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Climate Change in the U.S: Effects and Implications

Virginia Burkett

Rethinking Energy and Climate Strategies for Transportation,

August 29-September 1, 2011

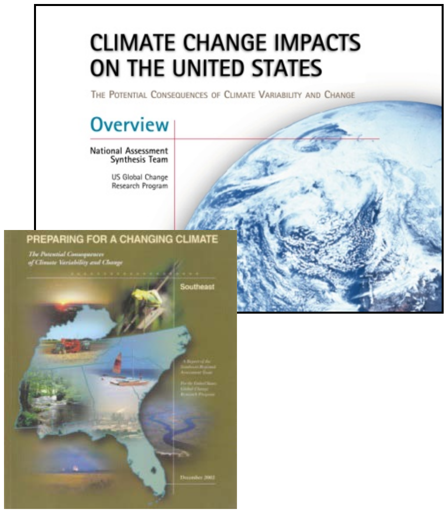
Asilomar Conference Grounds

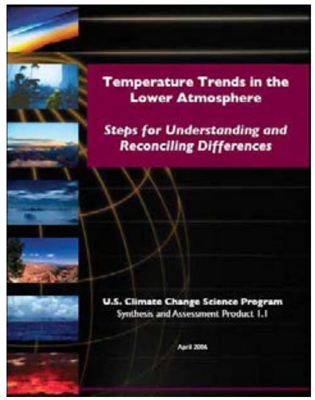
U.S. Department of the Interior

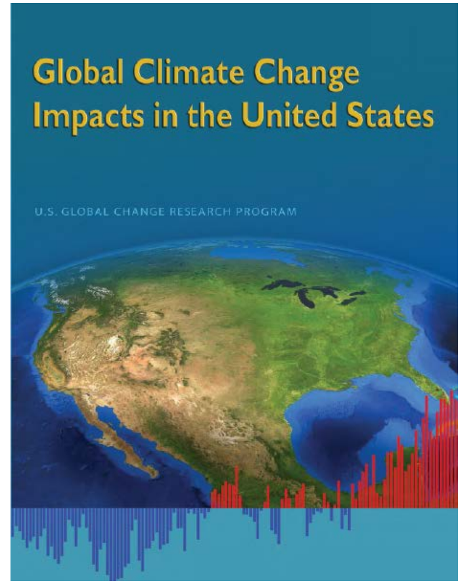
U.S. Geological Survey

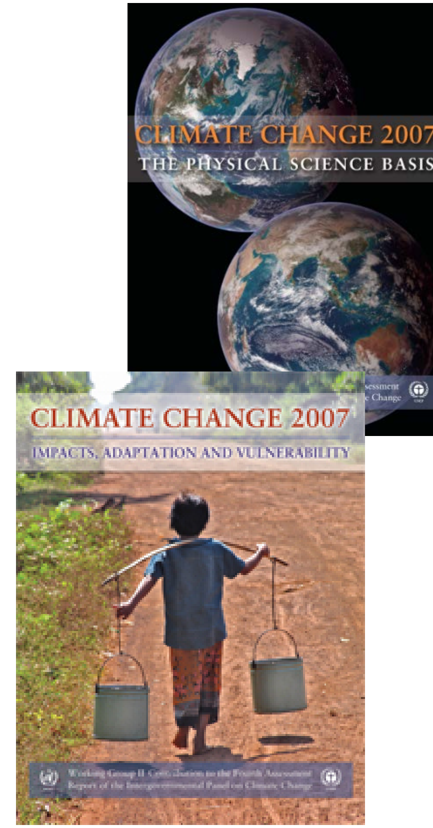
U.S. Global Change Research Program

National, Regional, and
Sectoral Assessments









Main Sources

Intergovernmental Panel on Climate Change

UNEP

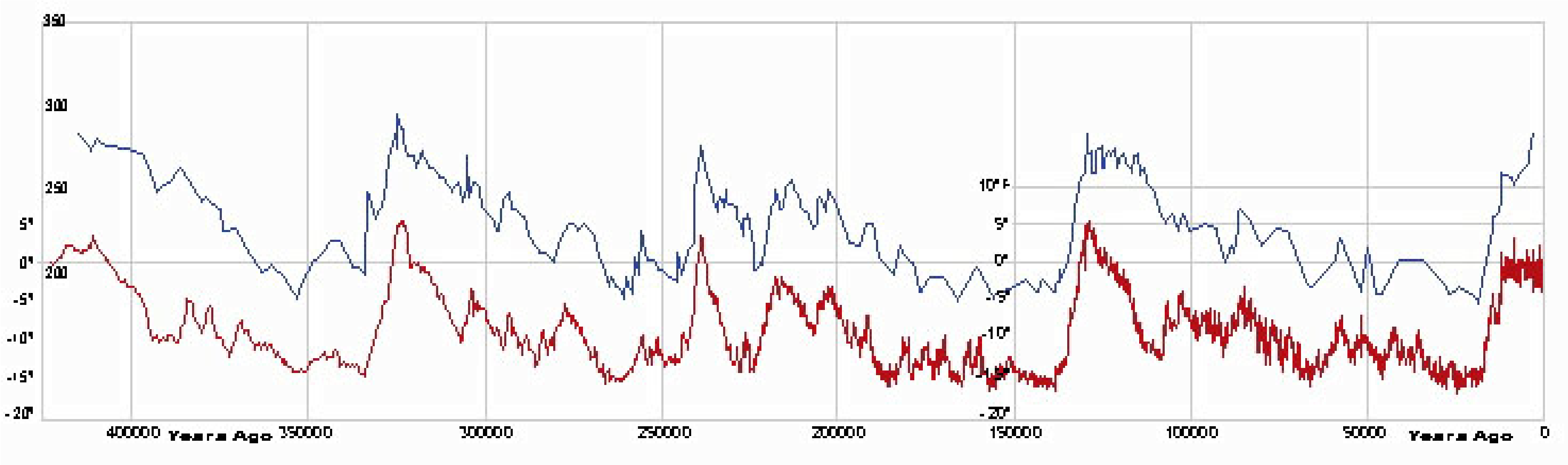
<u>IPCC Working Groups:</u>

WG I - Physical Climate Science
WG II - Impacts, Adaptation and Vulnerability
WG III - Mitigation

WMO

Past 400,000 Years:

CO_2 and Temperature



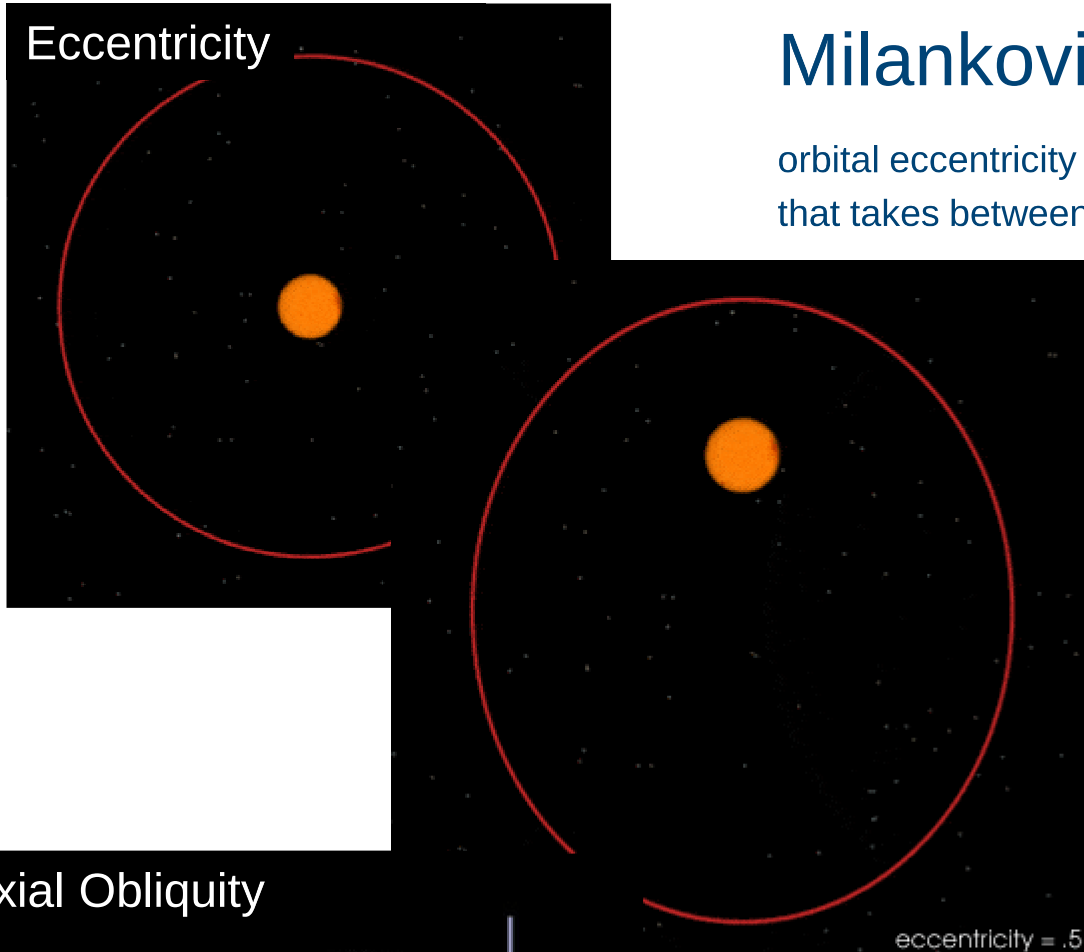
Upper, blue line = C02 level **Lower, red line = temperature**

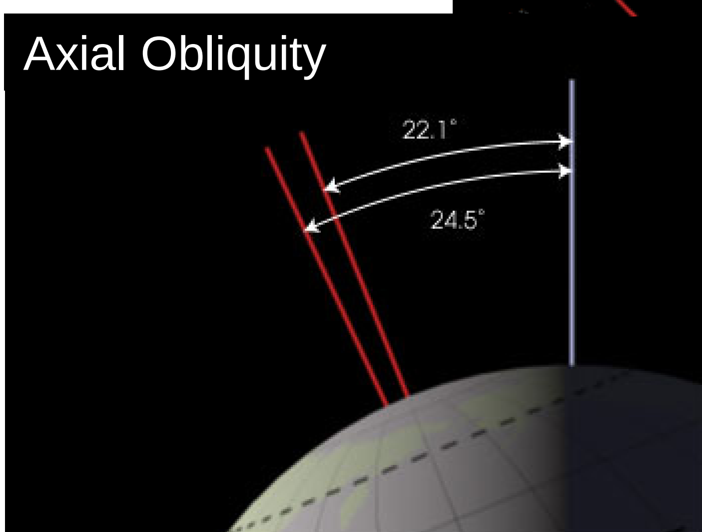
Temperature and $C0_2$ record from Vostok, Antarctica ice core project

(Petit *et al*. 1999)

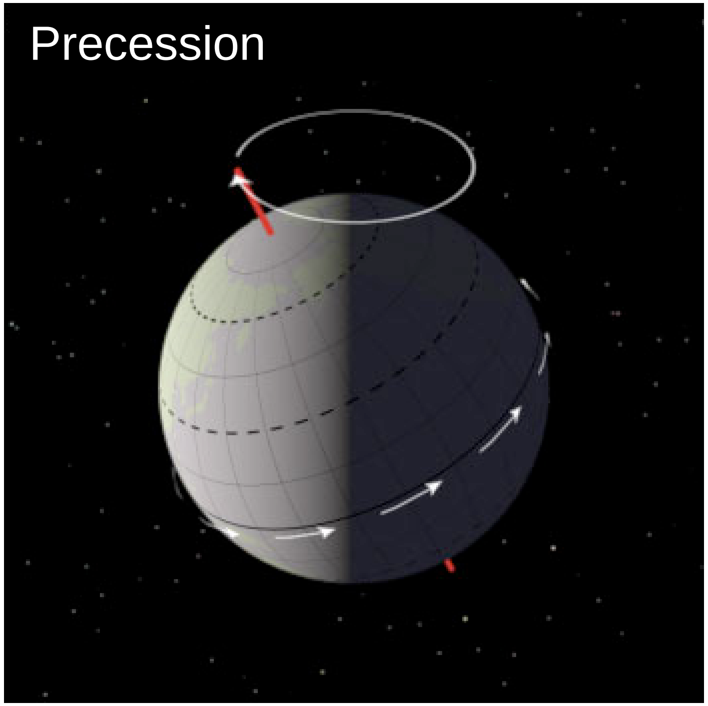
Milankovitch Cycles

orbital eccentricity affects the Earth-sun distance in a cycle that takes between 90,000 and 100,000 years

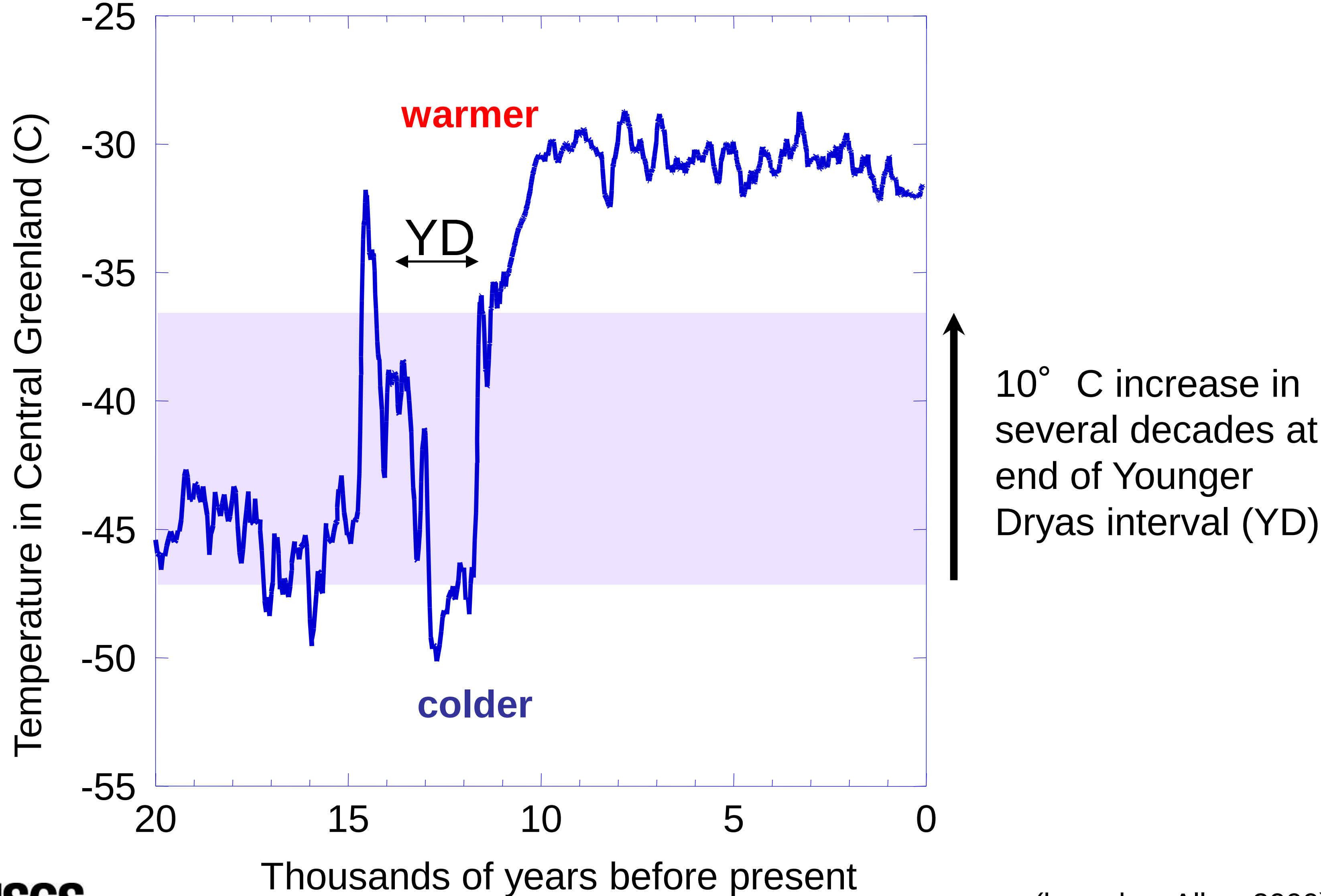




(Figures from NASA Earth Observatory)



Past 20,000 Years:



(based on Alley, 2000)

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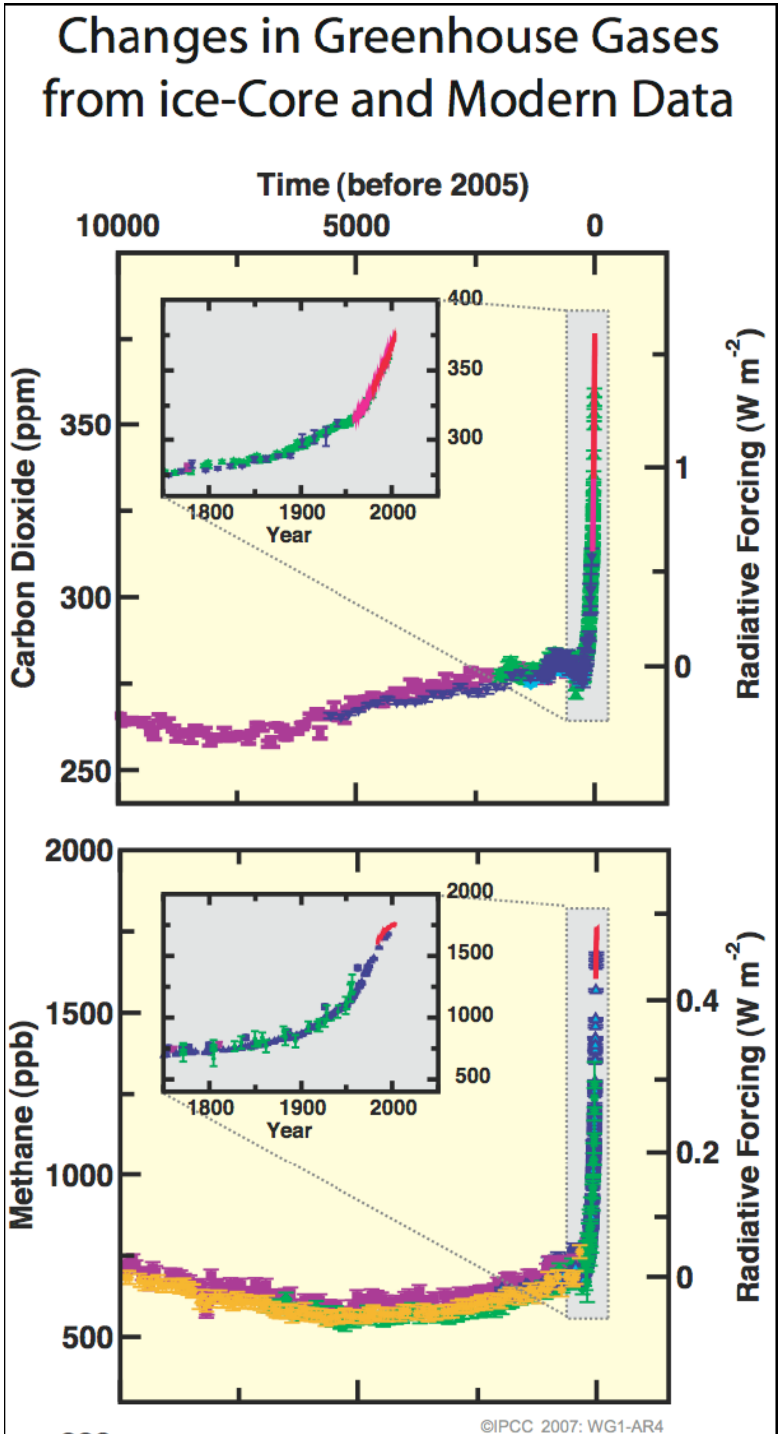
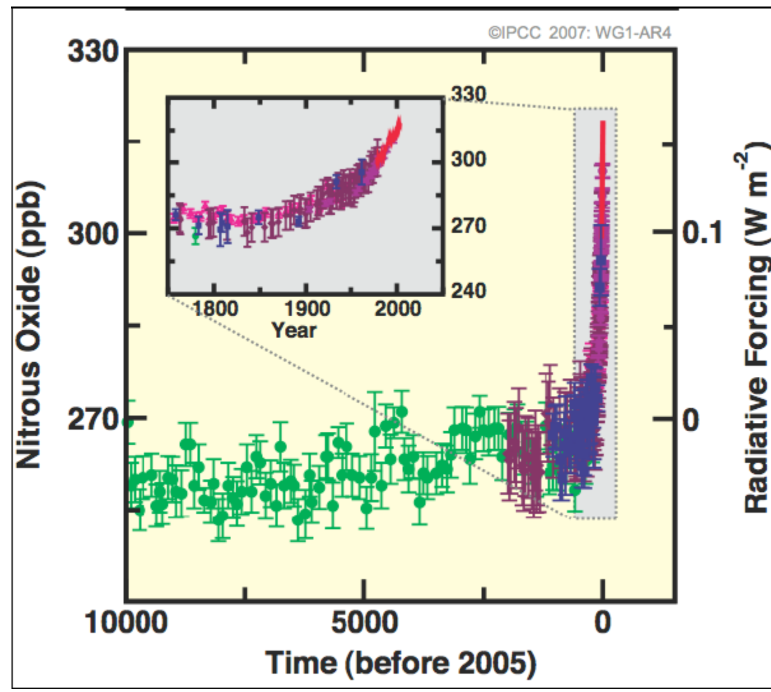


Past 10,000 Years:

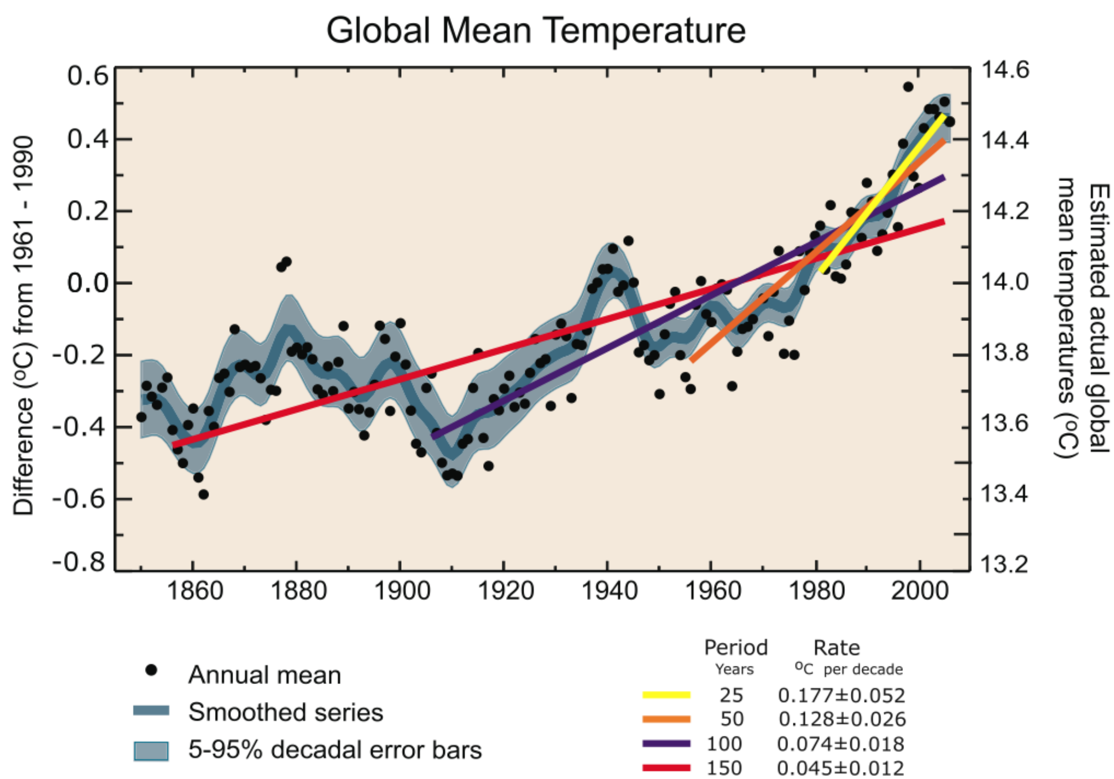


Past 100 years:

Atmospheric Change

- **CO_2 increased 35%, methane increased 150% compared to pre-industrial levels** (attributed to fossil fuel use & land use change)

- **Global average temperature increased 0.74 ºC over past 100 yrs, 0.65 ºC over past 50 years.**



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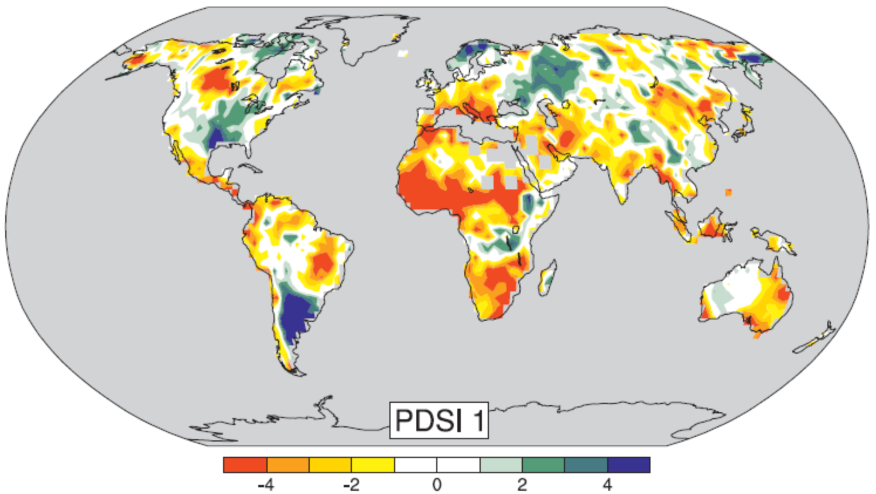
Atmospheric Change

- **Atmospheric water vapor increased** (consistent with T increase)
- **Total volume and intensity of rainfall increased over most land areas -- but so did the number of dry days**
- **Intensified droughts have occurred over wider geographical areas, especially the tropics and sub-tropics, since 1970.**

Global Average Trend in Monthly Palmer Drought Severity Index (1900 to 2002)



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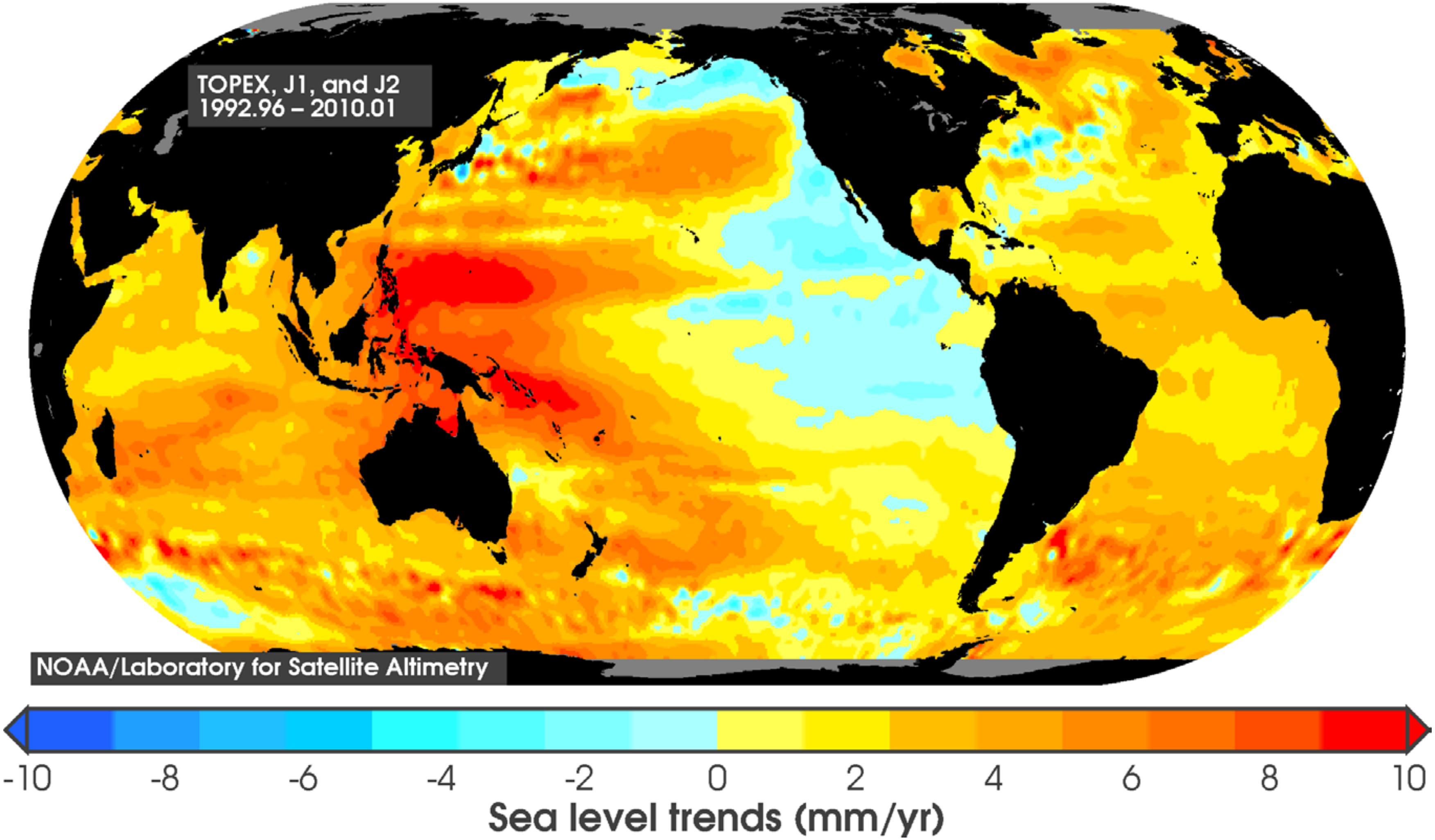
Ocean change:

- **Ocean temperature increased from surface down to at least 3000 m**
- **Increase in N. Atlantic hurricane activity**
- **Increase in ocean acidity**
- **Global sea level rise**
  - **1.7 mm/yr during 20th century**
  - **3.1 mm/yr during 1993-2003 (acceleration or natural variability?)**

Geographic Variability in the Rate of Sea Level Rise (1993-2010)



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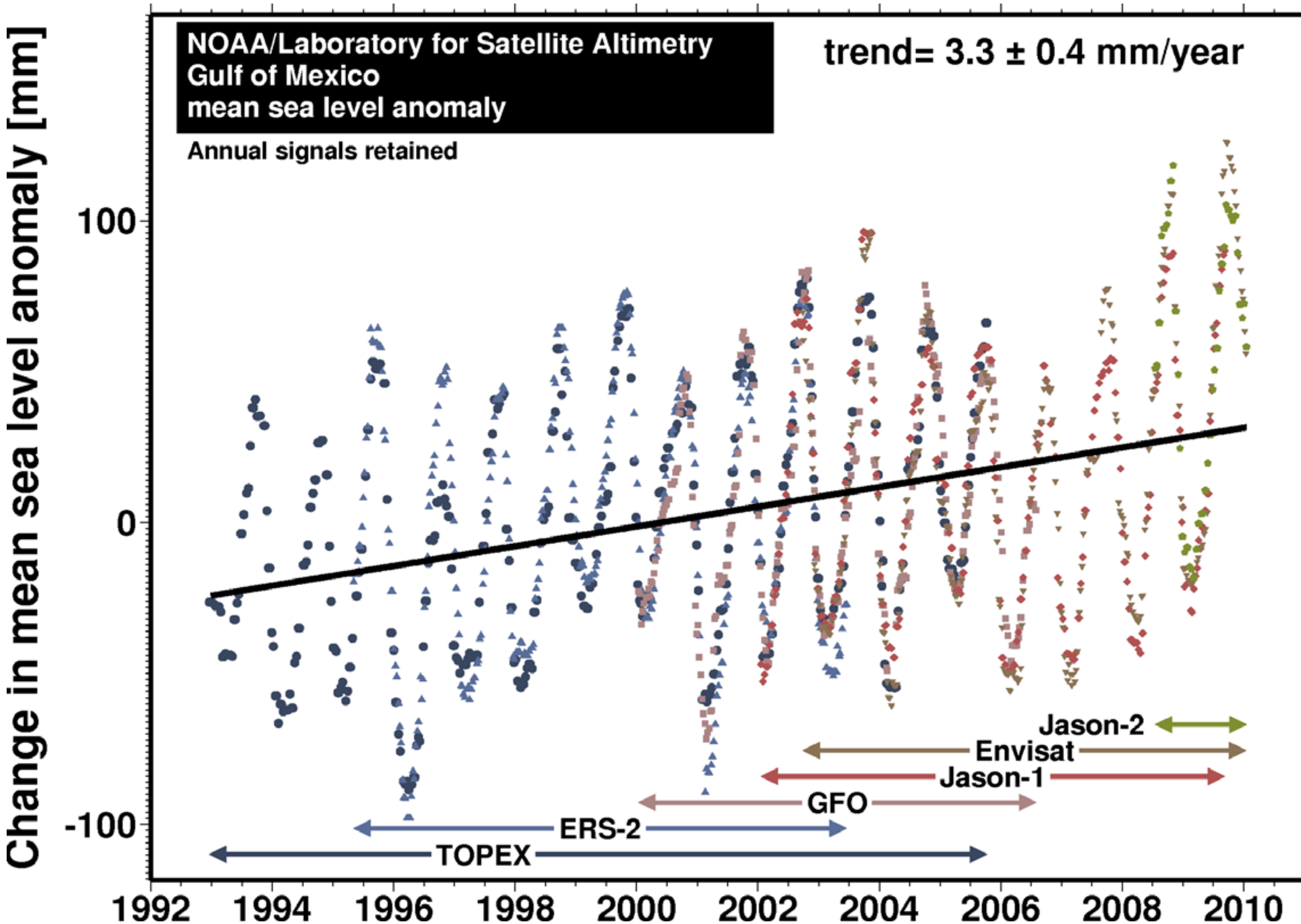
Gulf of Mexico – Satellite Altimetry Record

1993-2010



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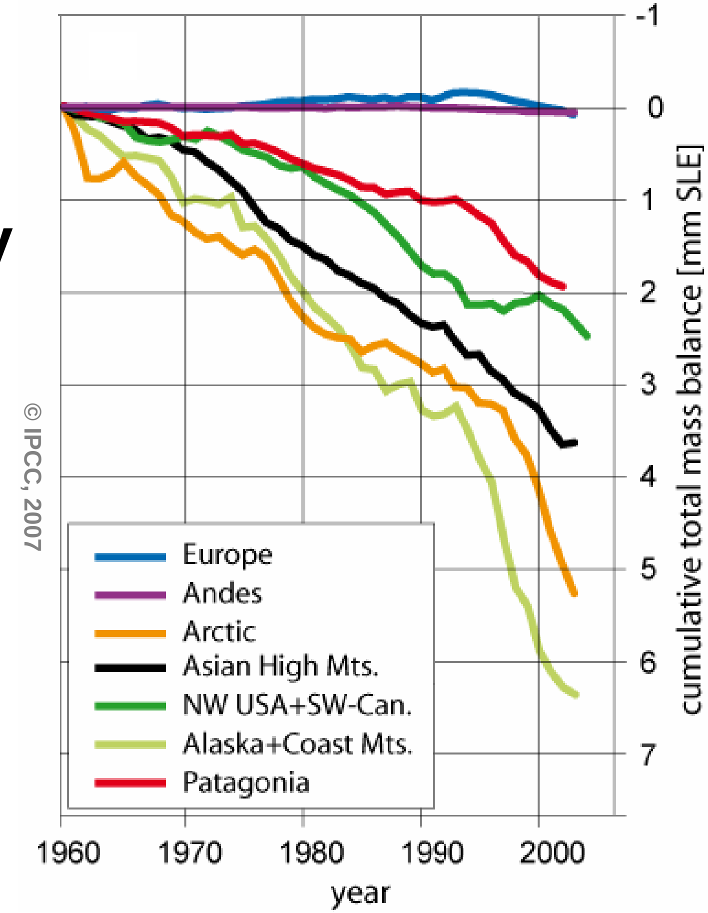
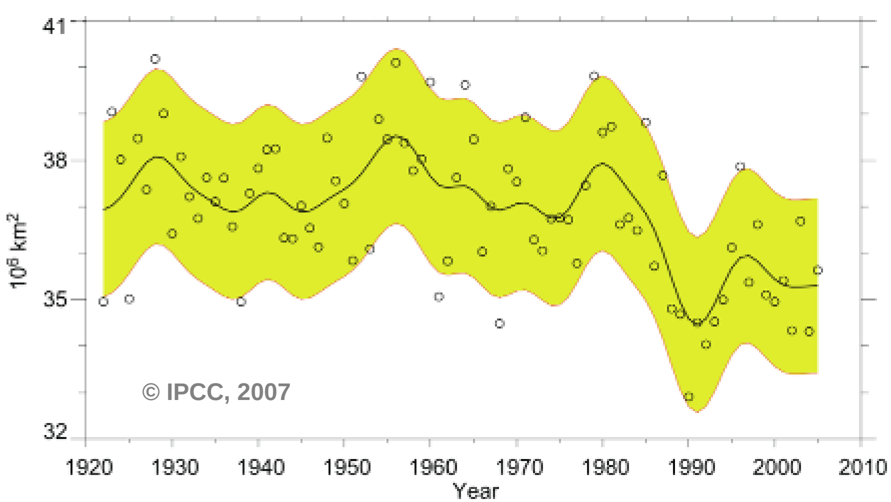
Change in ice and snow:

- Arctic summer sea ice has shrunk 7.4% per decade since 1978
- Less snow at low altitudes
- Mountain glaciers declined globally

Glacier Mass





March-April Snow Cover
in the Northern Hemisphere

Change in ice and snow:

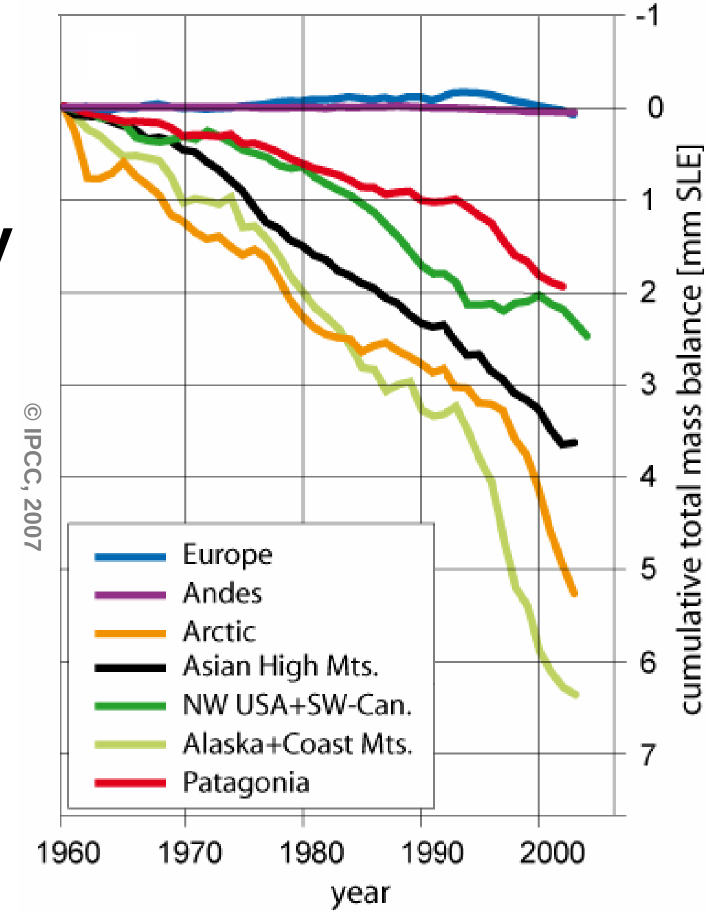
- Arctic summer sea ice has shrunk 7.4% per decade since 1978
- Less snow at low altitudes
- Mountain glaciers declined globally

Muir Glacier, Alaska

August 1941 | August 2004

NSIDC/WDC for Glaciology, Boulder, compiler. 2002, updated 2006. *Online glacier photograph database*. Boulder, CO: National Snow and Ice Data Center.

Glacier Mass



Other indicators of climate change:

- decline of permafrost
- collapse of ice dominated coastlines
- coral bleaching

Increase in ocean temperature of 1-2° C above summer maxima causes expulsion of coraline symbiotic algae

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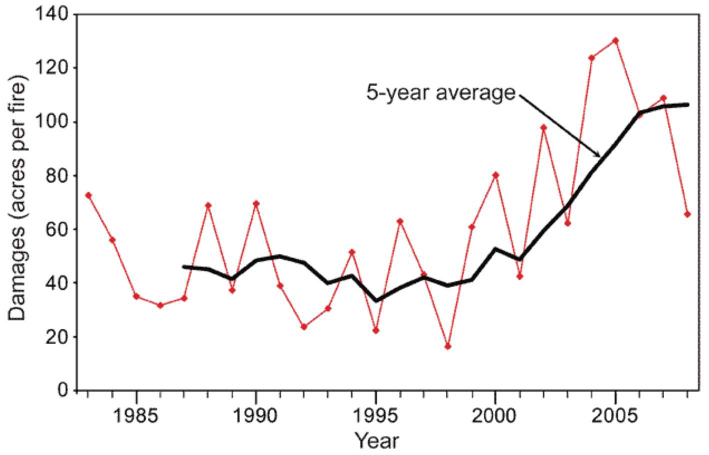
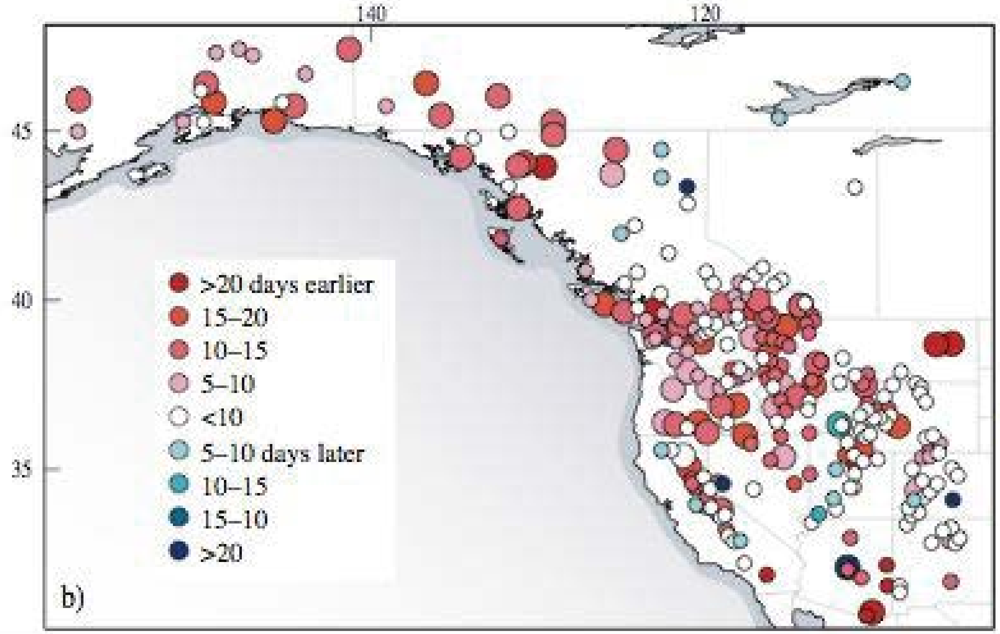
Other indicators of climate change:

- decline of permafrost and sea ice
- collapse of ice dominated coastlines
- coral bleaching
- changes in fire regime
- changes in streamflow patterns



Trend in U.S. Wildfire Size
(USGCRP 2009)



Trend towards earlier peak streamflow in snowmelt dominated watersheds of the US west and northeast

(Stewart et al., 2005)

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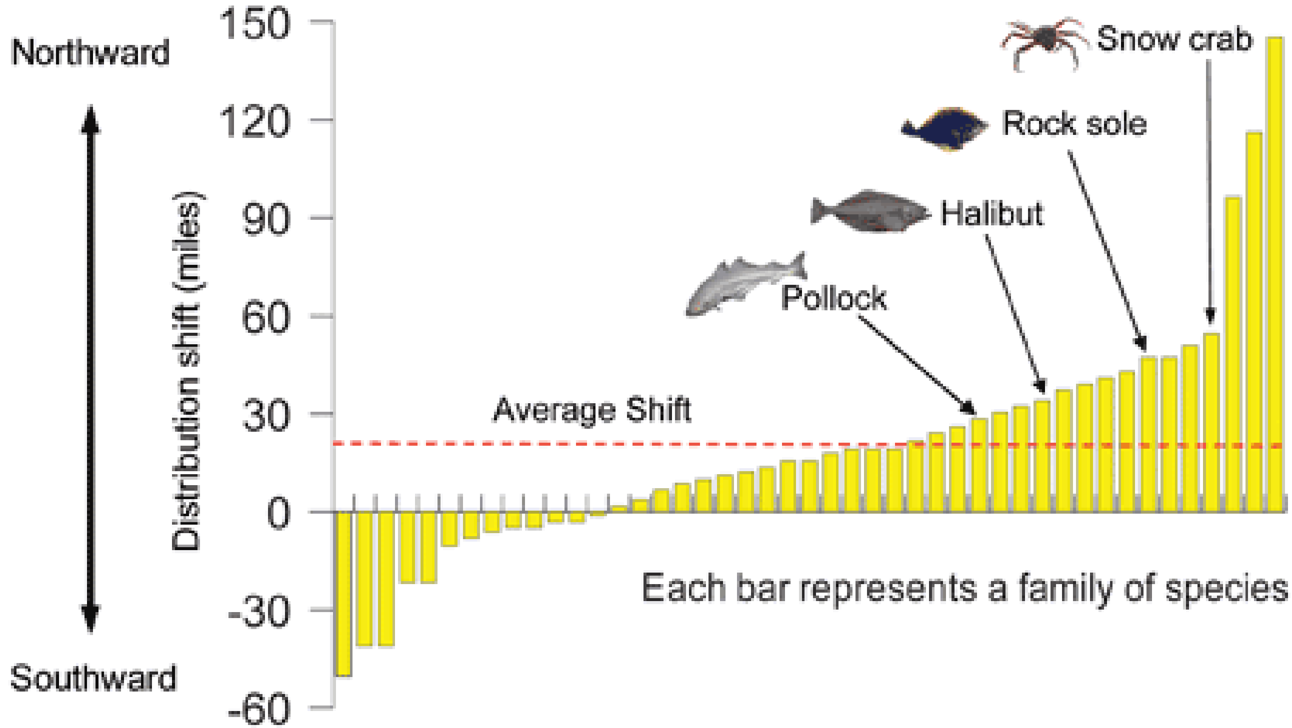
Other indicators of climate change:

- decline of permafrost and sea ice
- collapse of ice dominated coastlines
- coral bleaching
- changes in fire regime
- changes in streamflow patterns
- changes in timing of life cycle events of plants and animals
- changes in the distribution of plants and animals
- outbreaks of pests and pathogens (such as bark beetles)

Altered marine fisheries range and migration patterns

Marine Species Shifting Northward
1982 to 2006



On average, by 2006, the center of the range for the examined species moved 19 miles north of their 1982 locations. (USGCRP, 2009, based on Meuter and Litzow)

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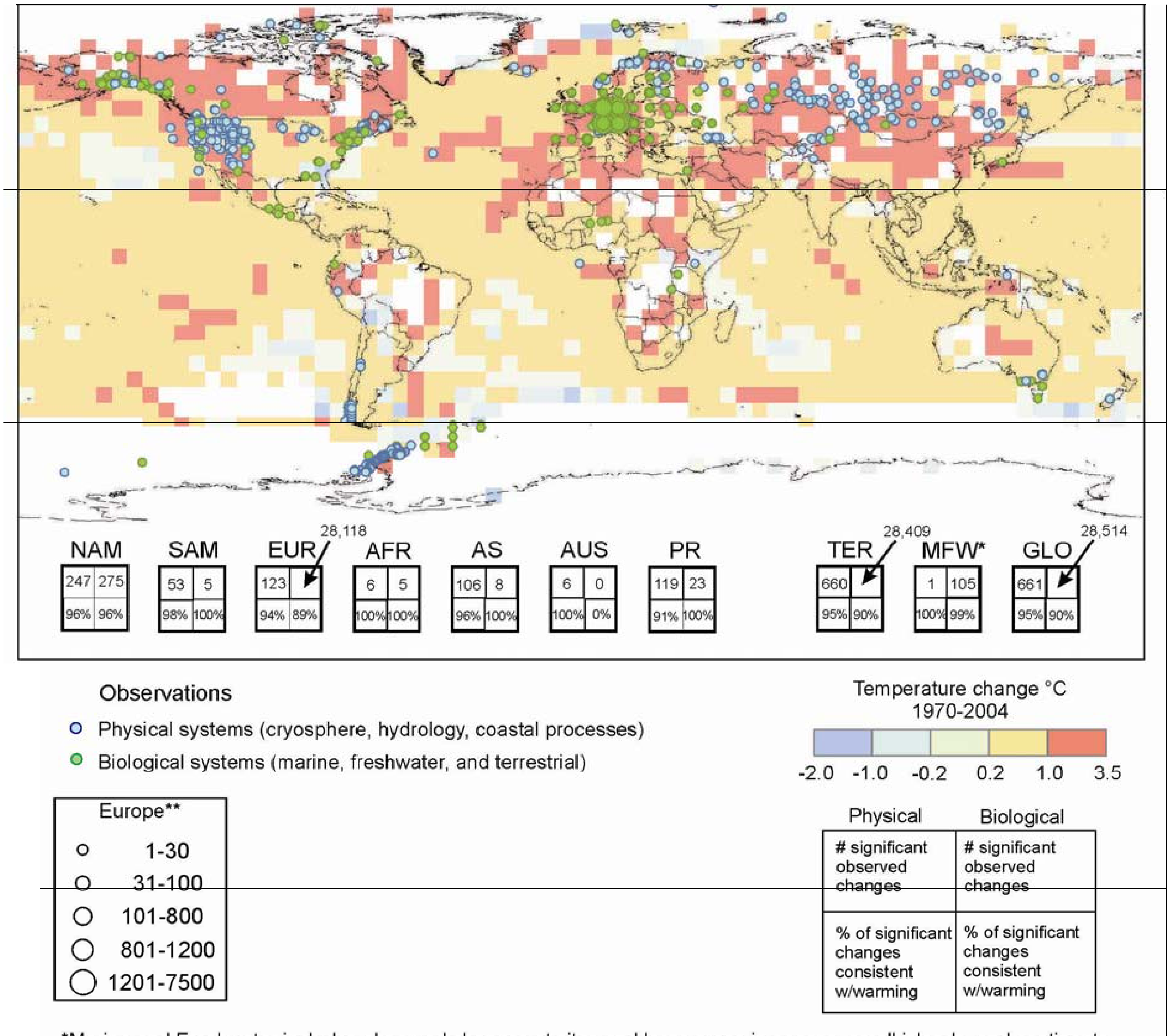
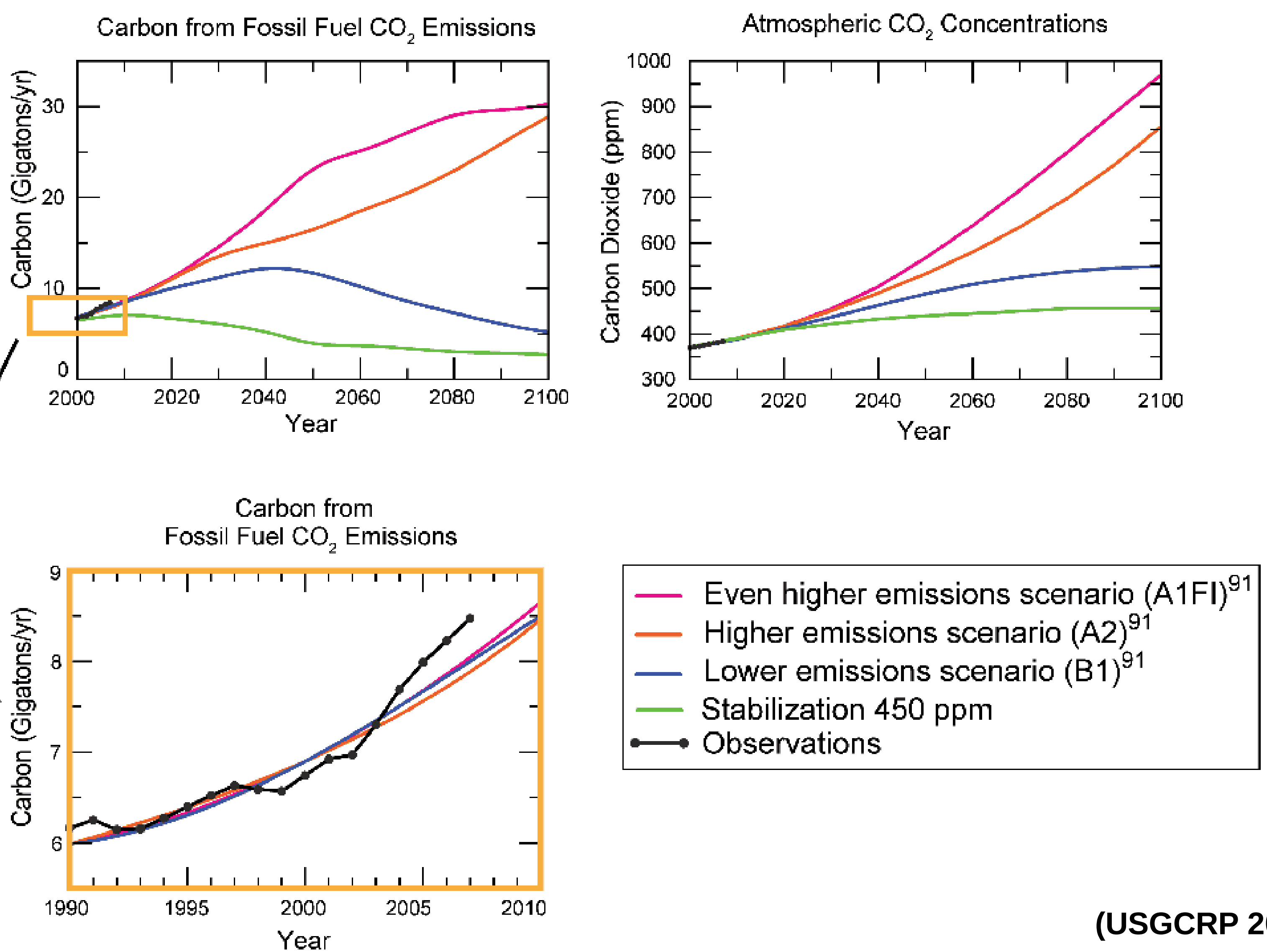
IPCC 2007 - Figure SPM-1. Locations of observed changes in physical systems and biological systems



Scenarios of Future CO_2 Emissions and Concentrations



(USGCRP 2009)

Projected future changes in climate

- Warming is expected to be about **0.4 ºC** during next **20 years**
- Warming is projected to be greatest over land and at high latitudes in the northern hemisphere
- **GHG emissions at or above current rates** would cause further warming and induce many changes in climate during the 21st century that would *very likely* be larger than those observed during the 20th century.
- Little difference in temperature outcomes until **2040** and beyond

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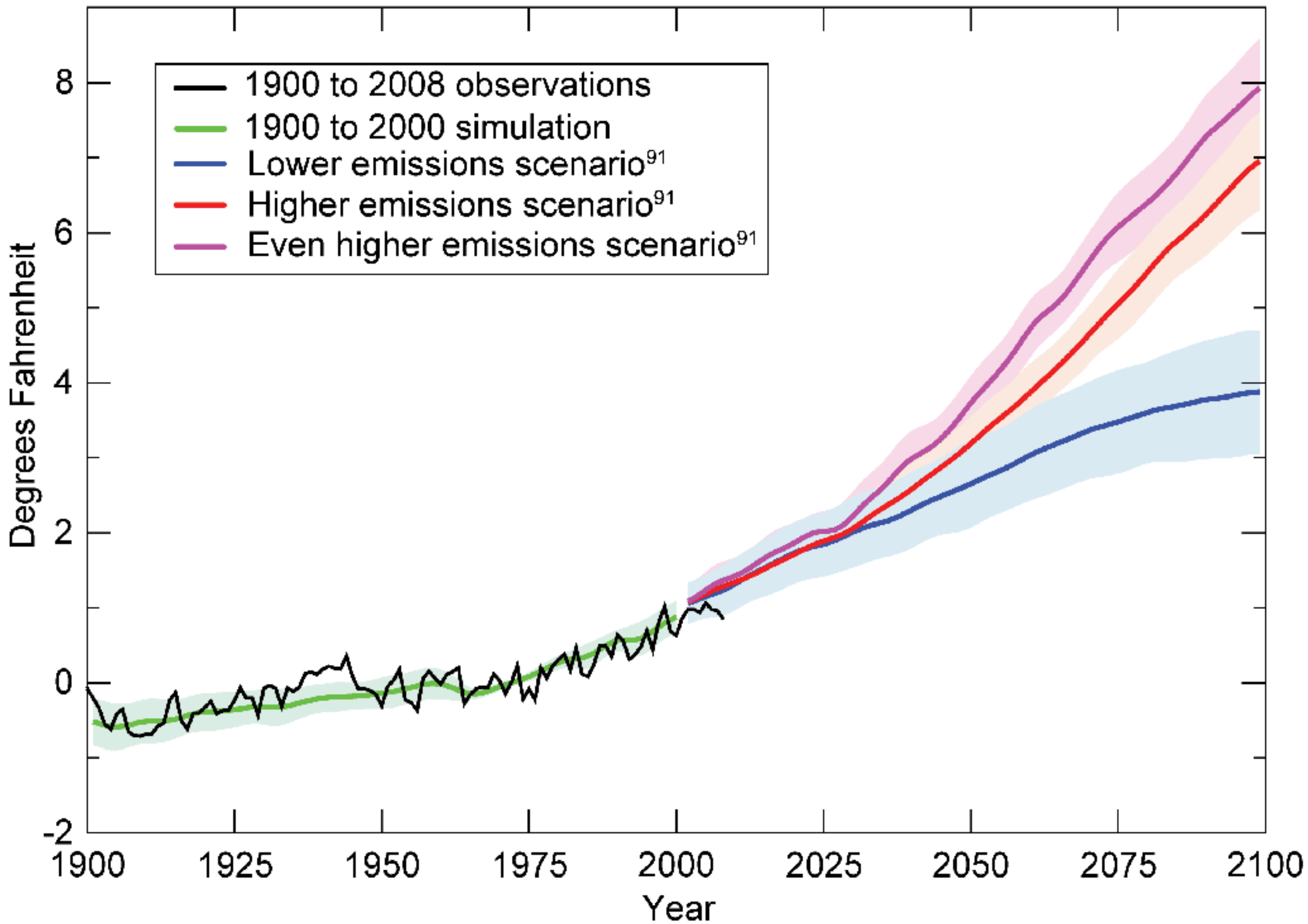
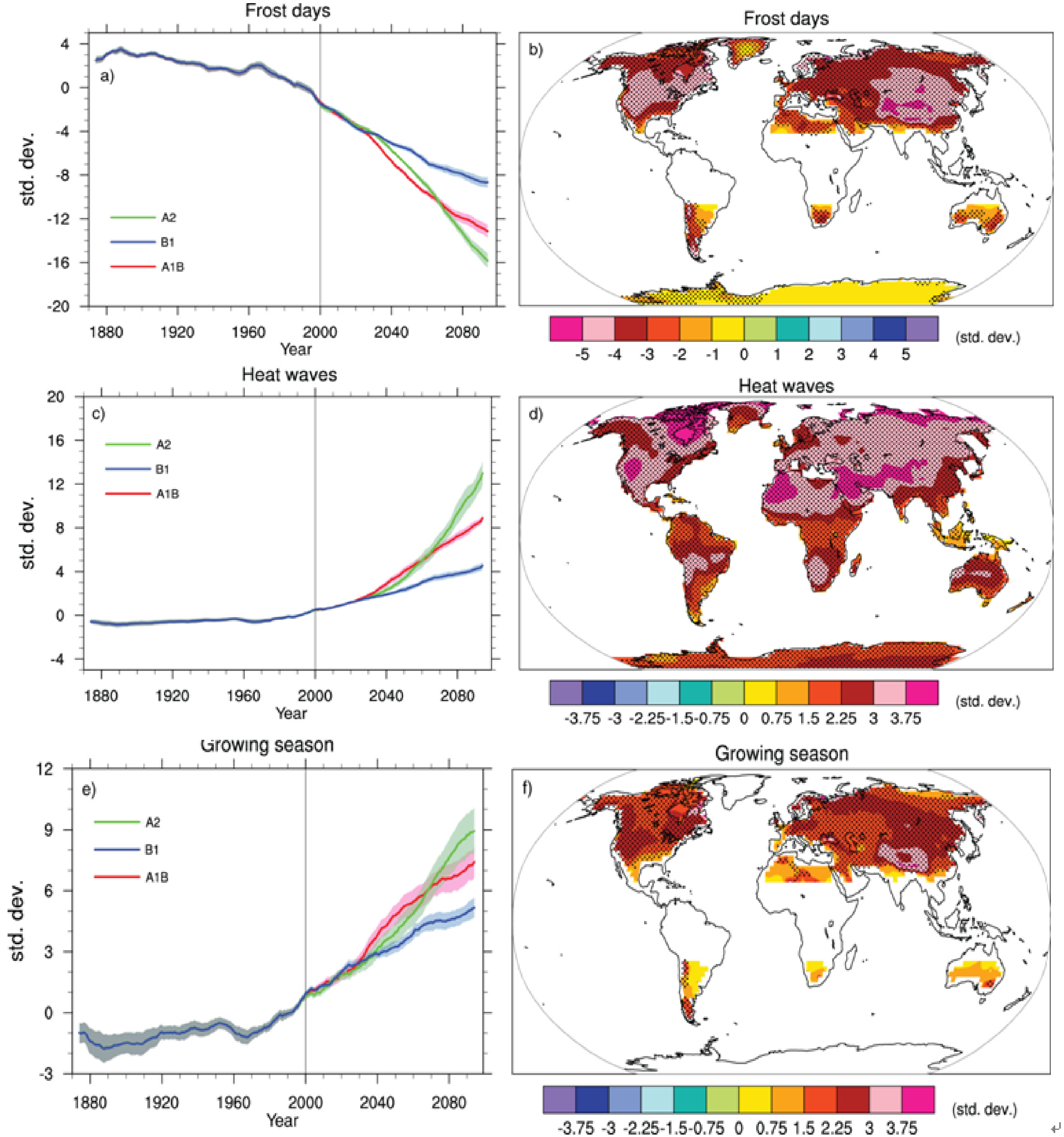
Observed and Projected Global Average Temperatures

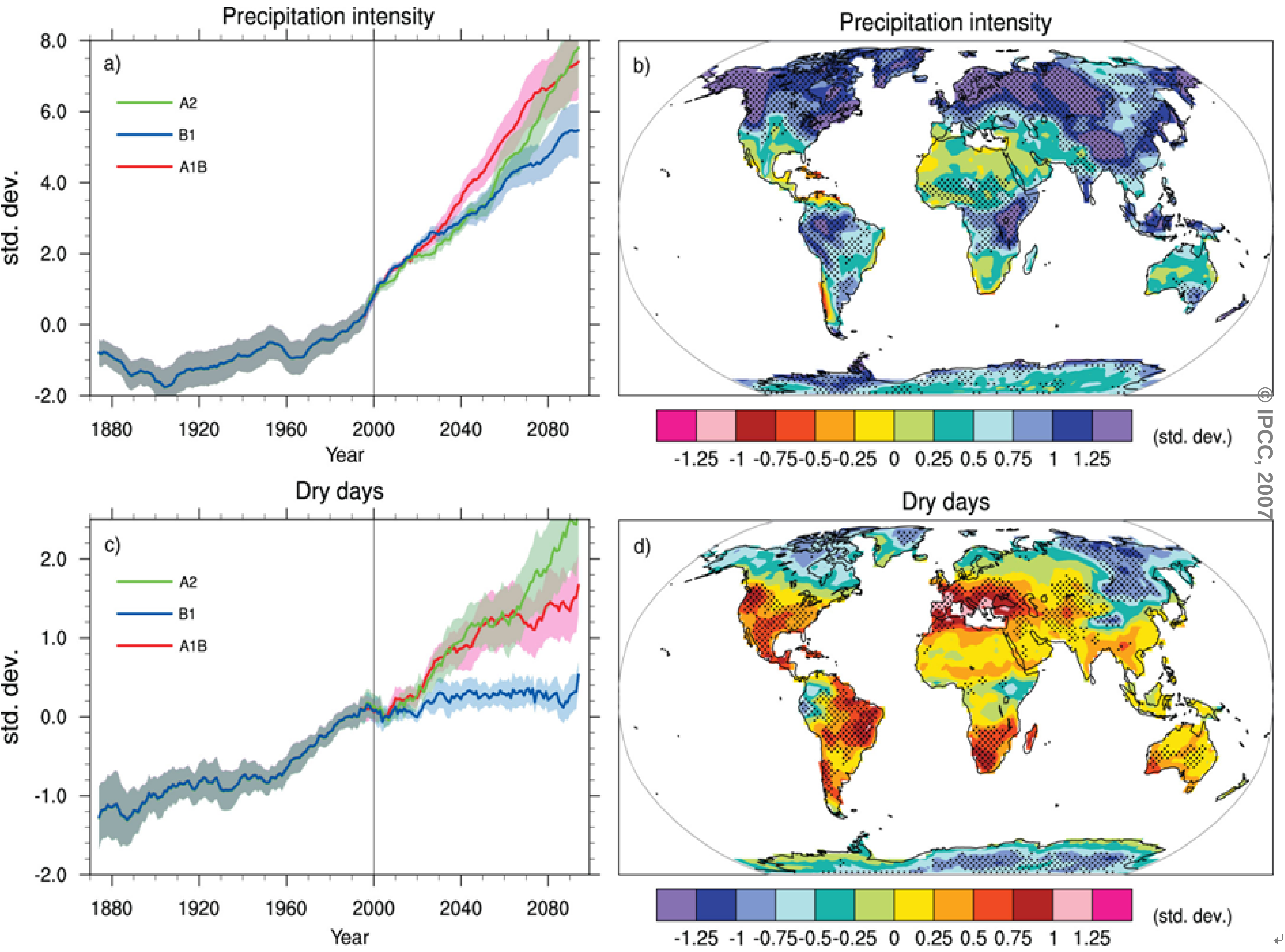
relative to the 1960-1979 average



(USGCRP 2009)



Frost days
a)
A2
B1
A1B
std. dev.
Year
b)
(std. dev.)
-5 -4 -3 -2 -1 0 1 2 3 4 5
Heat waves
c)
d)
-3.75 -3 -2.25 -1.5 -0.75 0 0.75 1.5 2.25 3 3.75
Growing season
e)
f)

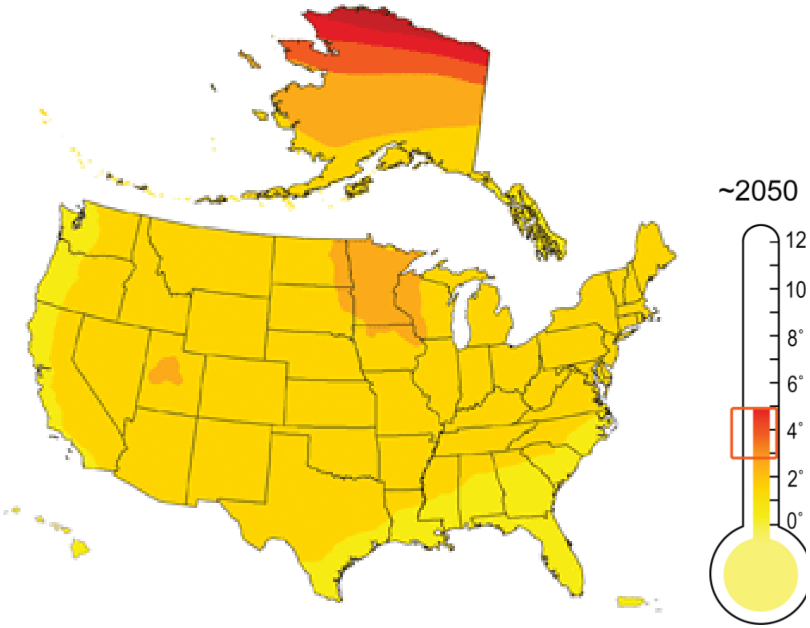


Precipitation intensity
a)
A2
B1
A1B
std. dev.
8.0
6.0
4.0
2.0
0.0
-2.0
1880 1920 1960 2000 2040 2080
Year
Precipitation intensity
b)
-1.25 -1 -0.75-0.5-0.25 0 0.25 0.5 0.75 1 1.25
(std. dev.)
© IPCC, 2007
Dry days
c)
A2
B1
A1B
std. dev.
2.0
1.0
0.0
-1.0
-2.0
1880 1920 1960 2000 2040 2080
Year
Dry days
d)
-1.25 -1 -0.75-0.5-0.25 0 0.25 0.5 0.75 1 1.25
(std. dev.)

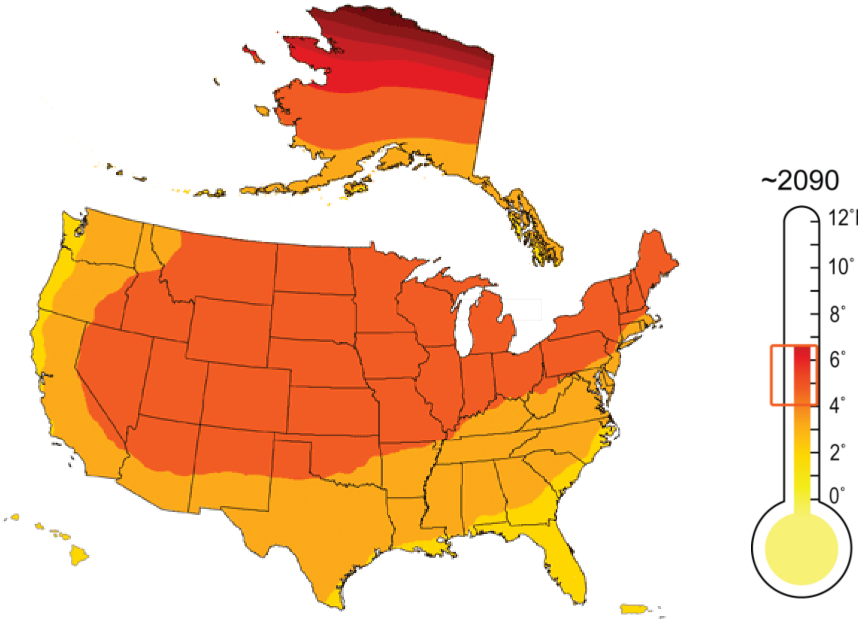
Projected U.S. Temperature Change (°F) under a Low Emissions Scenario

(compared to 1961-1979 Baseline)

Mid-Century
(2041-2059 average)



End-of-Century
(2080-2099 average)

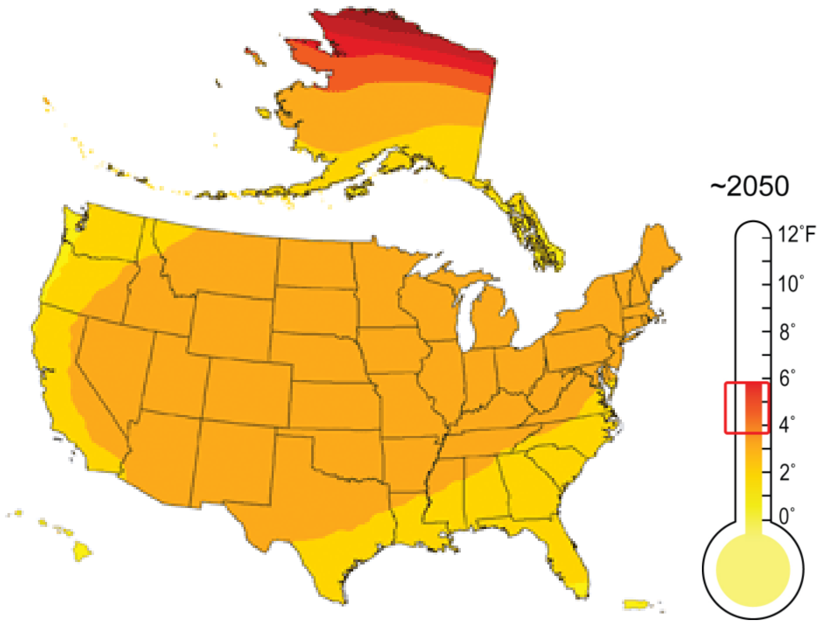


(USGCRP 2009)

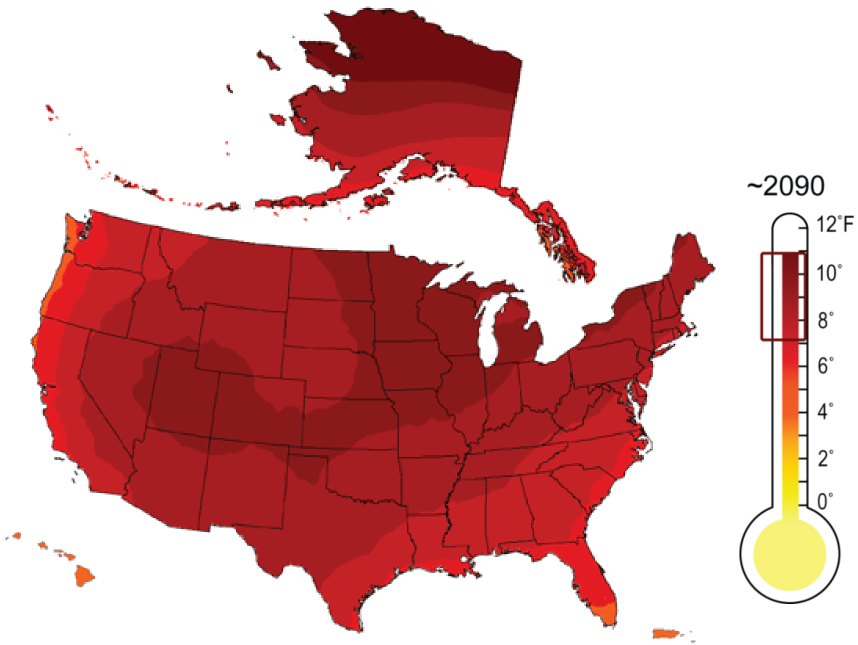
Projected U.S. Temperature Change (° F) under a High Emissions Scenario

(compared to 1961-1979 Baseline)

Mid-Century (2041-2059 average)



End-of-Century (2080-2099 average)



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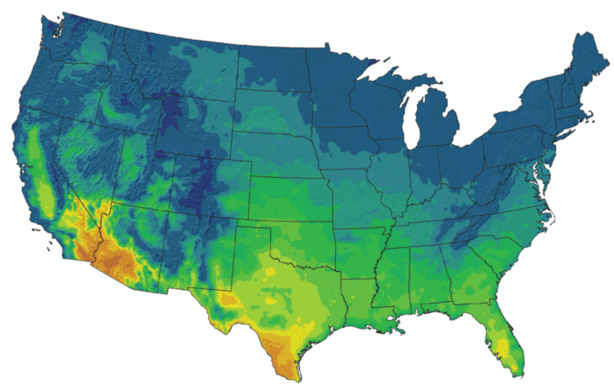
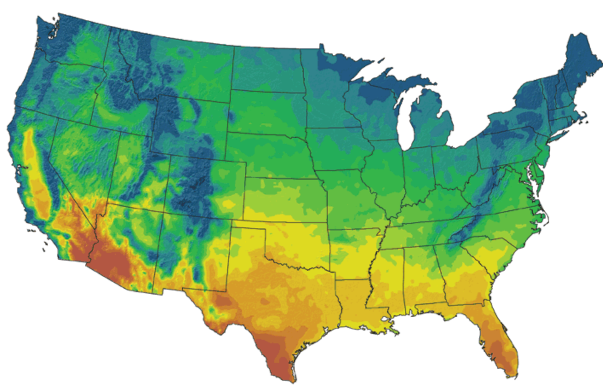
(USGCRP 2009)

Change in Number of Days Above 90°F

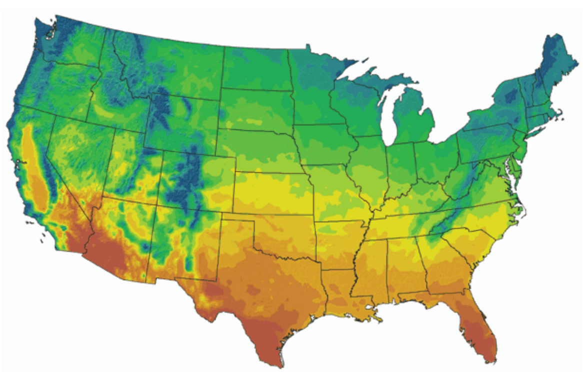
Recent Past
(1961-1979 Average)

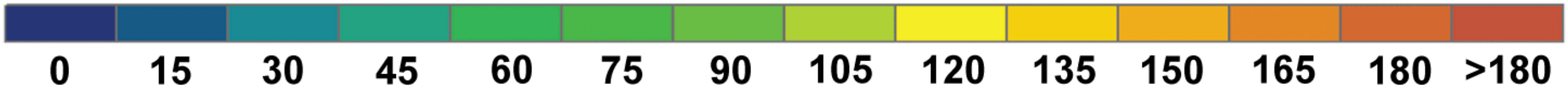


Projected End-of-Century
Lower Emissions Scenario
(2080-2099 average)



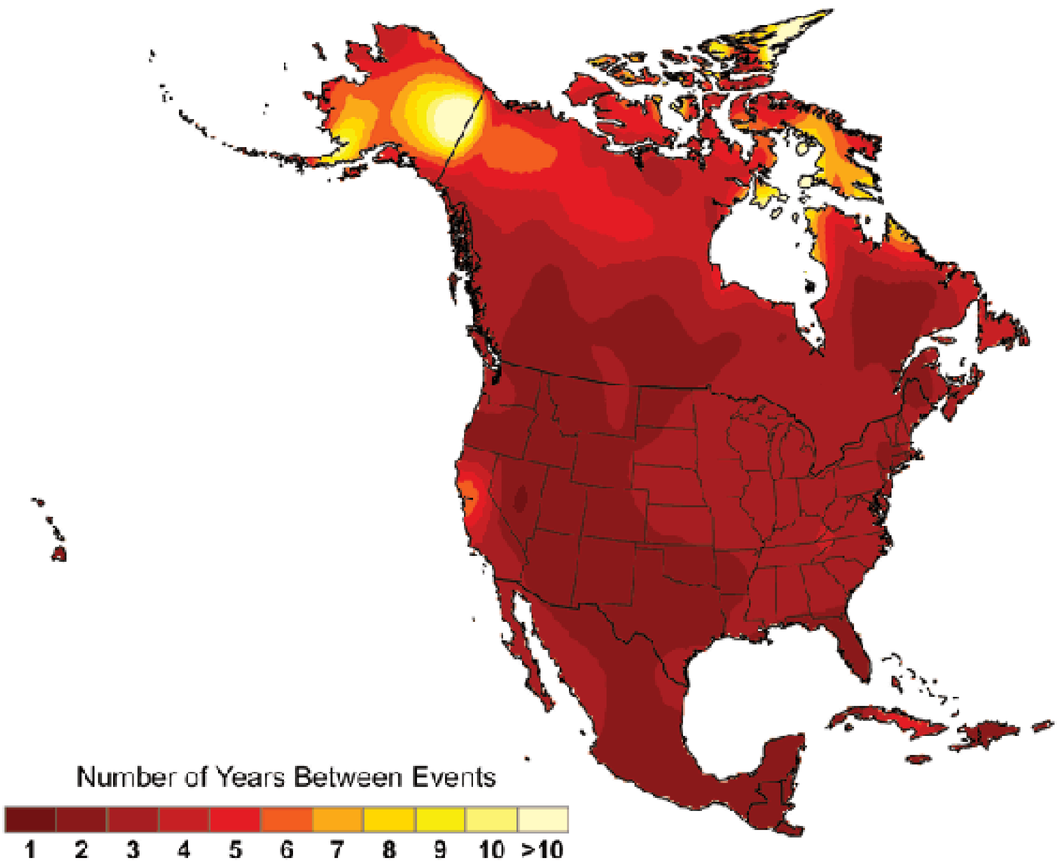
Projected End-of-Century
Higher Emissions Scenario
(2080-2099 average)





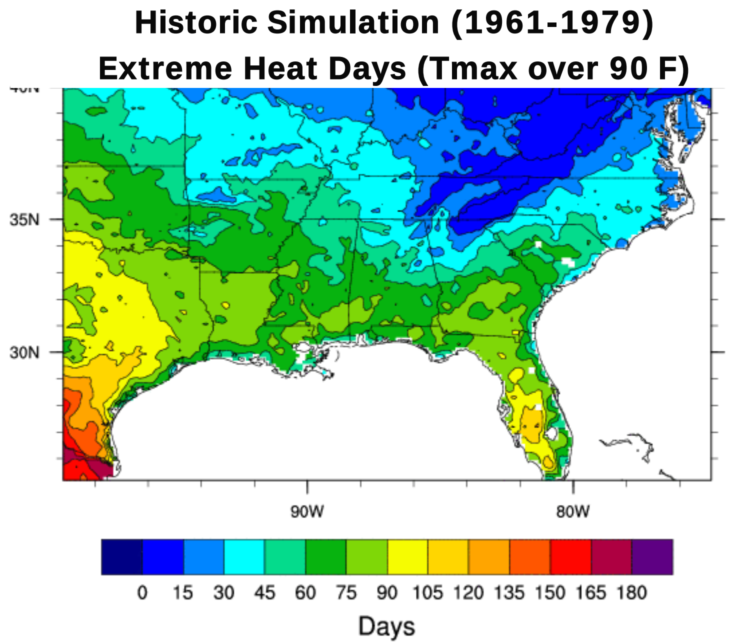
(USGCRP 2009)

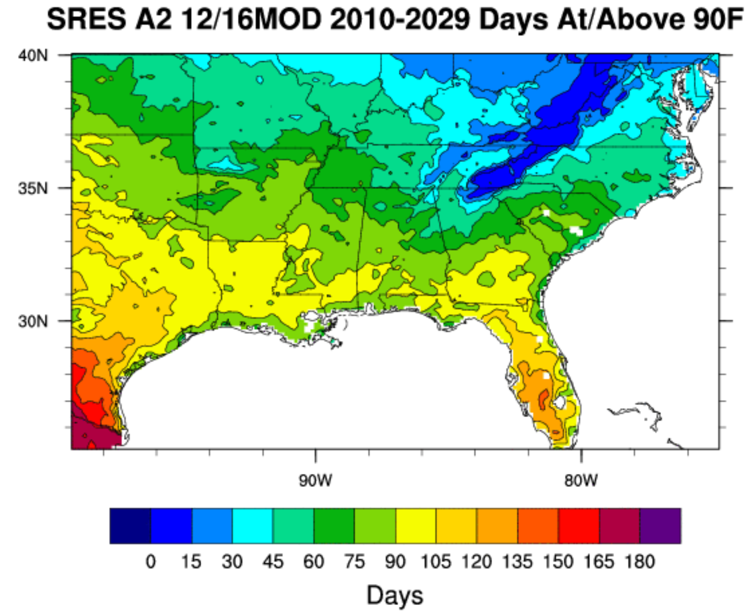
Projected Frequency of Extreme Heat



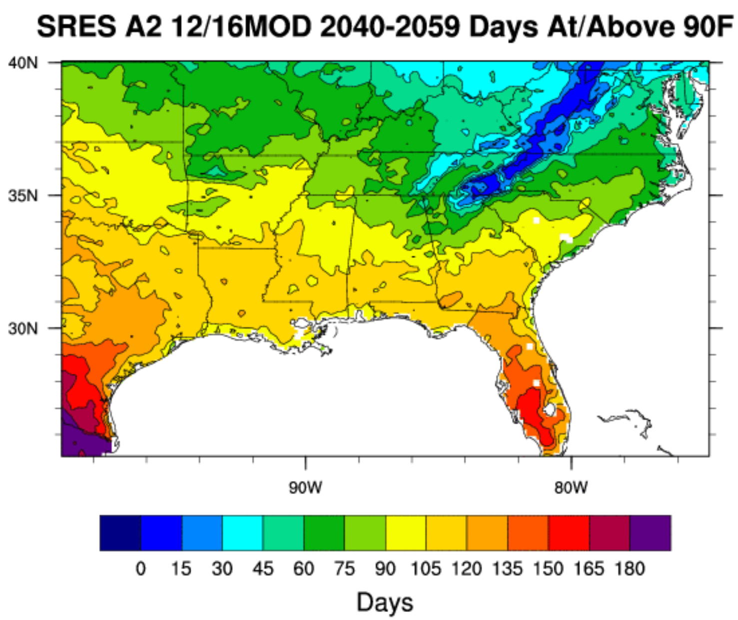
Simulations for 2080-2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more frequently by the end of the century under the higher emissions scenario.

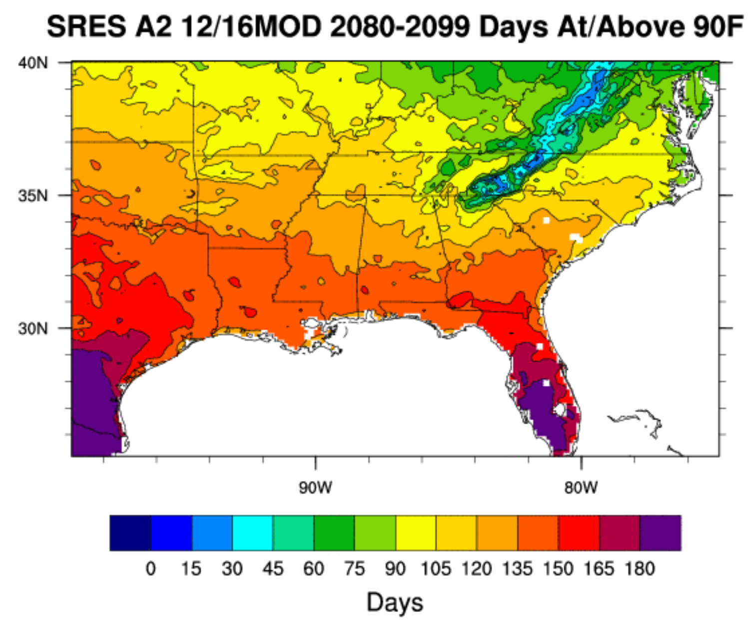
(USGCRP 2009)



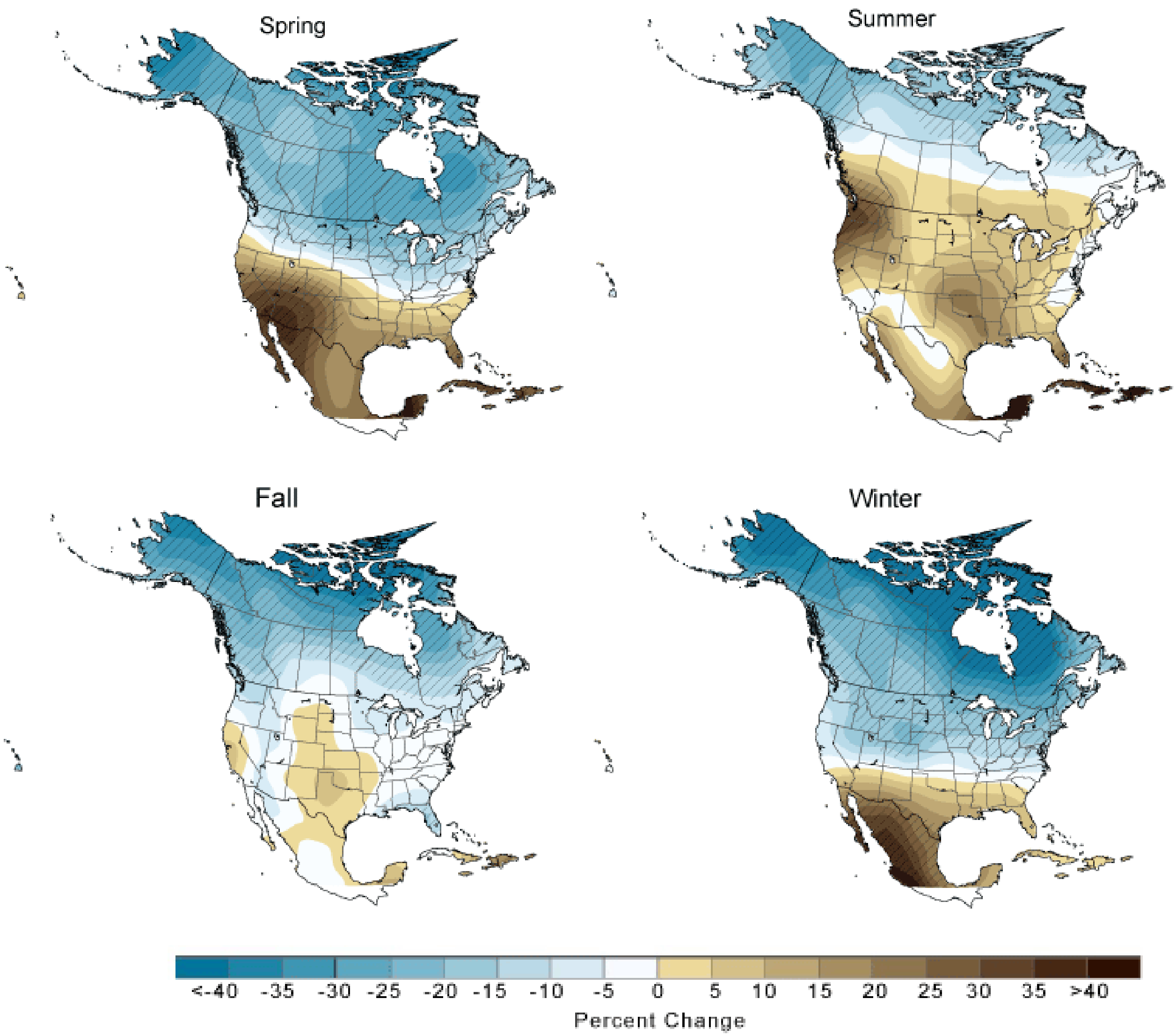


Extreme Heat Days (T max over 90 F)





Projected Change in Precipitation
by 2080-2090



These maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models under a high emissions scenario.

Confidence in the projected changes is highest in the hatched areas.

There is less confidence in exactly where the transition between wetter and drier areas will occur.

(USGCRP 2009)

Projected Change in Spring Precipitation – by 2090

areas of highest confidence in model prediction

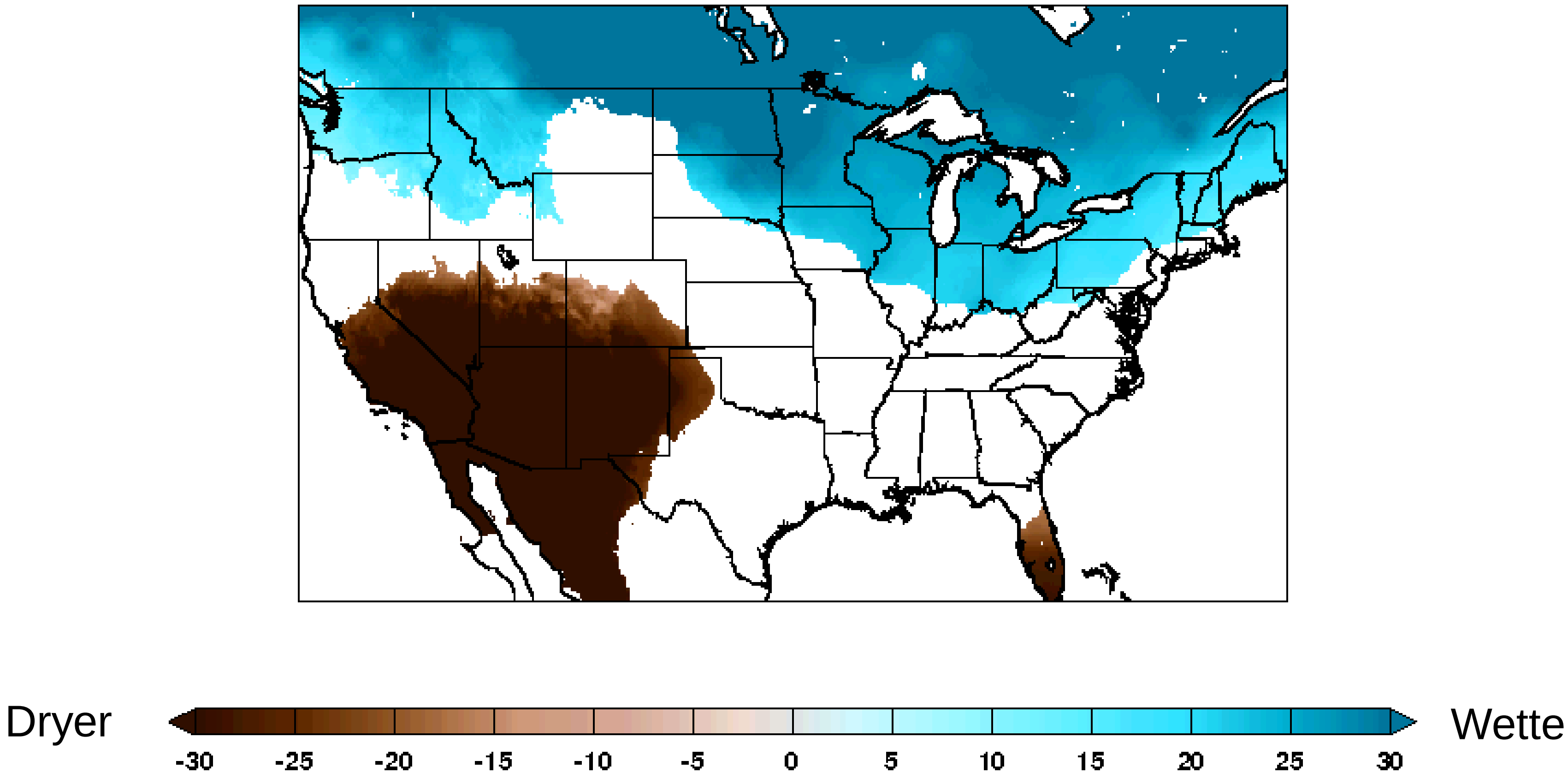


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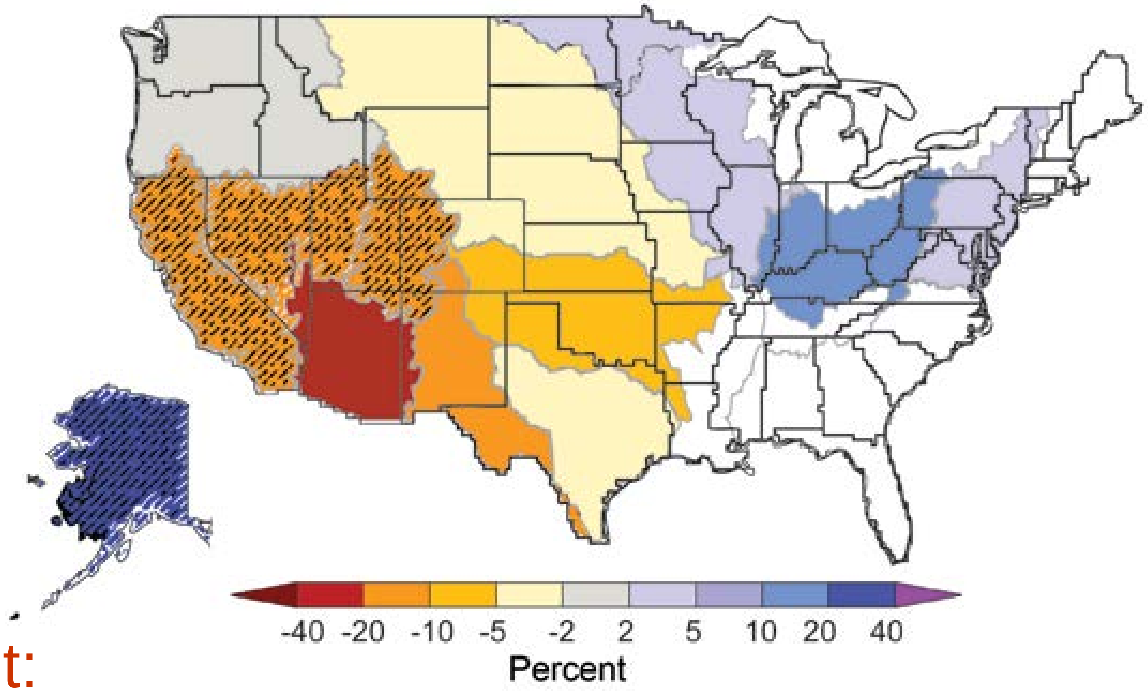
Figure courtesy of Mike Wehner, DoE and Katharine Hayhoe, Texas Tech for USGCRP, 2009

Projected Changes in Annual Runoff: 2041-2060

(relative to 1900-1970 baseline)



Strong model agreement:

- Dryer conditions in the southwest
- Wetter conditions in northern latitudes, particularly Alaska

Hatched areas in graphic indicate greater confidence due to strong agreement among model projections. White areas indicate divergence among model projections. Results are based on emissions in between the lower (B1) and higher (A2) emissions scenarios. **(USGCRP 2009)**

As the atmosphere and oceans warm and land ice declines, sea level rise is expected to accelerate

	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [c]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

(IPCC, WGI, 2007)

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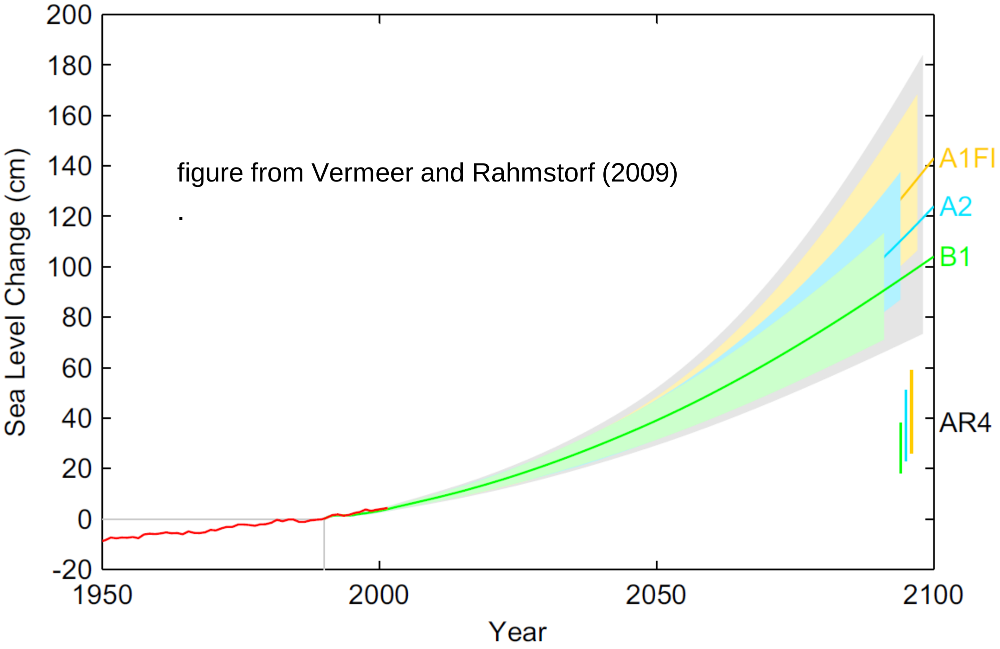
Several recent studies suggest 1-2 m of sea level rise this century

"Even for the lowest emission scenario (B1), sea-level rise is then likely to be 1 m; for the highest, it may even come closer to 2 m."

(Vermeer and Rahmstorf, PNAS, 2009)



"We find that IPCC projections of sea level rise 2090–2099 are underestimated by roughly a factor 3. The likely rates of twenty-first century sea level rise far exceed anything seen in the last 2,000 years. In comparison, the period 14000–7000 BP had an average rise rate of 11 mm/year (Bard et al. 1996). This is similar to rates we predict by the 2050s." (Grinsted et al., Climate Dynamics, 2009)

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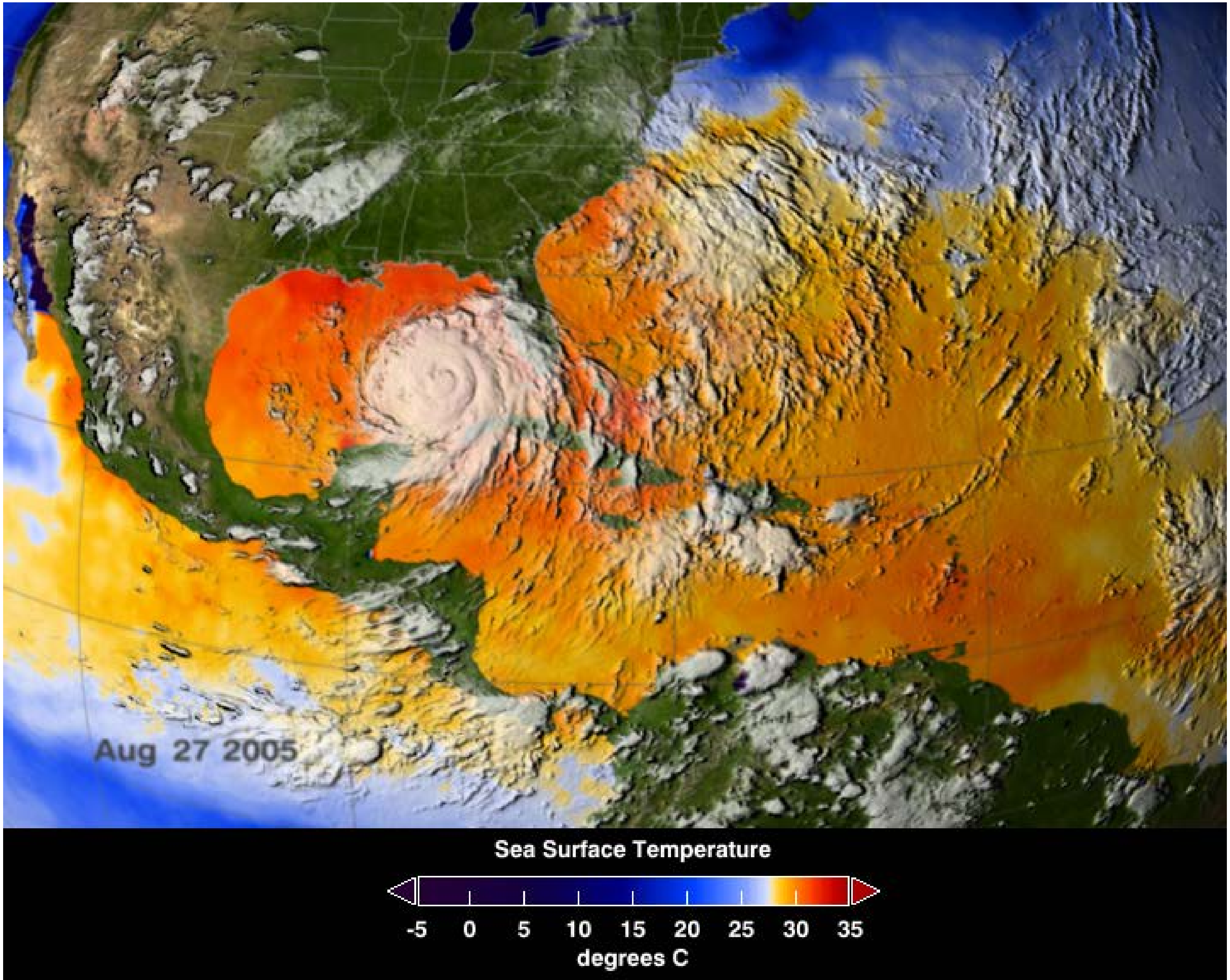
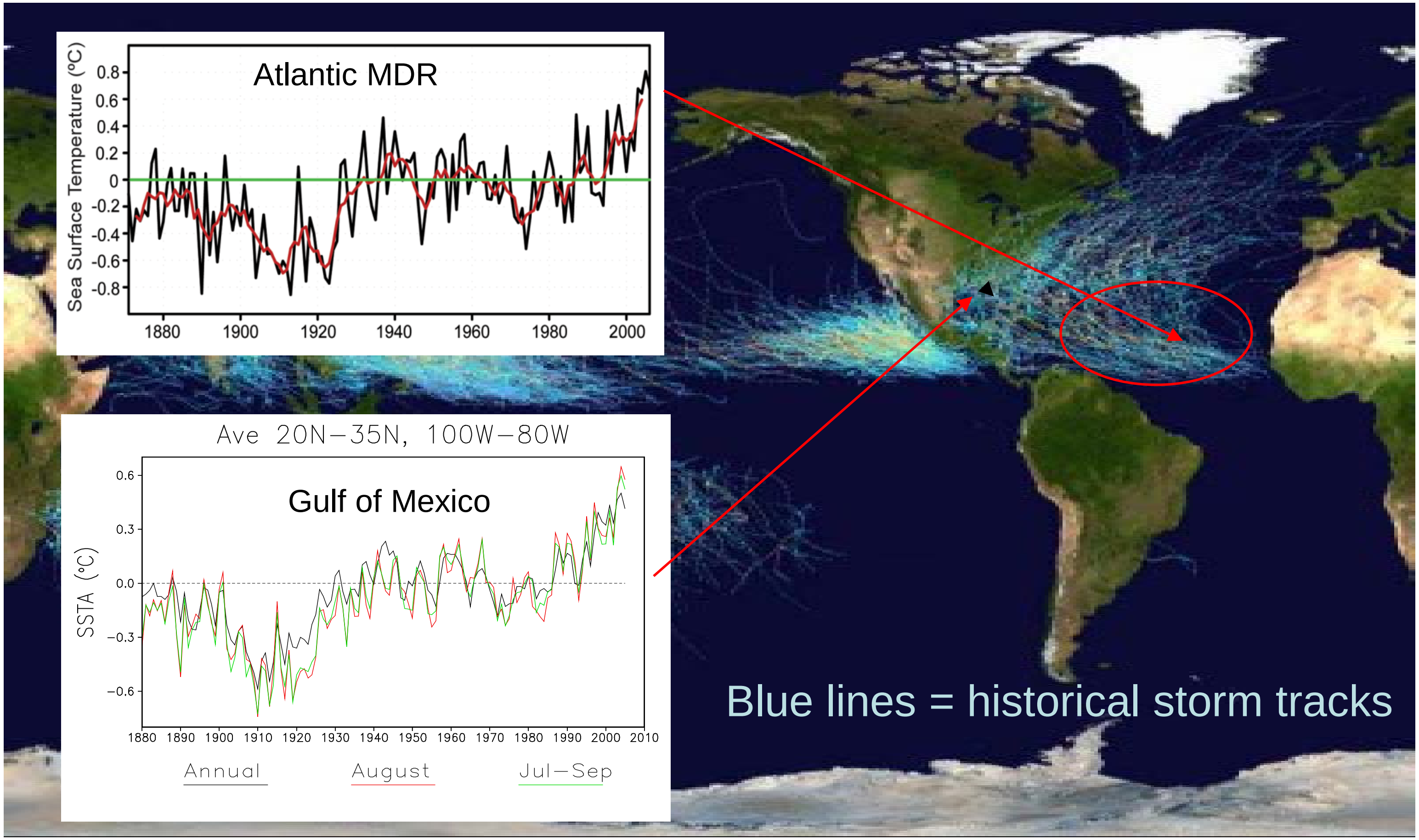
Increased temperature of the sea surface affects both the volume of the ocean and the propensity for hurricanes.





Sea Surface Temperature is expected to continue to increase in the Atlantic Main Development Region for Hurricanes and in the Central Gulf of Mexico

Upper graph: Bell et al., 2007
Lower Graph: Smith and Reynolds, 2004

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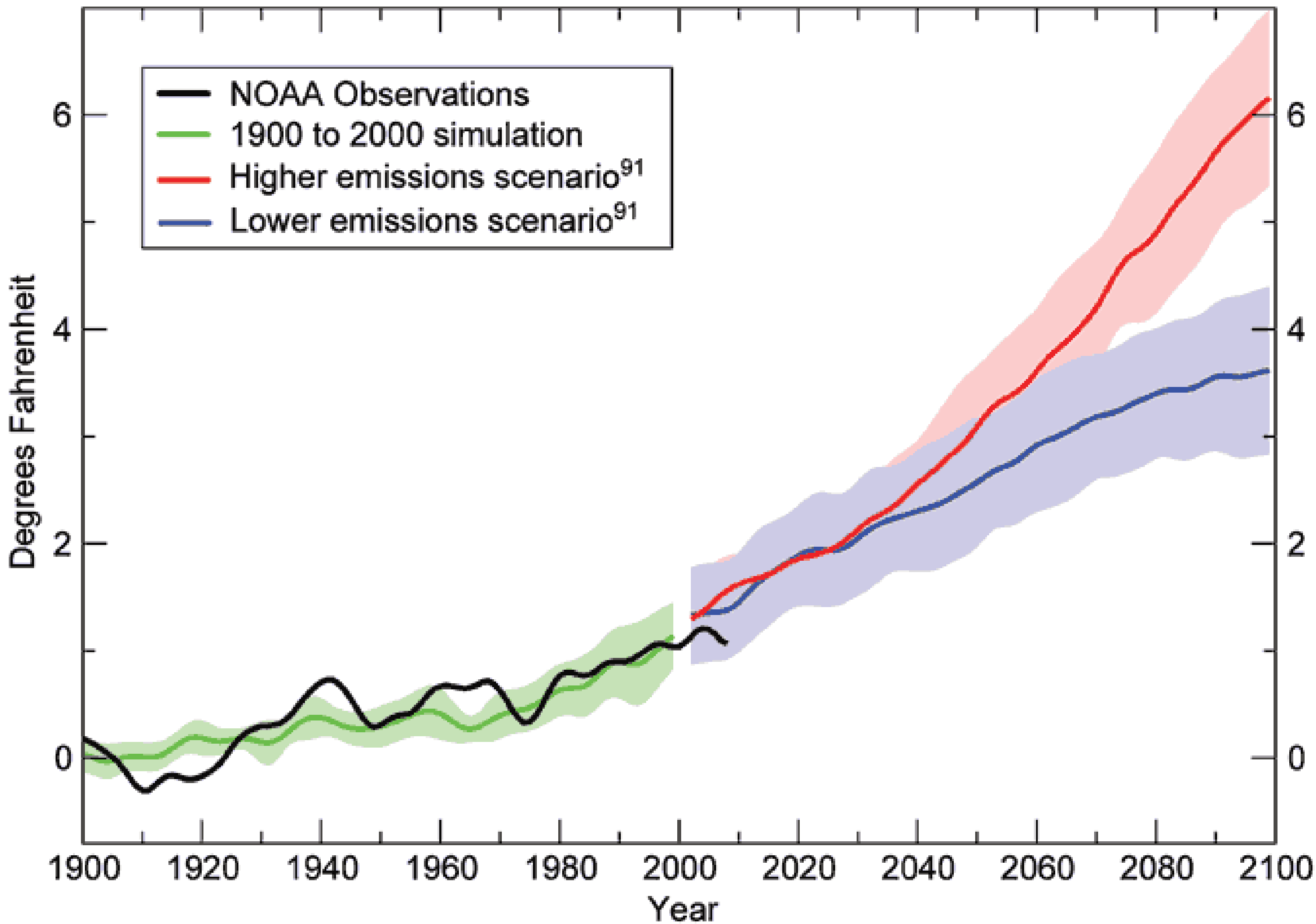
Observed and Projected SST Change

Atlantic Hurricane Formation Region



(USGCRP 2009)

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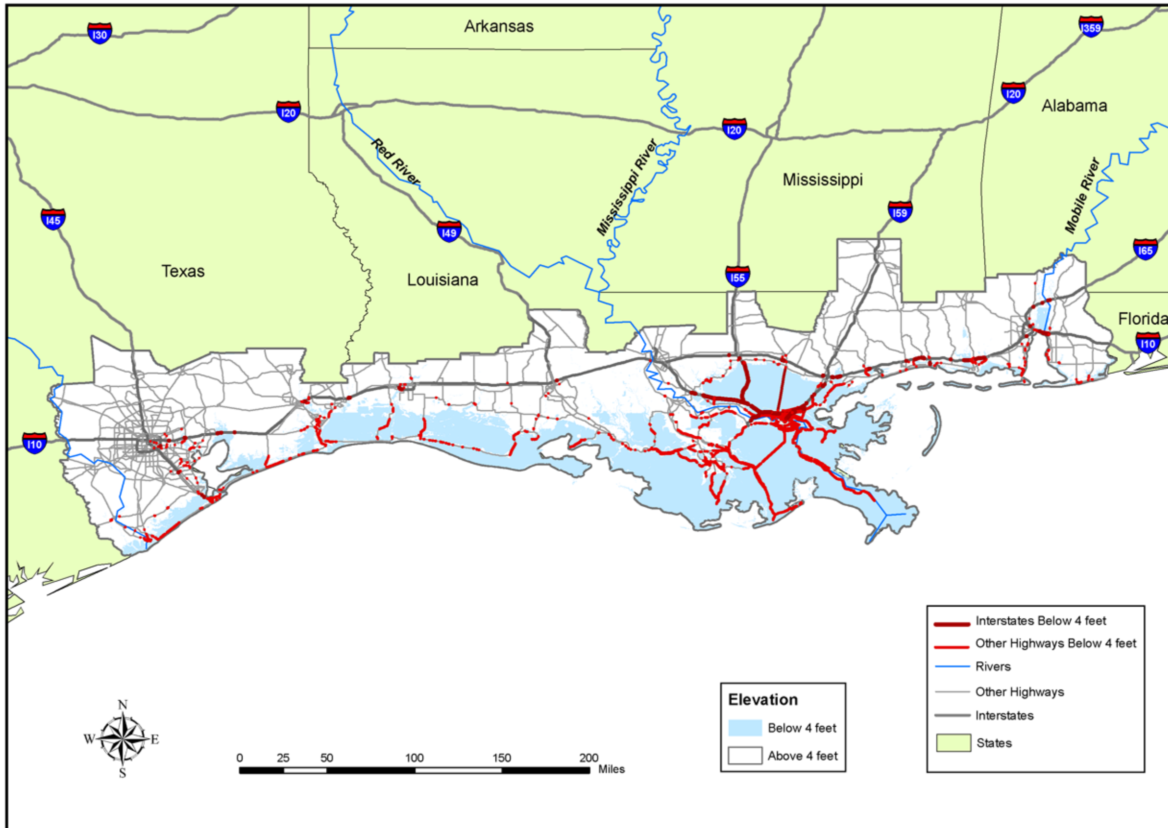
Coastal tidal and storm surge flooding increases due to sea level rise



Major highways at risk from a relative sea level rise of 122 cm (4 ft).

Source: DOT Gulf Coast Study Phase 1

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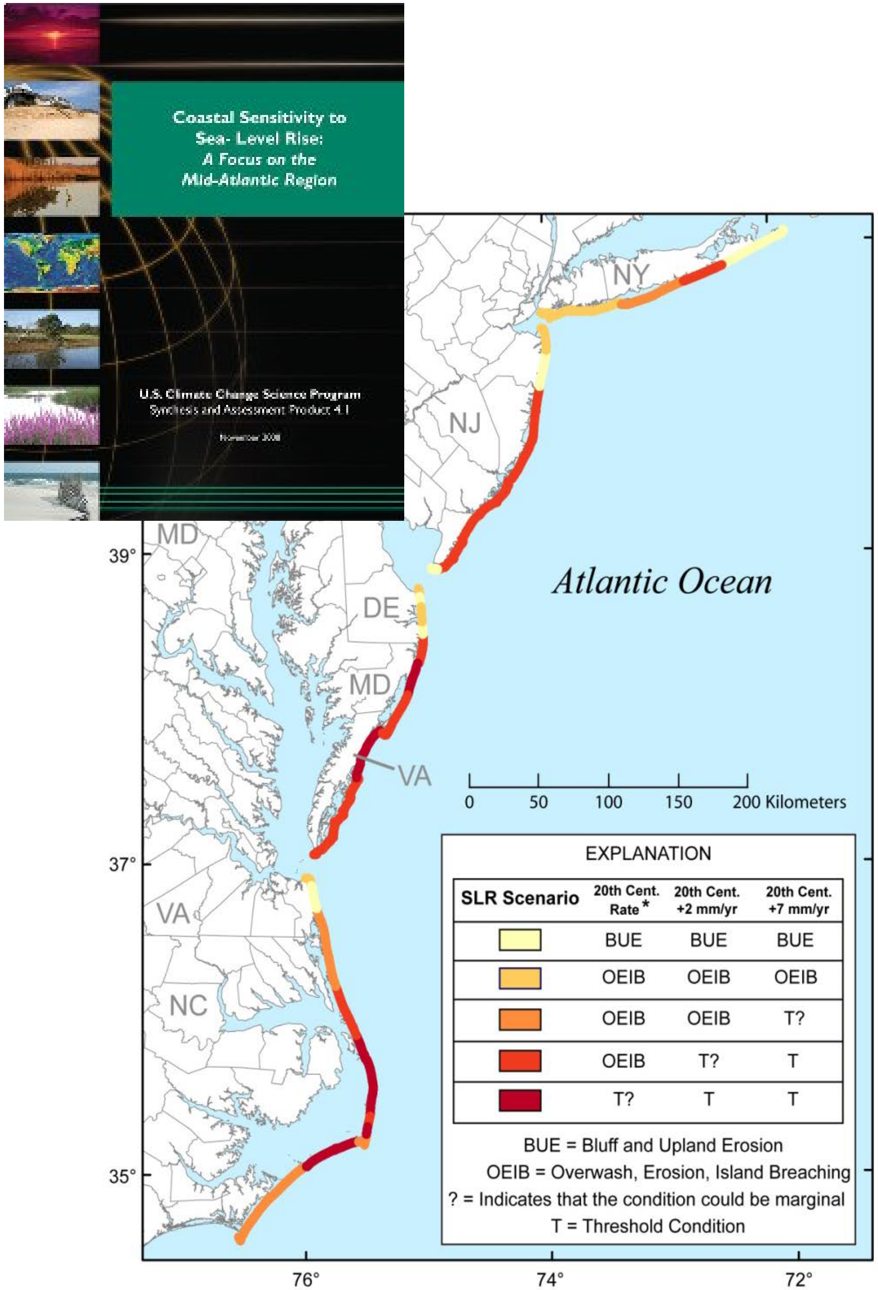
Mid-Atlantic Coastal Response

- It is *virtually certain* that erosion will dominate changes in shoreline position along the mid-Atlantic ocean coasts in response to sea-level rise and storms

- For higher sea-level rise scenarios, it is *very likely* that some portions of the mid-Atlantic coast will undergo large changes which will depend in part on local geologic and oceanographic conditions

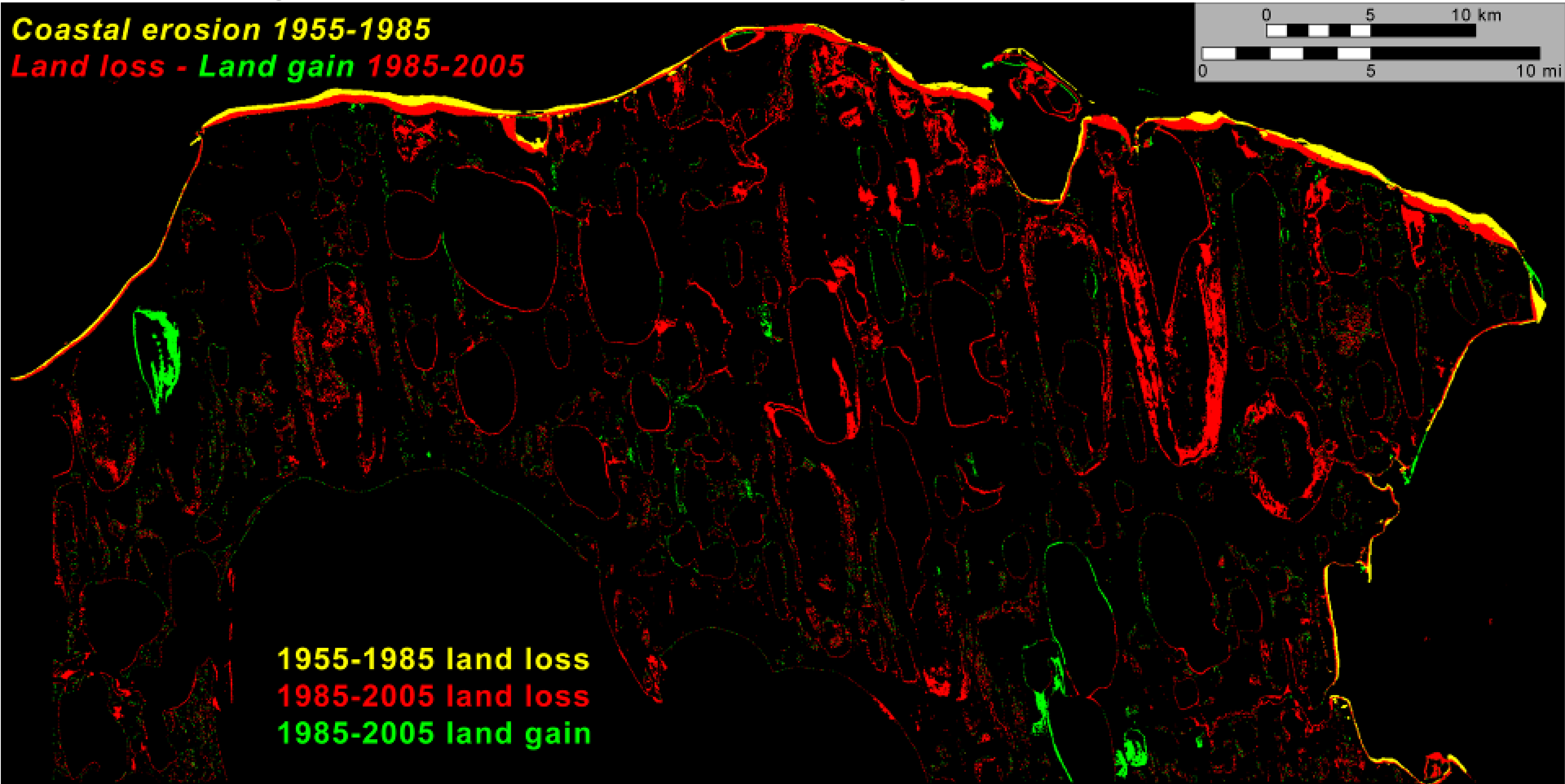
- Specifically, some barrier island coasts will likely cross a threshold and become prone to more rapid landward migration or segmentation (CCSP 2009)



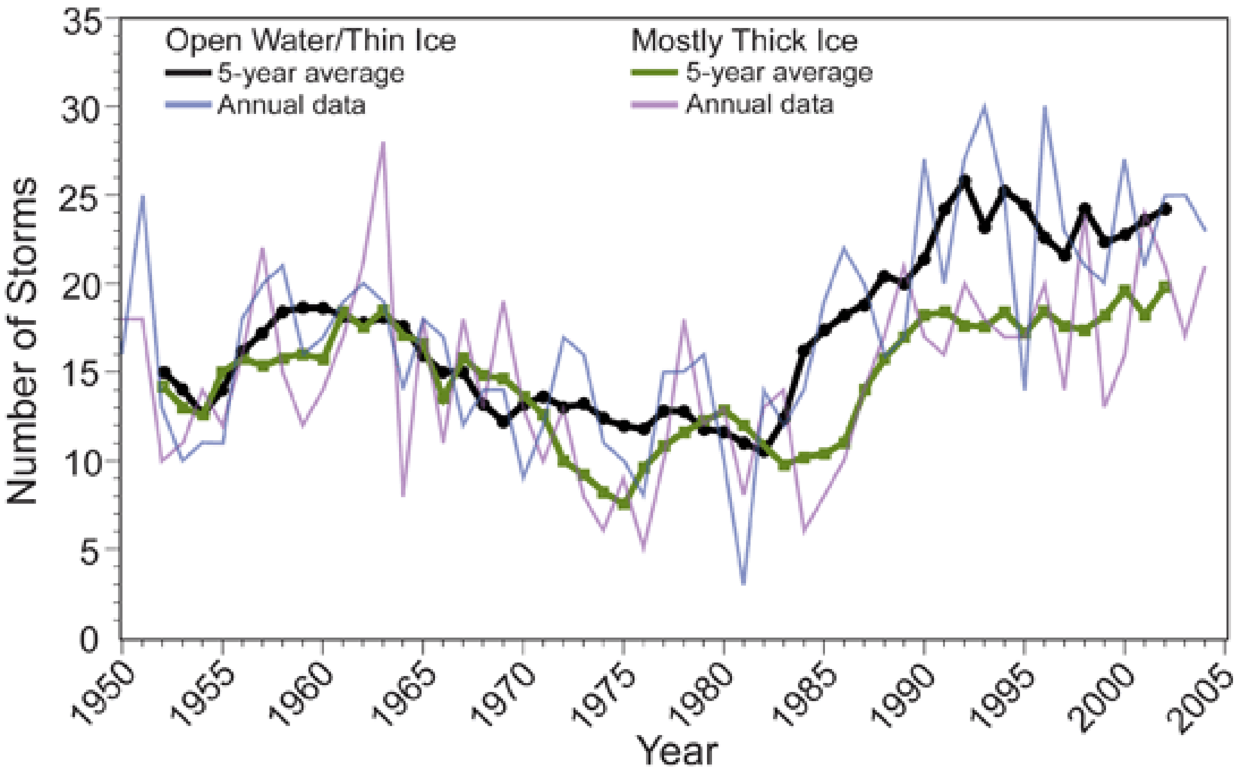
(CCSP, 2009)

A combination of factors make the Arctic coast particularly sensitive to climate change and extreme storm events:

- low relief
- ice-rich but otherwise unlithified sediments
- regional subsidence
- rising sea levels and diminishing sea ice



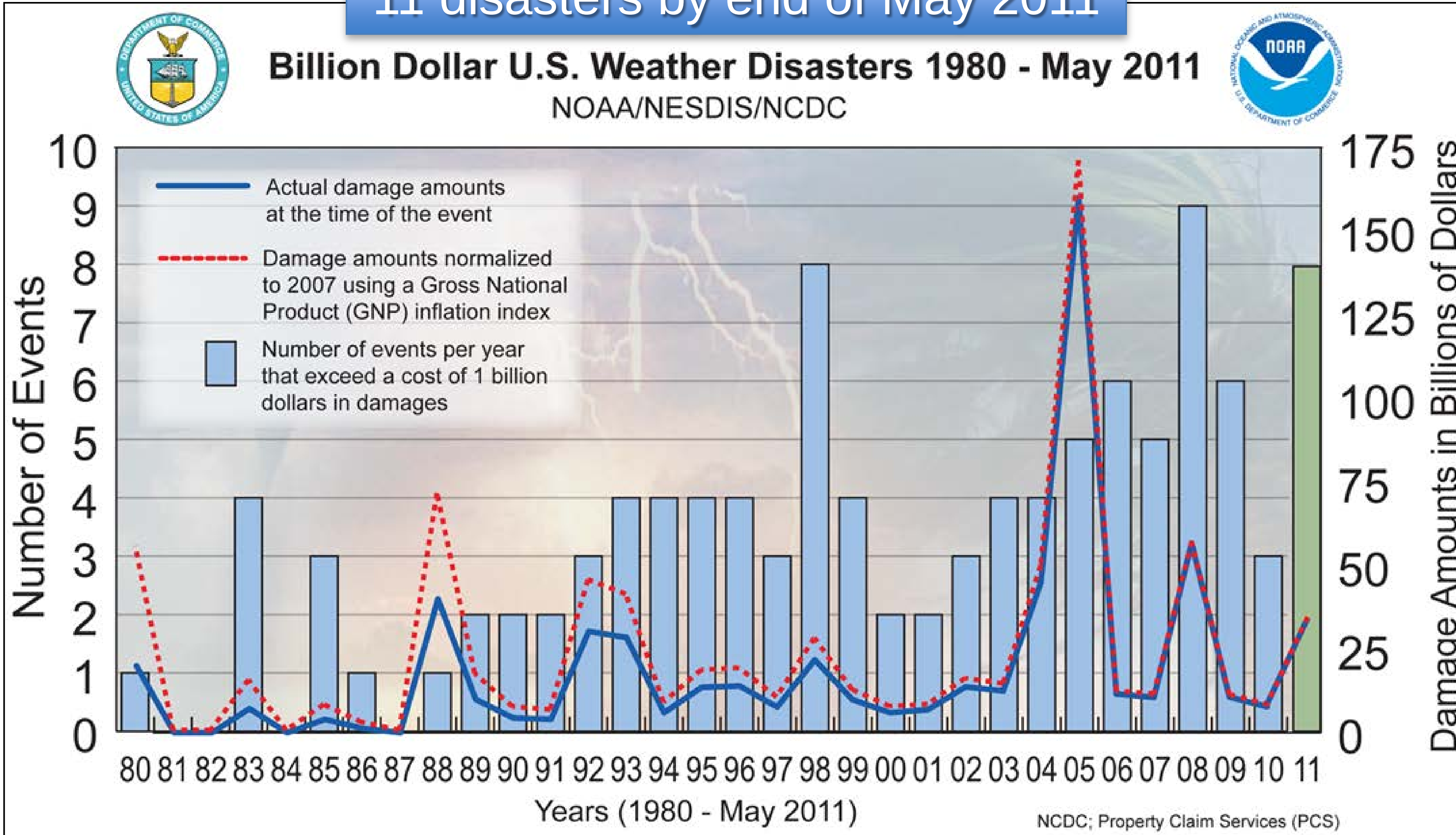
Annual Number of Storms at Barrow, Alaska, 1950-2004



The blue line indicates the annual number of open-water storms, those occurring in primarily ice-free water (July to December). The purple line indicates the number of storms occurring when thick sea ice is present (January to June). The black and green lines are smoothed using 5-year averages. (USGCRP 2009)

Billion Dollar Weather Disasters

11 disasters by end of May 2011



Note: 2011 figures only through May

Thresholds (tipping points), feedbacks and interactions in Earth system responses are poorly documented – surprises are likely.

• If Arctic sea ice disappears entirely and doesn't re-form, climate of N hemisphere would change drastically.

• Rapid ice-sheet disintegration (1-2 m per century sea-level rise) more likely as ΔT avg ≥ 1.5ºC.

• Tundra & permafrost are warming & thawing, with potential for CO_2 & CH_4 outpouring that would accelerate climate disruption overall and onset of any or all of the above.

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Mitigation

- Reduction of greenhouse gas emissions or enhancement of carbon sequestration (in the subsurface or in ecosystems)

Adaptation

- Purposeful actions taken to reduce undesirable effects or enhance positive effects of climate change

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