Avoid the Unmanageable, Manage the Unavoidable

Eight Interdisciplinary Lectures on Climate Change

Charles F. Kennel

Monday Evenings, 5:30-7 pm, Martin Johnson House

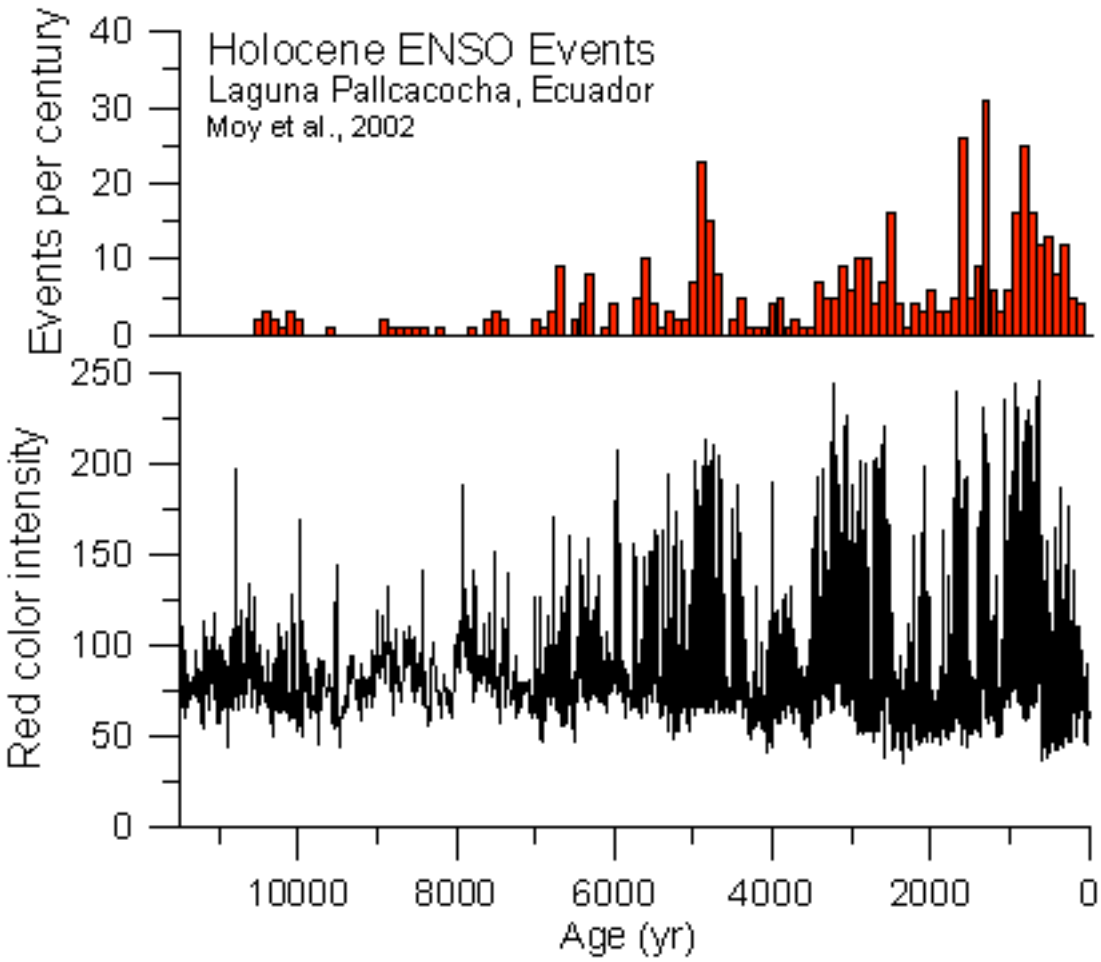
Scripps Institution of Oceanography, University of California San Diego

Dec 1: California Prepares to Adapt

The El Nino cycle, today and in the past; atmospheric rivers, floods and droughts; water resources and management; how California learned from air pollution; California's regional assessments; Impacts on regional natural systems, regional technical systems, and populations

The history of California is written in water, not ink, in great swings between abundance and dearth, the *El Nino* and *La Nina*. Their cycle is as important to Western North America as the monsoon is to India.

Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch

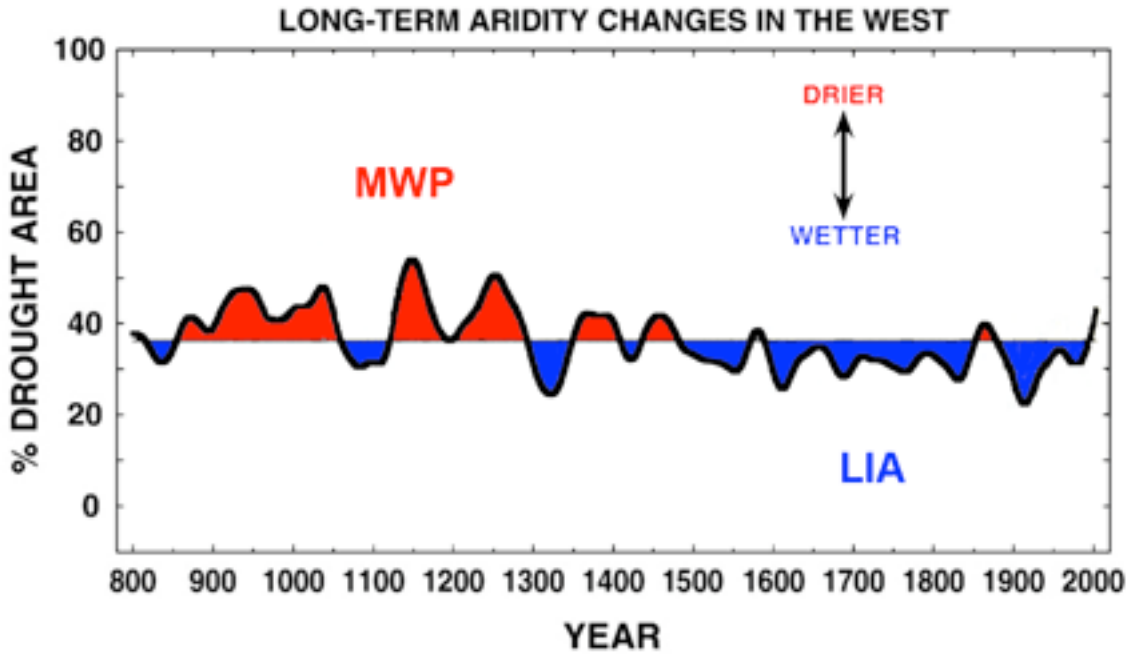


Christopher M. Moy, Geoffrey O. Seltzer, Donald T. Rodbell, & David M. Anderson, *Nature* 420, 162-165 (14 November 2002) | doi:10.1038/nature01194

Proxies tell us that El Niño events were extreme but infrequent in the period 12-8,000 years ago. A long paleoclimate record from this alpine lake in Ecuador shows a systematic change in El Niño activity during the Holocene. Between 8,000 and about 5,000 years ago, winters were dry. Starting around 5,000 years ago, around the end of the holocene climate optimum, *El Niño* floods became more frequent and the intervals about 3,000 and after 2,000 years ago were particularly stormy.

Bristlecone Pines like this one at the Great Basin National Park on Mt. Washington contribute to the tree-ring record of El Nino . Image: Great Basin National Park

Mega-Drought



In a review of multiple long tree-ring reconstructions of past drought (Palmer Drought Severity Index) conditions in North America, Cook et al. find evidence of "a number of unprecedented mega-droughts over the past millennium that clearly exceed any found in the instrumental records," including an amazing "epoch of significantly elevated aridity that persisted for almost 400 years over the AD 900-1300 period."

All major historical droughts of North America were caused by "the development of cool 'La Niña-like' SSTs in the eastern tropical Pacific"…They report that "La Niña-like conditions were apparently the norm …during much of the Medieval period," during which time the truly unprecedented 400-year mega-drought held sway.

Cook, E.R., Seager, R., Cane, M.A. and Stahle, D.W. 2007. North American drought: Reconstructions, causes, and consequences. Earth-Science Reviews 81: 93-134.

The Great California Mega-Flood Of 1862

Rain began Dec 24, 1861 and continued for 43 days

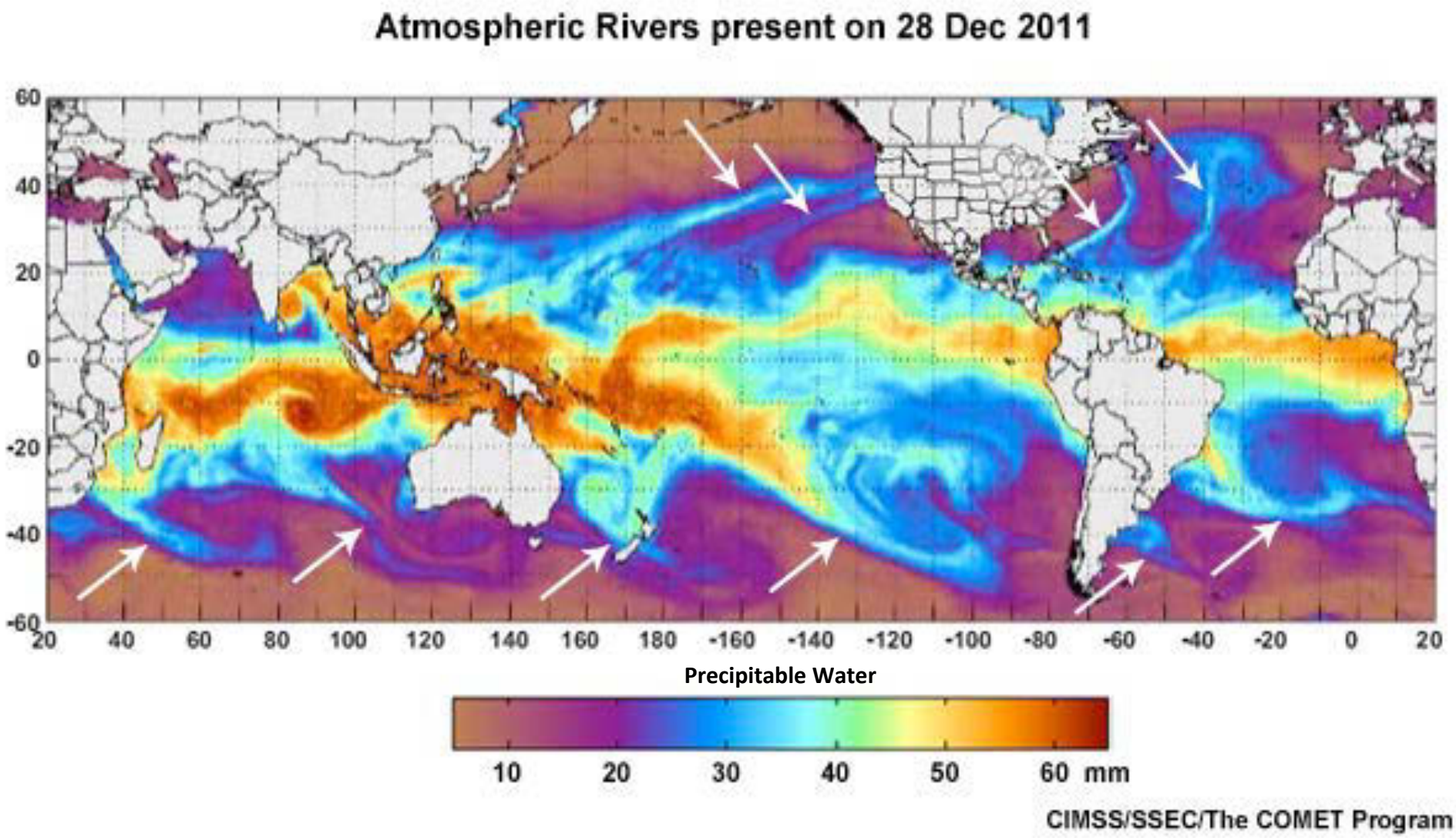
8.6 inches in December, 24 inches in January, 1862, and 7.5 inches in February

K Street, Sacramento
Jan. 10, 1862

A strong AR transports an amount of water vapor roughly equivalent to 7.5–15 times the average flow of liquid water at the mouth of the Mississippi River. On average, about 30-50% of annual precipitation in the west coast states occurs in just a few AR events

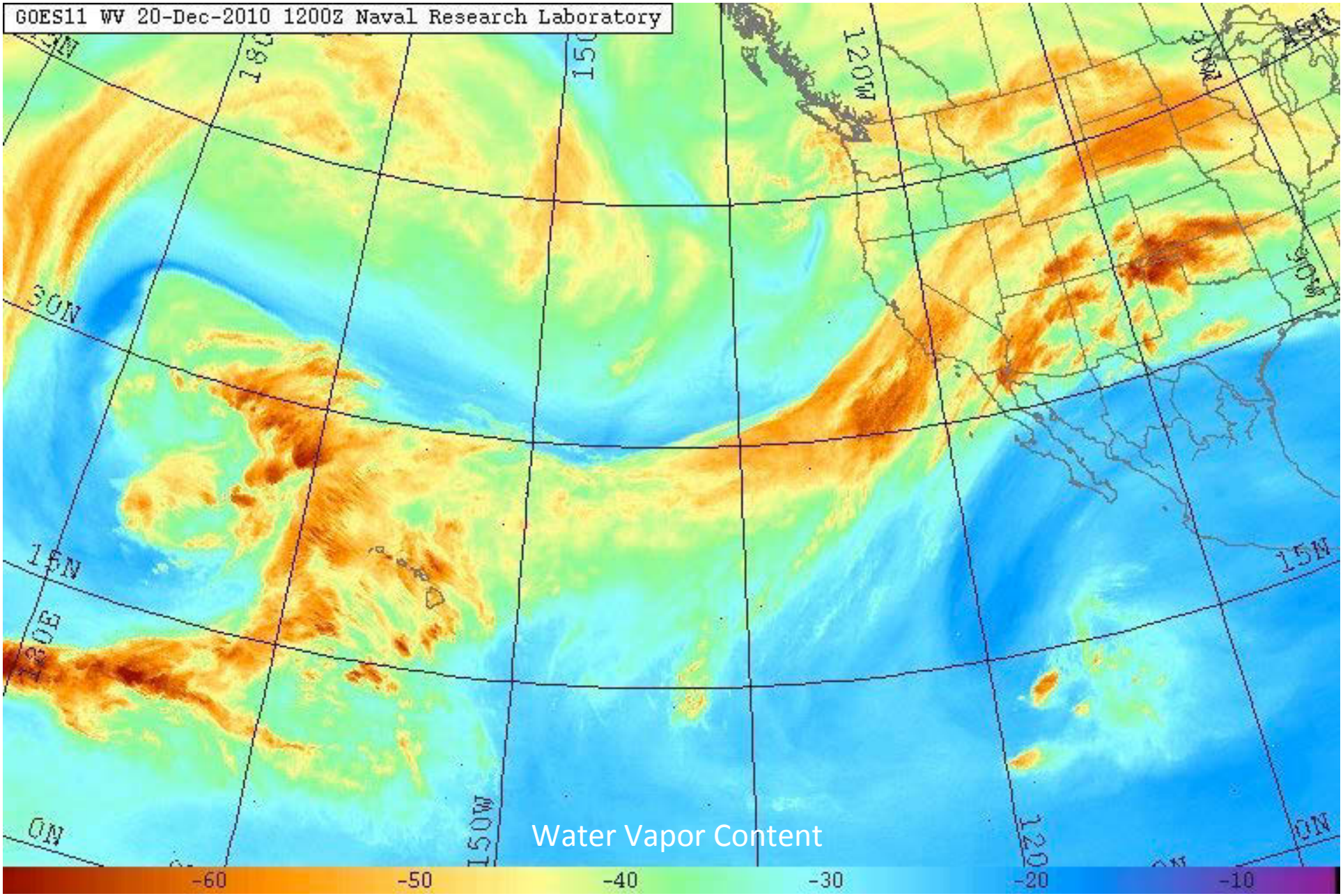
Atmospheric Rivers

A little bit of the tropics in the temperate zone



An Atmospheric River Streams Across Northern California

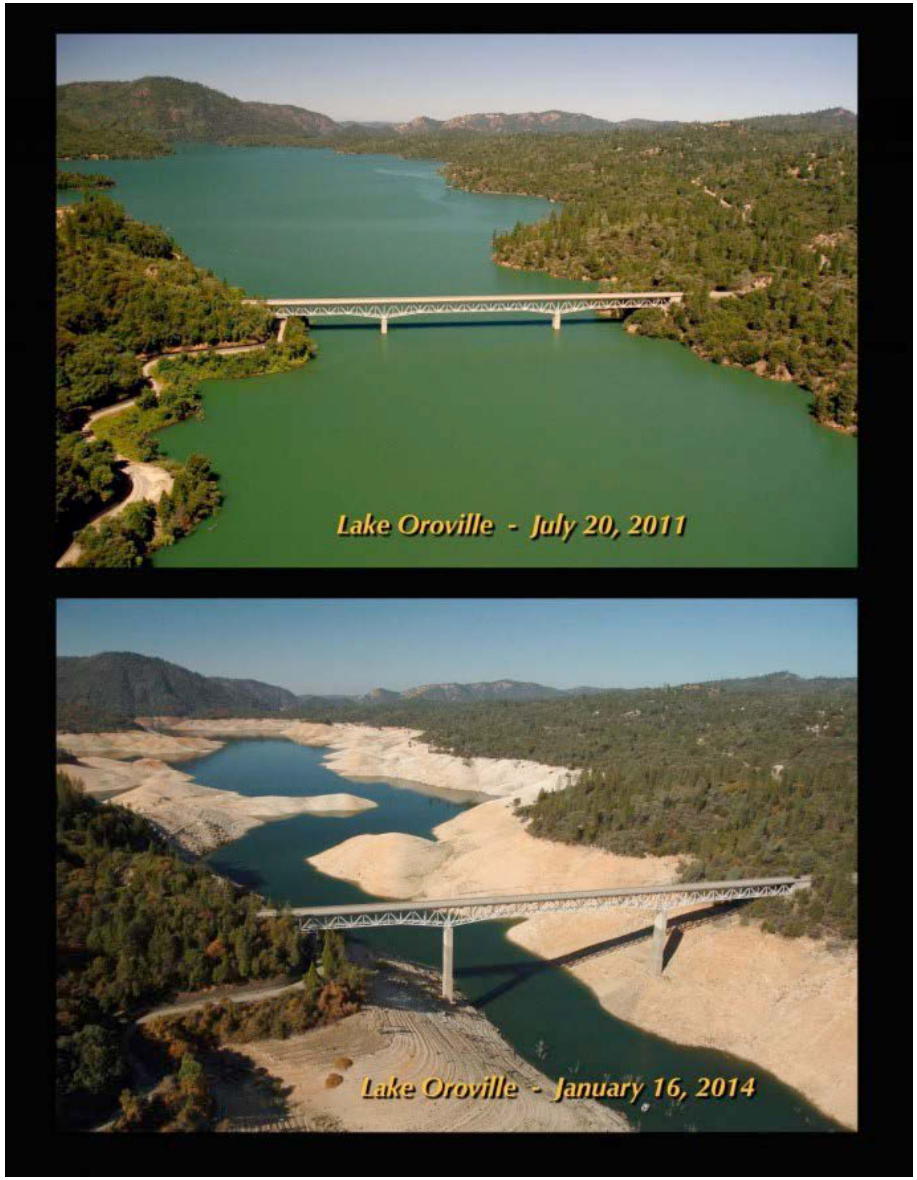
December 20, 2010




An Atmospheric River Encounters California's Coast
Mouth of Russian River


Storms Hit Sierra Nevada
More than 10 feet of snow in places
The Press Democrat, Dec 20, 2010

Lack of Sierra snowmelt prompts drastic State cutbacks



State officials announced they will not be able to make any deliveries from the State Water Project this year unless California receives significant additional rain and snowfall. It would be the first time in the system's 54-year history that there isn't enough water in reservoirs or in anticipated snowmelt to deliver supplies to agencies serving 25 million Californians and 1,000 square miles of farmland, said Mark Cowin, director of the Department of Water Resources.

"This is not a coming crisis. This is not an evolving crisis. This is a current crisis,"

Sacramento Press-Enterprise, Jan 31, 2014

Sacramento River Delta Catchment

In *El Nino* years, 1-in-20 storms provide almost as much as all other rain events

Continuing decline in Pineapple Express storms during today's extended *La Nina*

M. Dettinger and D.R. Cayan, Drought and the California Delta-A matter of extremes, June 2014

University of California e=Scholarship, http://escholarship.org/uc/item/88f1j5ht

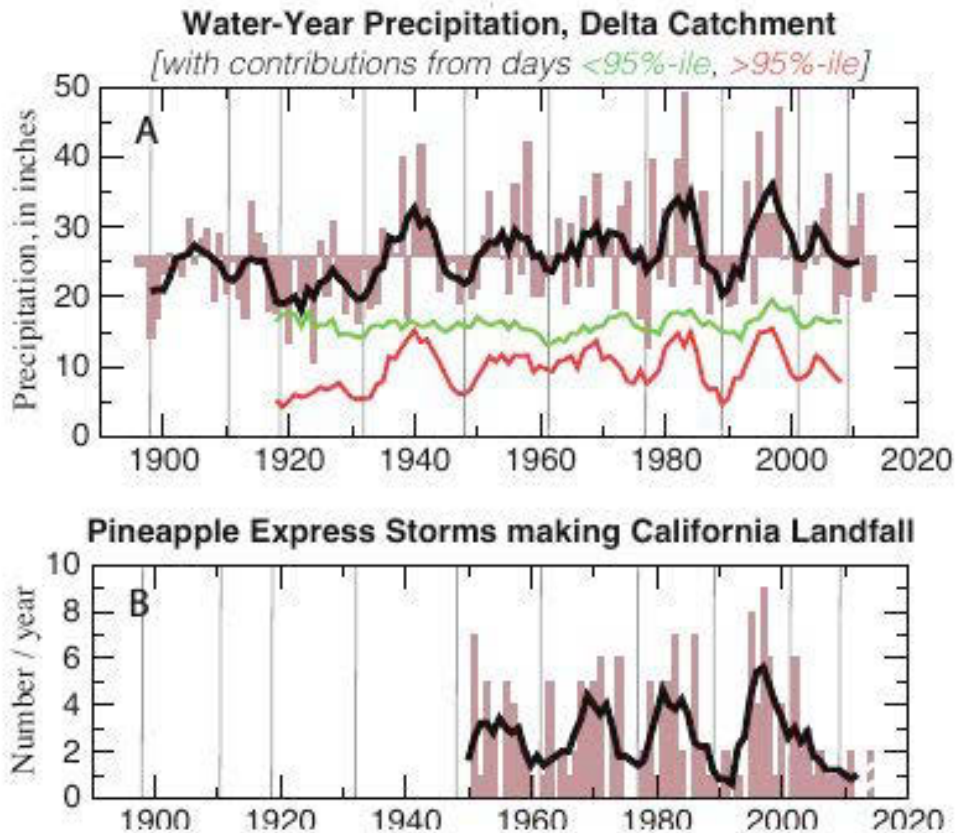
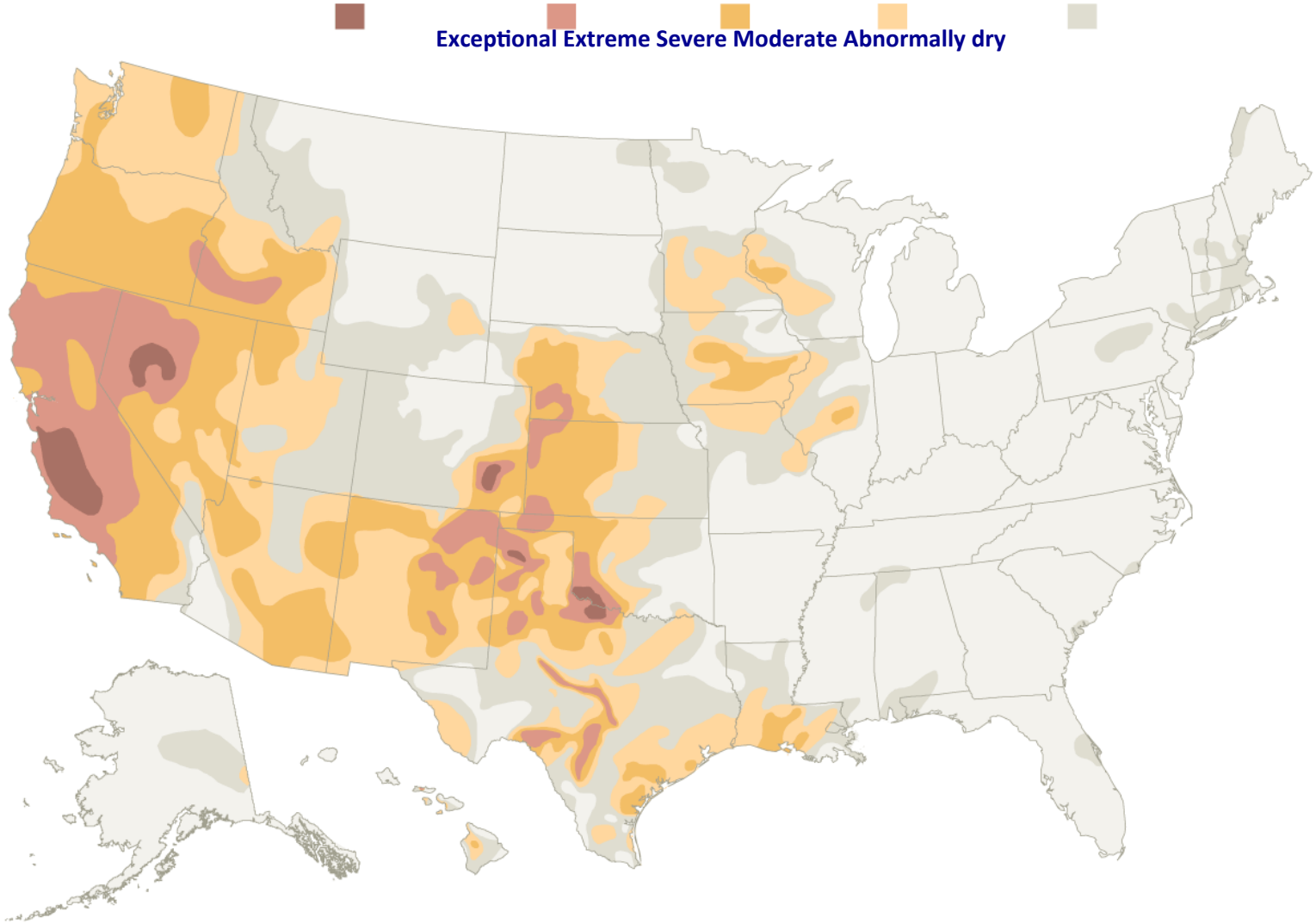


Figure 1 **(A)** Water-year precipitation totals (brown bars and black curve) in the Delta's catchment, 1895–present based on updated monthly Abatzoglou et al. (2009) data, and 5-year moving averages of contributions to these totals from the wettest 5% of wet days (days with precipitation >95th percentile; red curve) and all other wet days (<95th percentile; green curve) based on updated daily Hamlet et al. (2005) data, 1916–2010, and **(B)** numbers of pineapple-express storms making landfall between 35°N and 42.5°N per water year (using counts from Dettinger et al. 2011, updated through March 2014). Heavy curves are 5-year moving averages in both frames; vertical grey lines are approximate centers of persistent droughts in upper panel.

2014 Drought in US Western States

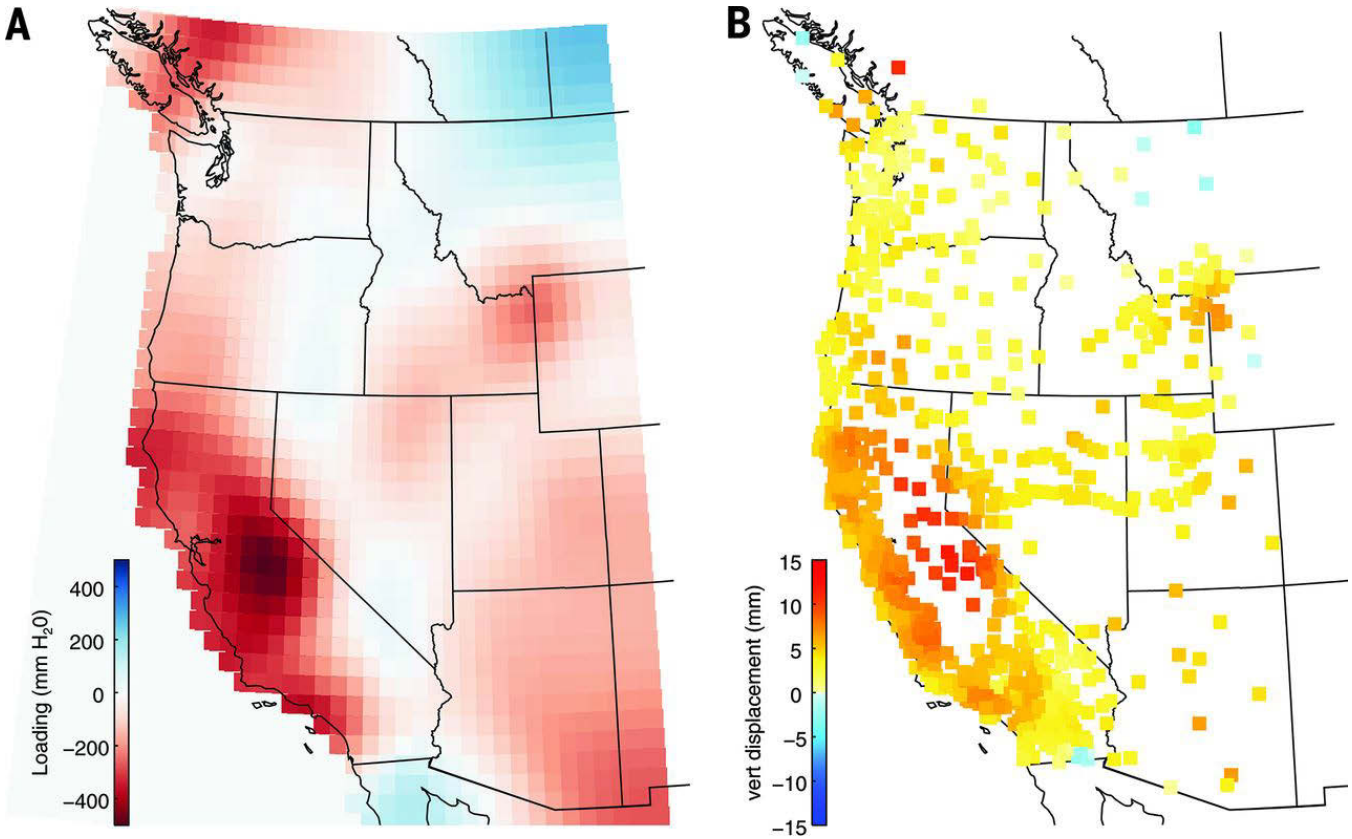


By the New York Times, Feb 16, 2014. Source: US Drought Monitor

Drought 2014: 240 Gigaton Water Deficit in Western USA

10 cm. or 4 inch layer over entire region

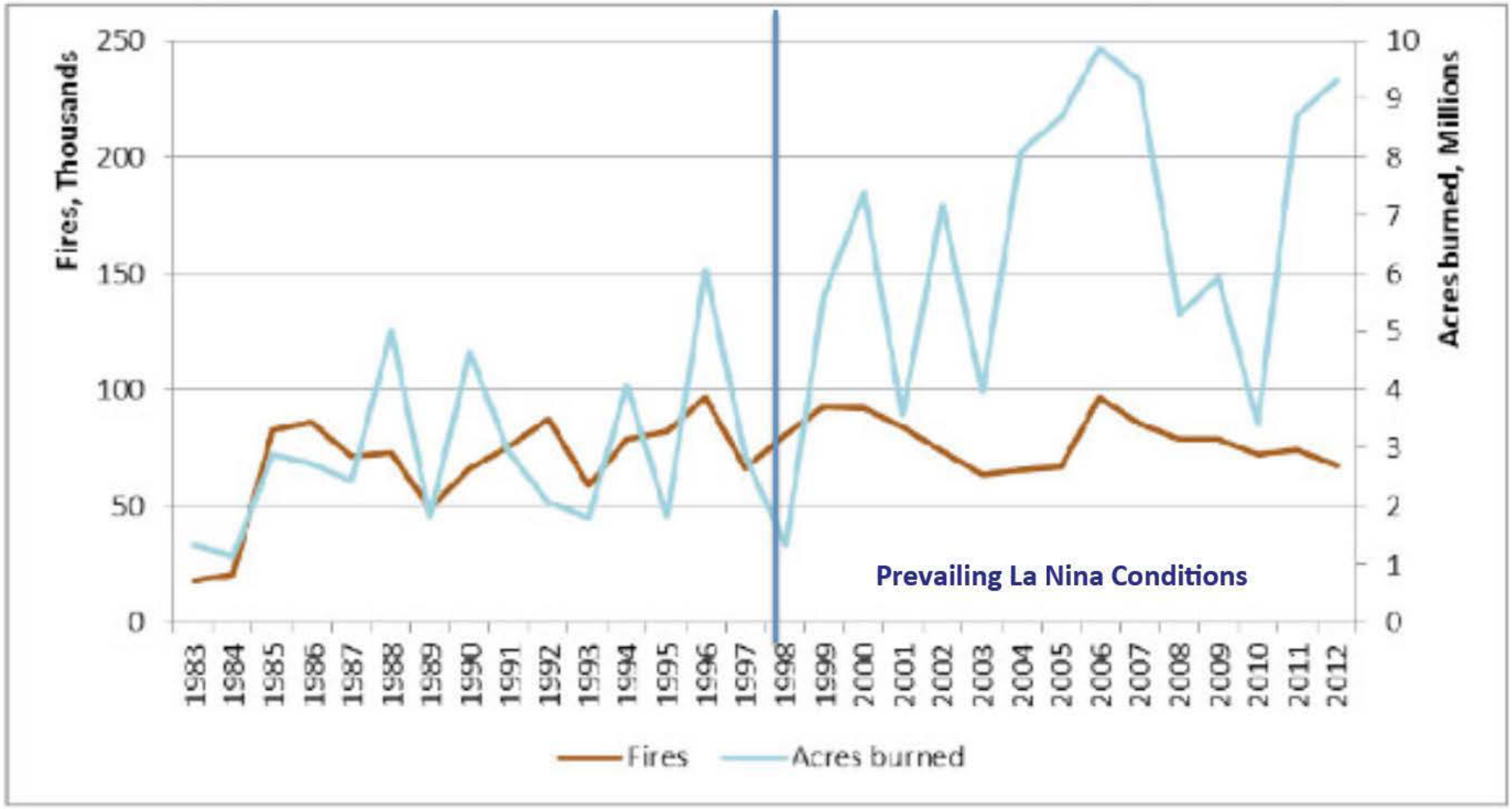
Equivalent to annual mass loss rate of Greenland Ice Sheet



Western USA Water Load (left) and Uplift (right) between March 2013-March 2014
771 GPS Sensor Network, NSF Plate Boundary Observatory

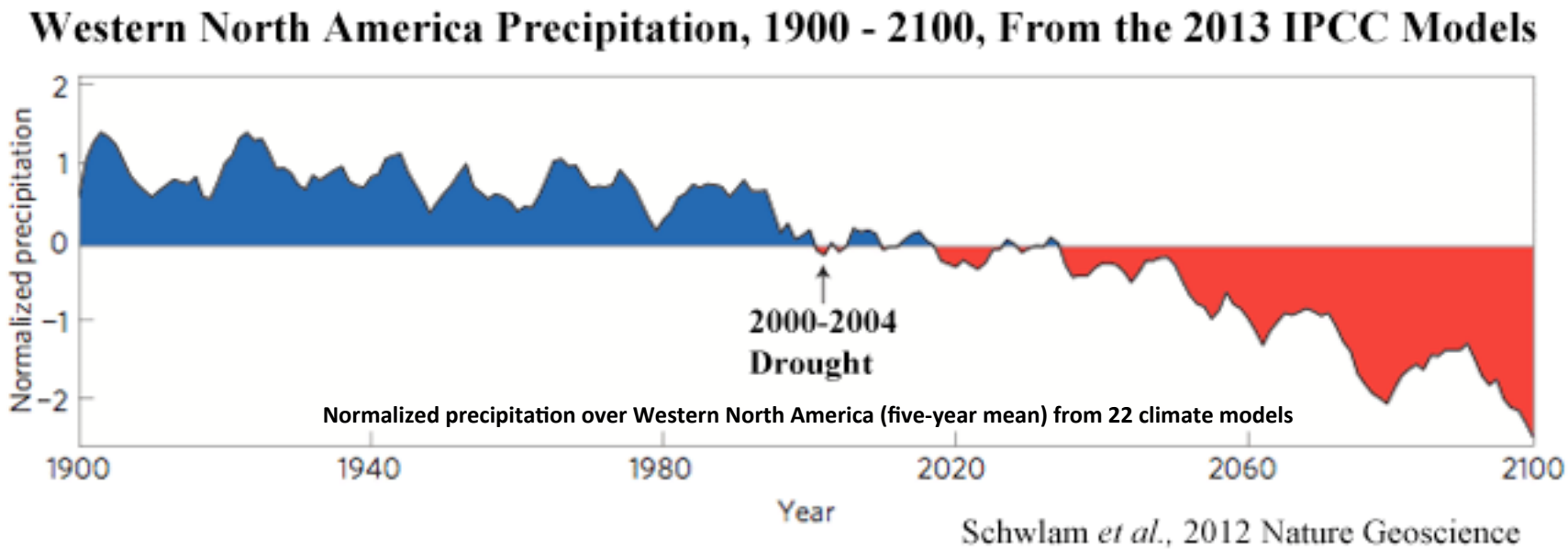
A.A. Borsa, D. Agnew, and D. Cayan, Ongoing drought-produced uplift in the western United States, *Science* 2014;345:1587-1590

Wildfire Burn Area Increased During "Hiatus"



Source: NIFC.

What can we say about California's Climate Future?



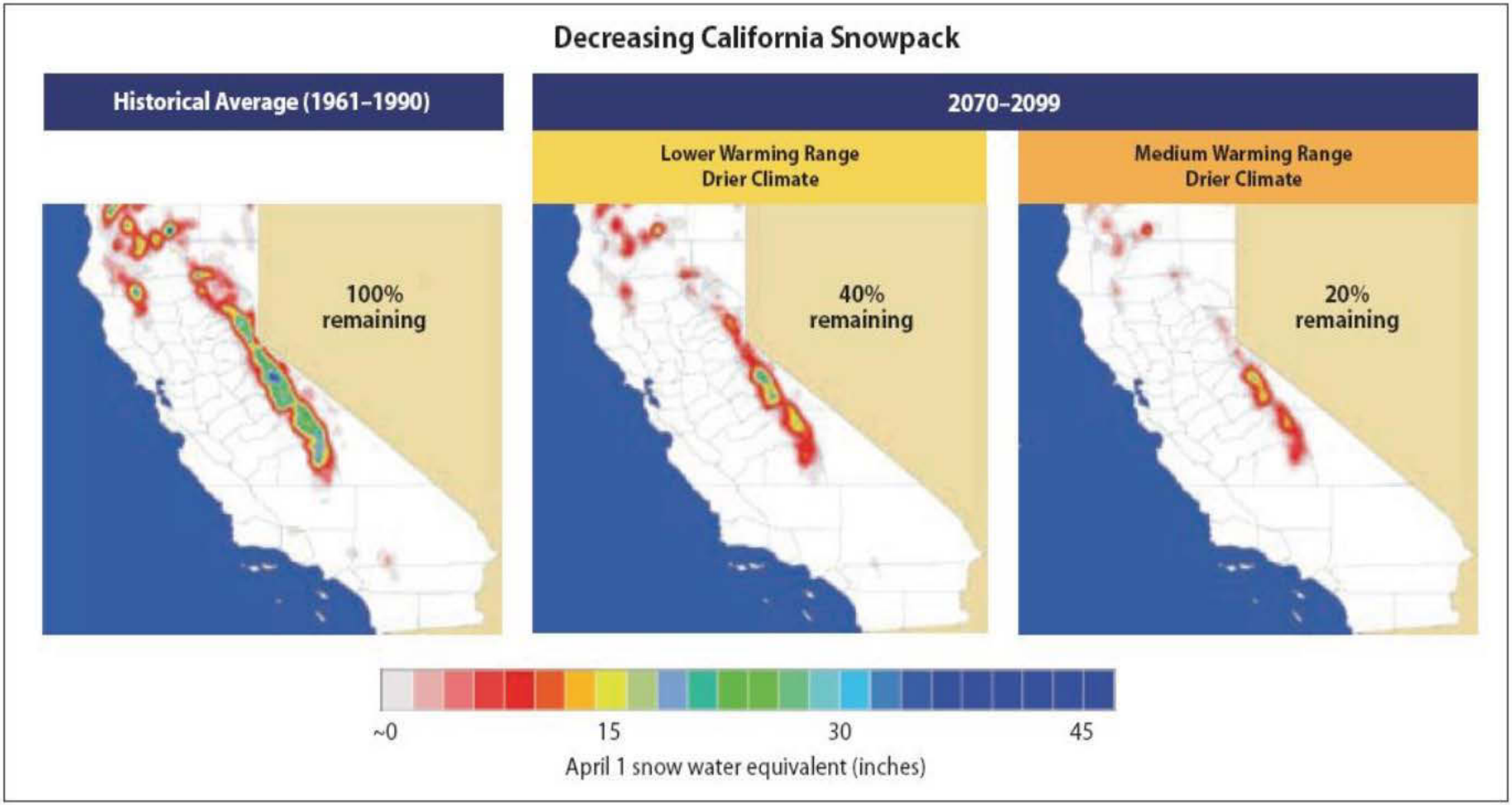
The horizontal line marks the precipitation level of the 2000 - 2004 drought, the worst of the past 800 years. Droughts of this intensity are predicted to be the new normal by 2030, and will be considered an outlier of extreme wetness by 2100.

"This impending drydown of western North America is consistent with present trends in snowpack decline as well as expected increases in aridity and extreme climate events, including drought, and is driven by anthropogenically forced increases in temperature with coincident increases in evapotranspiration and decreases in soil moisture. Although regional precipitation patterns are difficult to forecast, climate models tend to underestimate the extent and severity of drought relative to available observations. As such, actual reductions in precipitation may be greater than shown. Forecasted precipitation patterns are consistent with a probable twenty-first century megadrought."

Image credit: Schwalm et al., 2012, Reduction in carbon uptake during turn of the century drought in western North America, Nature Geoscience 5, 551-555, Published online 29 JULY 2012, DOI: 10.1038/NGEO1529, www.nature.com/naturegeoscience.

Sierra Nevada Snowmelt

The single most persuasive impact examined by the 2006 Assessment

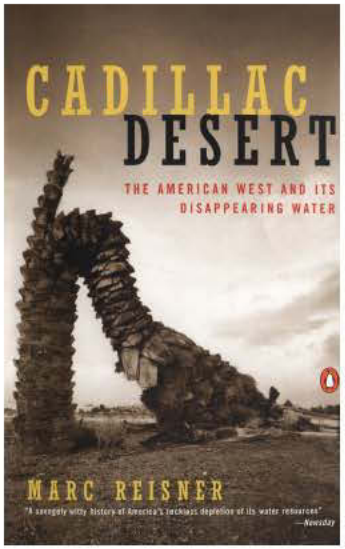


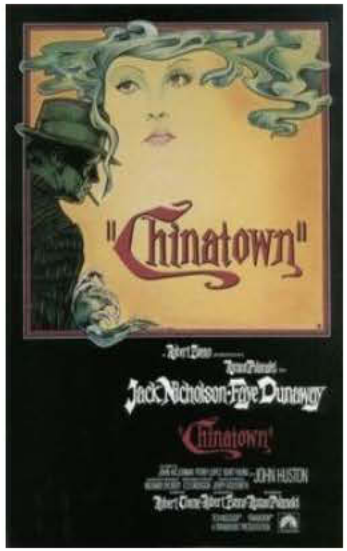
Luers A., Cayan D., Franco G., Hanemann M. and Croes B., California Climate Change Center (2006). Our Changing Climate: Assessing the Risks to California, p.7

"Science Linking Drought to Global Warming Remains Matter of Dispute", New York Times, Feb 16, 2014

Follow the Water

Where water flows, prosperity goes





70% of Southern California's water originates in the Sierra Nevada, transits the Bay-Delta watershed, and flows south and over the Tehachipis in aquaducts

Declining Colorado Flow to Southern California

50% chance by 2021 of a season when Lake Mead goes dry, due to upstream withdrawals, declining average rainfall, and Rocky Mountain snowmelt, together with La Nina

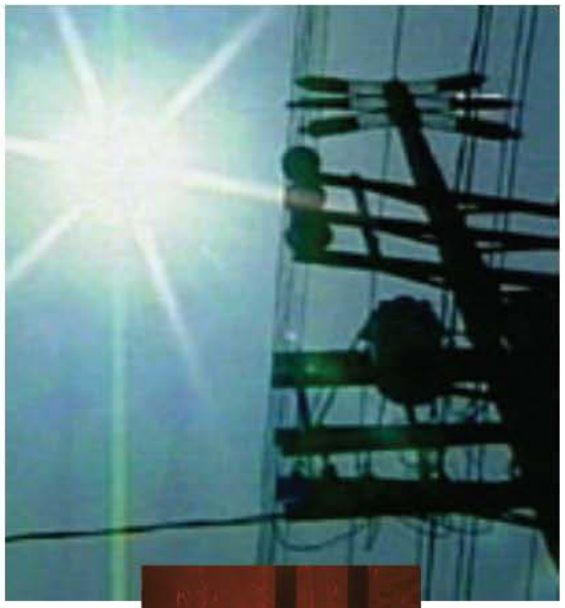
Water for Imperial Valley Agriculture and San Diego

Electricity for Las Vegas

Barnett, T. P., and D. W. Pierce (2008), When will Lake Mead go dry?, Water Resour. Res., doi:10.1029/2007WR006704

Heat Waves

"Extremely hot" days in Sacramento (at least 105°F) will become more common. By 2050, their number could increase fivefold (up to 20 days). By 2100, under business as usual, they could occur as much as ten times more often.

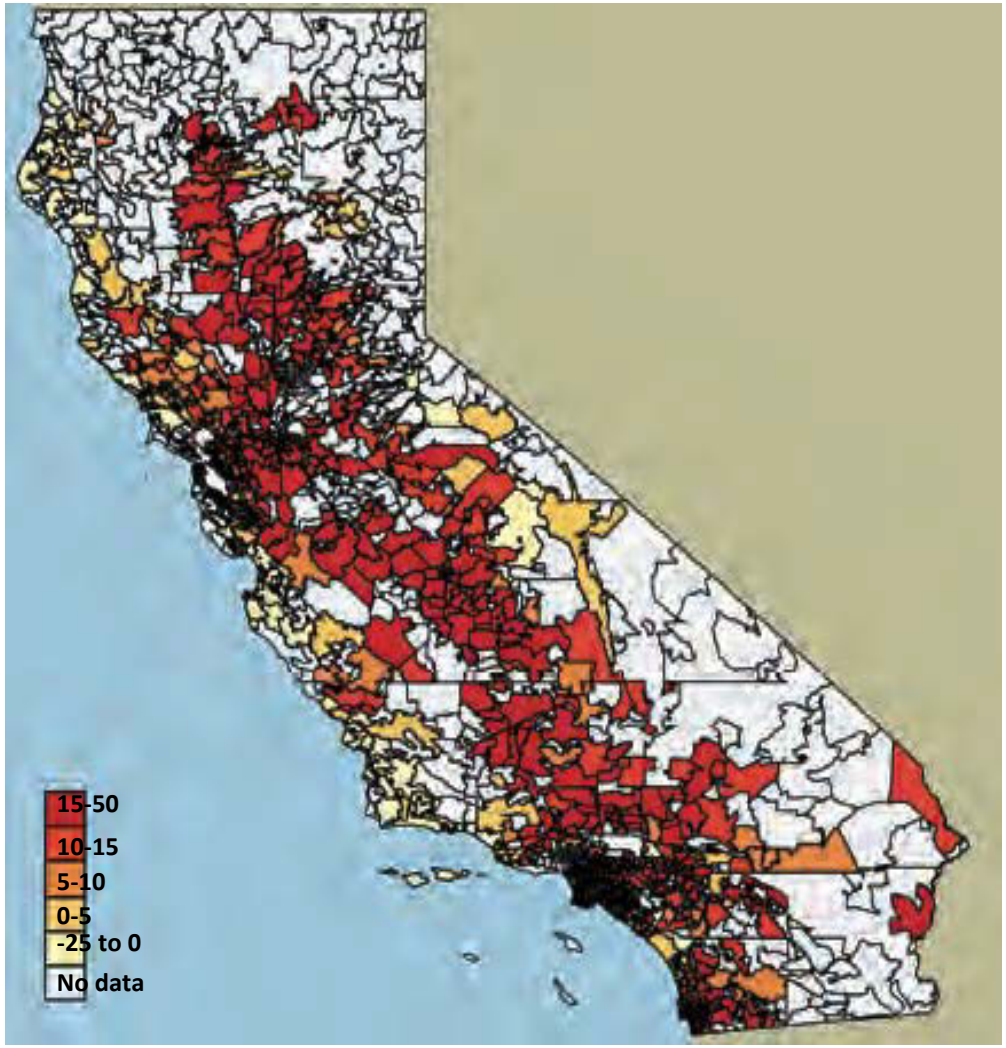


Electricity Consumption

Excess Mortality

Electricity Demand

Higher emissions scenario, end of this century compared to historical average, in percent



Our Changing Climate 2012: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California

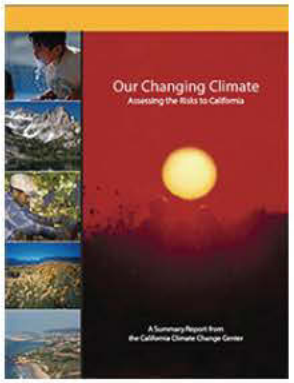
A Summary Report on the Third Assessment from the California Climate Change Center

California Wildfires

Climate change, population growth, urban-wildland development

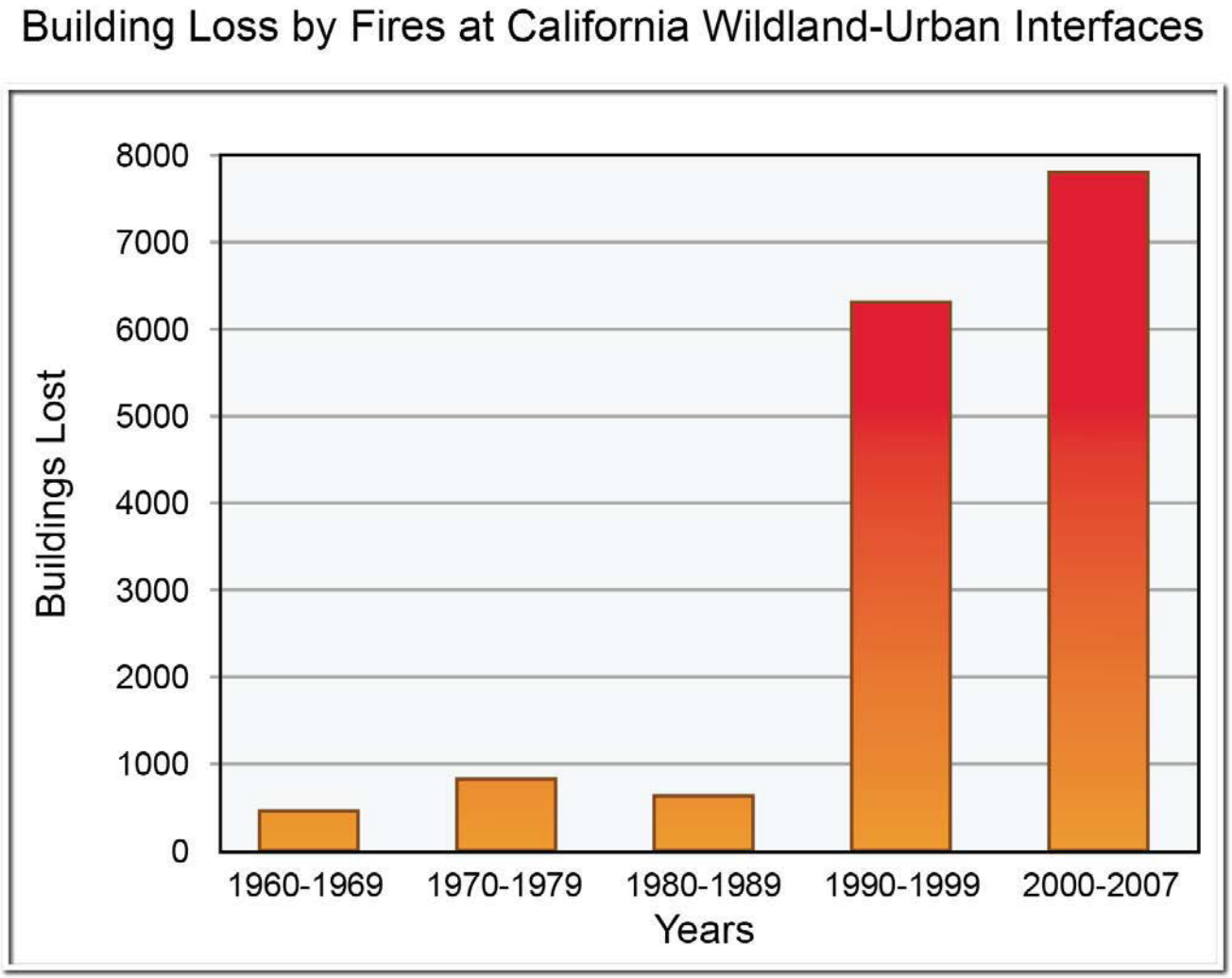
According to Reuters News Service, at least 13 people have been killed in the state's deadliest outbreak of fires in more than a decade. About 30,000 homes were endangered by the fires, driven by warm Santa Ana winds, which had consumed more than 330,000 acres, or 500 square miles — almost half the size of the state of Rhode Island — of dense, dry brush and trees. More than 7,000 firefighters battled the spreading flames.

CREDIT: NOAA



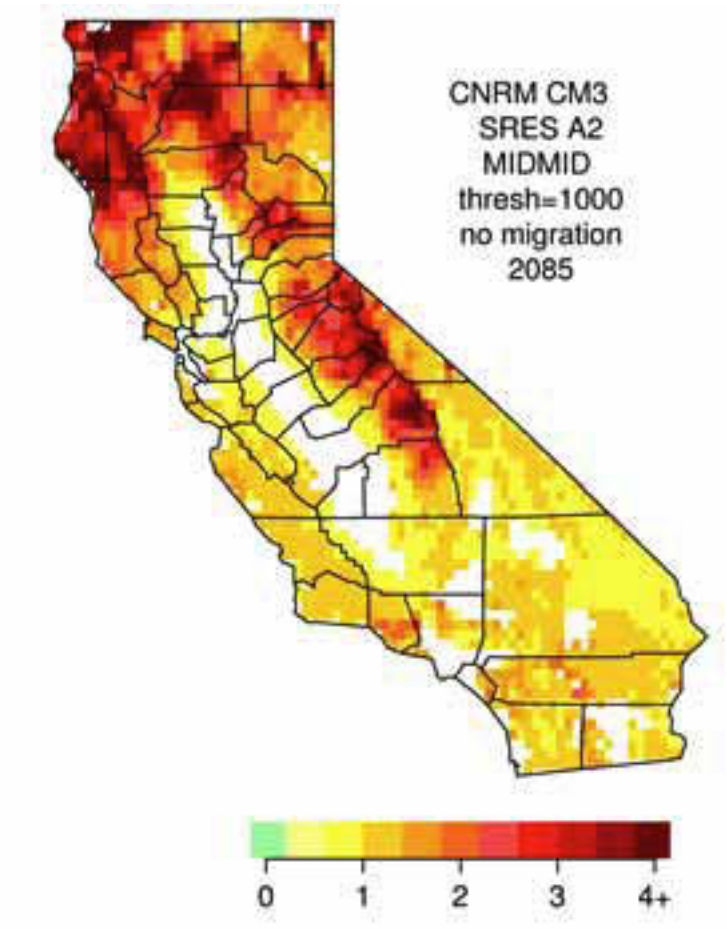
Wildfire Risk: Structures

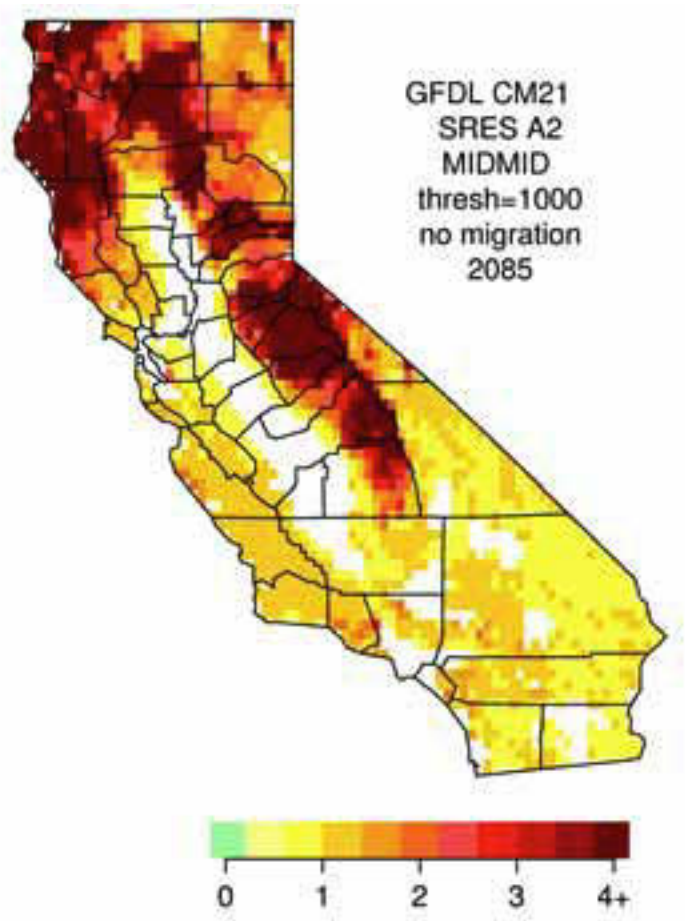
Number of buildings lost from the 25 most destructive wildland-urban interface fires in California history from 1960–2007



US National Climate Assessment, 2013, Redrawn from Stephens et al. 2009

2085 Wildfire Risk Relative to 1971-2000





2085 Predicted burned area as a multiple of 1971-2000 predicted area burned. Panels show SRES A2 scenarios with the location of fire regimes fixed.All scenarios show large increases in burned area in forests of the Sierra Nevada, northern California Coast , and southern Cascade ranges. A value of "1" indicates burned area is unchanged, while 4+ indicates that burned area is 400% or more of the reference period.

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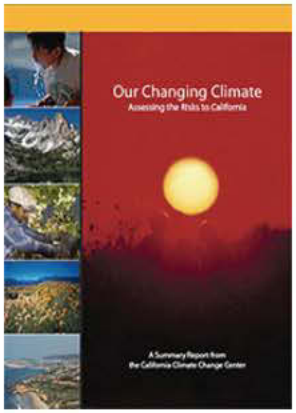
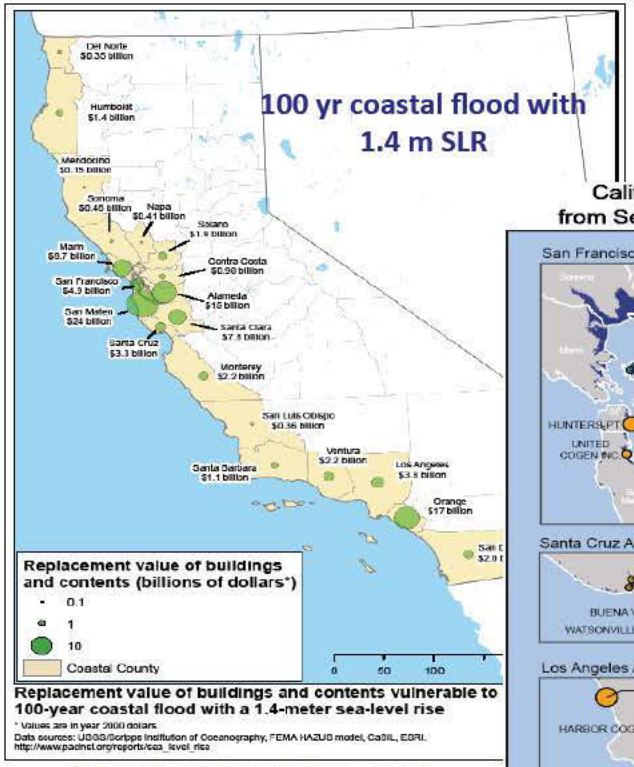

Our Changing Climate
Assessing the Risks to California
A Summary Report from
the California Climate Change Center


Rising Sea Level
2006 projection for 2100: 6-30 inches
2012 projection for 2100: 31-55 inches


Our Chang ng
C mate 2012
Vu nerab ty &
Adaptat on
to the Increas ng
R sks from C mate
Change n

Coastal Infrastructure At Risk

Capital Assets Only

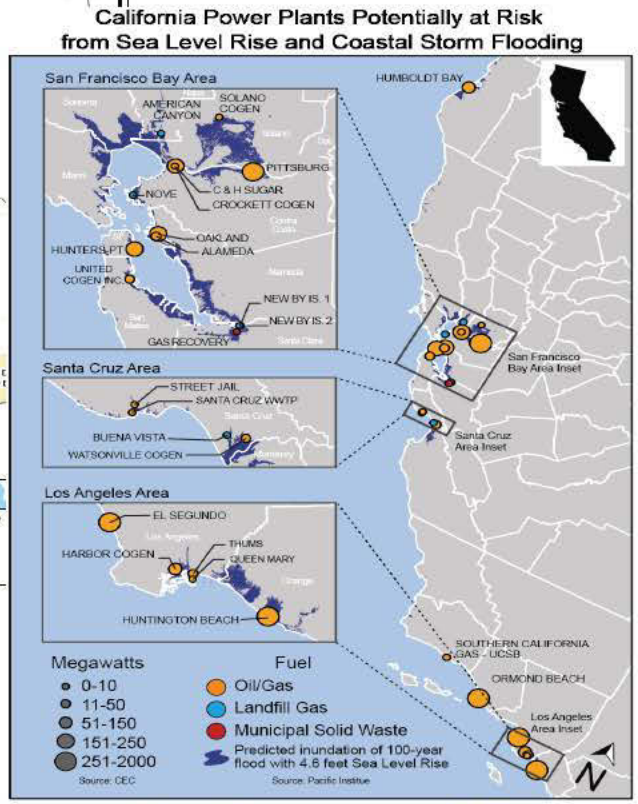


Replacement value of buildings and contents vulnerable to 100-year coastal flood with a 1.4-meter sea-level rise

* Values are in year 2000 dollars

Data sources: USGS/Scripps Institution of Oceanography, FEMA HAZUS model, CaSIL, ESRI.
http://www.pacinst.org/reports/sea_level_rise

2009 California Climate Assessment



National Climate Assessment, 2013

San Onofre

La Jolla

The Big Gulp

CALFED BAY-DELTA PROGRAM

California's Second Biggest Nightmare

Levee failure during storm surge at high tide leading to salt water intrusion

California

The most thoroughly assessed state in the Union

Smog Prepared California for Climate Change

California Environmental Protection Agency
AIR RESOURCES BOARD

In 1960s, California had the highest ozone levels (600 ppb) ever recorded anywhere

- Stage 1 alerts (O_3>200 ppb) more than half the time

Since then, California's population doubled and economy grew dramatically

- Number of vehicles up 170%, vehicle-miles tripled

Last stage 1 alert was in 1998

- Peak CO down by 87%, NO_2 83%, SO_2 90% since 1968, when CARB was founded

Bart E. Croes, Atmos. Environment, 47, 562-563, 2012

California agencies work intimately with the science community

- **2001-California Climate Action Registry**
  - California industry, universities and agencies report GHG emissions
  - Registry provides methodology and certifies result
  - Transitioned to The Climate Registry (North America) in 2010

- **2003-California Climate Change Center founded**
  - First US state-funded climate change research program
  - Focus on mitigation strategies and California impacts

- **2005-California Climate Action Team**
  - Multi-Agency working groups (Agriculture, Biodiversity, Energy, Forestry, Land Use, Oceans, Public Health, Research, State Government Operations, Water) collaborate with Climate Change Center scientists
  - "Polycentric" governance mechanism thereby established

- **2005-Executive order S-3-05 requires adherence to goals of Kyoto Protocol (80% below 1990 by 2050)**

- **2006-First Assessment, *Our Changing Climate,* identifies risks to California**

- **2006-California Legislature passes *Global Warming Solutions Act (AB 32)***

- **2008-Executive order S-13-08 requires adaptation planning**

- **2009-Second California Assessment proposes adaptation strategies**

- **2012-Third California Assessment focuses on regions**

California Climate Action Team

Polycentric* decision-making

Integrated Waste Management Board

Cal/EPA

Waste Management Board
Air Resources Board
Transportation & Housing

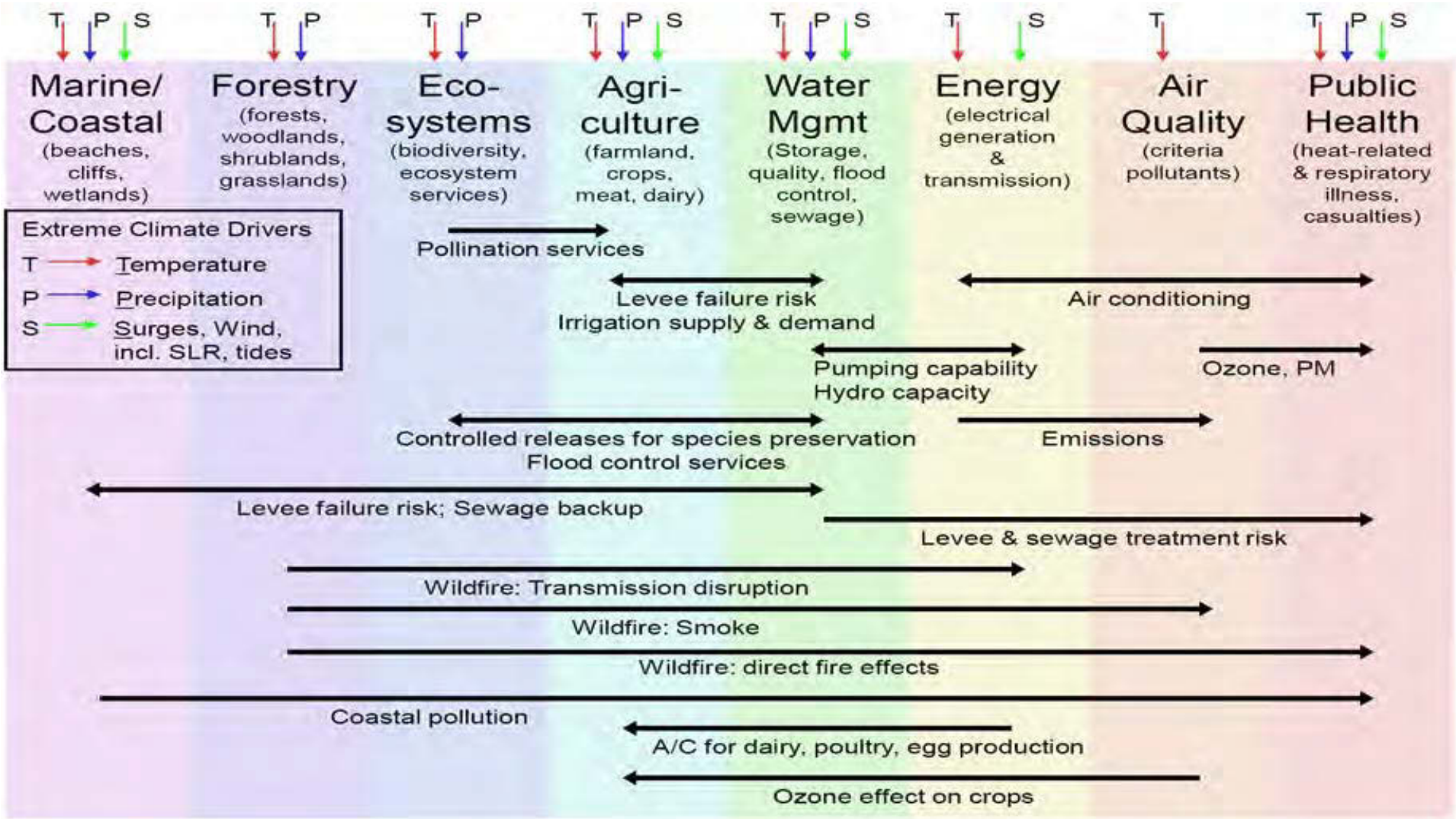
CALIFORNIA Climate ACTION TEAM

Public Utilities Commission
Energy Commission
Resources Agency
Department of Food & Agriculture

*Ostrom, E., Beyond Markets and States: Polycentric Governance of Complex Economic Systems, *American Economic Review 100 (June 2010):* 1–33http://www.aeaweb.org/articles.php?doi=10.1257/aer.100.3.1

Why a Climate Action Team is Needed

Inter-sector interactions require polycentric decision-making

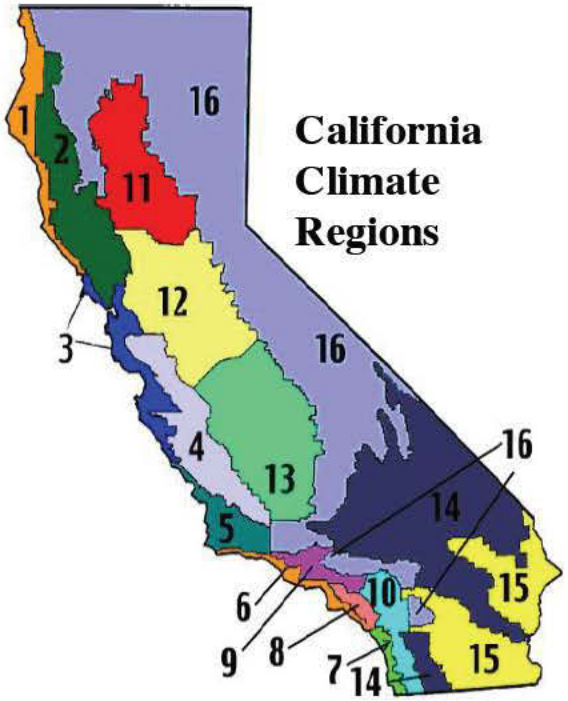


2009 California Climate Adaptation Strategy

Regional Diversity

Polycentric Decision Making

Each environmental issue has its own natural region
Rigorous science respects natural boundaries
Spans of authority do not match natural regions

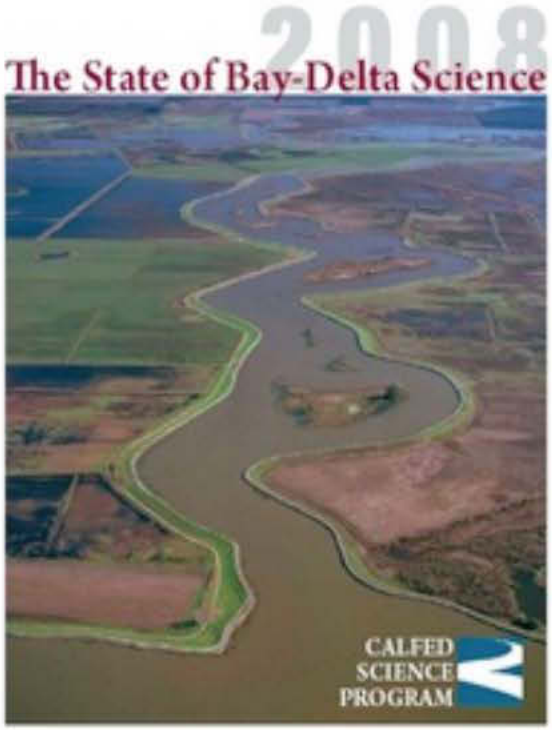


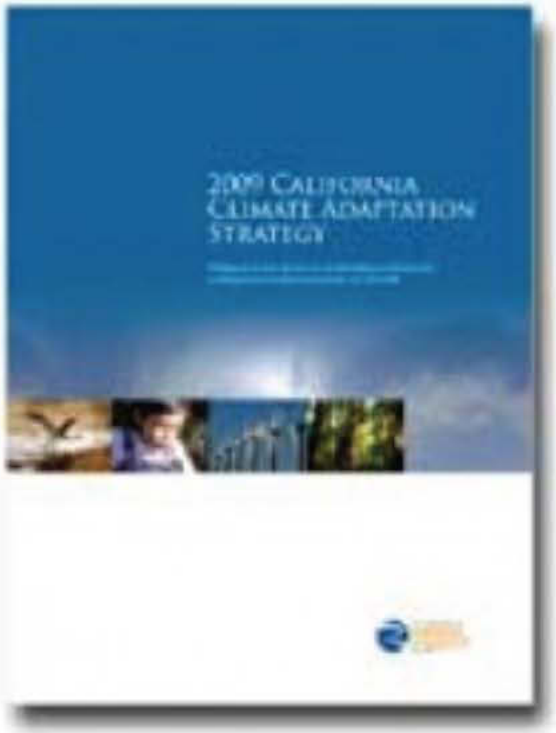
Regional Decision Support

Complex information potentially enabling adaptive management
Locale by locale, county by county, town by town

Knowledge Action Partnerships

Scientists working directly with polycentric decision consortia





Consortium of Federal and State Agencies with jurisdictions in the bay-delta system

CALFED science program

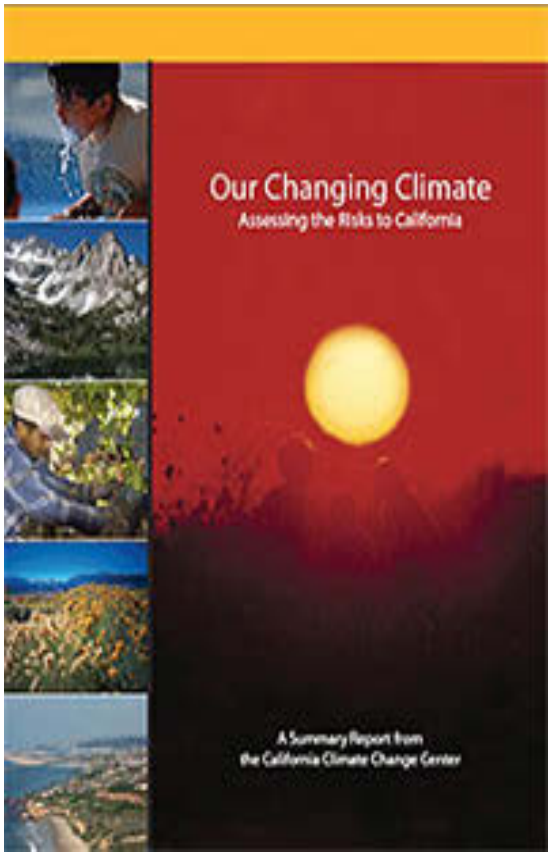
California Climate Action Team, a council of resource management agencies

California Climate Change Center

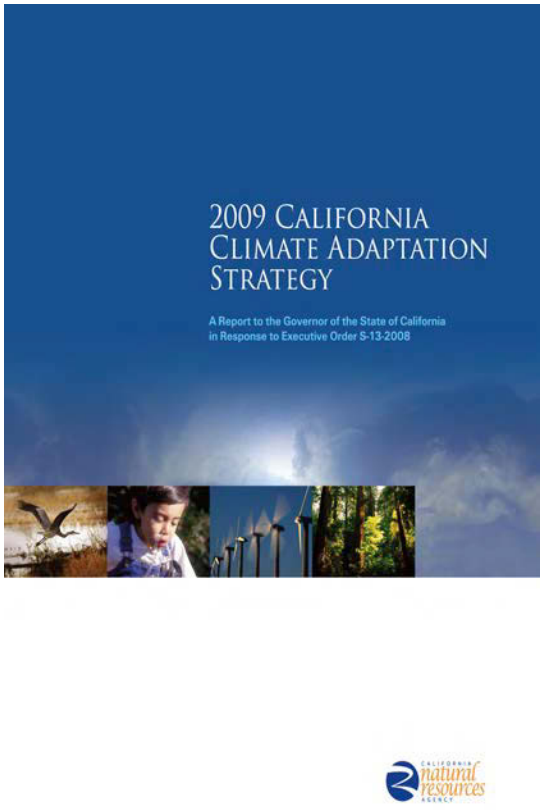
Repeated Assessment

The key to adaptive management

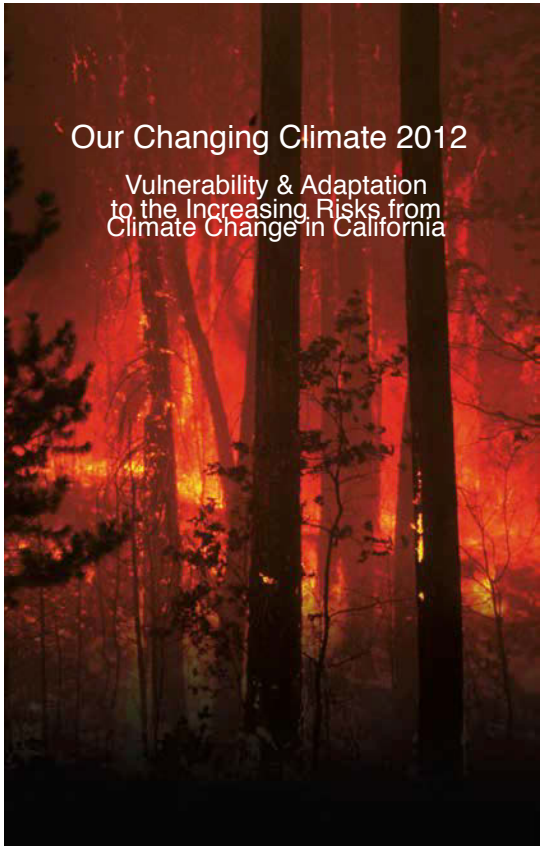
Executive Order S-3-05 charged the Secretary of the California Environmental Protection Agency to report to the Governor and the State Legislature by January 2006 and periodically thereafter on the impacts of global warming to California.



2006



2009

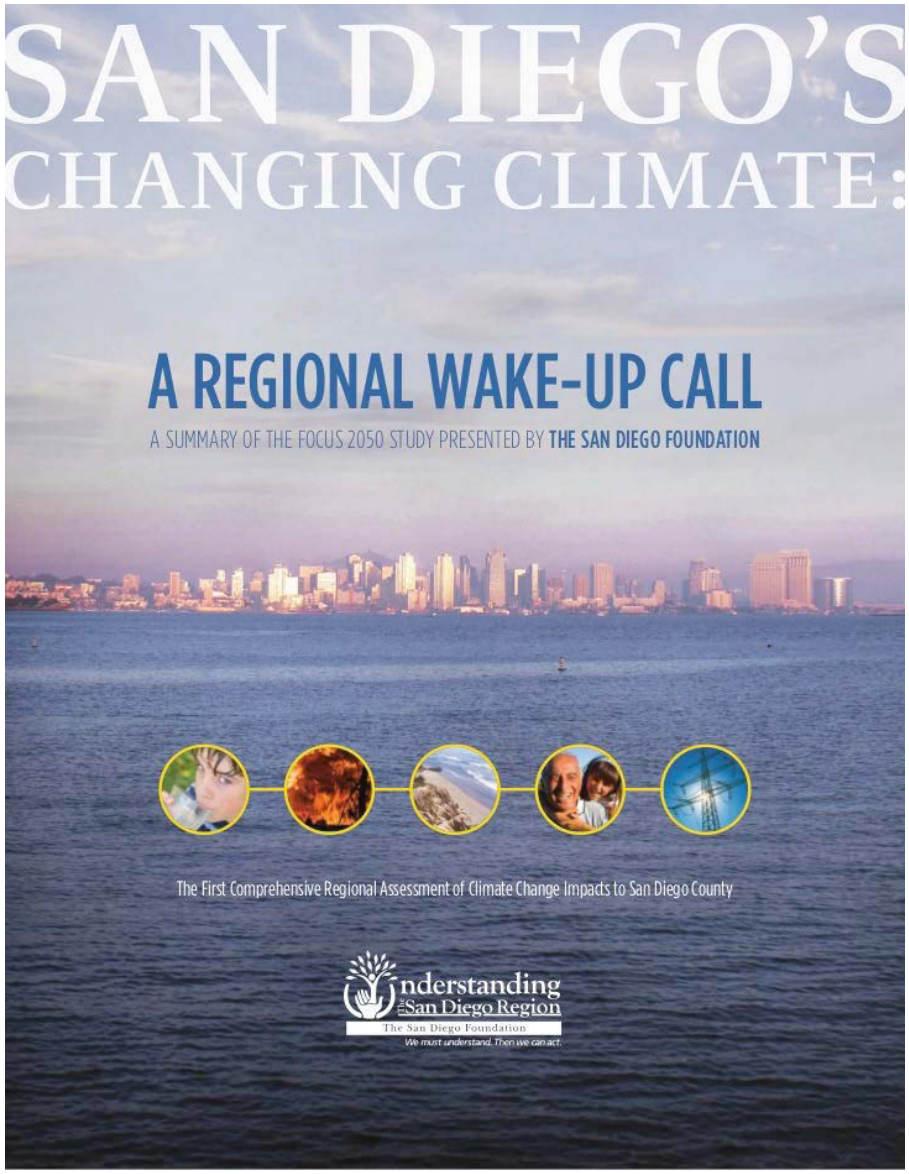


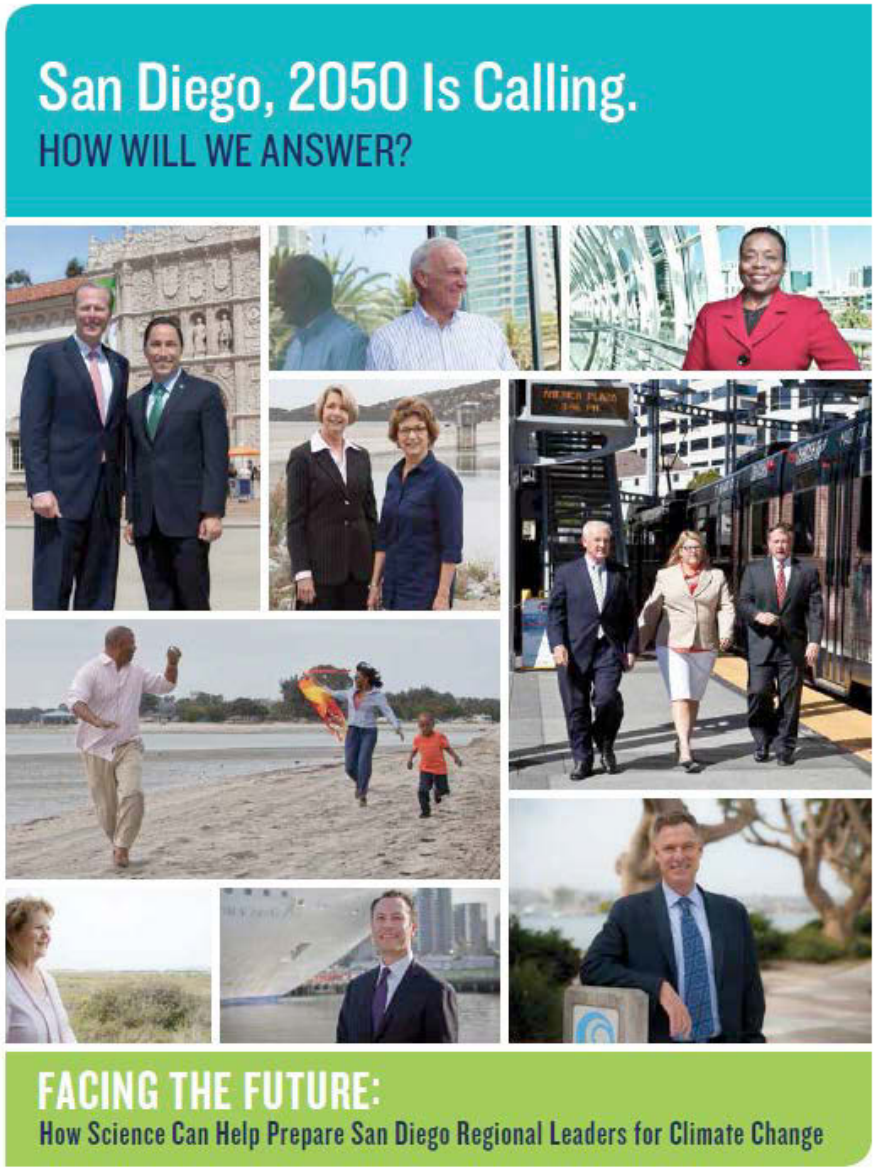
2012

Think Globally, Assess Regionally, Act Locally

Prospects of Local Impacts Inspire Community Action

San Diego Foundation





Impact of Impact Assessments

Assessment of Adaptation Risks Motivated Mitigation

California is the world's 12th largest emitter

"38501. The Legislature finds and declares all of the following:
Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California. The potential adverse impacts of global warming include the exacerbation of air quality problems, a reduction in the quality and supply of water to the state from the Sierra snowpack, a rise in sea levels resulting in the displacement of thousands of coastal businesses and residences, damage to marine ecosystems and the natural environment, and an increase in the incidences of infectious diseases, asthma, and other human health-related problems."

California Assembly Bill 32, 2006

The Impact of Impact Assessments

The Western Climate Initiative, 2007, 15% below 1990 by 2020

Coalition of the Willing

WCI Partners and Observers

U.S. Partner jurisdictions comprise 19% of the total U.S. population and 20% of the U.S. GDP
Canadian Partner jurisdictions comprise 79% of the total Canadian population and 76% of the Canadian GDP.

Manitoba

GDP ..... 48,586 Million C$
Population..... 1,186,700
Largest Source of Emission .. Transportation

British Columbia

GDP ..... 190,214 Million C$
Population..... 4,380,300
Largest Source of Emission .. Transportation

Washington

GDP ..... 311,270 Million US$
Population..... 6,468,424
Largest Source of Emission .. Transportation

Oregon

GDP ..... 158,233 Million US$
Population..... 3,747,455
Largest Source of Emission .. Transportation

California

GDP ..... 1,812,968 Million US$
Population..... 36,553,215
Largest Source of Emission .. Transportation

Arizona

GDP ..... 247,028 Million US$
Population..... 6,338,755
Largest Source of Emission .. Electricity*

*includes tribal lands

Ontario

GDP ..... 582,019 Million C$
Population..... 12,803,900
Largest Source of Emission ... Transportation

Quebec

GDP ..... 298,157 Million C$
Population..... 7,700,800
Largest Source of Emission ... Transportation

Montana

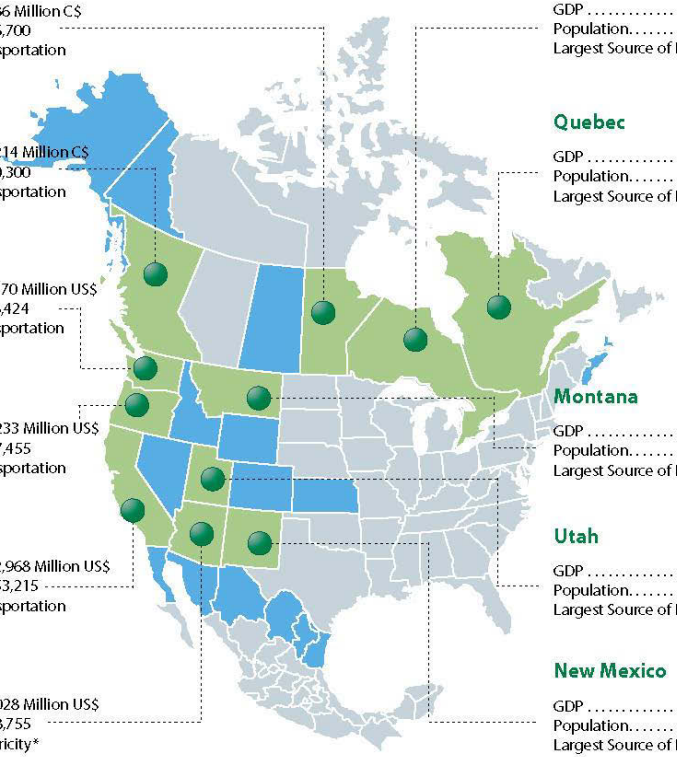
GDP ..... 34,253 Million US$
Population..... 957,861
Largest Source of Emission ... Electricity

Utah

GDP ..... 105,658 Million US$
Population..... 2,645,330
Largest Source of Emission ... Electricity

New Mexico

GDP ..... 76,178 Million US$
Population..... 1,969,915
Largest Source of Emission ... Electricity



Partners Observers

Observers

CANADA: Nova Scotia, Saskatchewan, Yukon; **UNITED STATES:** Alaska, Colorado, Idaho, Kansas, Nevada, Wyoming;
MEXICO: Baja California, Chihuahua, Coahuila, Nuevo Leon, Sonora, Tamaulipas

What will happen to *me*?

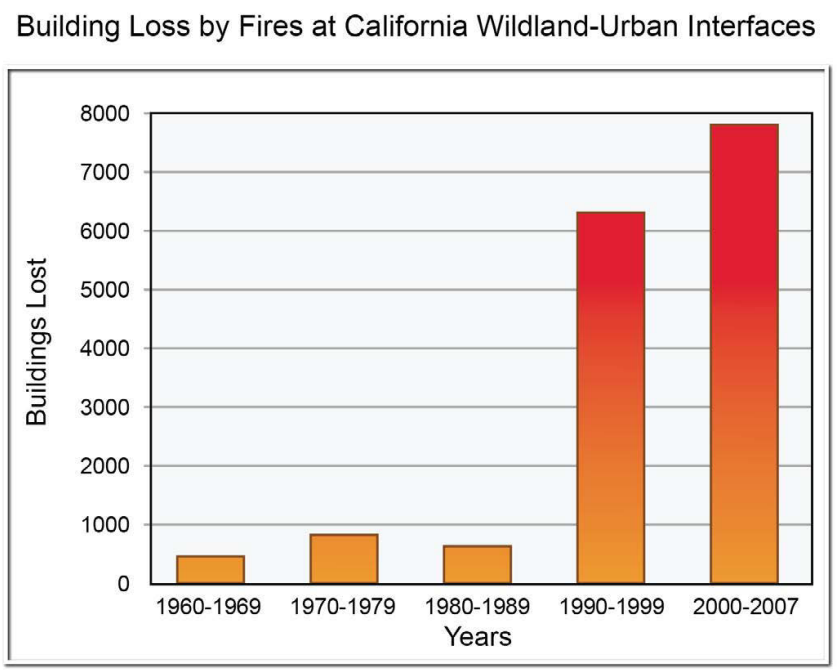
The most important question in environmental science

Answering it is the key to progress on adaptation

Wildfire Risk: Transmission Lines

Changing probability in fire risk by end of century compared to 1961-1990, higher emissions scenario

Our Changing Climate 2012: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California



Wildfire Risk: Structures

Number of buildings lost from the 25 most destructive wildland-urban interface fires in California history from 1960–2007

NCA 2013, Redrawn from Stephens et al. 2009 .