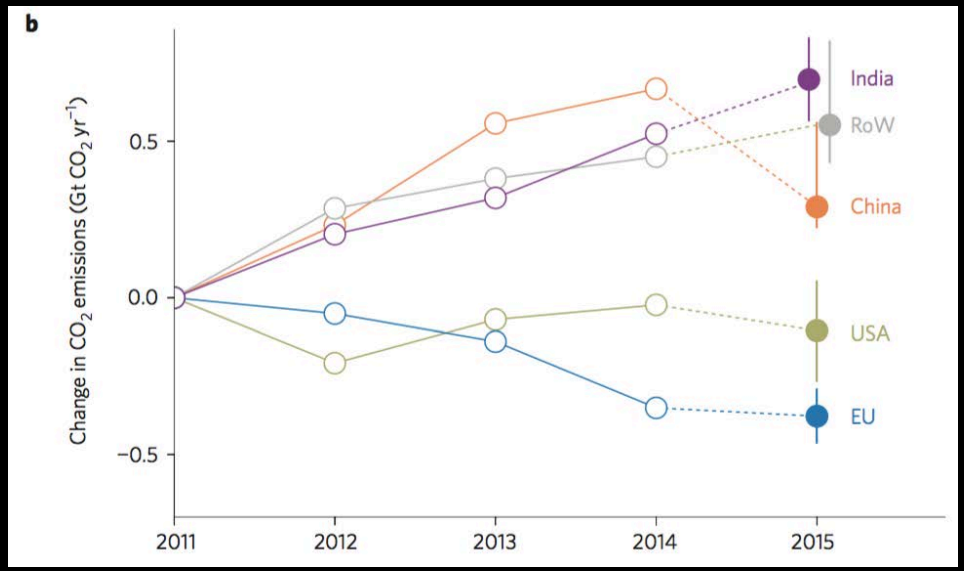
NATURE CLIMATE CHANGE | VOL 6 | JANUARY 2016 |

Reaching peak emissions

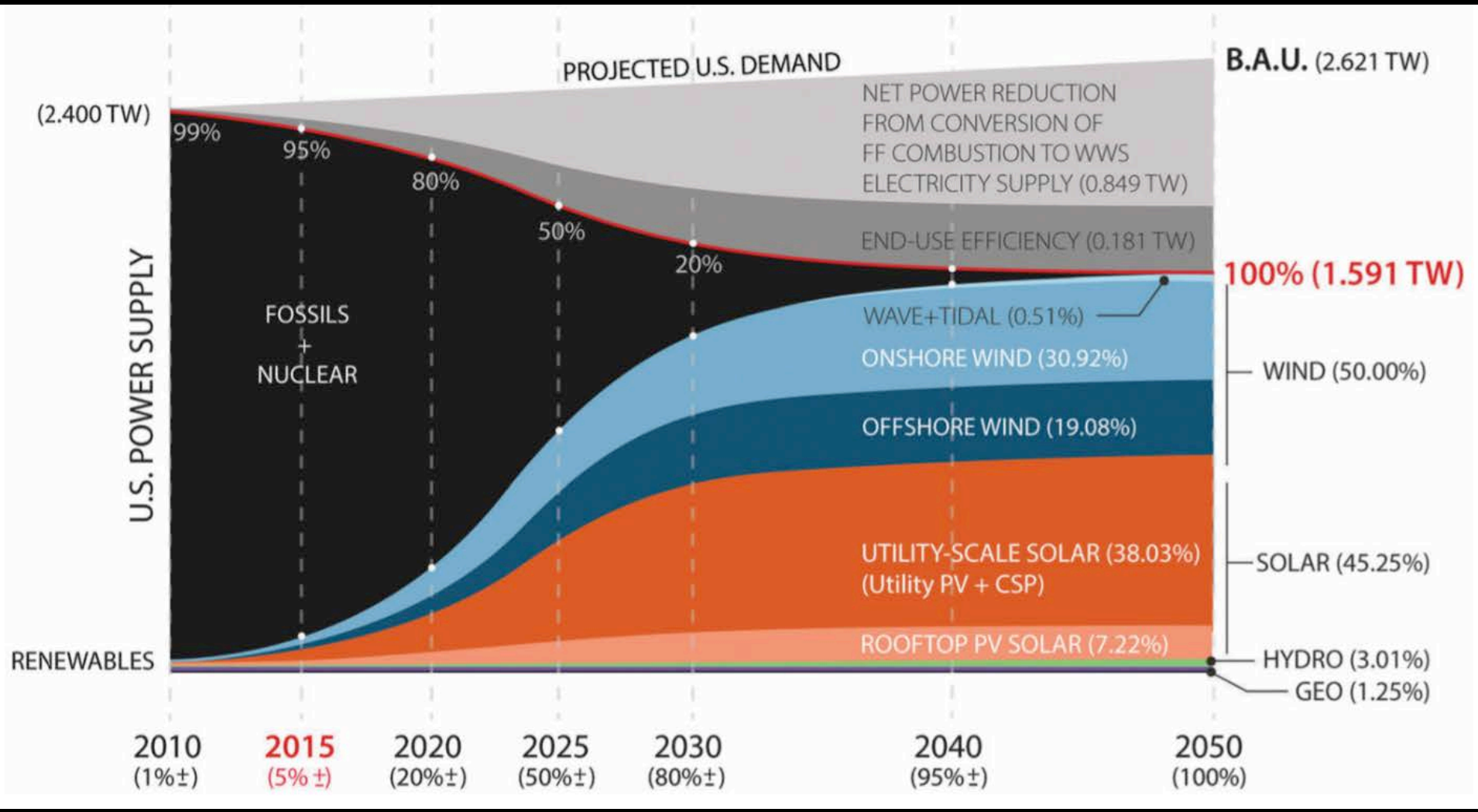
Robert B. Jackson, Josep G. Canadell, Corinne Le Quéré, Robbie M. Andrew, Jan Ivar Korsbakken, Glen P. Peters and Nebojsa Nakicenovic

Rapid growth in global CO_2 emissions from fossil fuels and industry ceased in the past two years, despite continued economic growth. Decreased coal use in China was largely responsible, coupled with slower global growth in petroleum and faster growth in renewables.





A Path to Renewables for All U.S. Energy Use



Solutions
Some Good, Some Bad

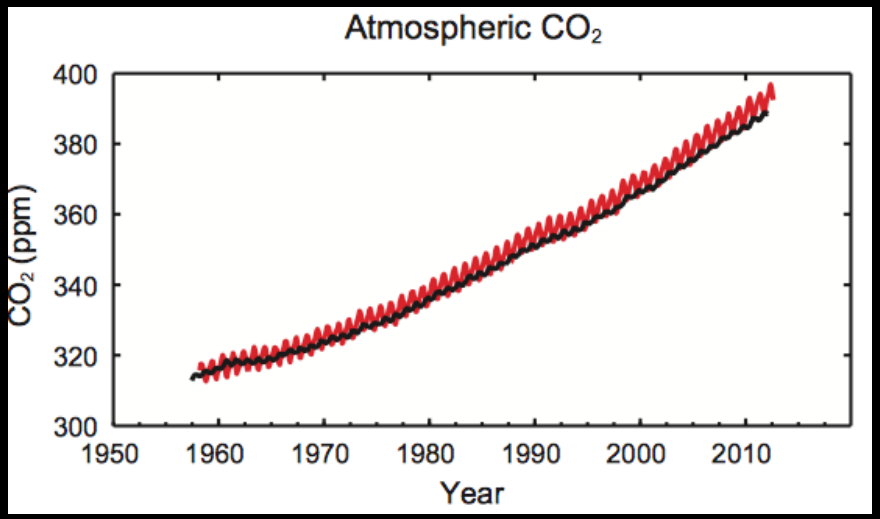
- System Benefits Charge
- Continued Municipal Conservation 1%/Year
- Desalination ?
- Weather Modification ?
- Markets
- Diets ?
- Reductions / Flex in Agriculture
- Water Law Changes

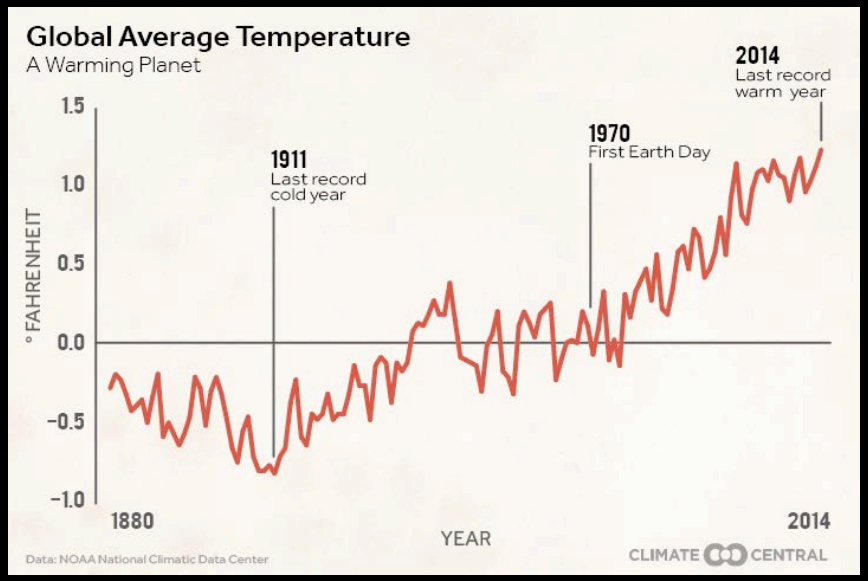
Conclusions

- Climate Change Defining Issue of 21st Century
  - Water at the heart of impacts
  - We can "legislate" away drought
    - Have technical/economic capacity to banish climate change…but maybe not political will
  - Solutions at hand, but need to pursue with all possible haste
- Many Water Solutions Possible
  - But nothing is easy…

"Perhaps you'd like a second opinion?"

- Earth is about 60F warmer than it should be
- Very Small Concentrations of Greenhouse Gasses (GHGs) are the cause. CO_2 is most important one.
- Earth's Temperatures have fluctuated widely over its 4.5B year history But NOT during human ascendency of last 2k years
- Humans are adding enormous amounts of GHGs to the atmosphere every day and it is increasing over time. On a path to double CO2 by 2050
- Planet is now 1.8 F warmer due to GHG emissions. No other plausible explanation for the warming
- Total Warming will be related to GHG concentrations, not emissions



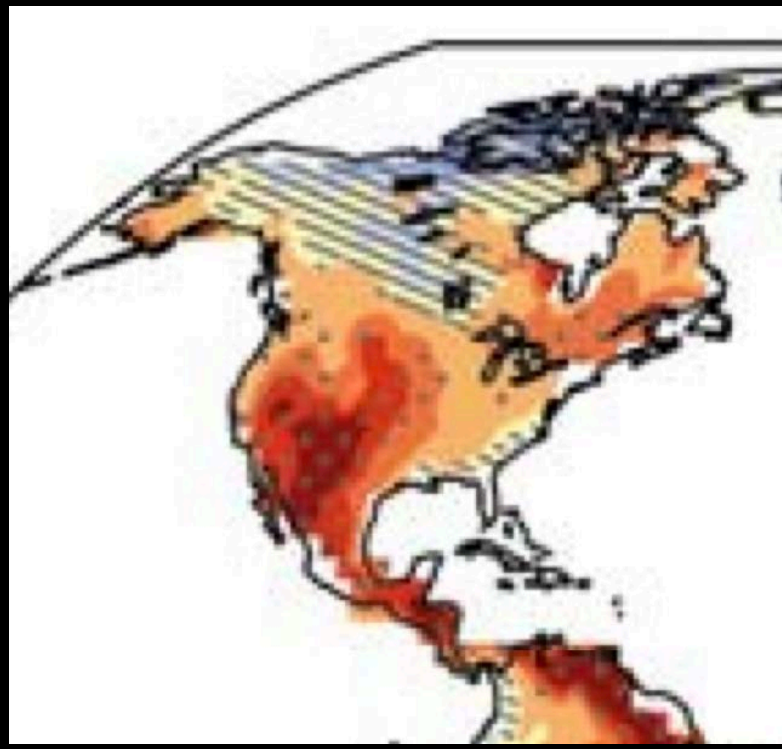


*Climate Change Basics

Projected Drying in U.S. Southwest

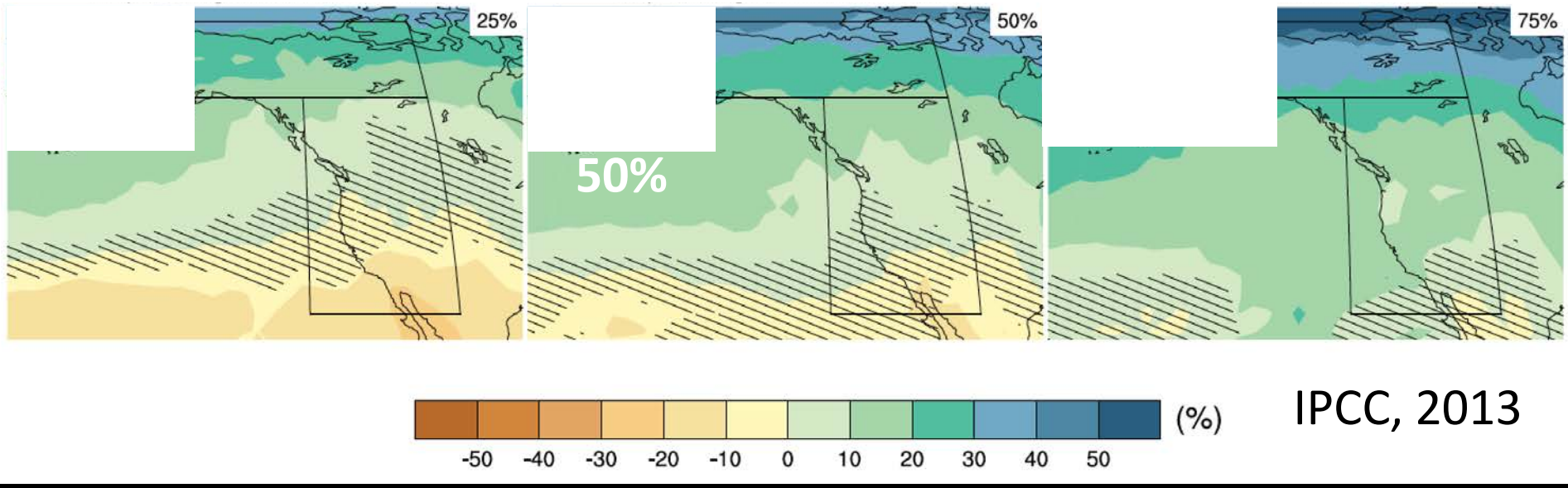
- "Regional to global-scale projections of soil moisture and drought remain relatively uncertain compared to other aspects of the water cycle. Nonetheless, drying in the Mediterranean, southwestern U.S. and south African regions are consistent with projected changes in Hadley circulation, so drying in these regions as global temperatures increase is likely for several degrees of warming under the RCP8.5 scenario."

Soil Moisture @2100



Latest Climate Model Projections
(Ensemble average of 39 global models)

Projected Annual Precipitation Change by the End of Century
Given Continued High Emissions

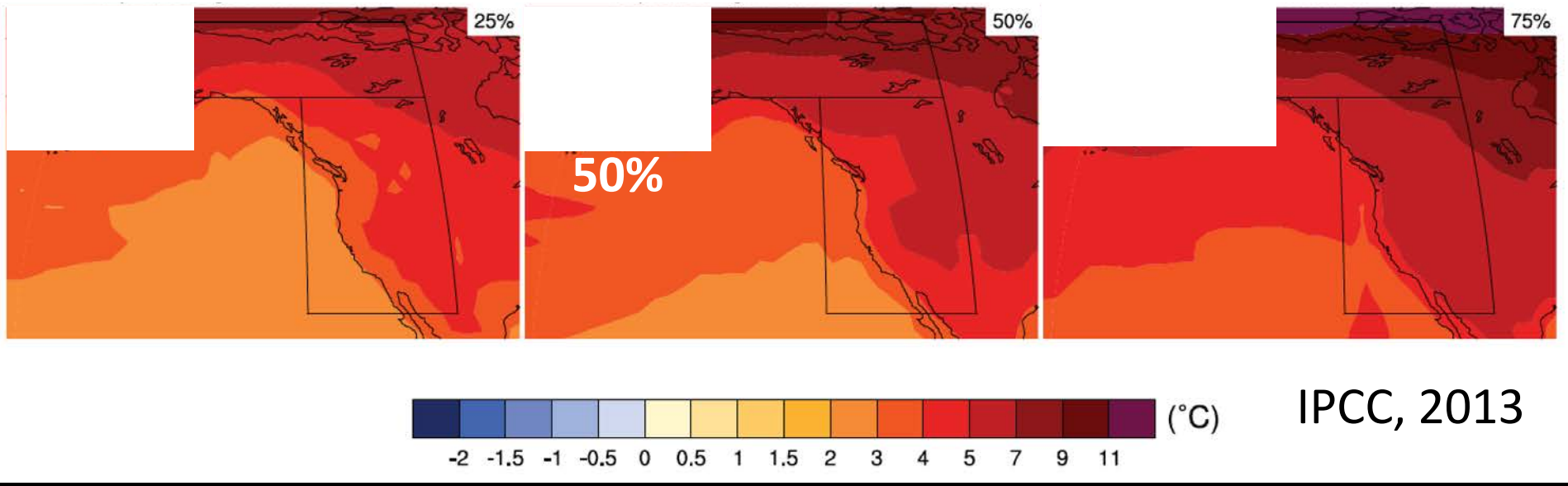


IPCC, 2013

Bottom-line: North gets wetter, South drier. But note that precip is not runoff.

Latest Climate Model Projections
(Ensemble average of 39 global models)

Projected Annual Temperature Change by the End of Century
Given Continued High Emissions

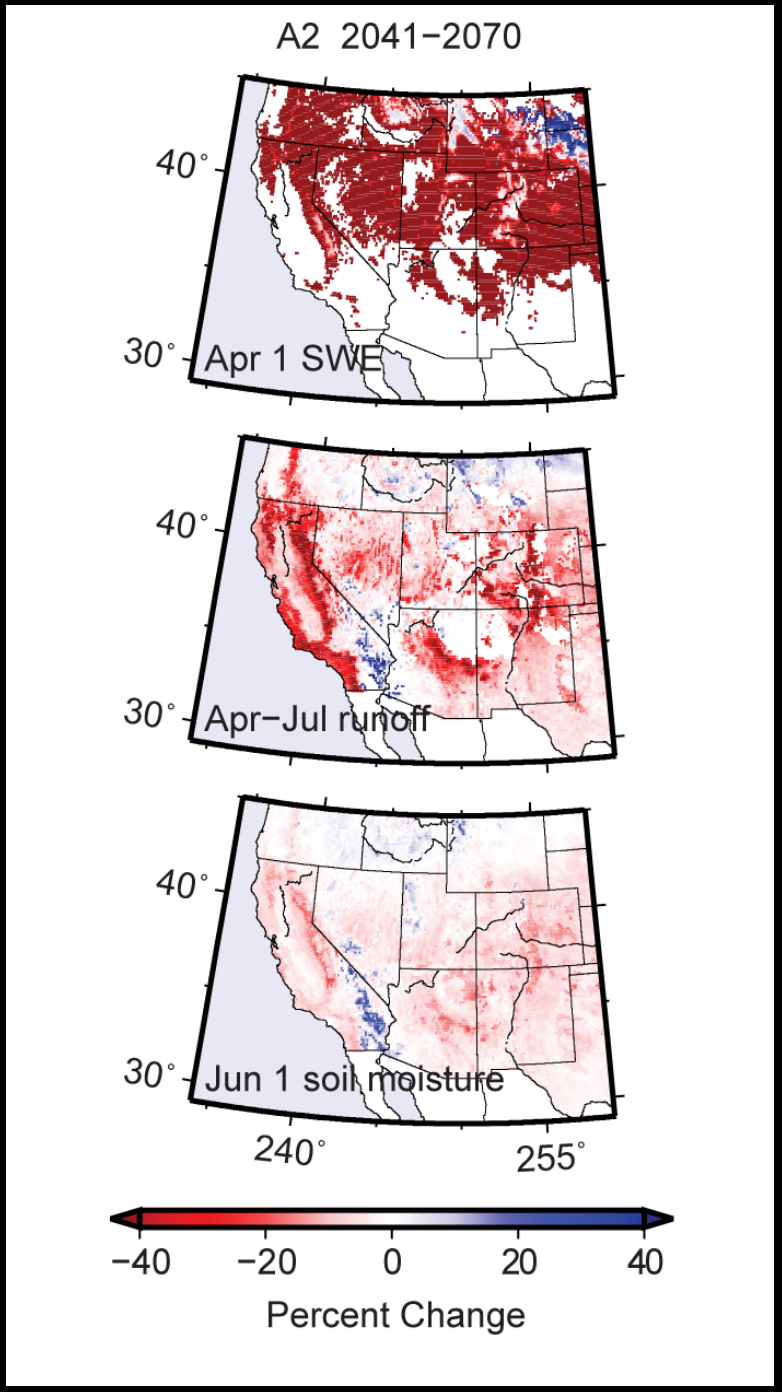


IPCC, 2013

Bottom-line: Western US will get hotter for sure, perhaps much hotter

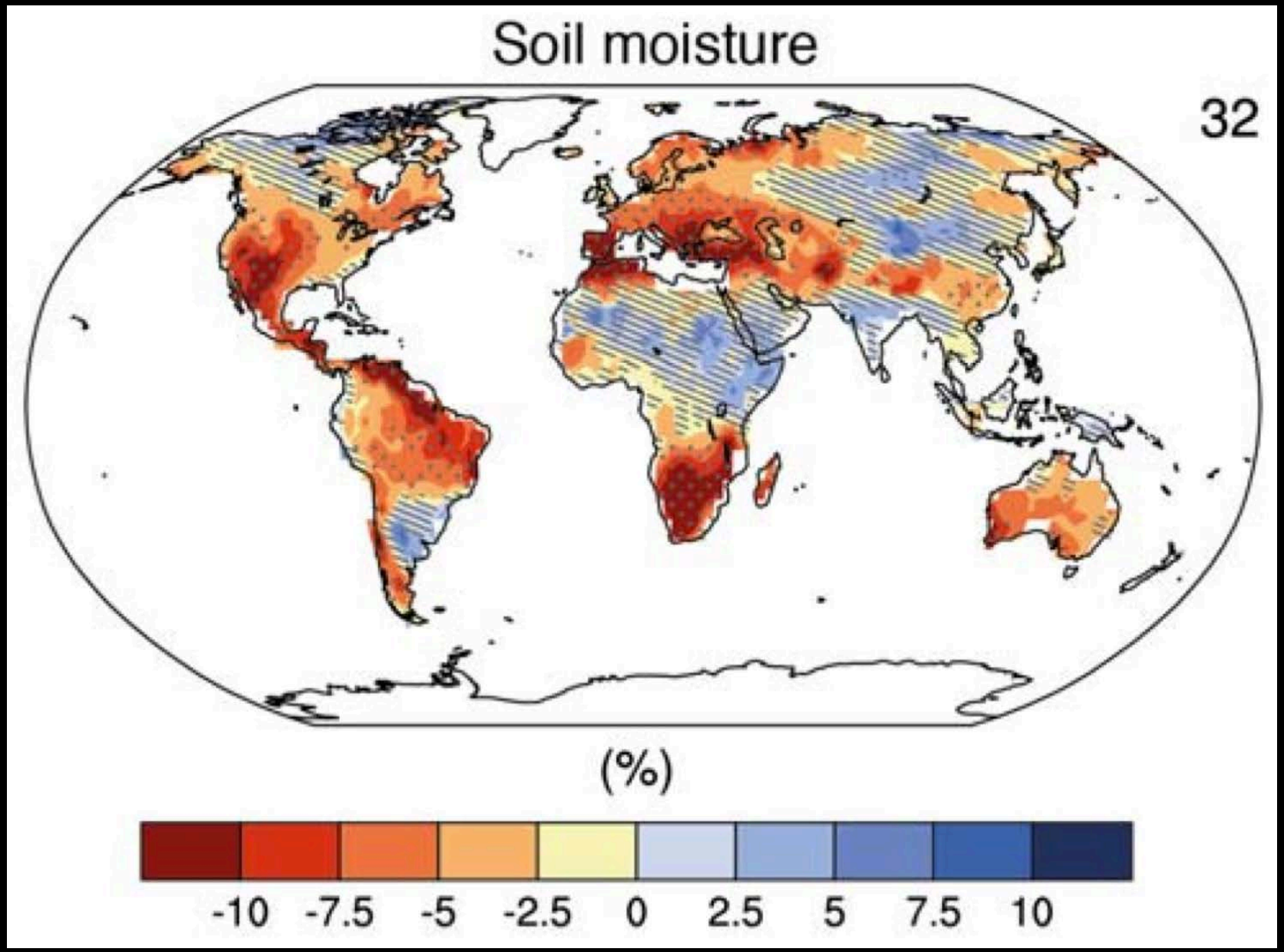
Projected Changes in Snowpack, Runoff, and Soil Moisture

- Declines in April 1 Snow (SWE) indicate the start of runoff will advance into March
- Total Snow may or may not change depending on precipitation changes
- Not shown: increases in runoff during the Winter



Source: 2014 National Assessment

IPCC FAR Results RCP 8.5 at 2081 to 2100



CLIMATE CHANGE

Dry Times Ahead

Jonathan Overpeck[1] and Bradley Udall[2]

The climate of the western United States could become much drier over the course of this century.

- 2F Warming since 1900
- Snowpack Reductions and Changes in Runoff Timing Already Present
- Most Severe Drought since records kept
- Powell and Mead at 50% of capacity now, full 2000
- Tree Mortality Rates High
- Increase in Wildfire Frequency
- Drought may be natural, but exacerbated by higher temperatures
- Snowpack Reductions and Runoff Timing attributed to climate change
- Continued drying likely as temperatures increase and storm tracks shift
- Megadroughts independent of climate change a possibility with severe consequences if combined with warming

Science, February 1, 2008

POLICYFORUM

CLIMATE CHANGE

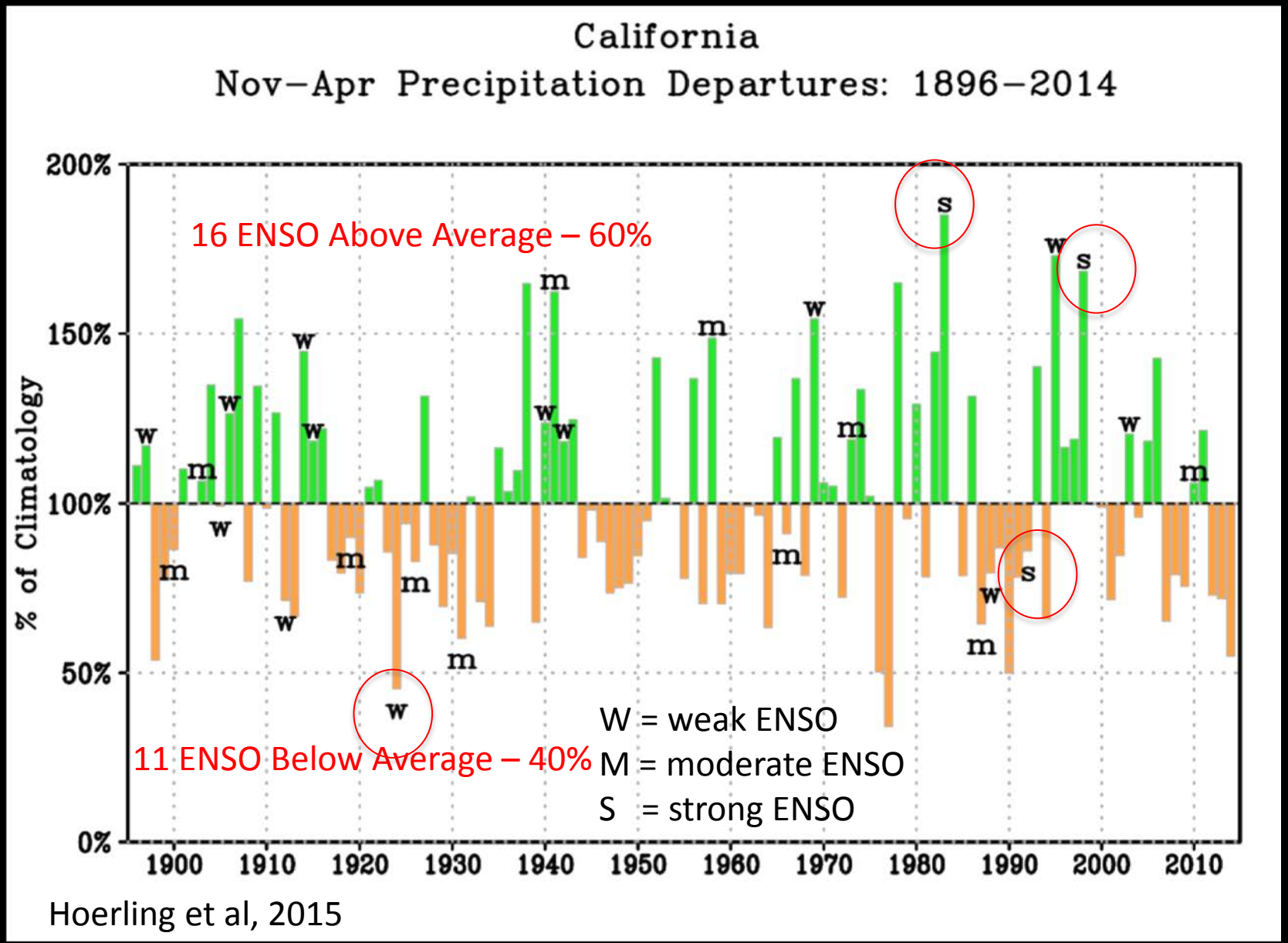
Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

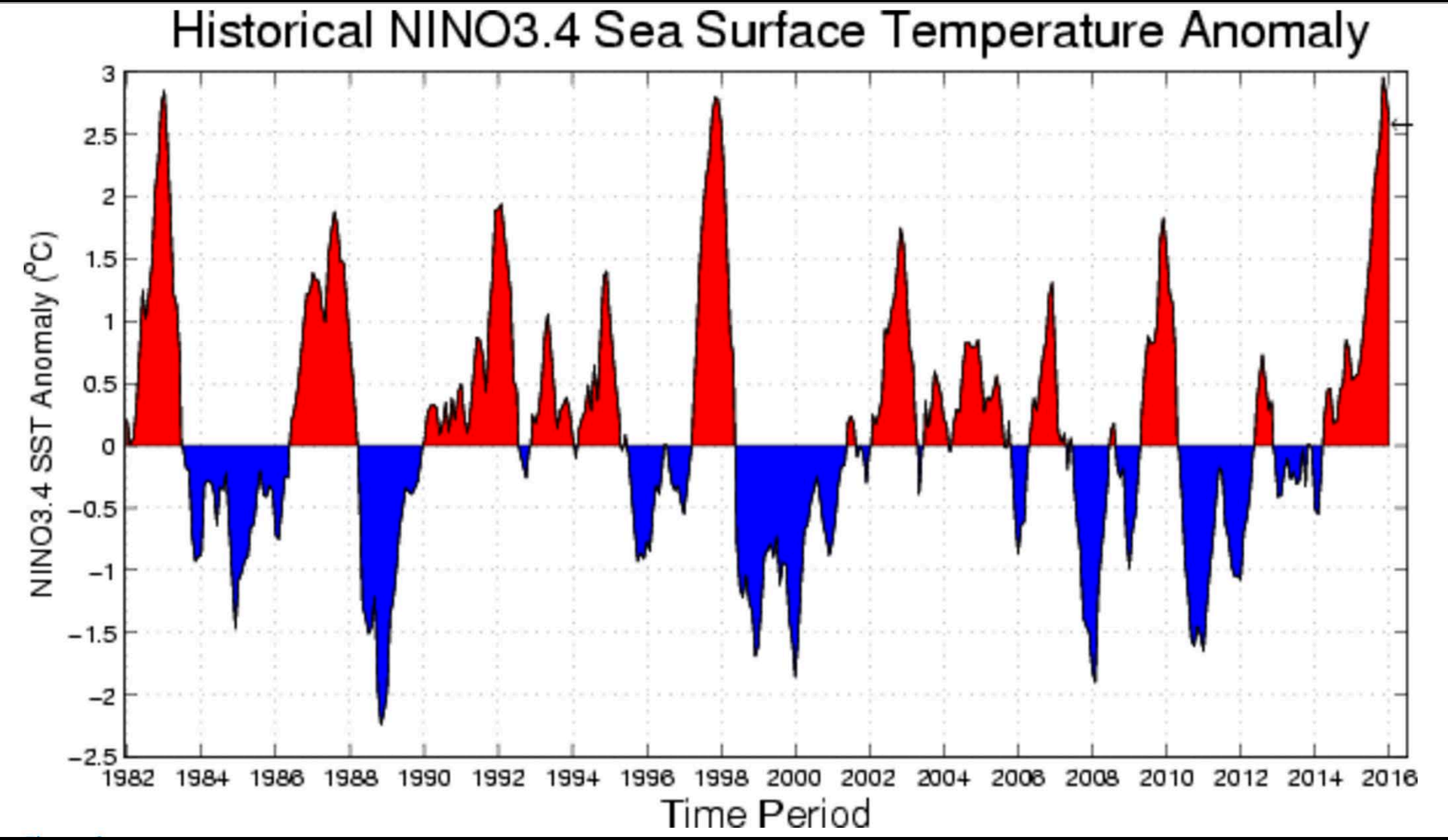
- Water resource planning uses “climate stationarity” – climate of the future = the climate of the past
- Less and less true as we move forward
- Both supply and demand are changing
- New water projects have substantial uncertainty

Historic ENSO Years – 27 in total



Hoerling et al, 2015

One Measure of El Nino – Southern Oscillation



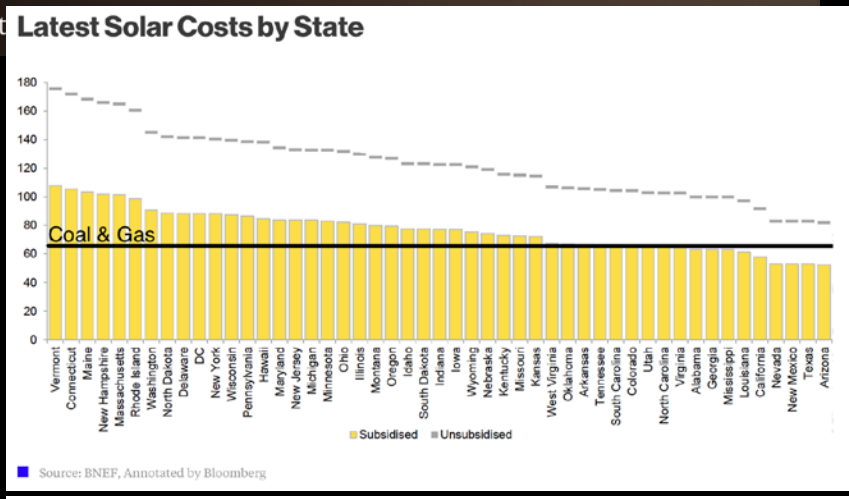
Reasons for Climate Optimism

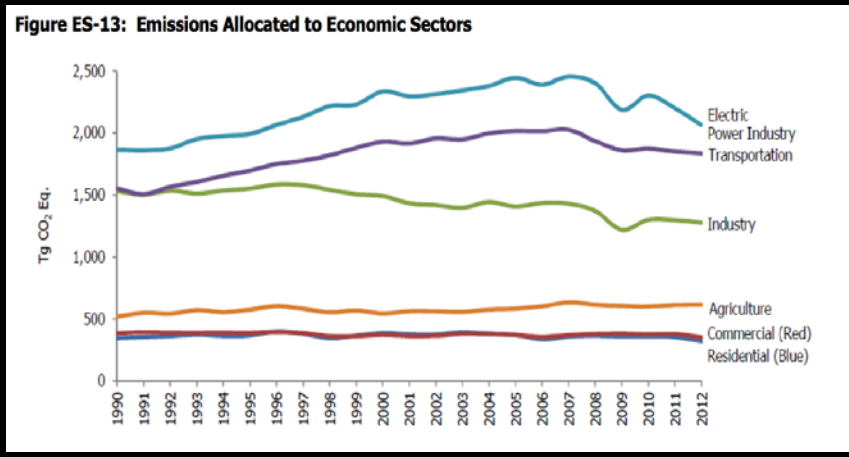
- Technology
  - PV - $10 to $0.50 over 2 decades
  - Wind less than Gas Now
  - 200 Fewer Coal Plants (325 now)
  - LED Lights
  - Nissan Leaf Battery $15k to $5k
  - Storage a top priority but not needed for a while
- International Commitments at Paris
  - First Ever Agreement with 195 Countries
- US Efforts
  - Clean Power Plan – no more coal built
  - 32% by 2032 relative to 2005
  - US GHG Emissions have likely peaked
- World Efforts
  - Emissions declined globally last year
- Science Implications
  - Will be able to rule out higher emissions soon
- Future still a challenge
  - Will blow by 2C warming most likely
  - We just spent 20 years wasting time on getting an interanational agreement

BloombergBusiness

Bloomberg Business

Solar and Wind Just Passed Another Big Turning Point





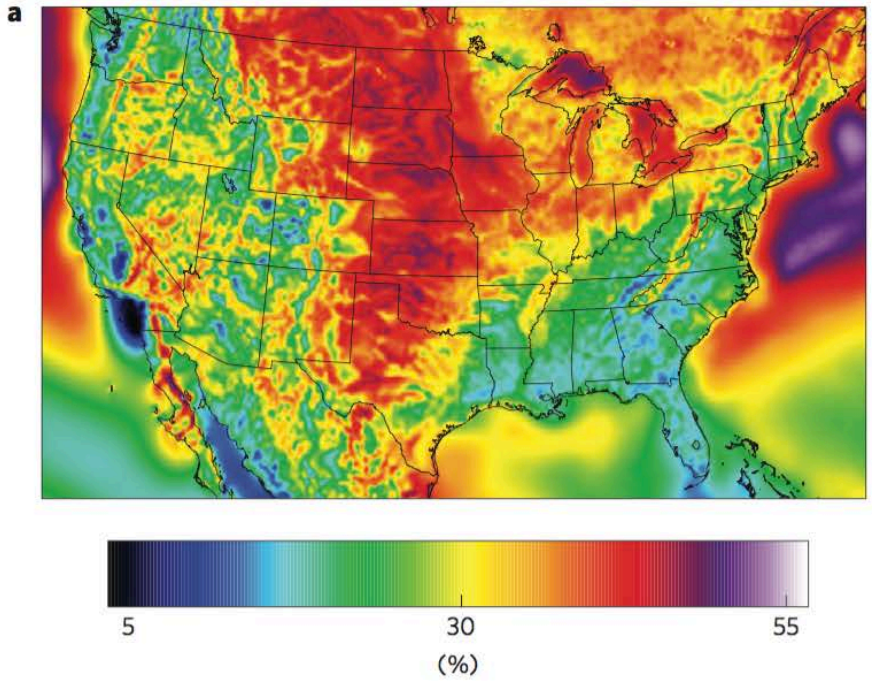
nature climate change

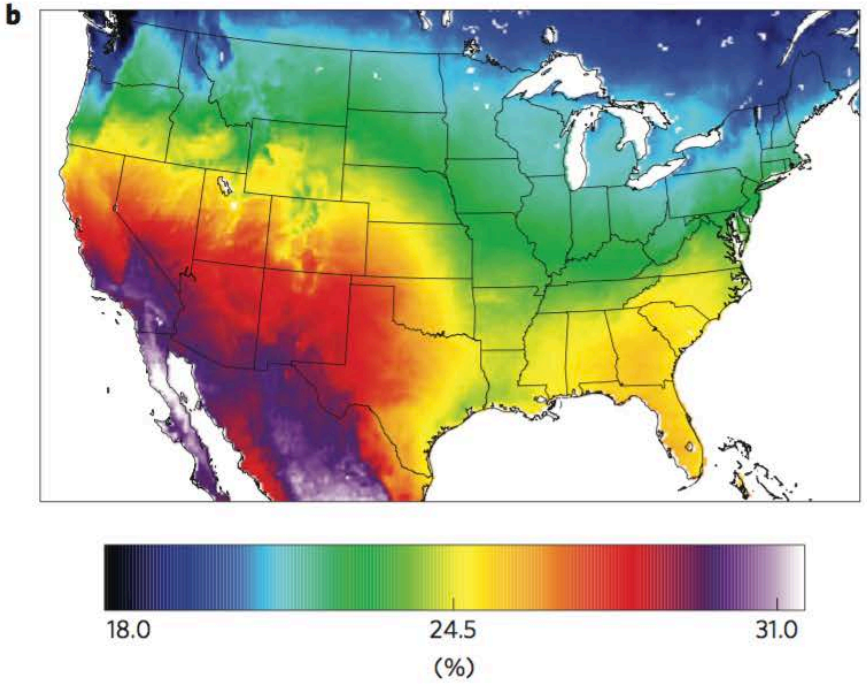
ARTICLES

PUBLISHED ONLINE: 25 JANUARY 2016 | DOI: 10.1038/NCLIMATE2921

Future cost-competitive electricity systems and their impact on US CO_2 emissions

Alexander E. MacDonald[1*†], Christopher T. M. Clack[1,2*†], Anneliese Alexander[1,2], Adam Dunbar[1], James Wilczak[1] and Yuanfu Xie[1]





Energy & Environmental Science

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100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States†

Mark Z. Jacobson,*[a] Mark A. Delucchi,[b] Guillaume Bazouin,[a] Zack A. F. Bauer,[a] Christa C. Heavey,[a] Emma Fisher,[a] Sean B. Morris,[a] Diniana J. Y. Piekutowski,[a] Taylor A. Vencill[a] and Tim W. Yeskoo[a]

- Replaces ALL lost jobs in current energy sector +2m
- Saves ~$250/year per person in energy costs at 2050
- 80% renewable by 2035, 100% by 2050
- Avoids ~50,000 premature deaths per year
- Uses very little land base ~0.4%

CURRENT RESERVOIR CONDITIONS