Avoid the Unmanageable, Manage the Unavoidable

What can we expect from the climate in the coming decades, and what can we do?

J. H. Plumb Auditorium, Christ's College, Thursdays, 5:30 to 7 pm

Charles F. Kennel

Director, Vice-Chancellor, and Distinguished Professor Emeritus,
Scripps Institution of Oceanography,
University of California, San Diego

Distinguished Visiting Fellow,
Christ's College, Cambridge

Visiting Research Fellow,
Centre for Science and Policy
University of Cambridge

Feb 20: California and the Arctic

The first and most advanced regional assessments
Impacts on regional natural systems, regional technical systems, and populations
Assessments-the first step in adaptive management

The Arctic

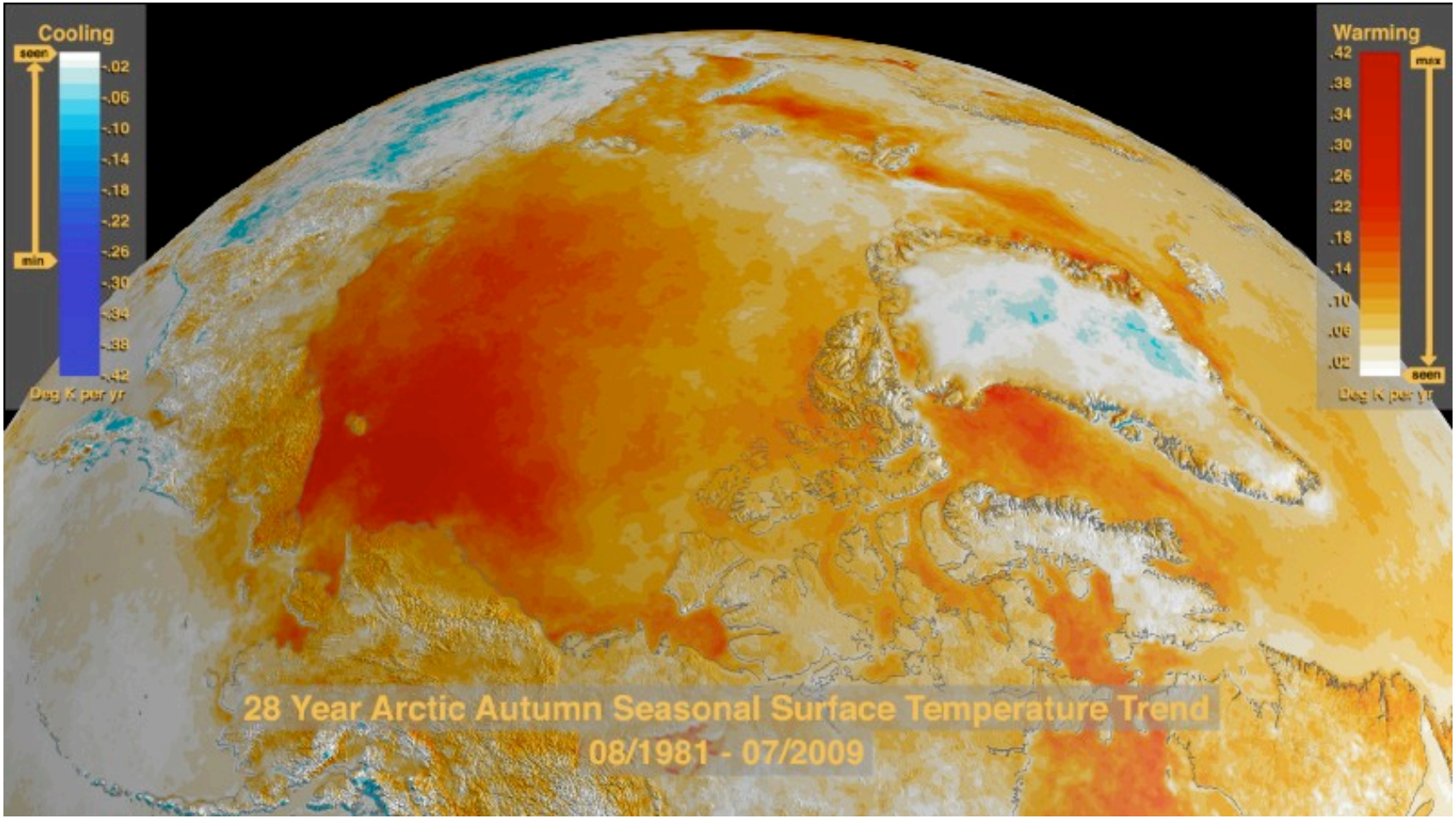
Early Warning System

US Department of Defense, "Arctic Strategy", November, 2013

Polar Amplification of Climate Warming

Largest 1981-2009 Warming Over Land

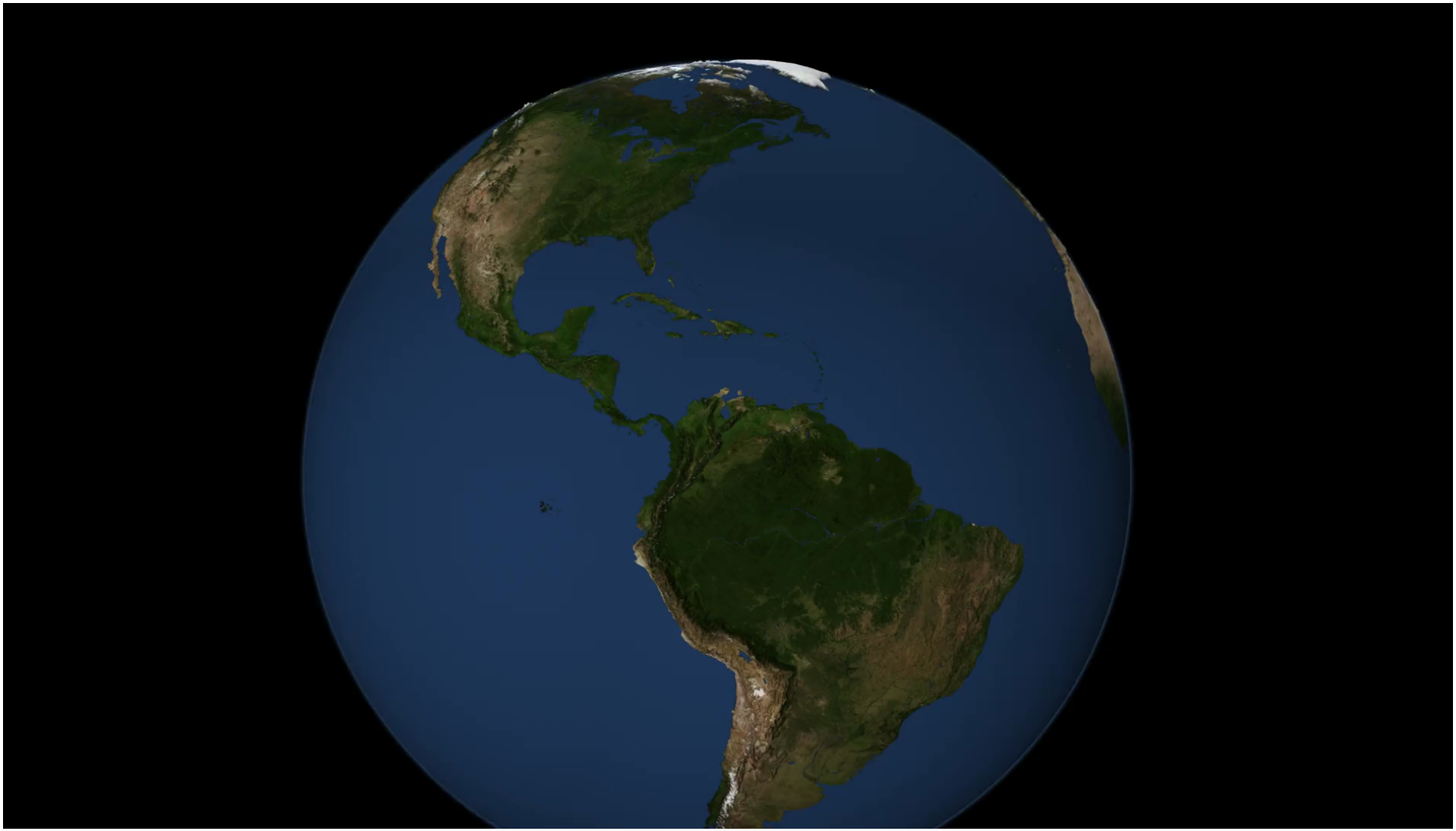
Maximum rate 0.42C/year



NASA Goddard Visualization Center

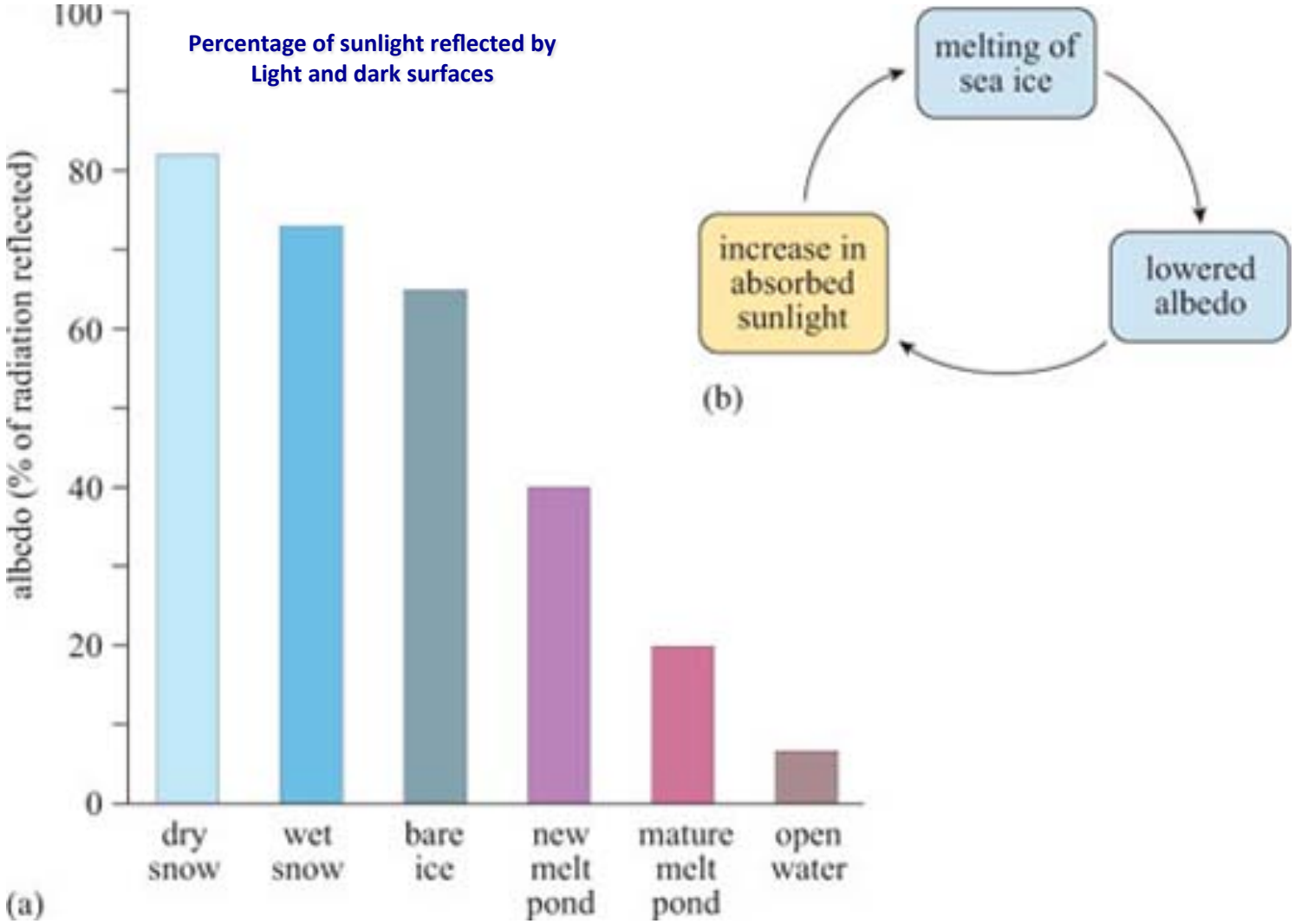
Summer Arctic Sea Ice Area.

The sea ice extent in September 2012 was more than 40% below the median for 1979-2000



Snow and Ice Albedo

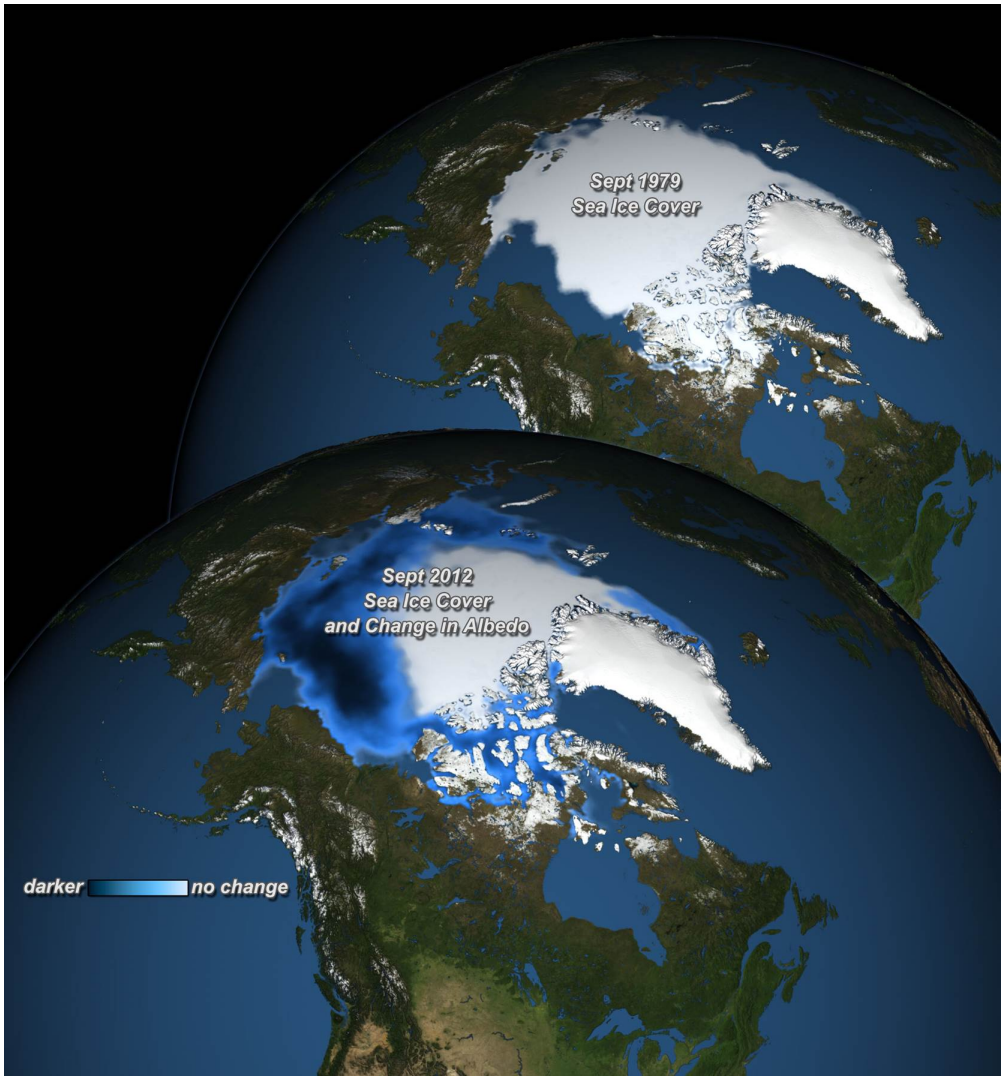
Changes Destabilize the Climate In either direction



Arctic Region Ice Albedo Change, 1979-2011

52% to 48%, 6.4 W/m2 since 1979

Averaged over globe, ¼ Greenhouse gas forcing over past 30 years

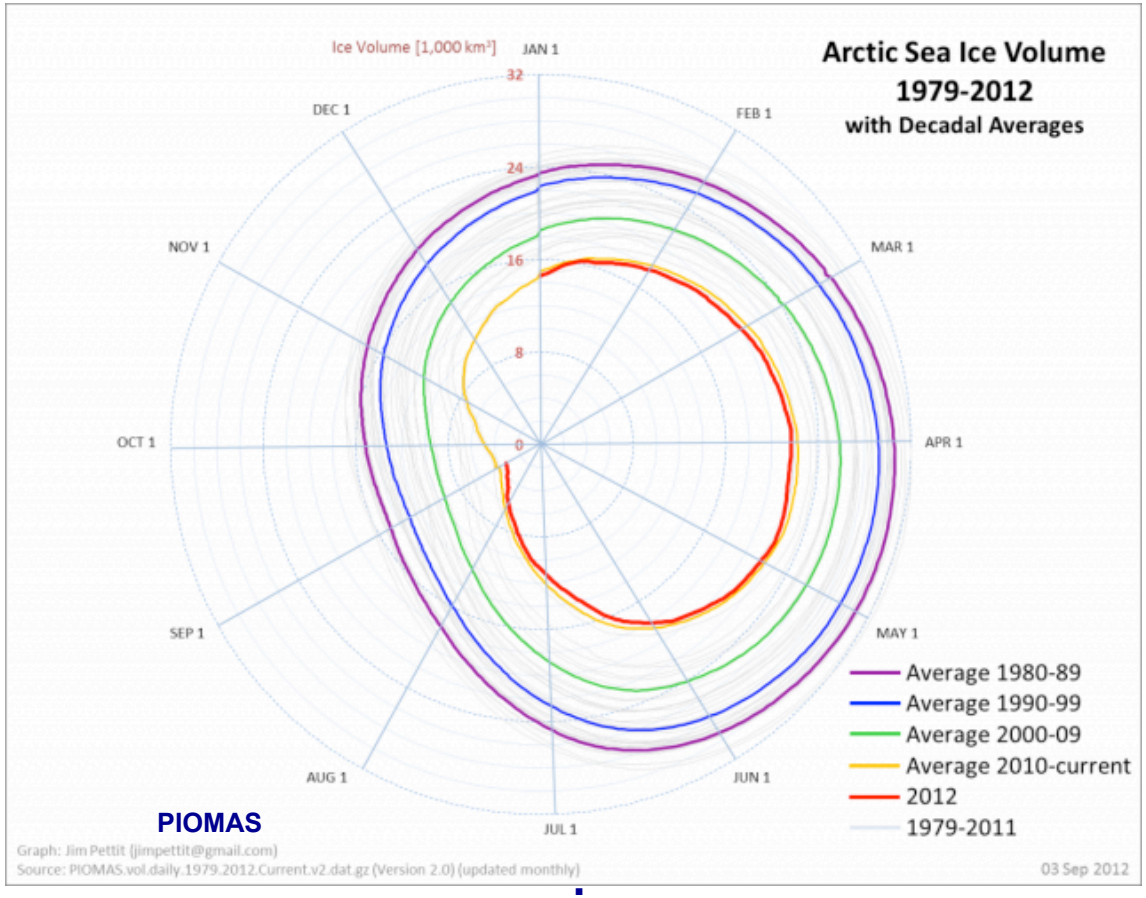


K. Pistone, I. Eisenman, and V. Ramanathan, PNAS, Feb. 18, 2014

Arctic Sea Ice Volume

The Death Spiral

US Intelligence agencies had been tracking sea ice thickness since the 1970s; by the 1990s, Project MEDEA was reporting a 10%/decade decline in thickness. Thickness, when multiplied by satellite measurements of area, gives the volume.

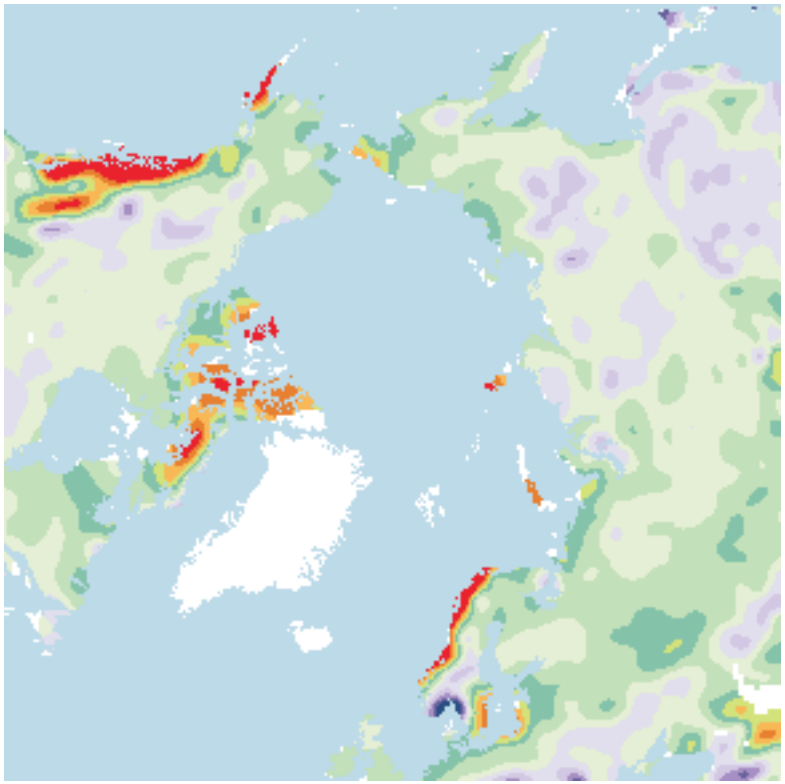


2012 September volume is about ¼ of 1980-1989 volume

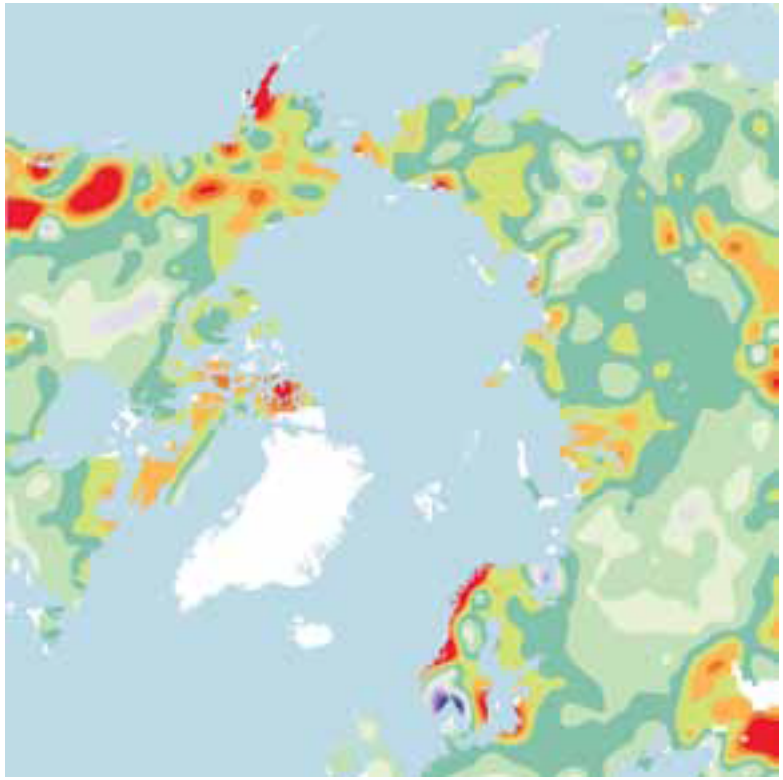
(Figure and data from National Snow and Ice Data Center)

“The largest and most consistent change in snow cover is earlier disappearance in spring”

Snow, Water, Ice, Permafrost Assessment, (SWIPA), 2011



Later Snow onset, Autumn



Earlier Snow melt, Spring

Change in snow-cover duration for autumn (snow-cover onset period) and spring (snow-cover melt period) between 1972/73 and 2008/09. Red = 10 days change

Arctic Snow Cover

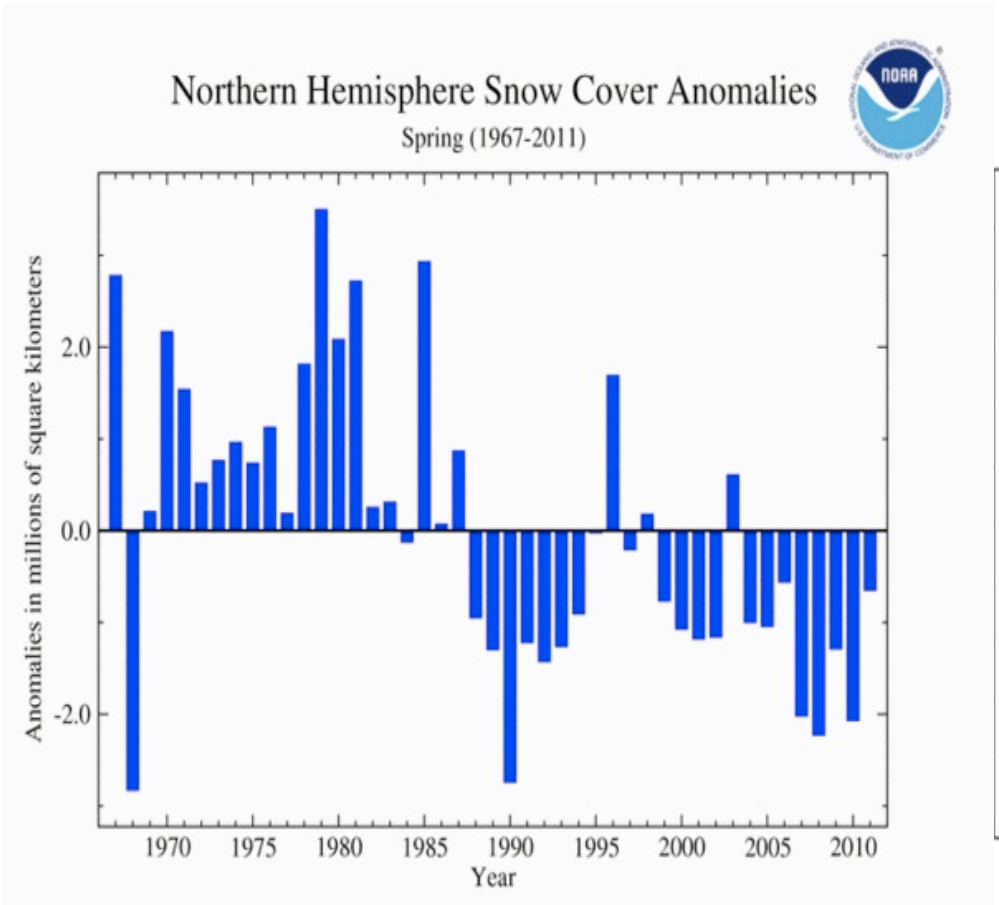
Extent and duration of snow cover are decreasing throughout the Arctic

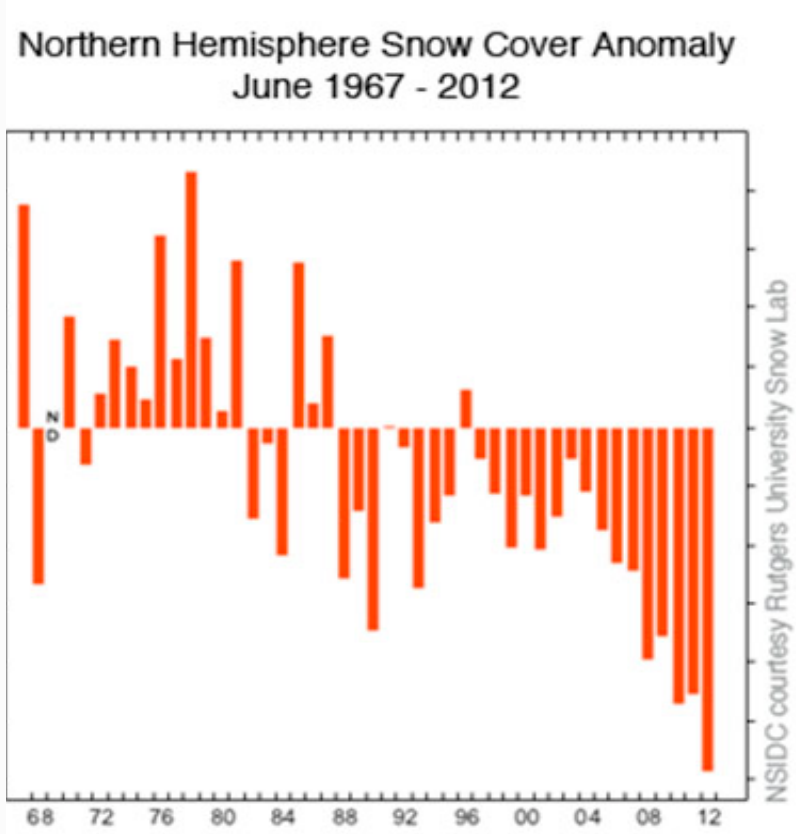
Alaska and Fennoscandia coastal regions seeing largest decreases in duration

Land area covered by snow in early summer decreased by 18% since 1966

Snow depth may increase but time average cover decreases because of earlier snow melt

Snow, Water, Ice, Permafrost Assessment, (SWIPA), 2011

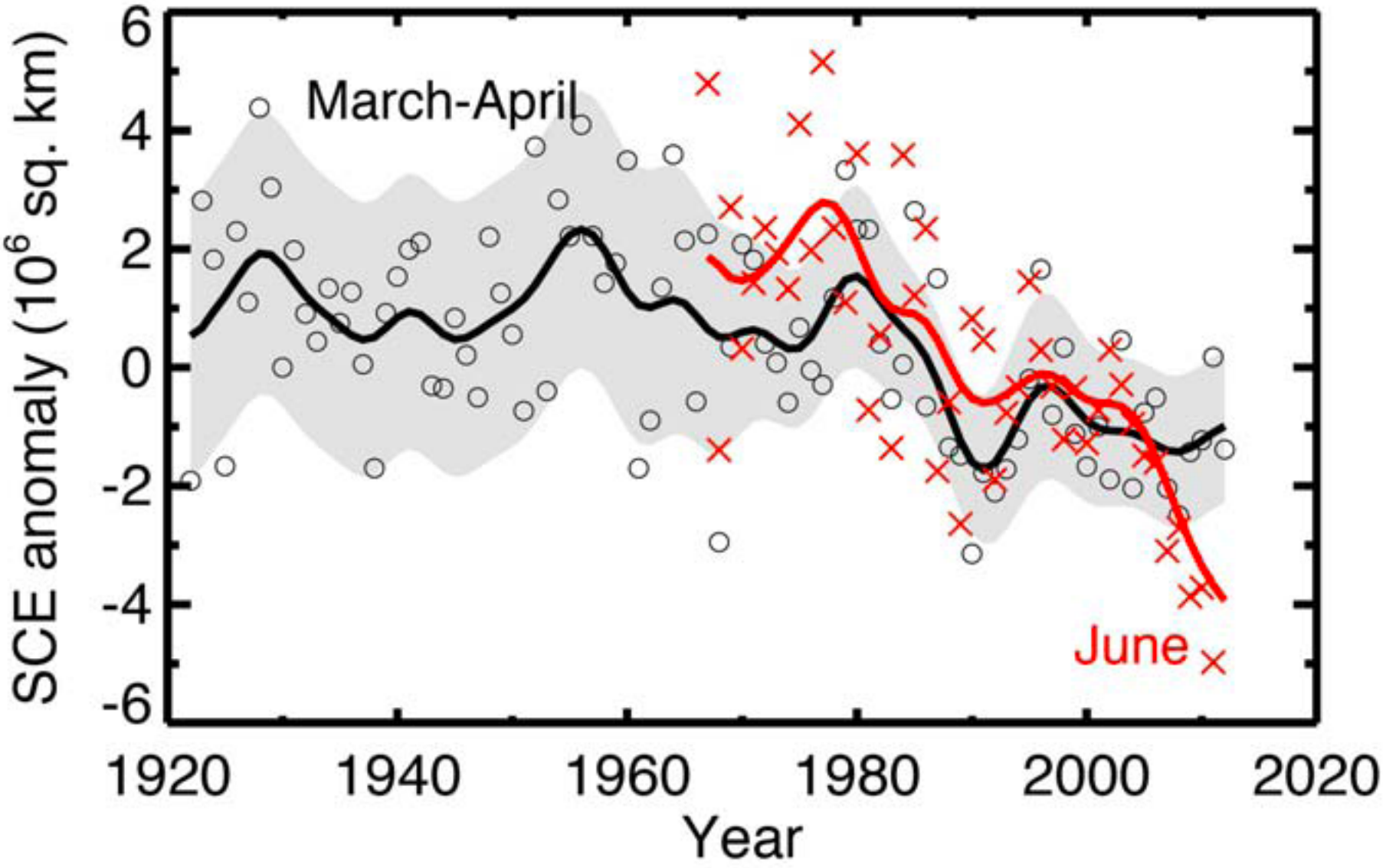




Snow area and duration together with hours of sunlight matter for albedo effect

Northern Hemisphere Snow Cover Extent

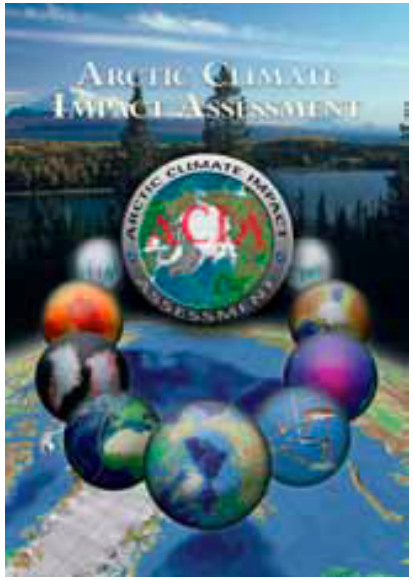
March-April, circles, June, crosses

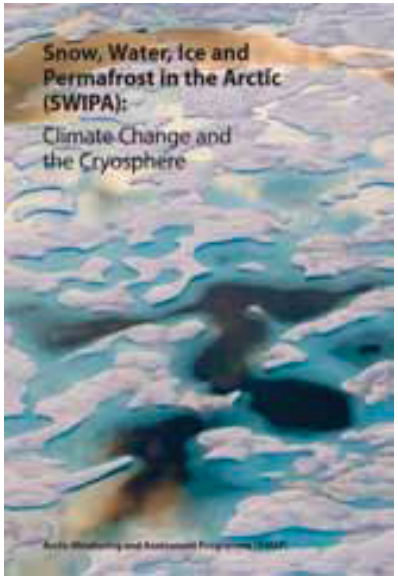


A Regime Shift In Progress

ACIA, 2005: Polar Amplification a reality

SWIPA, 2011: Warming accelerated and changed character after 2000





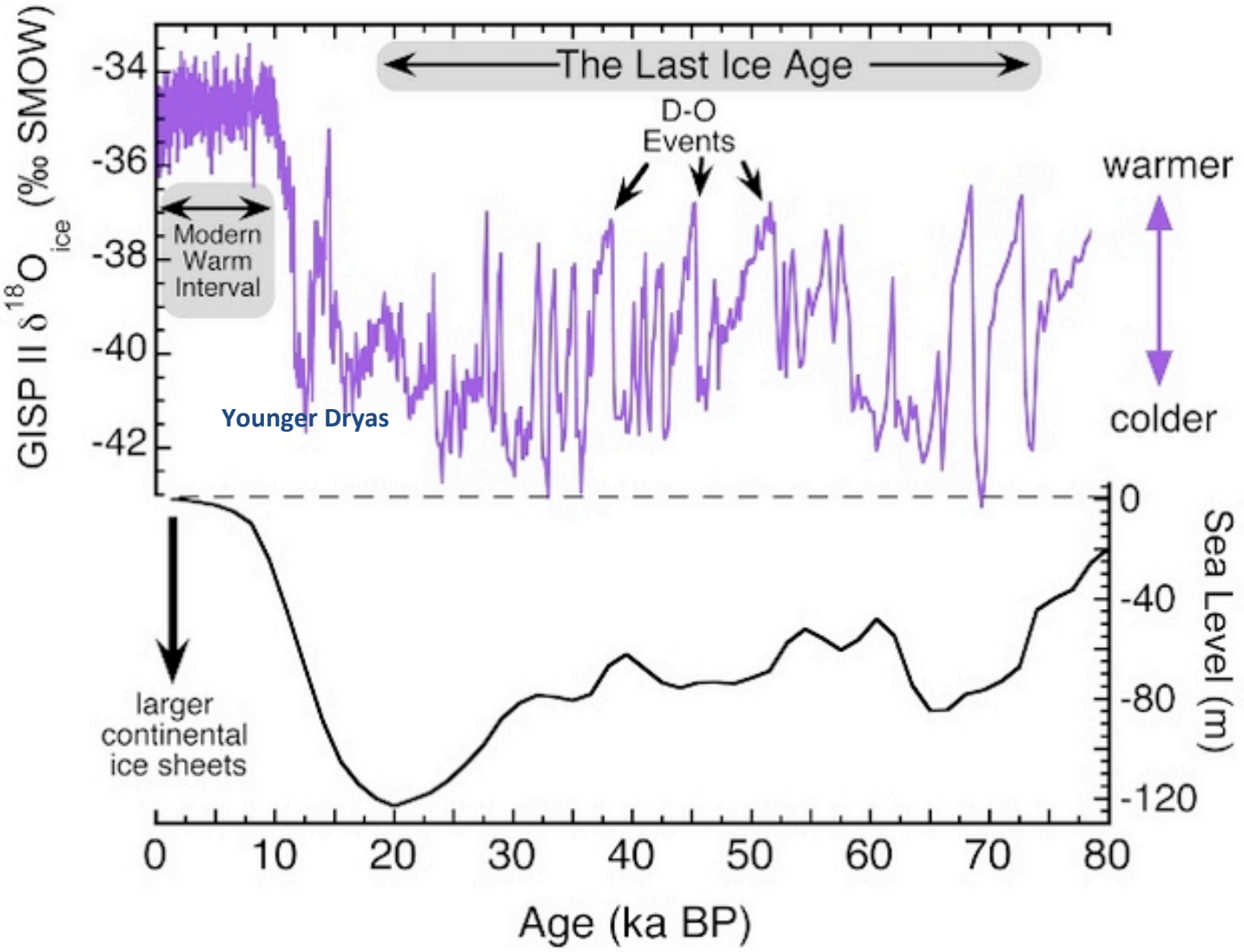
SWIPA: 2005-2010 were the warmest years ever recorded.
Recent warming has been fastest in spring and autumn, whereas before 2000, it was in winter, consistent with GCMs.
Warming is now faster over the oceans than over land.
Both changes suggest that declines in snow cover (spring) and sea-ice extent (fall) are accelerating Arctic climate change.

Screen, J.A. and I. Simmonds, The Central Role of Diminishing Sea Ice in Recent Arctic Temperature Amplification, Nature 464, 1334–1337 (29 April 2010) doi:10.1038/nature09051

What goes on in the Arctic does not stay in the Arctic

The Last Ice Age

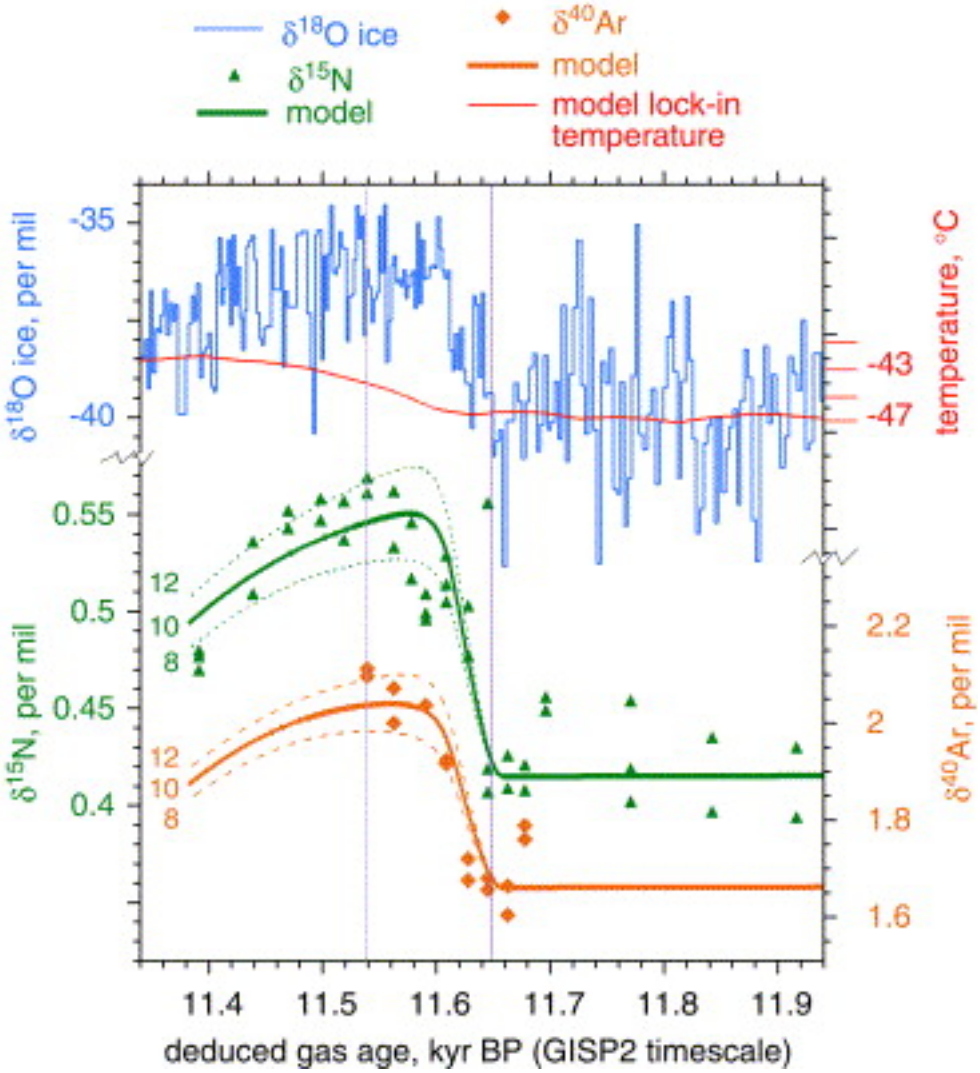
When ice was a truly major feature of the climate system, the global climate was highly variable



Schmidt, M. W. & Hertzberg, J. E. (2011) Abrupt Climate Change During the Last Ice Age. Nature Education Knowledge 3(10):11

Global Temperature: "Younger Dryas" Mini-Ice Age

10 to 100 year fluctuations dispersed hunter-gatherer communities



Alexi M. Grachev, Jeffrey P. Severinghaus, A revised +10±4 °C magnitude of the abrupt change in Greenland temperature at the Younger Dryas termination using published GISP2 gas isotope data and air thermal diffusion constants, Quaternary Science Reviews, 24, Issues 5–6, Pages 513–519, March 2005

For possible relationship to origins of agriculture, see

J. Feynman and A. Ruzmaikin, Climate stability and the development of agricultural societies, Climatic Change (2007) 84:295-311

William J. Burroughs, *Climate Change in Prehistory: The End of the Reign of Chaos,* Cambridge University Press, pp. 355, 2009

Arctic Watersheds

10% of present global fresh water flows into 1% of the ocean volume

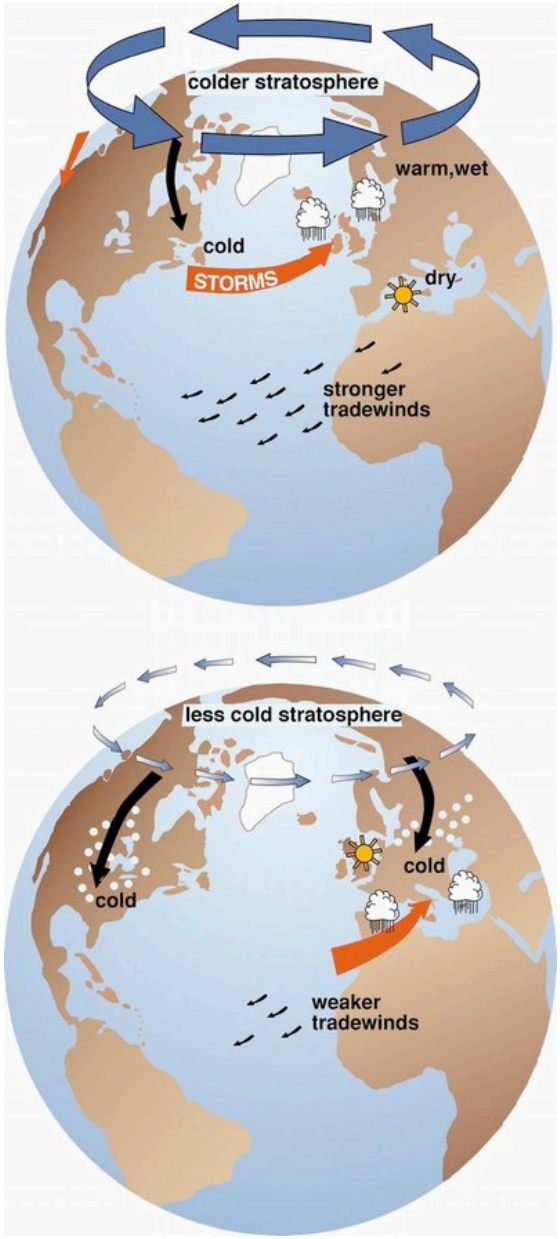
All the main sources of freshwater entering the Arctic Ocean are increasing– river discharge, rain/ snow, and melting glaciers, ice caps, and the Greenland Ice Sheet. Recent calculations estimate that an extra 7700 km3 of freshwater – equivalent to one meter of water over the entire land surface of Australia – has been added to the Arctic Ocean in recent years (SWIPA, 2011). The addition of fresh water on top of salty can change ocean circulation patterns.

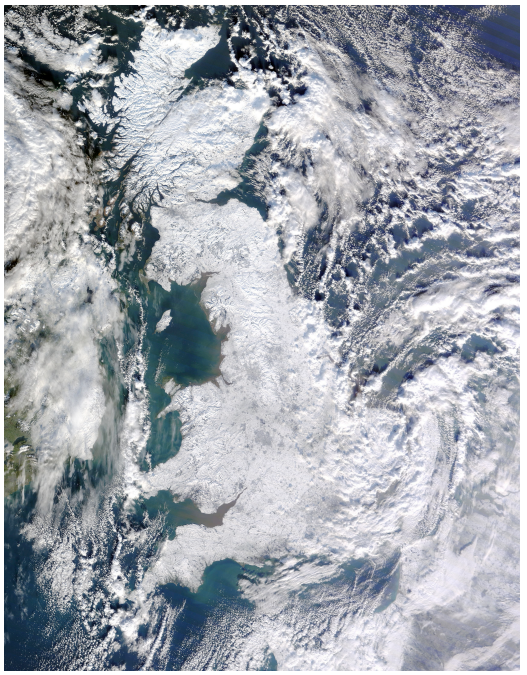
Robert M. Holmes, Michael T. Coe, Greg J. Fiske, Tatiana Gurtovaya,James W. McClelland, Alexander I. Shiklomanov, Robert G. M.Spencer, Suzanne E. Tank, and Alexander V. Zhulidov, *Climate Change Impacts on the Hydrology and Biogeochemistryof Arctic Rivers*

Arctic warming may be sending wintry weather south

Sea ice and snow melt, warmer lower atmosphere, and stratospheric warming affect circulation patterns across Northern Hemisphere

US Snowmageddon, Feb 7, 2010





UK Snowmageddon, January 7, 2010

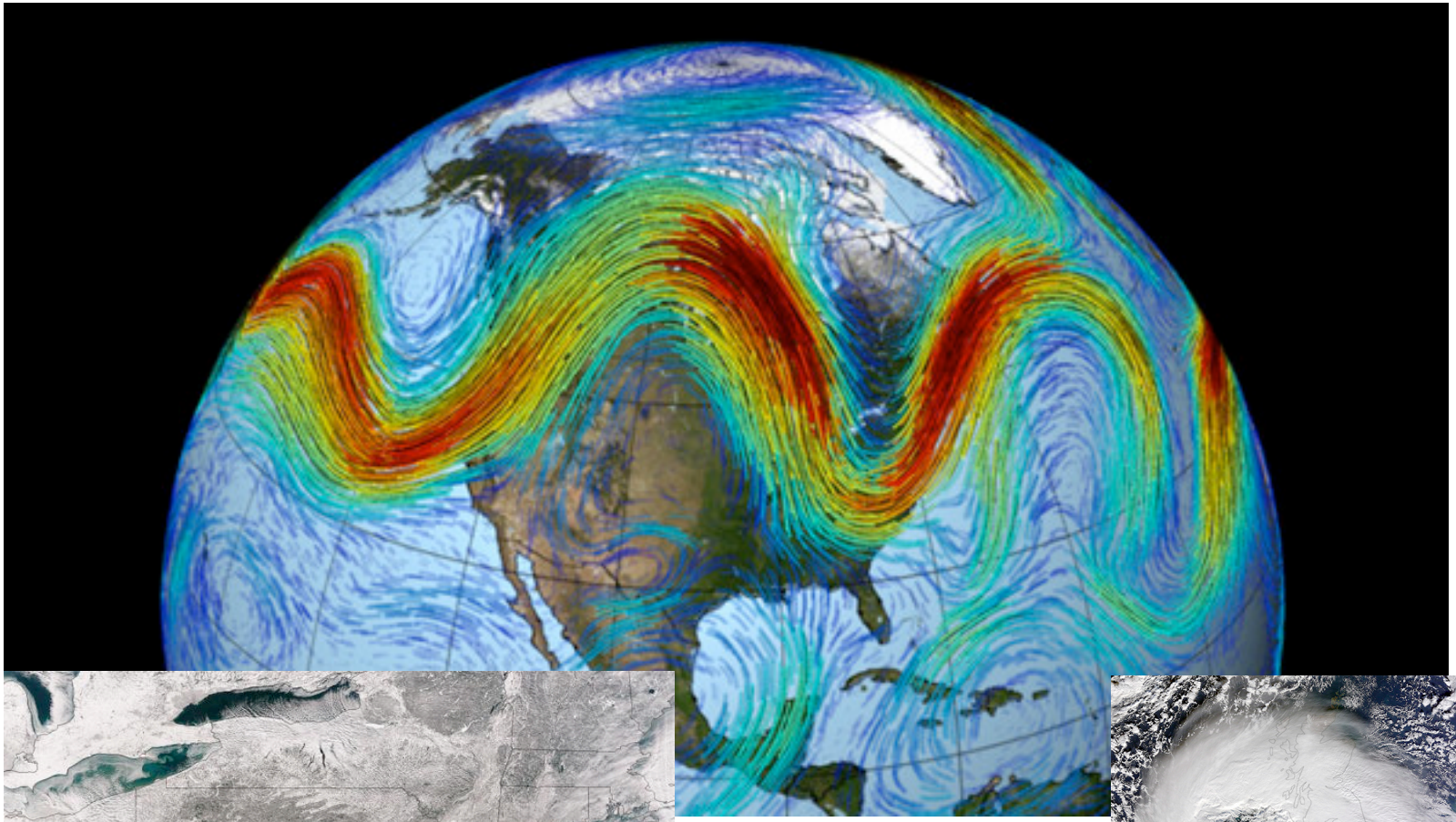
Winter 2009–2010: A case study of an extreme Arctic Oscillation event. Cohen, J., *et. al.,* Geophysical Research Letters, Volume 37, Issue 17, September 2010,DOI: 10.1029/2010GL044256

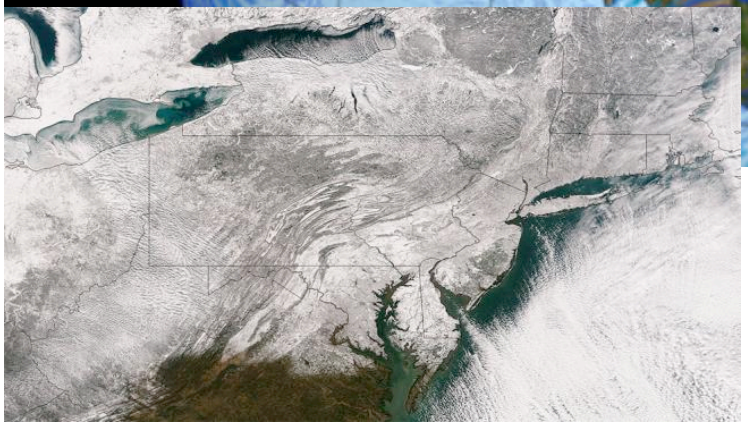
Arctic warming favours extremes, Vladimir A. Semenov
Nature Climate Change. 2, 315–316. (2012)
doi:10.1038/nclimate1502

Liu, J., *et. al.,* Arctic Sea Ice and Winter Snowfall, *PNAS, volume 109, 11,* 4074-4079, 2012

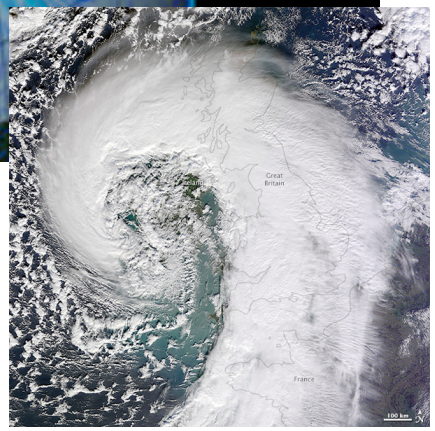
Wandering Polar Jet Stream

Most Precipitation On Record Since 1766





Jan 3, 2014



Feb 12, 2014

Ecological Impacts of Arctic Climate Change

Permafrost

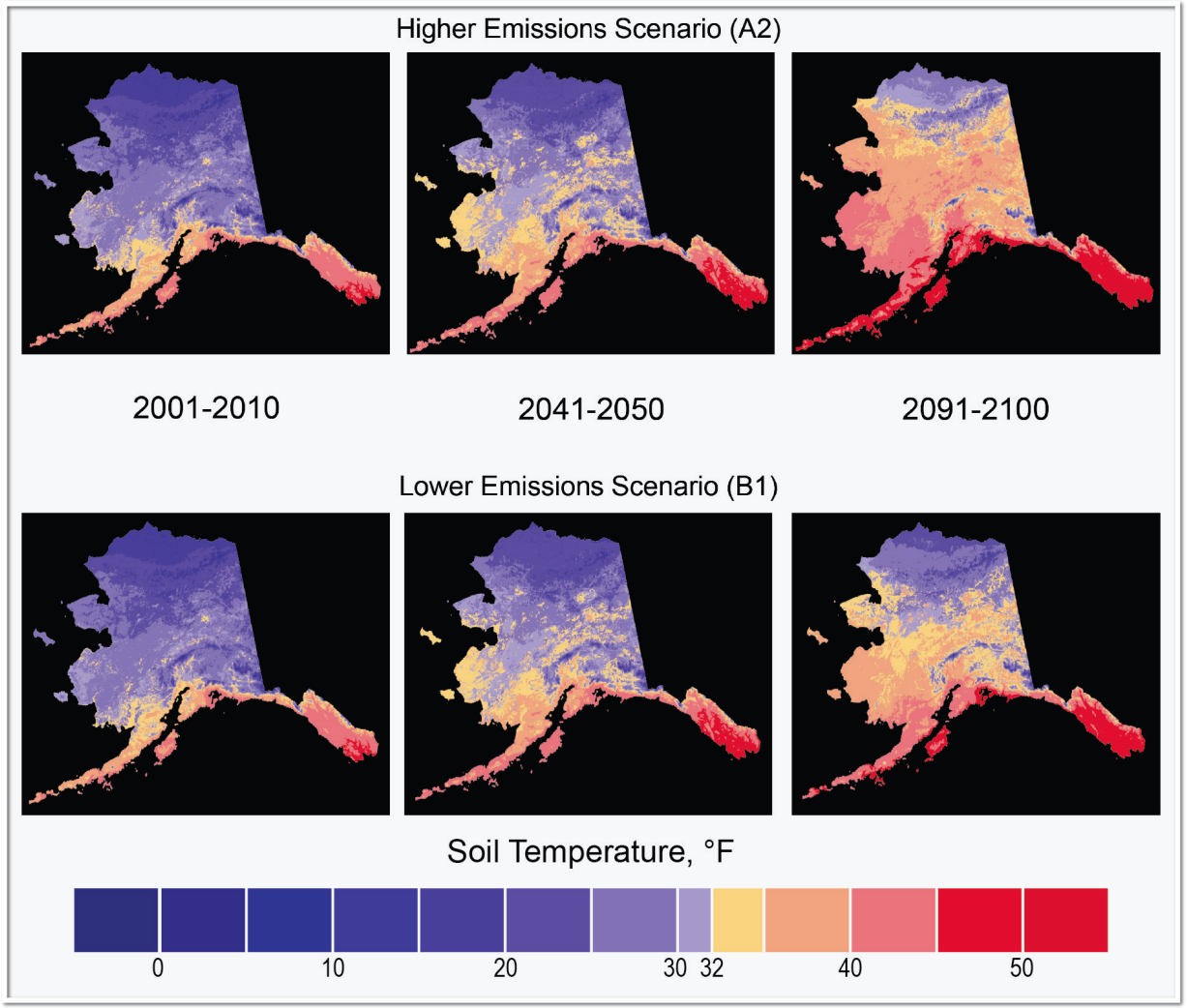
Permafrost has warmed by up to 2 °C since the 1980s. Its southern limit has moved northward in Russia and Canada. The depth of soil above the permafrost that thaws each summer has increased in Scandinavia, Arctic Russia west of the Urals, and inland Alaska.

Warming could liberate methane and increase warming rate
A possible "tipping point"

Alaska Permafrost Melt Scenarios

Vigilance=Monitoring: Know in advance whether a tipping point is approaching
"Vigilance, Not Panic", *Global Change, 79,* IGBP, October 2012

The Big Thaw



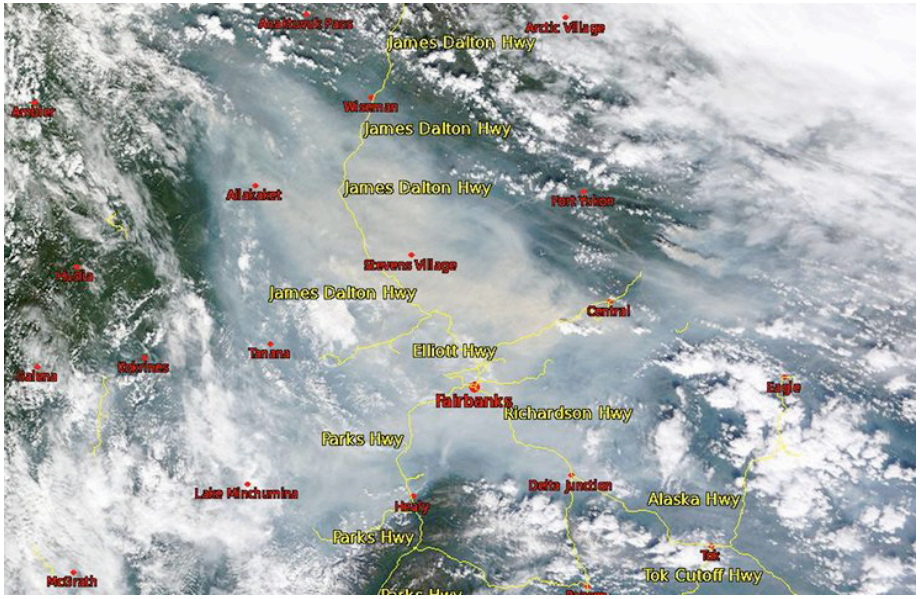
Projections for average annual ground temperature at 3.3-foot (one-meter) depth over time. Blue shades represent areas below freezing (where permafrost is present at the surface), and yellow and red shades represent areas above freezing (permafrost-free at the surface) (Markon et al. 2012).

Summer Drying of Interior Alaska

Drying Lakes and Changing Habitat

Progressive lake drying in northern forest wetlands in the Yukon Flats National Wildlife Refuge, Alaska. Foreground orange area was once a lake. Mid-ground lake once extended to the shrub. (Photograph by May-Le Ng). Alaska accounts for 81% of the National Wildlife Refuge System and provides breeding habitat for millions of migratory birds that winter in more southerly regions of North America and on other continents (Griffith and McGuire 2008). Wetland loss would also reduce waterfowl harvest in Alaska, where it is an important food source for Native Peoples.

Increasing Wildfires



Warm and dry conditions fueled wildfires as the season advanced steadily during July, 2009. By month's end, nearly 2 million ac/809,371 ha had burned. Smoke from numerous wildfires plagued the interior during the month with Fairbanks International Airport reporting 14 days where the visibility was reduced to 6 mi/9.7 km or less breaking the previous record for July of 13 days set during the record breaking wildfire season of 2004 in which 6.6 million ac/472,133 km burned. On average Fairbanks experiences 1 smoke day during the month of July.

Great Alaskan Wildfires of 2007

Normally, the tundra is wet in summer because of permafrost melt below, but 2007 was exceptionally hot and dry. The wildfires that year consumed 50 years of vegetation growth in the burn area and put as much CO2 into the atmosphere as the state's vegetation absorbs in a year. If such fires recur once every 100 years, ecosystem can recover. If they recur every 10 years, all bets are off.

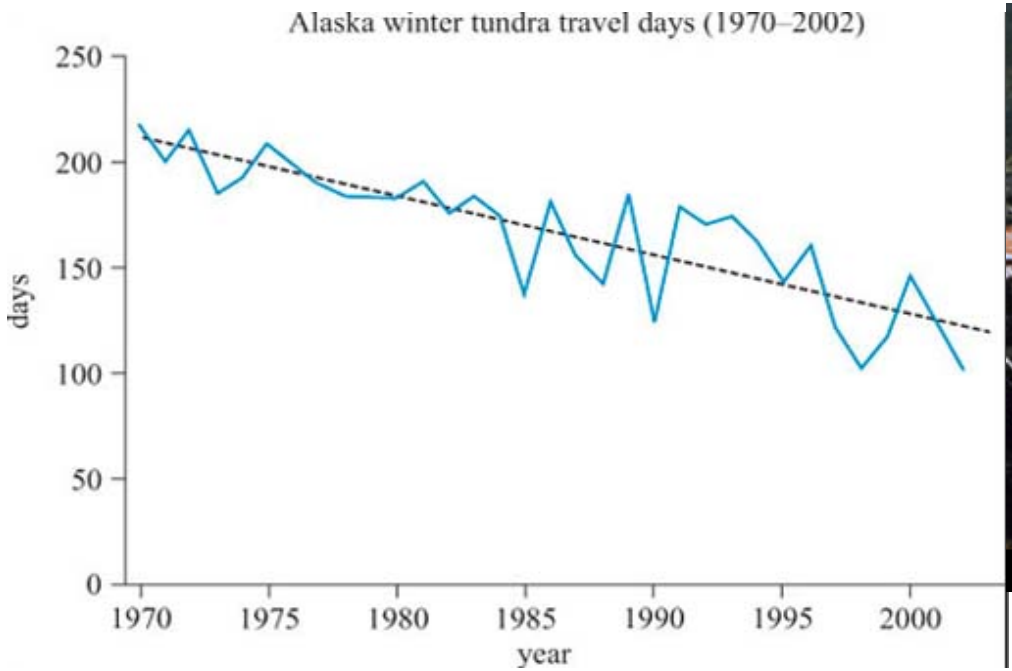
Sea Ice Loss Brings Big Changes to Arctic Life

Reductions in sea ice alter food availability for many species from polar bear to walrus, make hunting less safe for Alaska Native hunters, and create more accessibility for Arctic Ocean marine transport. Photographs by Gary Hufford and Carleton Ray; Caleb Pungowiyi; and Patrick Kelley.

Social, Economic, and Political Impacts of Arctic Climate Change

Some practical consequences of tundra melt

Many people in Alaska count on permafrost to be there



Houses undermined by melting Permafrost

Alaska has strict rules for vehicle travel on permafrost to prevent environmental damage. When it is too warm, travel is not allowed. The duration of allowed permafrost travel set by the Alaska Department of Natural Resources is a climate change proxy. In the last 25 years the number of days on which oil exploration is allowed on the tundra has more than halved.

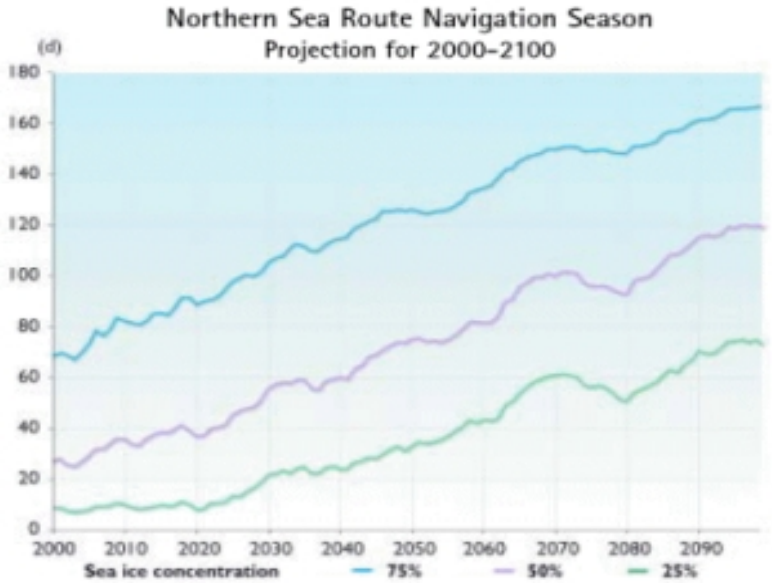
Permafrost is a slow moving underground river of ice. Above ground structures anchor their foundations in the ice below, and permafrost flow stresses foundations at the best of times; when the permafrost melts, the structures are destroyed.

Retreat of sea ice from shore exposes coastal villages to storm surges

Shishmaref could eventually disappear

Village of Shishmaref, Alaska. Notice the trash can in the image on the left, before the storm, and in the image on the right, after the storm. Images courtesy of Nome Nugget Newspaper.

2009 report of the US Global Change Research Program



The graph shows the projected increase in days of the navigation season through the Northern Sea Route as an average of five ACIA model projections.

Northern Sea Route and Northwest Passage

The length of the navigation season may double by 2050, perhaps earlier

Europe-Pacific shipping distance reduced by 40%

Churchill, Manitoba: high hopes for its seaport

Black Carbon Pollution from Trans-Arctic Shipping

BC warms atmosphere, accelerates ice melt

Is it too late for an Arctic Clean Air treaty/agreement?

J. J. Corbett, D. A. Lack, J. J. Winebrake, S. Harder, J. A. Silbermam, and M. Gold,
Arctic shipping emissions inventories and future scenarios, Atmos. Chem. Phys., 10, 9689–9704, 2010
www.atmos-chem-phys.net/10/9689/2010/ doi:10.5194/acp-10-9689-2010

Race Between Sovereignty and Cooperative Governance

Economics:

Pristine fisheries
Mineral rights
Oil exploration
Shipping

Governance:

Navigation,
Resource rights,
Environment,
Pollution

P.A. Berkman and O.R. Young, Governance and Environmental Change in the Arctic Ocean, Science, 324, 3390340,April 17, 2009

The Arctic: A Security Issue

Now, powers do not prepare to launch missiles over the Arctic, they contest over using the Arctic

Military powers beef up Arctic presence
Wall Street Journal, April 16, 2012

Canadians willing to fight to keep true North free
Toronto Globe and Mail, Jan 25, 2011

Arctic Security Means More than Sovereignty
Toronto Globe and Mail, Jan 26, 2011

Britain Spearheads "Mini-NATO" In Arctic Ocean, Baltic Sea
Posted 15. Feb, 2011, ArcticSecurity.org in Canada, Denmark, Finland, NATO, Norway

Arctic Body Comes In from the Cold
Wall Street Journal, May 14, 2013

California

The most thoroughly assessed state in the Union

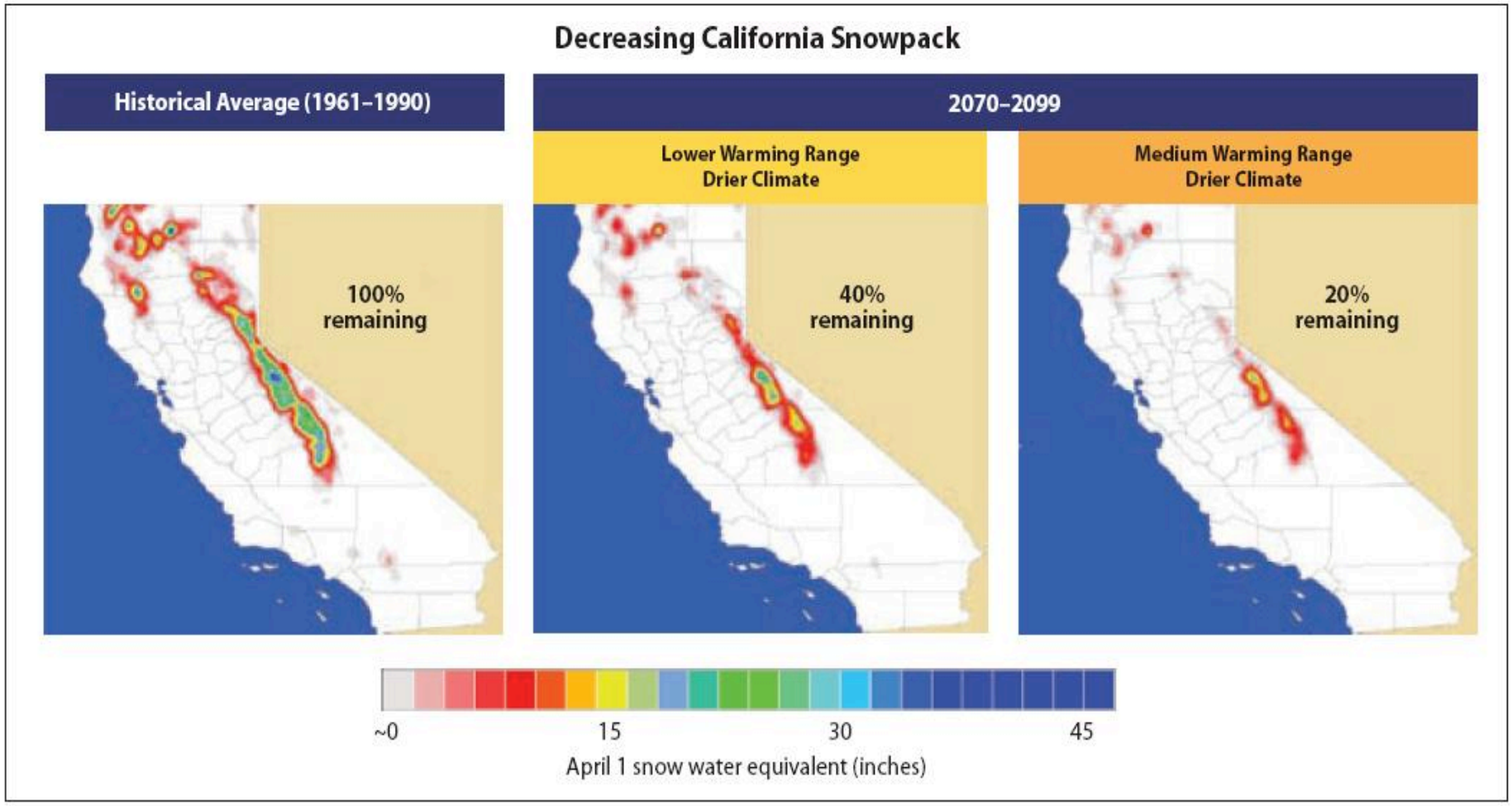
DROUGHT: Lack of Sierra snowmelt prompts drastic state cutbacks

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

Sierra Nevada Snowmelt

The single most persuasive impact examined by the 2006 Assessment

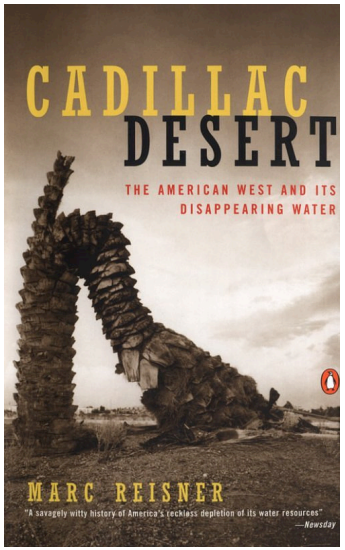


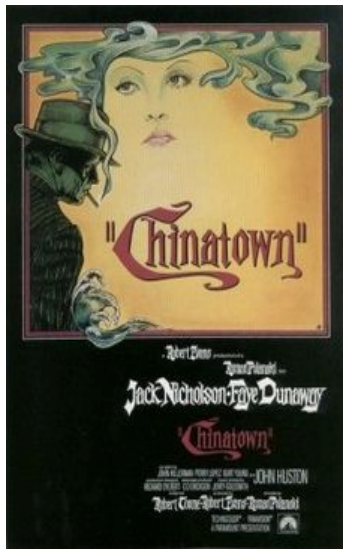
Luers A., Cayan D., Franco G., Hanemann M. and Croes B., California Climate Change Center (2006). Our Changing Climate: Assessing the Risks to California, p.7

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

Follow the Water

California's history has been written in water, not ink





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

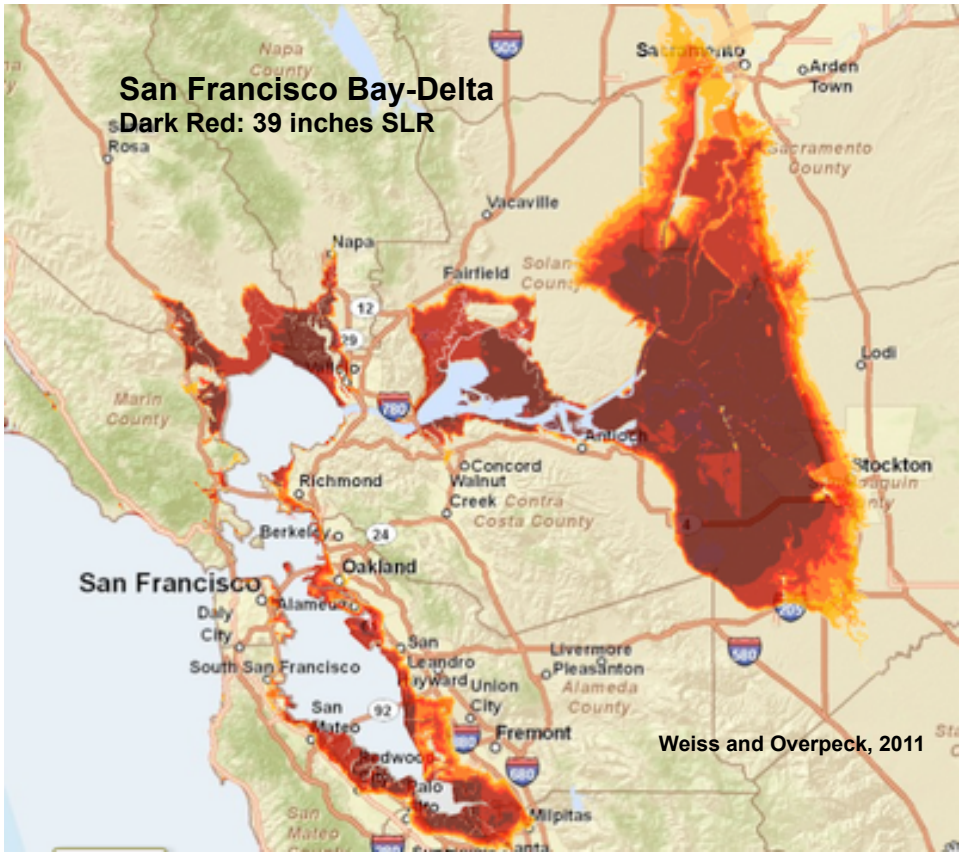
50% chance by 2021 of a season when Lake Mead goes dry, due to upstream withdrawals, declining average rainfall, and Rocky Mountain snowmelt, together with La Nina

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

The Big Gulp

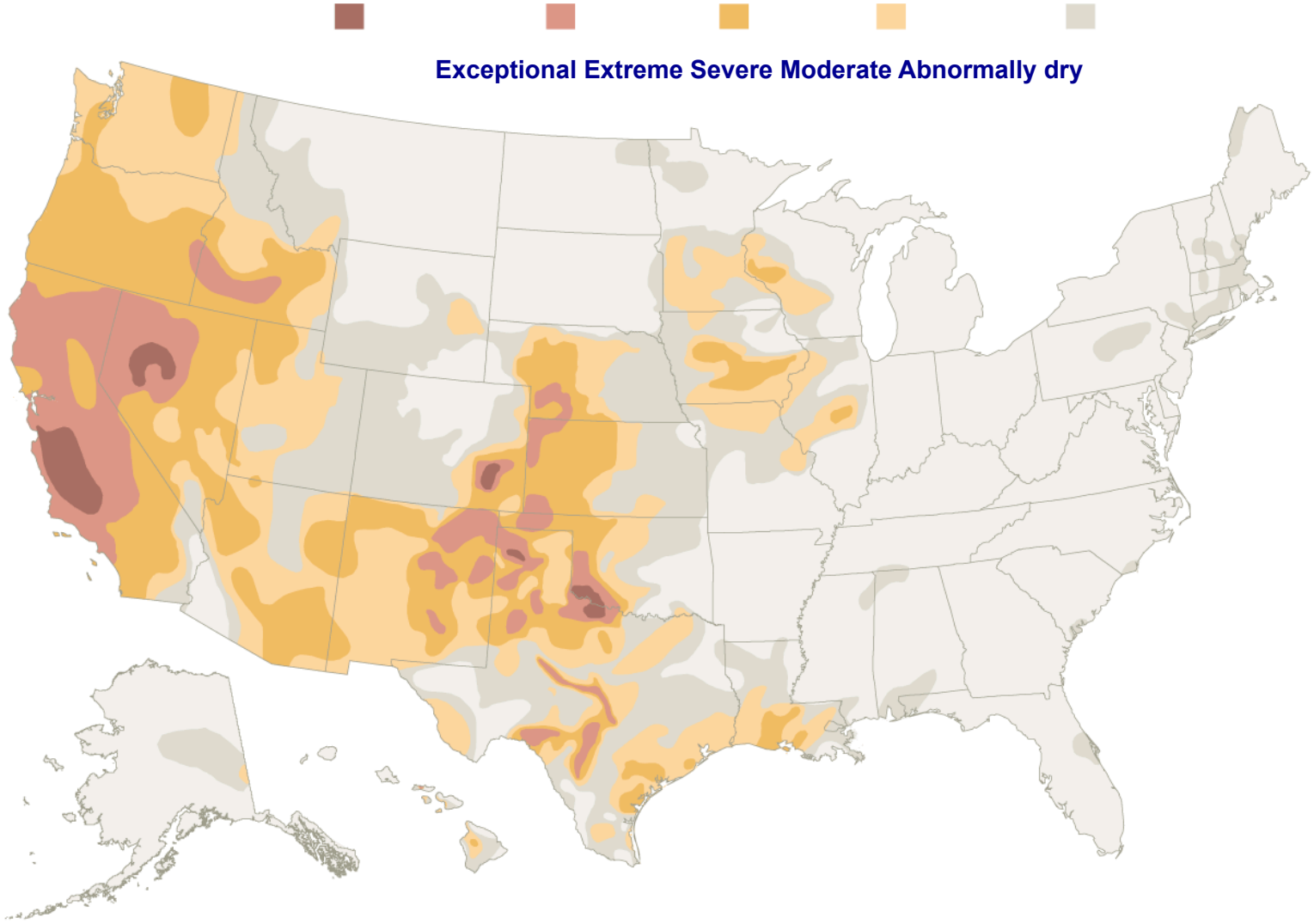


CALFED BAY-DELTA PROGRAM

California's Biggest Nightmare

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

2014 Drought in US Western States



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

Heat Waves

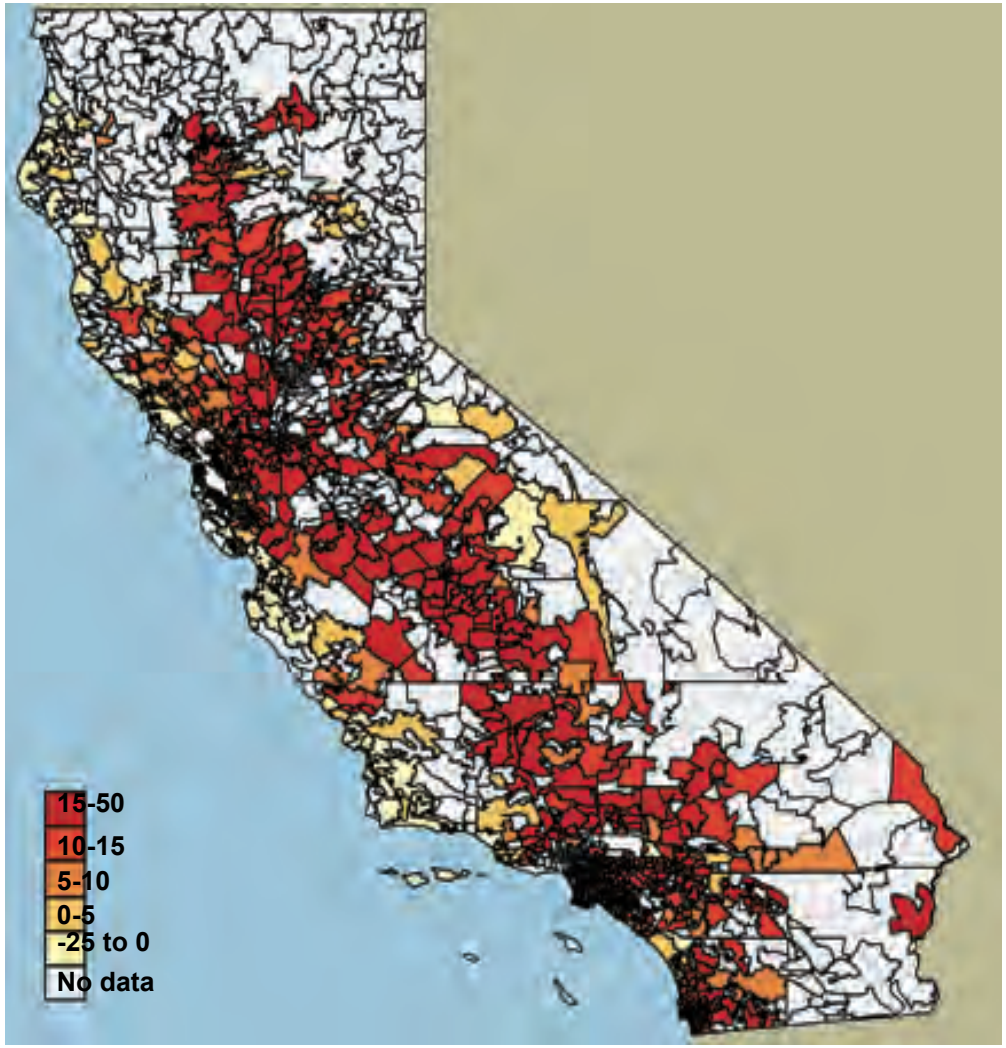
"Extremely hot" days in Sacramento (at least 105°F) will become more common. By 2050, their number could increase fivefold (up to 20 days). By 2100, under business as usual, they could occur as much as ten times more often.

Electricity Consumption

Excess Mortality

Electricity Demand

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

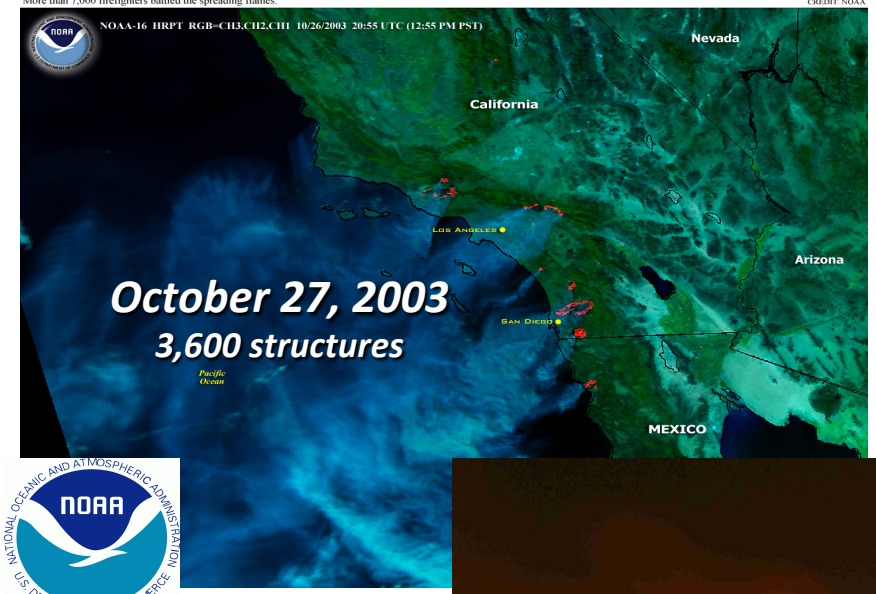


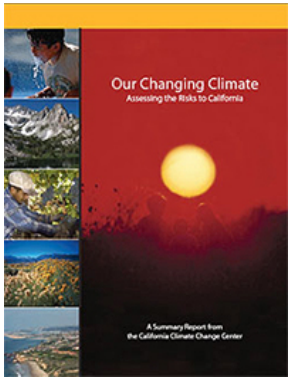
California Wildfires

Climate change, population growth, urban-wildland development

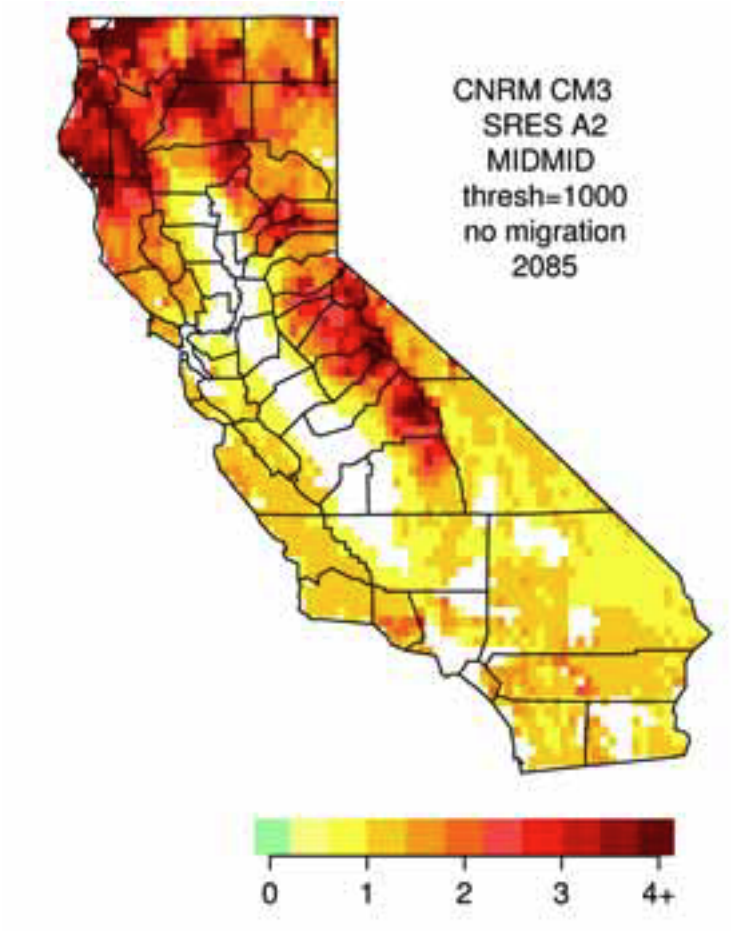
According to Reuters News Service, at least 13 people have been killed in the state's deadliest outbreak of fires in more than a decade. About 30,000 homes were endangered by the fires, driven by warm Santa Ana winds, which had consumed more than 330,000 acres, or 500 square miles — almost half the size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

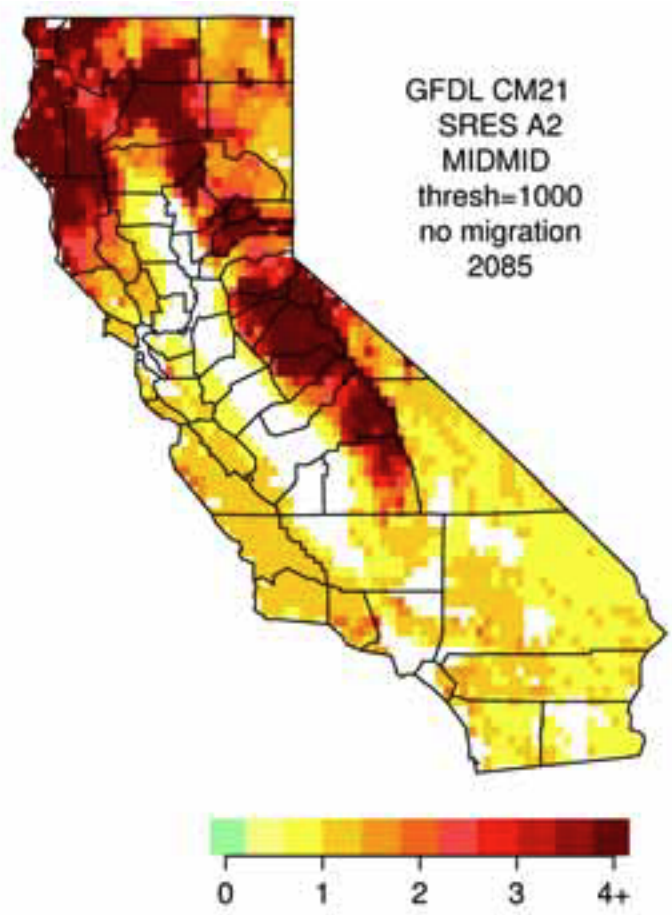
CREDIT: NOAA





2085 Wildfire Risk Relative to 1971-2000



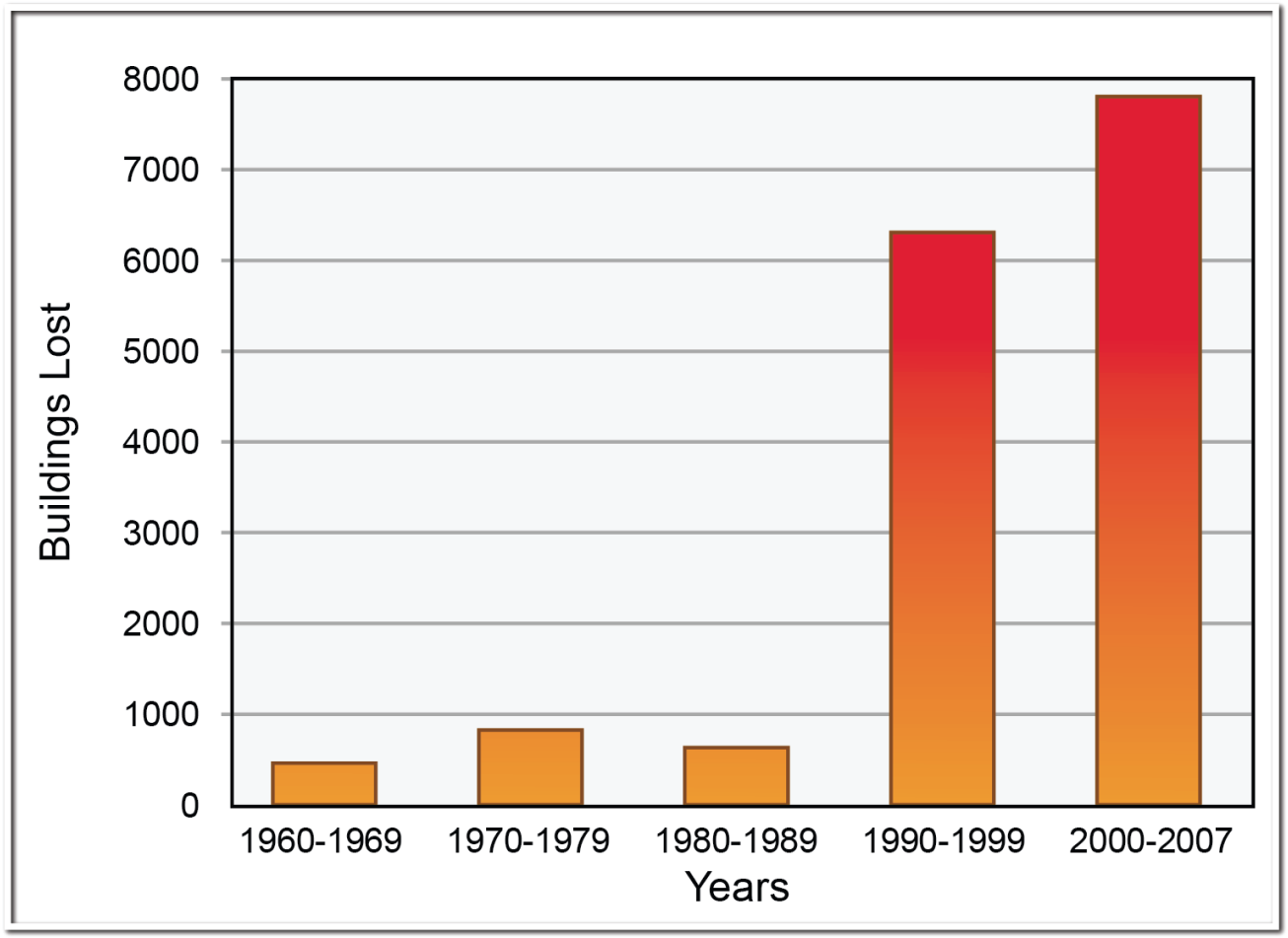


2085 Predicted burned area as a multiple of 1971-2000 predicted area burned. Panels show SRES A2 scenarios with the location of fire regimes fixed.All scenarios show large increases in burned area in forests of the Sierra Nevada, northern California Coast , and southern Cascade ranges. A value of "1"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

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

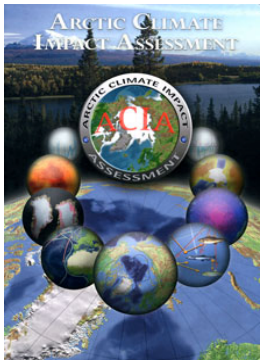
Wildfire Risk: Structures

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

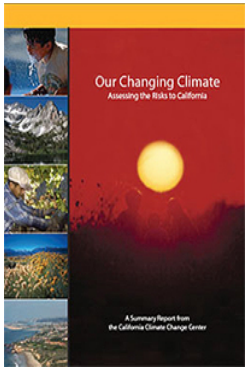


US National Climate Assessment, 2013, Redrawn from Stephens et al. 2009

Arctic and California Climate Change Assessments



Two of the earliest *regionally-led* impact assessments (2005, 2006)



Scientists and regional decision makers prepare assessments

- International Arctic Science Council & Arctic Council (8 nations)
- California Climate Change Center & California Climate Action Team (19 State Agencies)

Arctic assessments have a multi-national perspective

- International treaties and agreements govern the Arctic
  - Each of the 8 Arctic Council members must seek approval of a distant home government
- ACIA an IPCC for the Arctic Council-a sub-global regime complex
- Hope that ACIA would inspire action at both the inter-Arctic and global levels
  - What happens in the Arctic does not stay in the Arctic

California's perspective is the State

- Impacts were close to home, emphasis on practical action
- Direct political influence- preamble to AB 32 lists conclusions of 2006 assessment
- The California Climate Action Team can and did take administrative action

Commitments to update and, for California, adaptive management

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 (O3>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%, NO2 83%, SO2 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

Cal/EPA

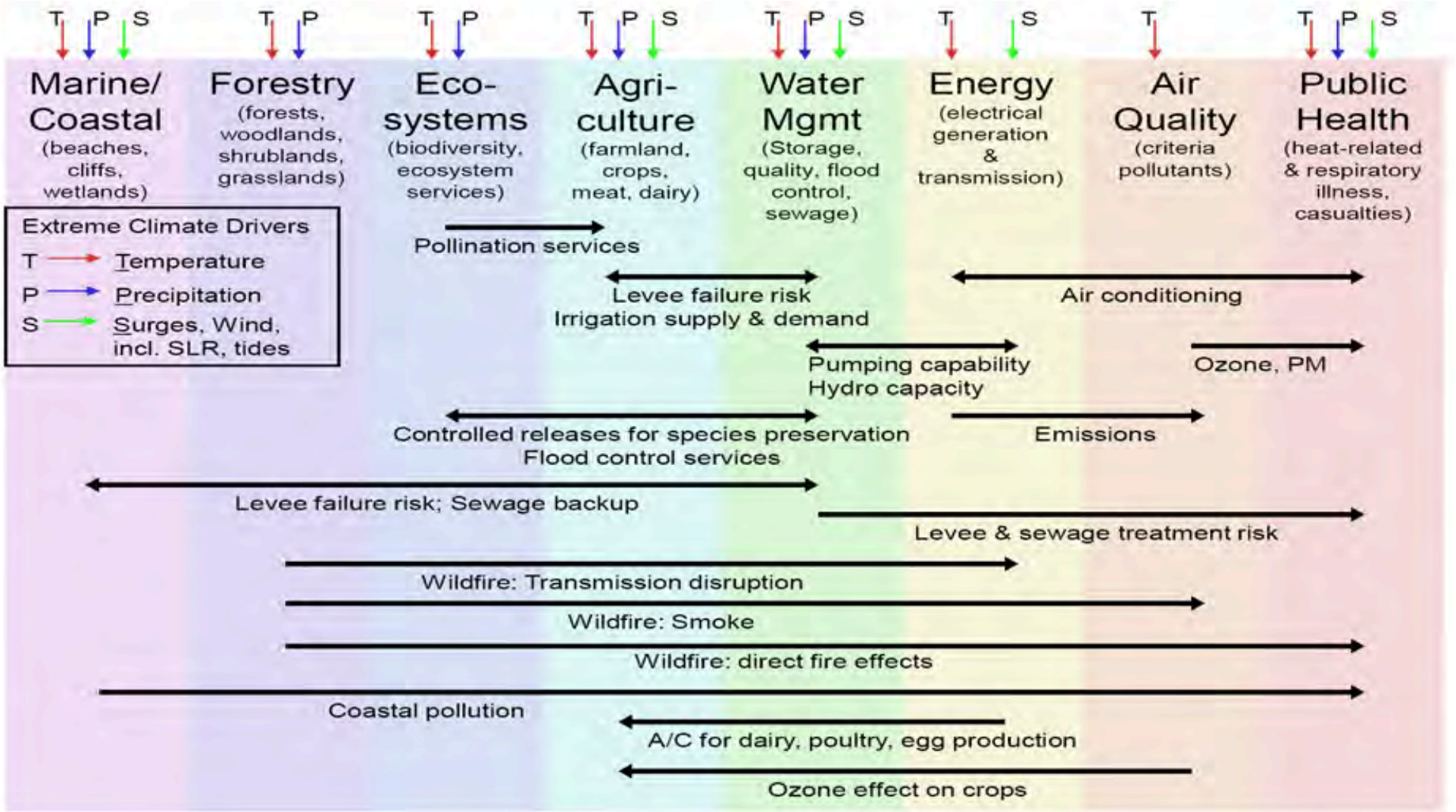
Waste Management Board
Air Resources Board
Transportation & Housing

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 requiring polycentric decision-making



2009 California Climate Adaptation Strategy

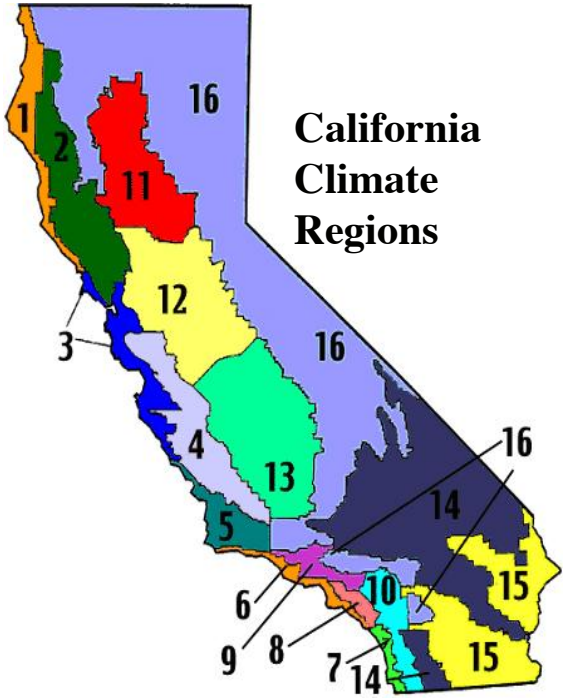
Regional Diversity

Polycentric Decision Making

Each environmental issue has its own natural region

Rigorous science respects natural boundaries

Spans of authority do not match natural regions



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

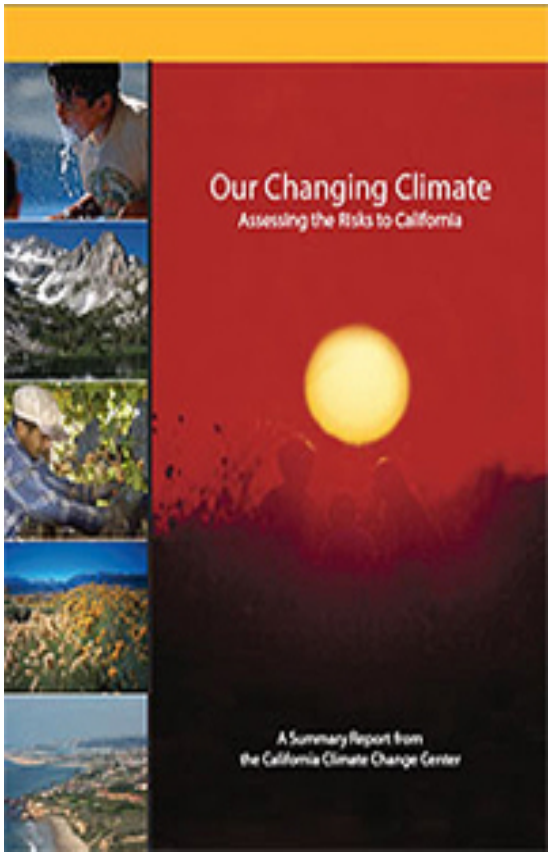
California Climate Action Team, a council of resource management agencies

California Climate Change Center

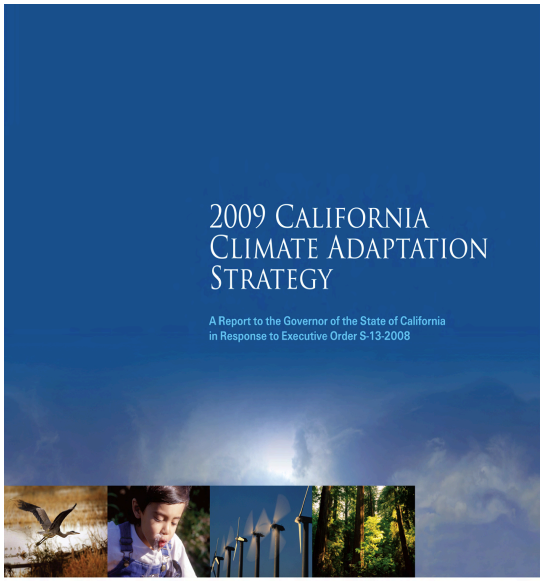
Repeated Assessments

The key to adaptive management

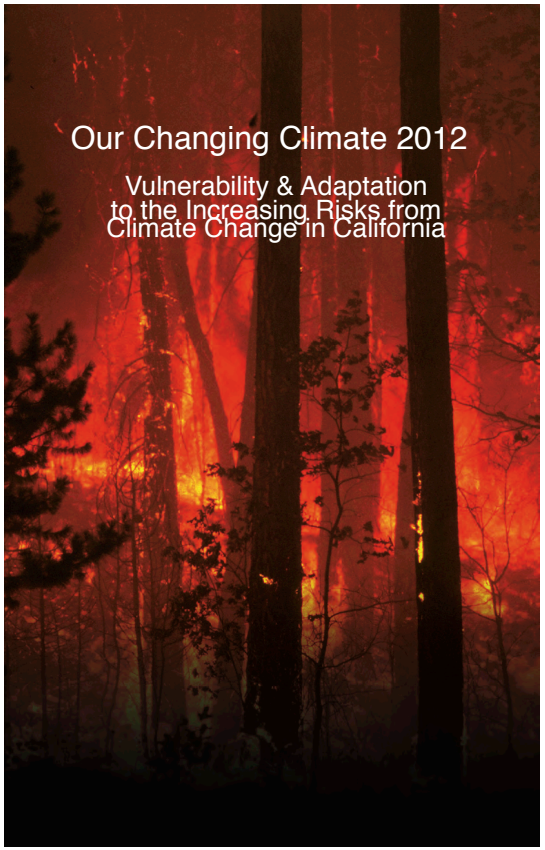
Executive Order S-3-05 charged the Secretary of the California Environmental Protection Agency to report to the Governor and the State Legislature by January 2006 and periodically thereafter on the impacts of global warming to California.



2006



2009

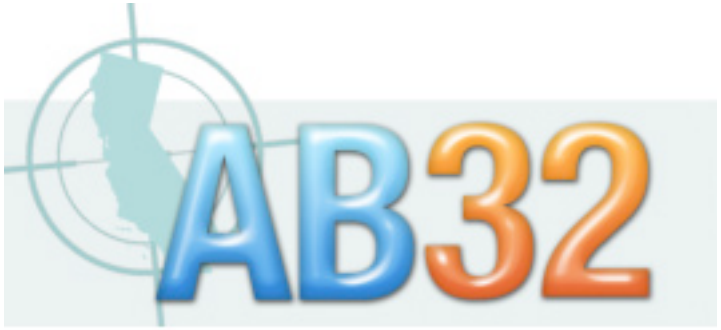


2012

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

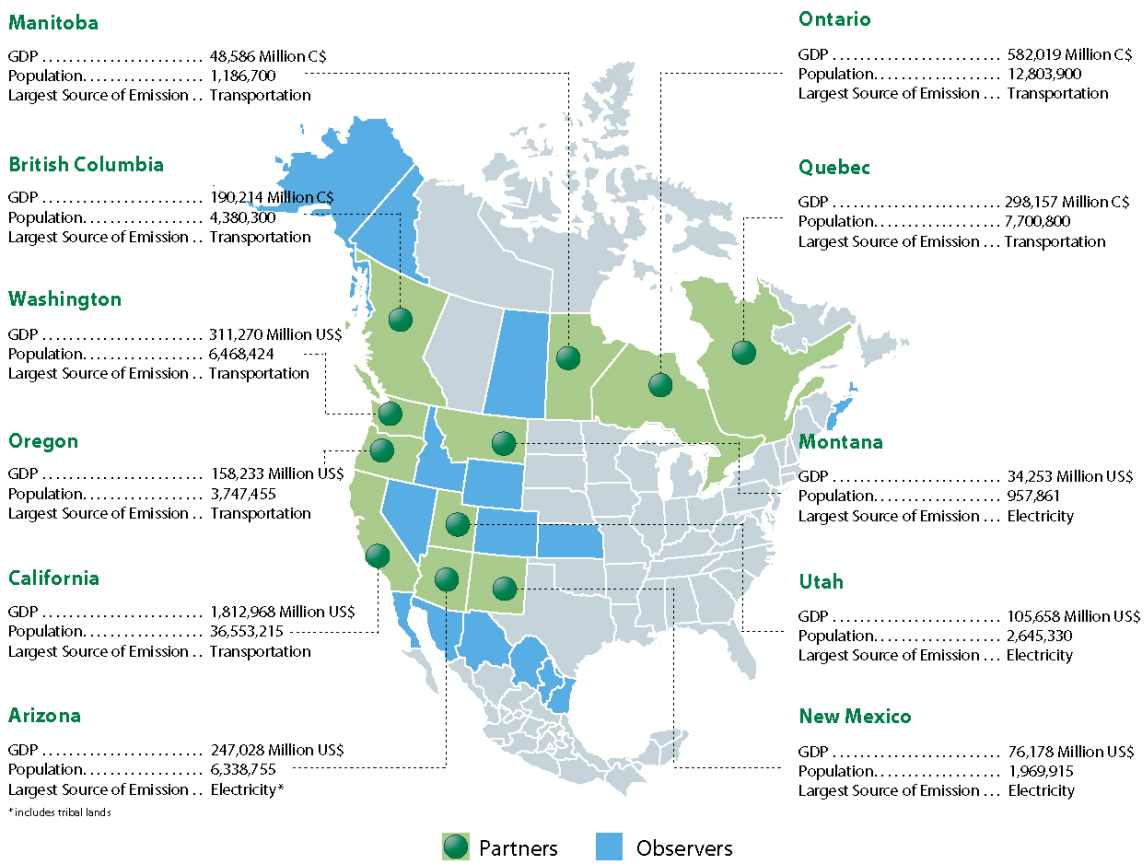
The Impact of Impact Assessments

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.



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