A Global Perspective on Climate Change and Water

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Conference on Drought and Climate Change
San Juan, Puerto Rico
23-24 April 2015

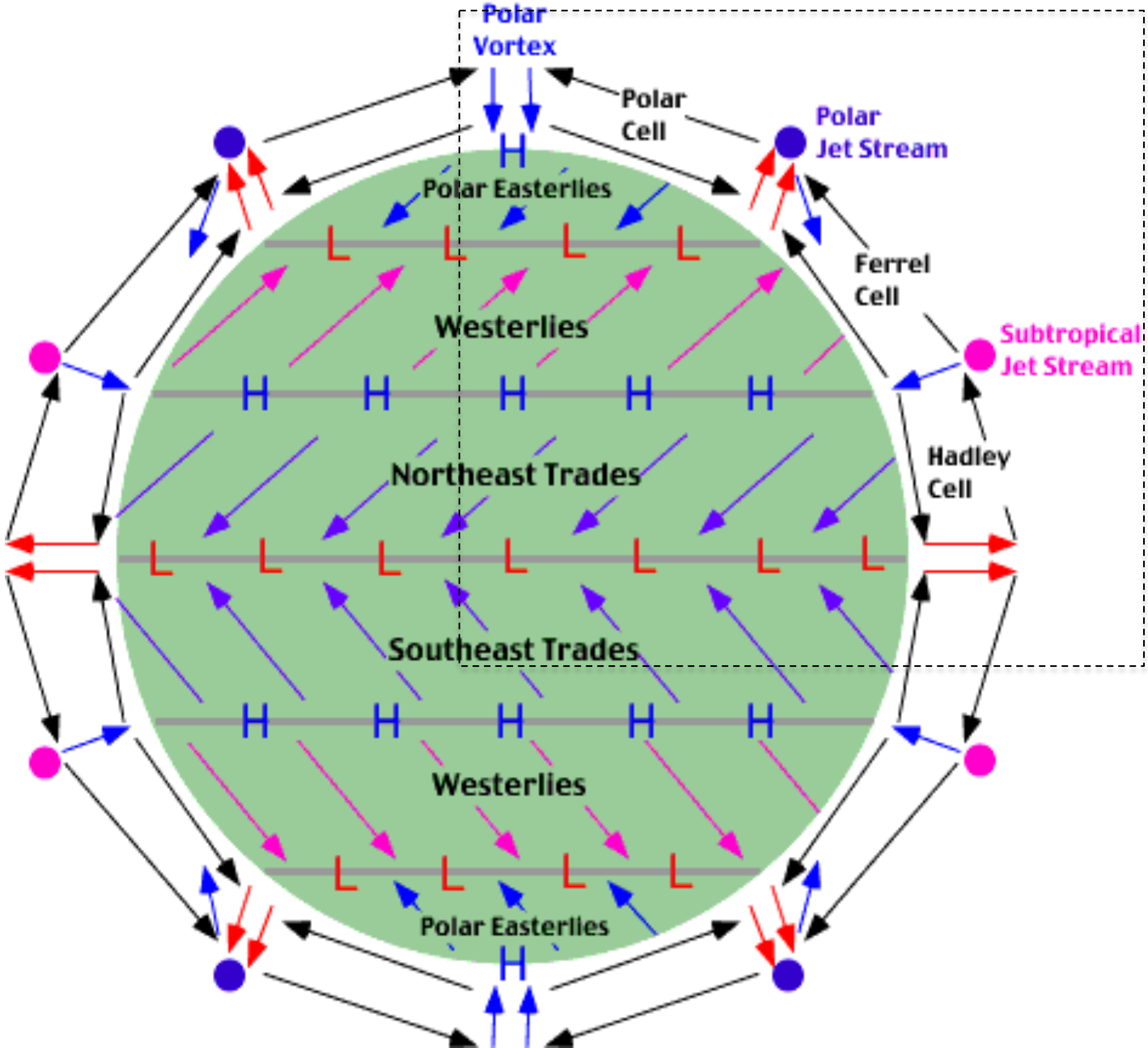
OUTLINE

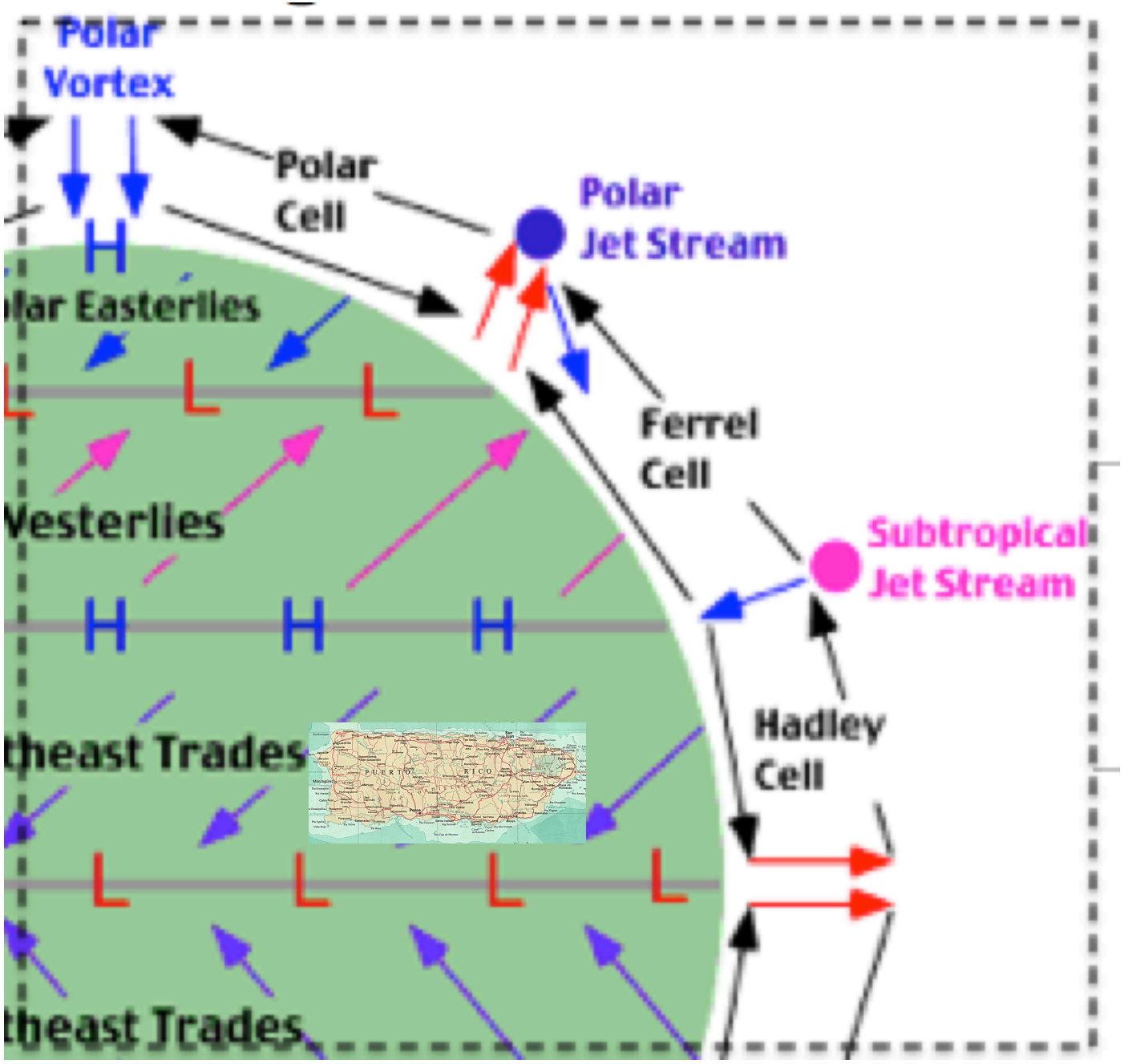
- **Weather and Climate**
  - Global Circulation Patterns
  - Climate in the Caribbean
  - Observed Climate Change

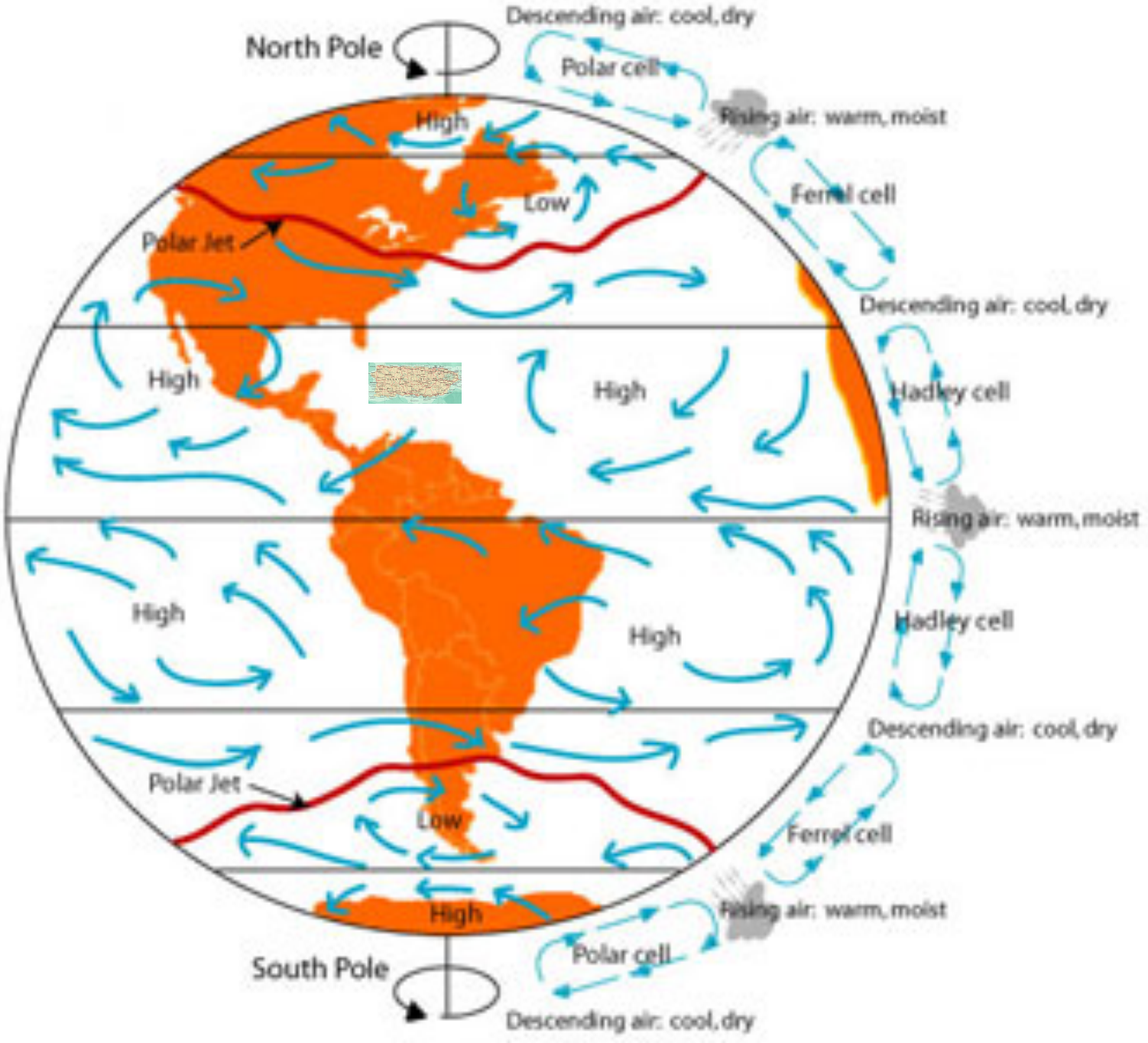
- **Drought**
  - Meteorological, Hydrological and Agricultural Drought
  - Drought Intensification

- **Climate Model Projections**
  - Representative Concentration Pathways
  - Projected Temperature, Evaporation and Precipitation
  - Sea Level Rise, Hurricanes, Storm Surge
  - Summary of Impacts

A Simple Schematic of Large-Scale Circulation




Polar
Vortex
Polar
Cell
Polar
Jet Stream
lar Easterlies
Ferrel
Cell
Subtropical
Jet Stream
Westerlies
Hadley
Cell
theast Trades
theast Trades


North Pole
Descending air: cool, dry
Polar cell
Rising air: warm, moist
Ferrel cell
Descending air: cool, dry
Hadley cell
Rising air: warm, moist
Hadley cell
Descending air: cool, dry
Ferrel cell
Rising air: warm, moist
Polar cell
Descending air: cool, dry
South Pole
High
Low
Polar Jet
High
High
High
High
Polar Jet
Low
High

Preliminary CAM5 hi-resolution simulations (0.25°, prescribed aerosols)

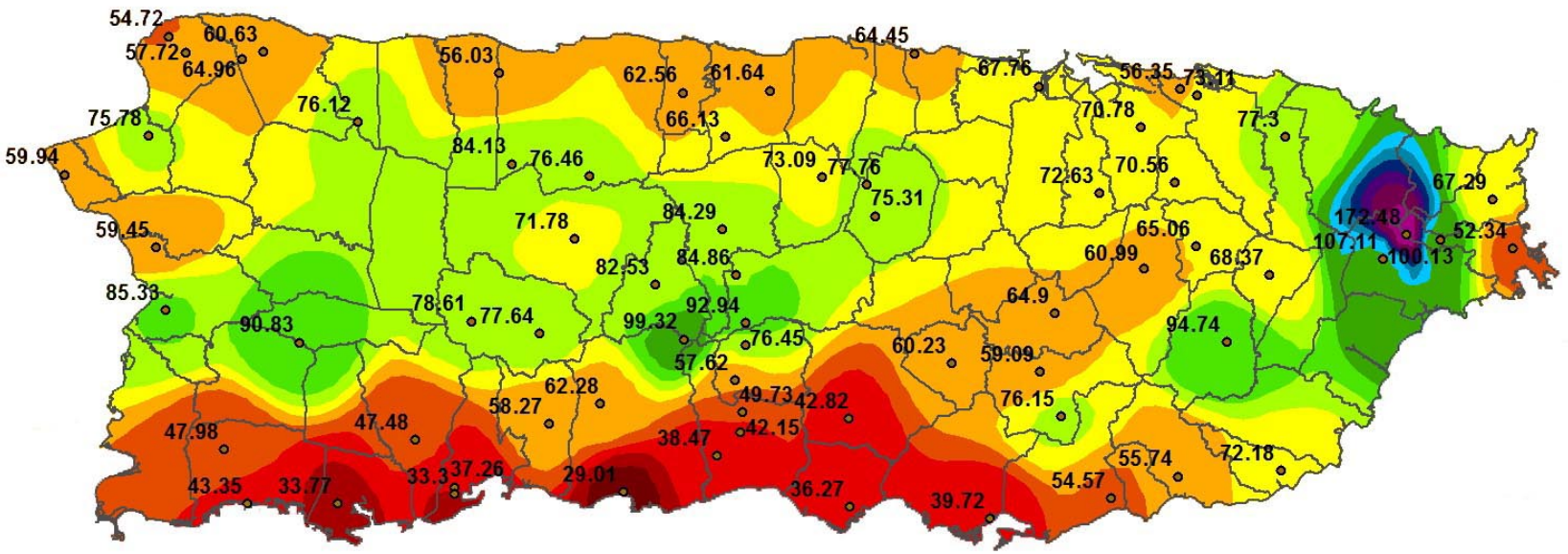
Michael Wehner, Prabhat, Chris Algieri, Fuyu Li, Bill Collins
Lawrence Berkeley National Laboratory

Kevin Reed, University of Michigan

Andrew Gettelman, Julio Bacmeister, Richard Neale
National Center for Atmospheric Research

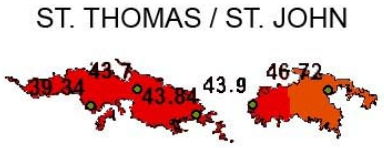
June 1, 2011

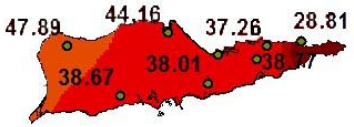
Mean Annual Rainfall 1981 - 2010



Annual Rainfall (Inches)

25 - 30	55 - 60	85 - 90	115 - 120	145 - 150
30 - 35	60 - 65	90 - 95	120 - 125	150 - 155
35 - 40	65 - 70	95 - 100	125 - 130	155 - 160
40 - 45	70 - 75	100 - 105	130 - 135	160 - 165
45 - 50	75 - 80	105 - 110	135 - 140	165 - 170
50 - 55	80 - 85	110 - 115	140 - 145	170 - 175





ST. CROIX

Observed Changes in the Climate System

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history.

Recent climate changes have had widespread impacts on human and natural systems.

Climate Change

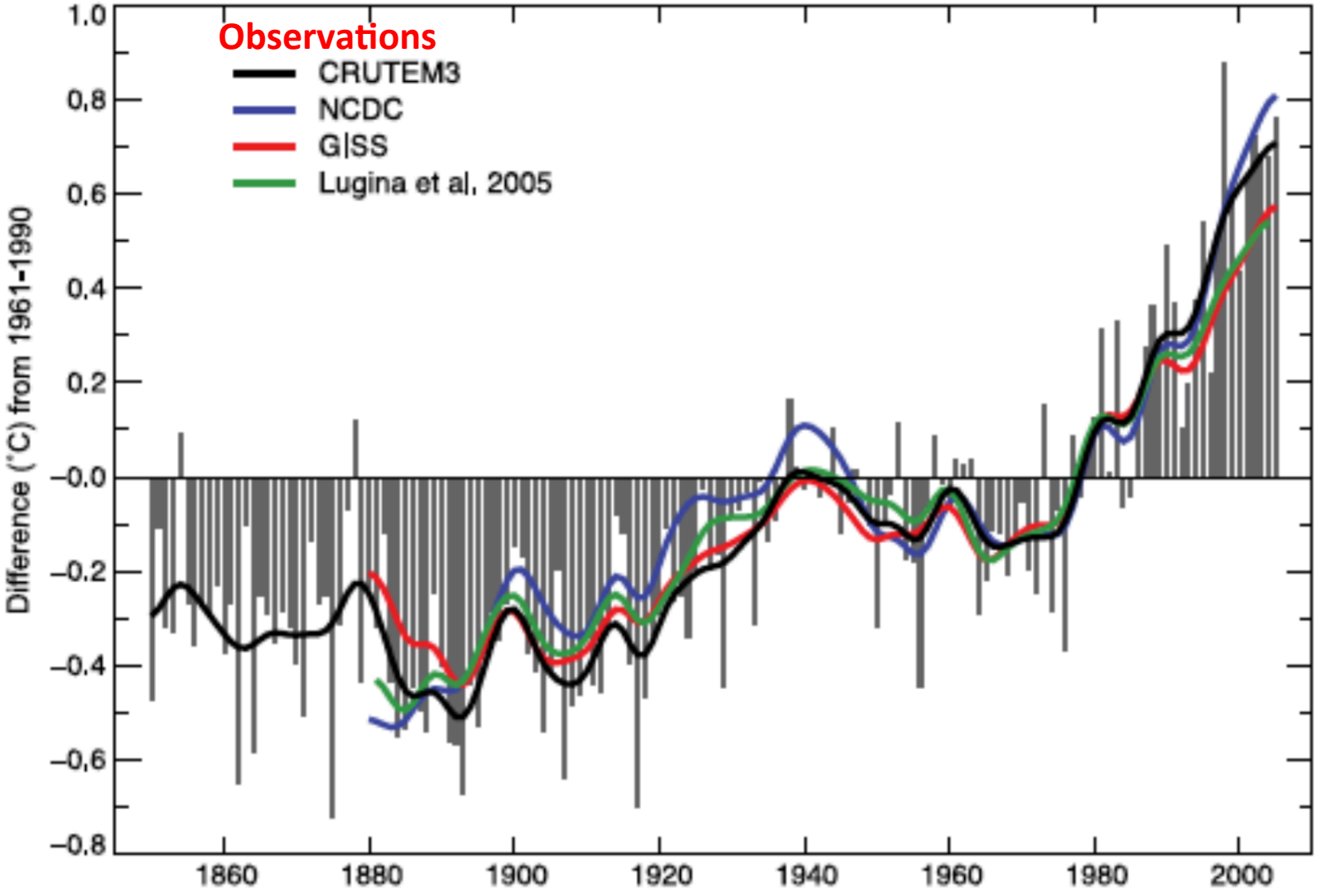
Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.

The last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years.

The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

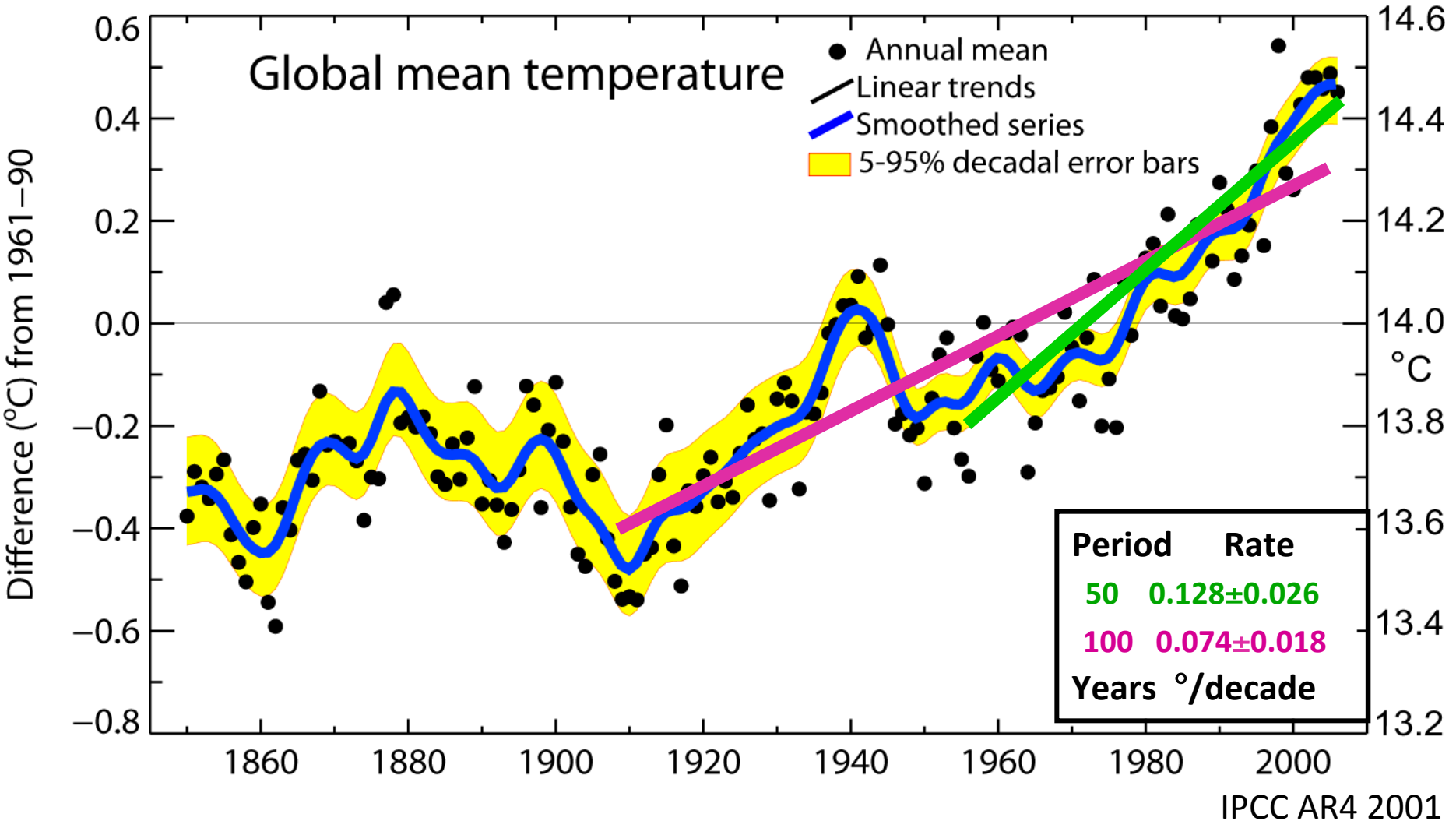
Intergovenmental Panel on Climate Change

Global averaged land and ocean surface temperature show a warming of 0.85°C over the period 1880 to 2012



Global mean temperatures are rising faster with time

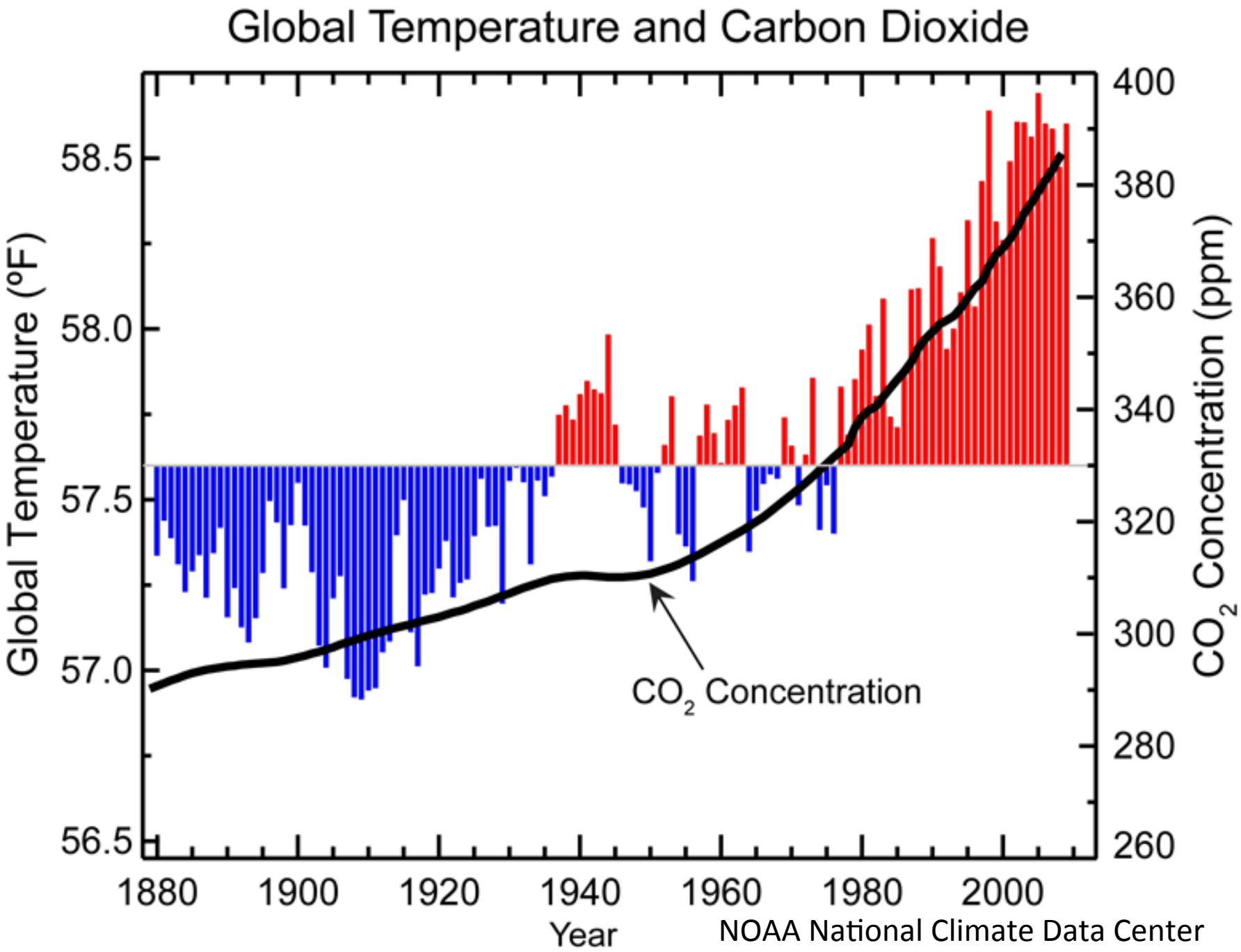
"The balance of evidence suggests a discernable human influence on global climate" **Ben Santer, IPCC 1995**



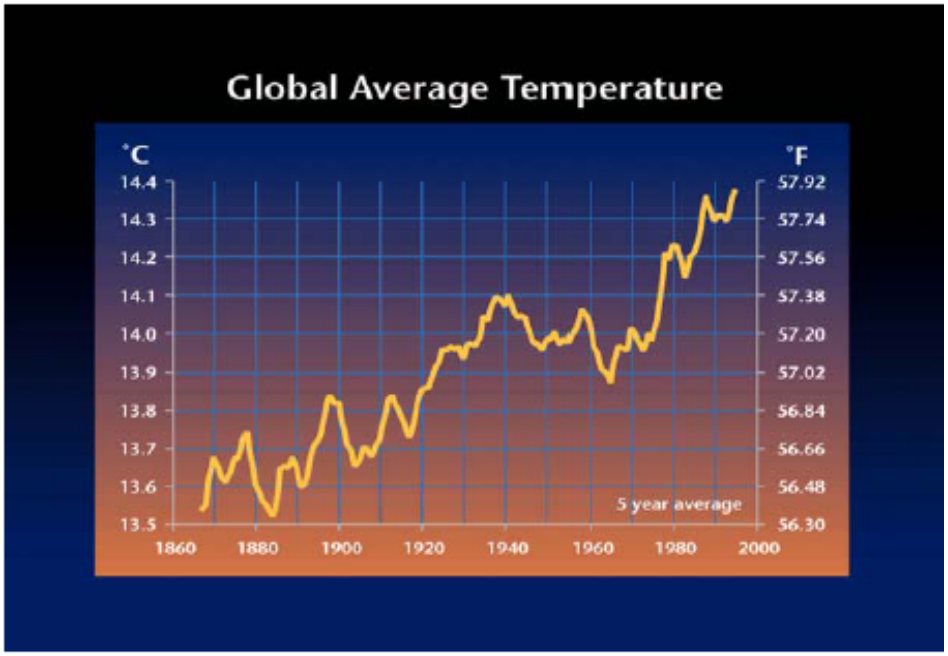
IPCC AR4 2001

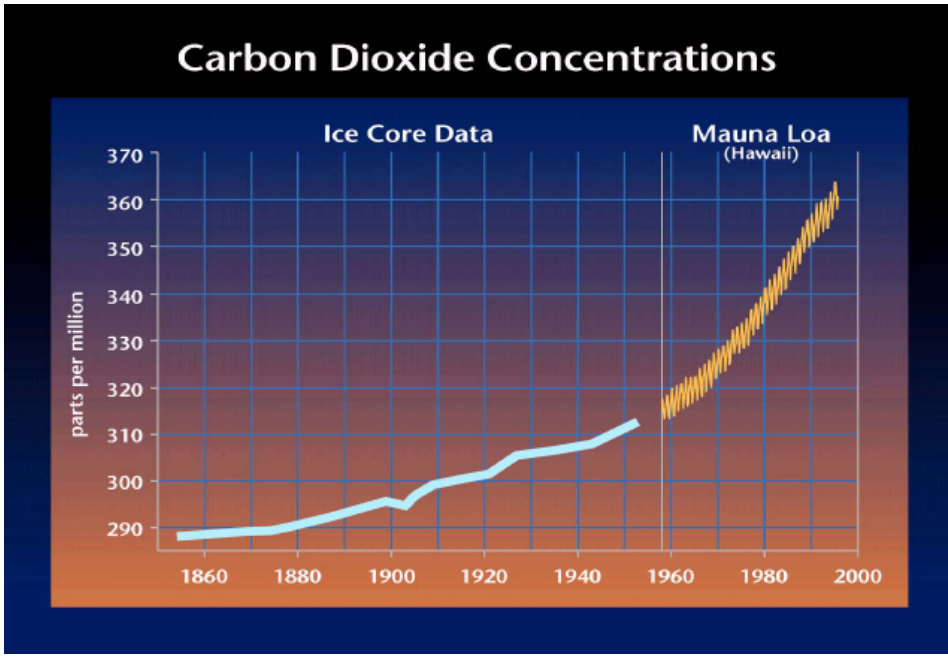
The IPCC Fifth Assessment Report

95% Certainty (extremely Likely) global warming is due to fossil fuel emissions (*increased Carbon Dioxide*) released by powerplants, cars, etc.


Global Temperature and Carbon Dioxide
Global Temperature (°F)
58.5
58.0
57.5
57.0
56.5
400
380
360
340
320
300
280
260
CO2 Concentration (ppm)
CO2 Concentration
1880
1900
1920
1940
1960
1980
2000
Year
NOAA National Climate Data Center

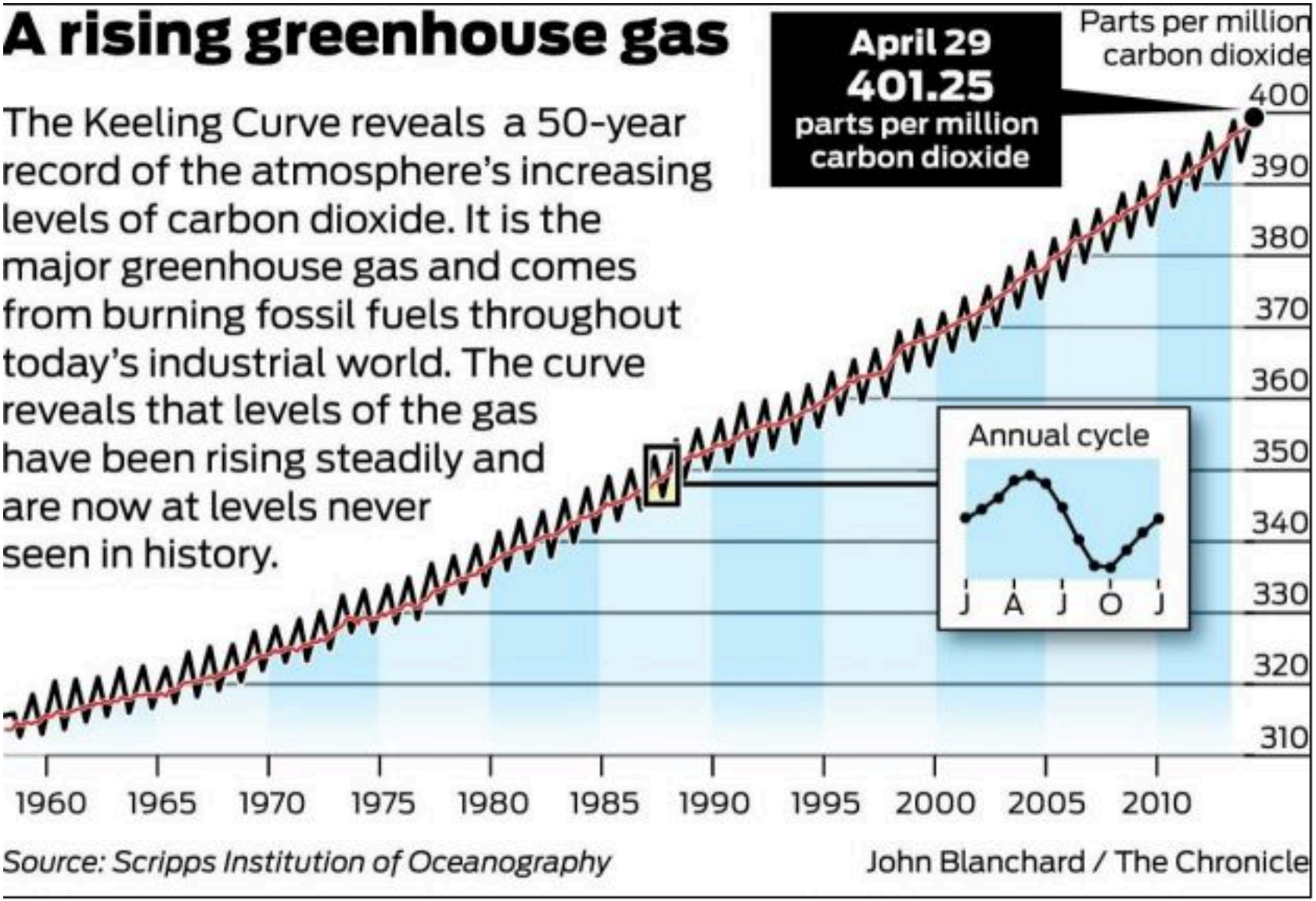
Temperature and CO_2 Increases are Proportional

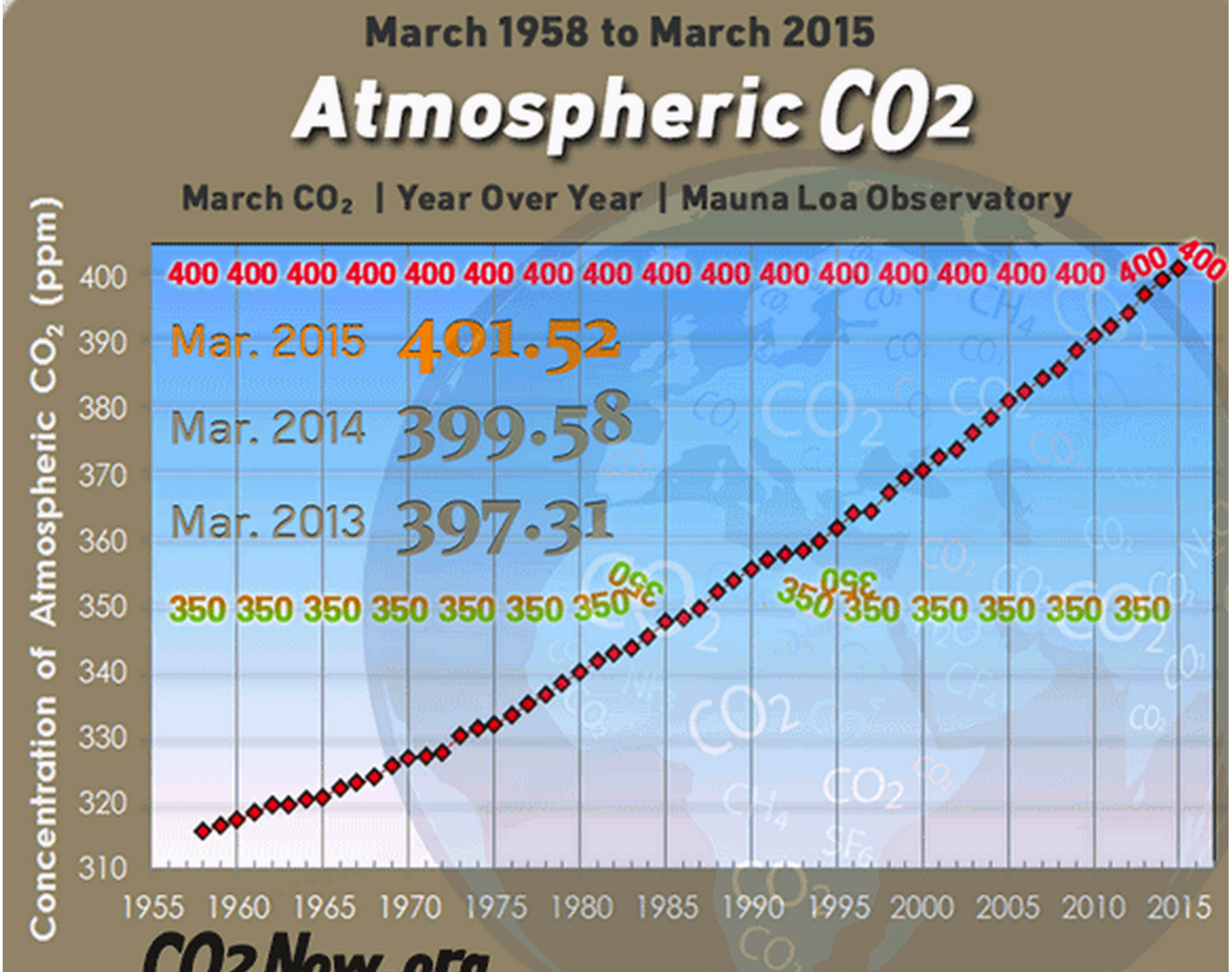




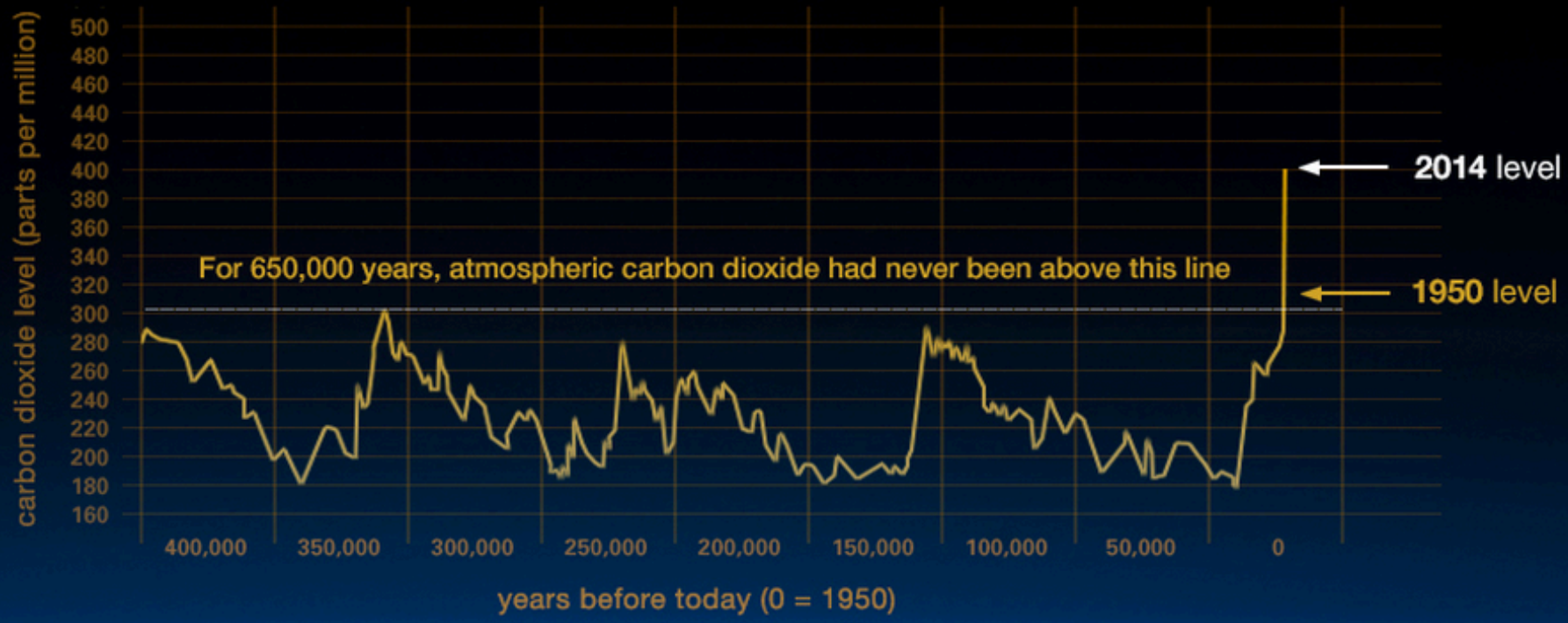
Intergovernmental Panel on Climate Change, 2001

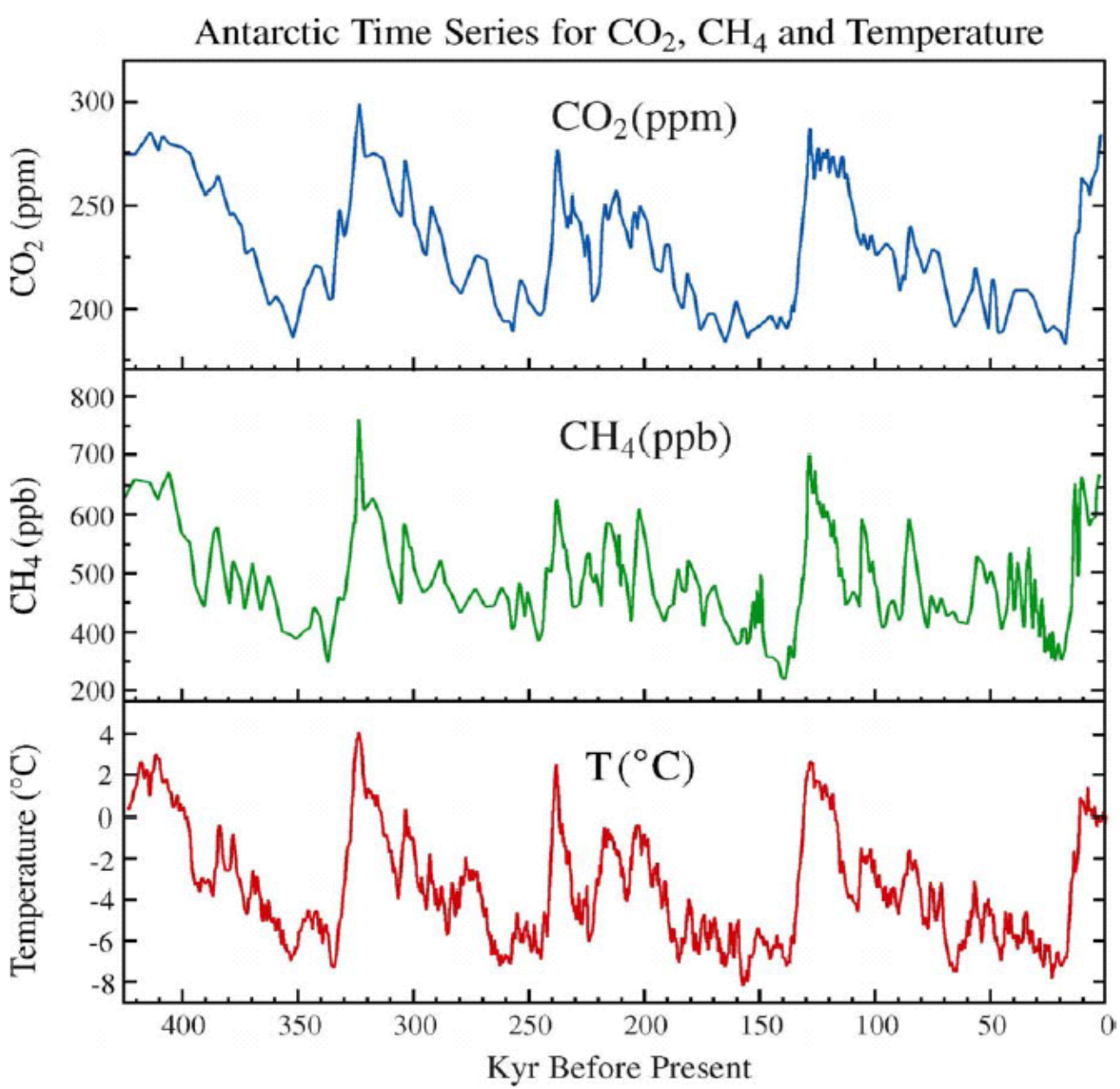
April 2013: CO2 exceeds 400PPM




March 1958 to March 2015
Atmospheric CO2
March CO2 | Year Over Year | Mauna Loa Observatory
Concentration of Atmospheric CO2 (ppm)
400 400 400 400 400 400 400 400 400 400 400 400 400 400 400 400 400 400
Mar. 2015 401.52
Mar. 2014 399.58
Mar. 2013 397.31
350 350 350 350 350 350 350 350 350 350 350 350 350 350 350 350 350
400
390
380
370
360
350
340
330
320
310
1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015
CO2Now.org

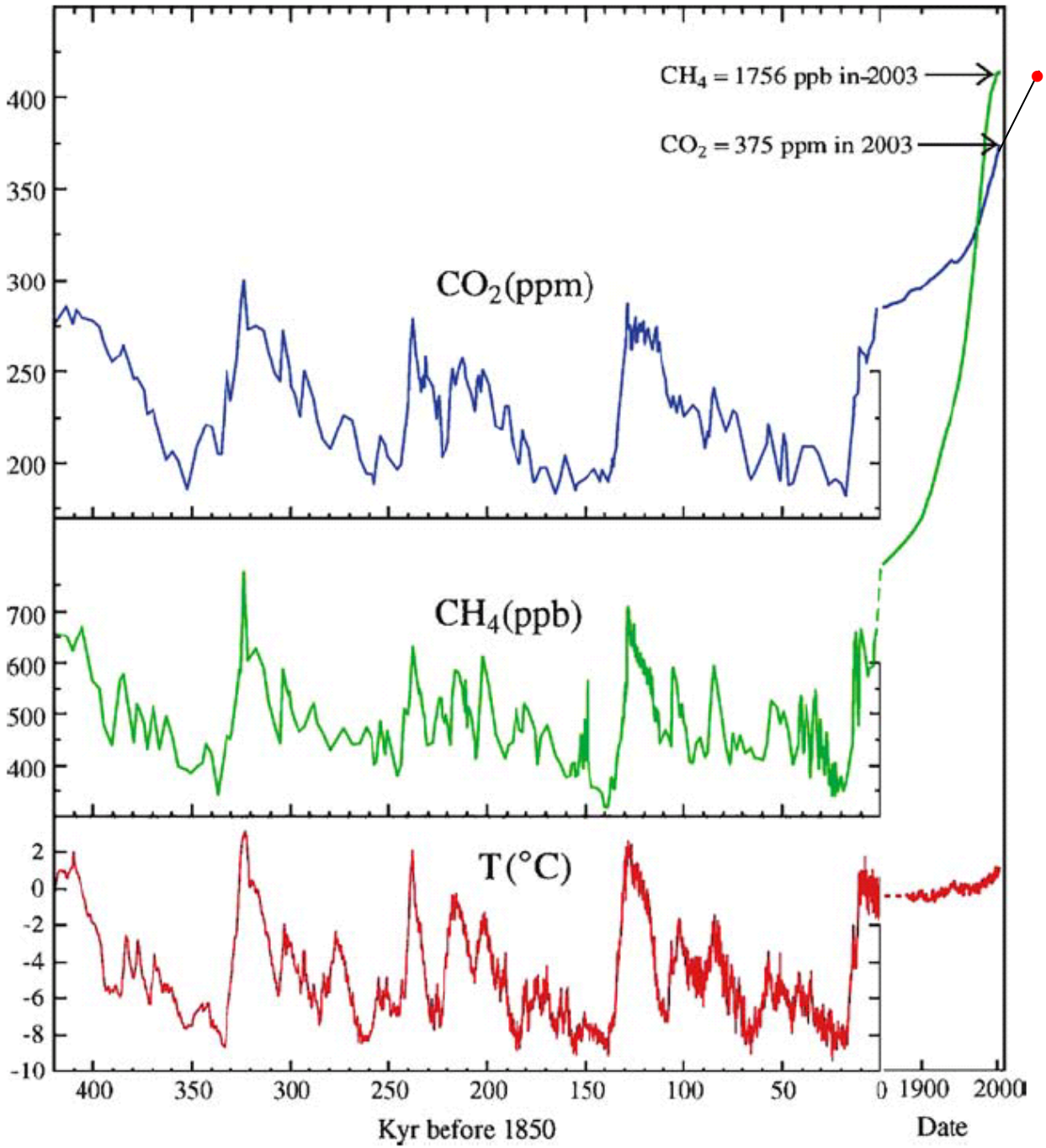
Atmospheric carbon dioxide is at its highest level in human history





CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.



> 400ppm May 2013, March 2015

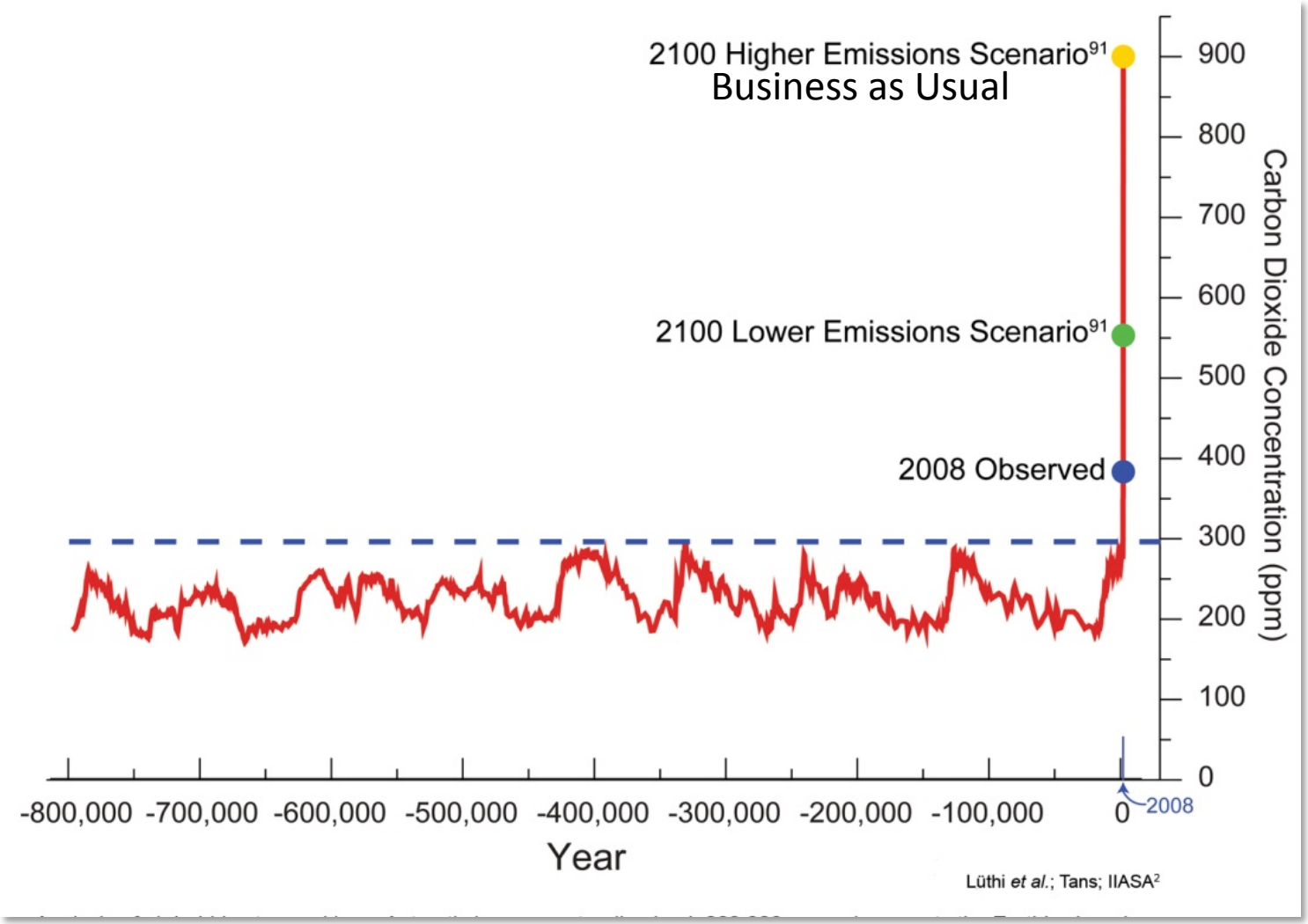
The Last 500,000 years

and

the last 200 years

J. Hansen

Current levels of atmospheric CO_2 have not occurred for at least the last 800,000 years



U.S. Climate Change Science Program State of Knowledge Report (2009)

Are Changes in Solar Radiation Causing Warming

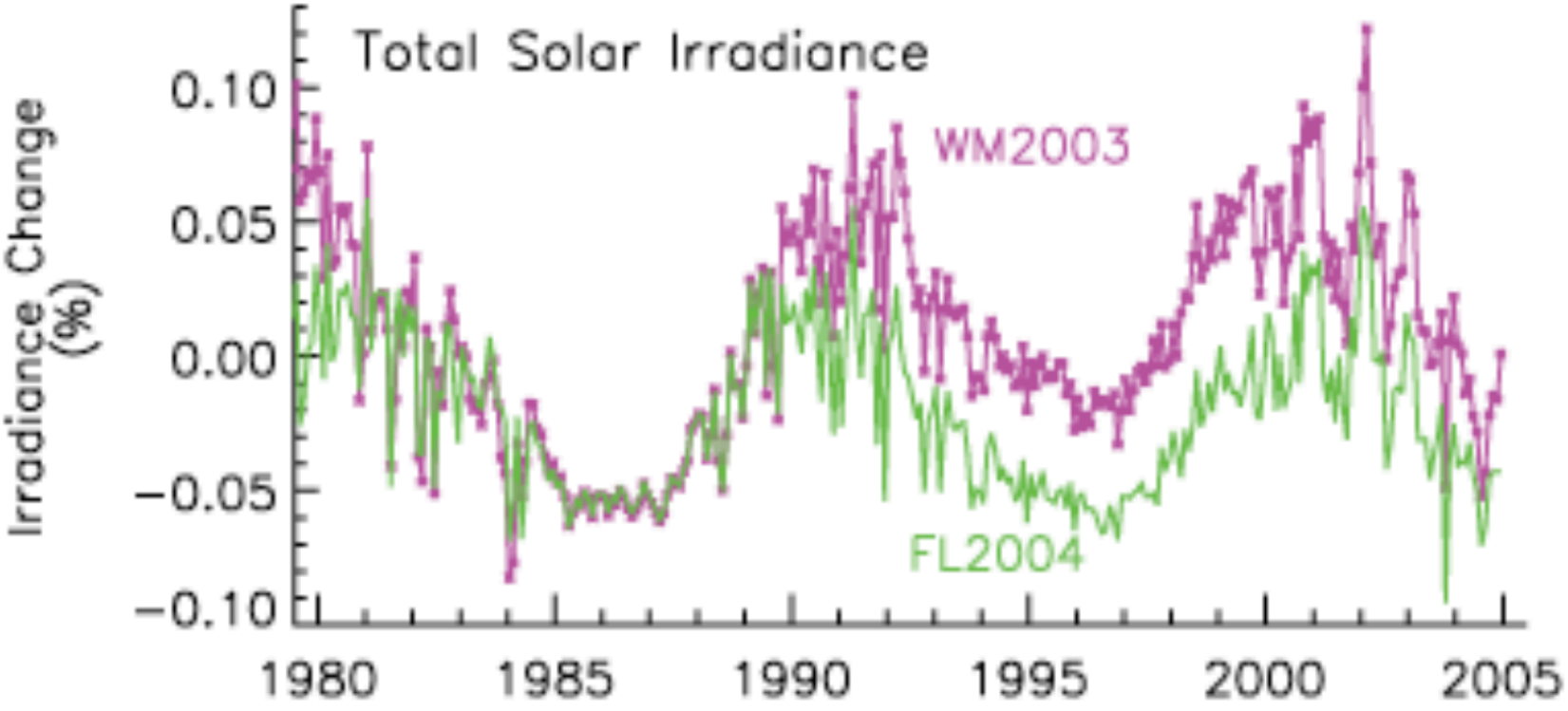
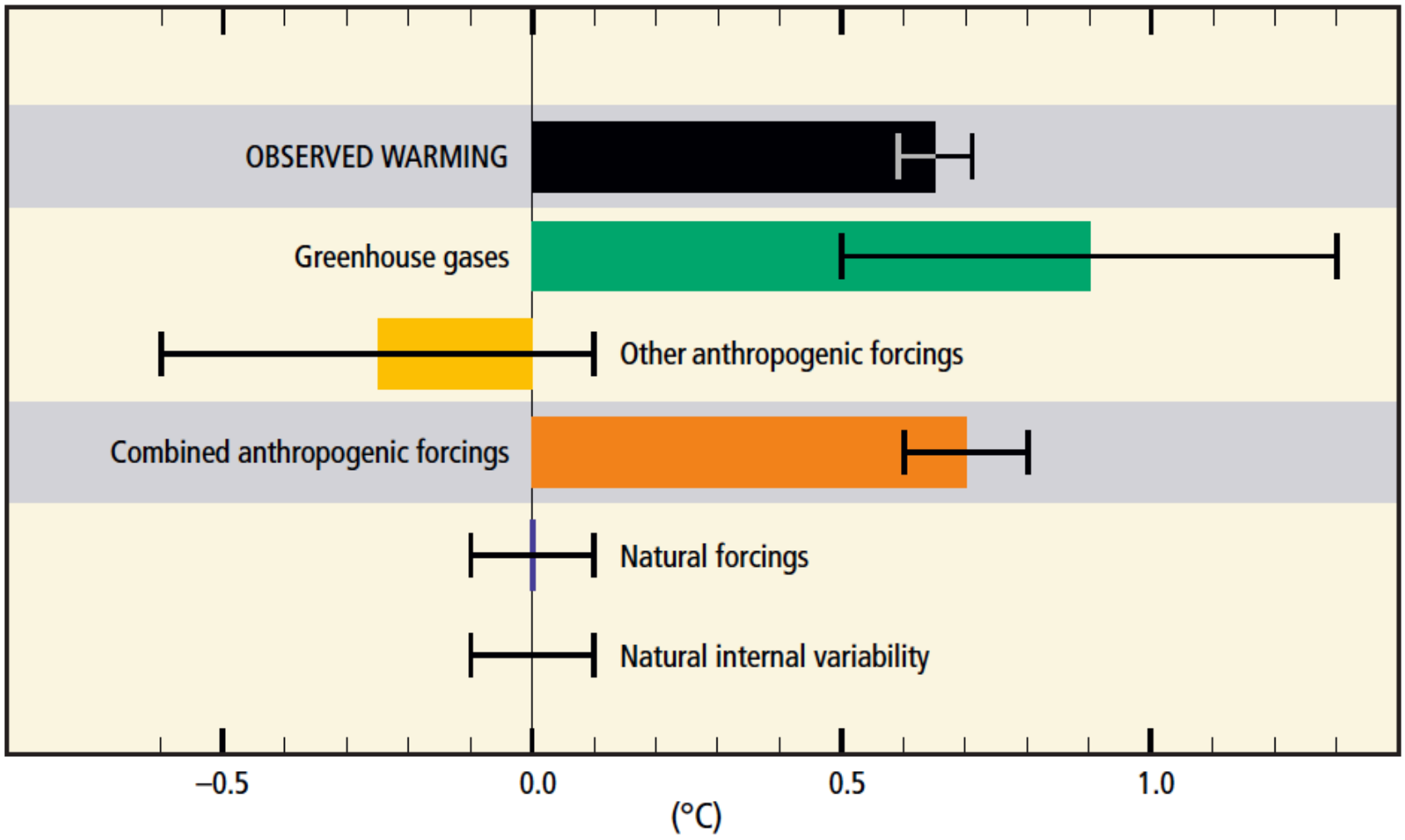
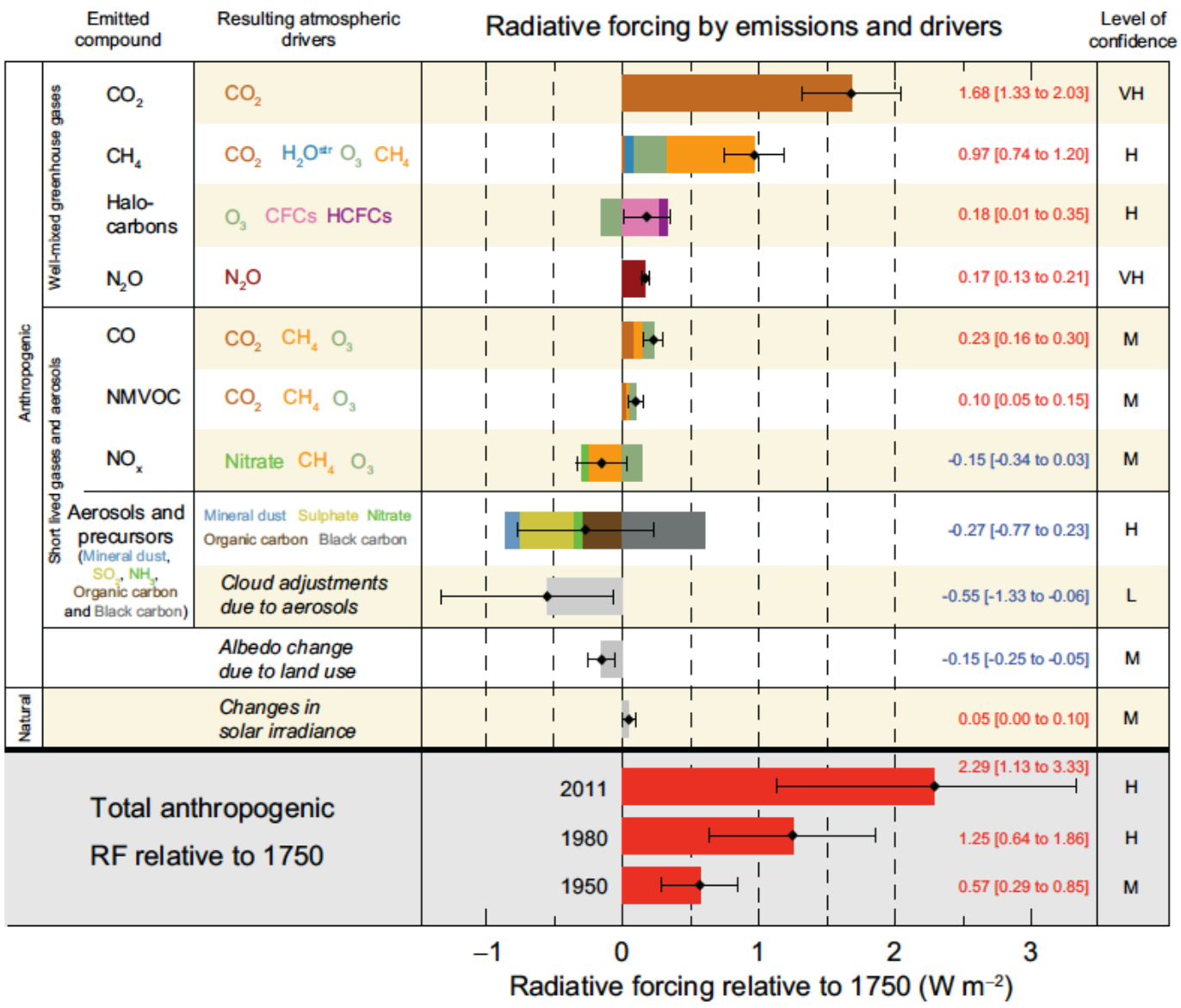
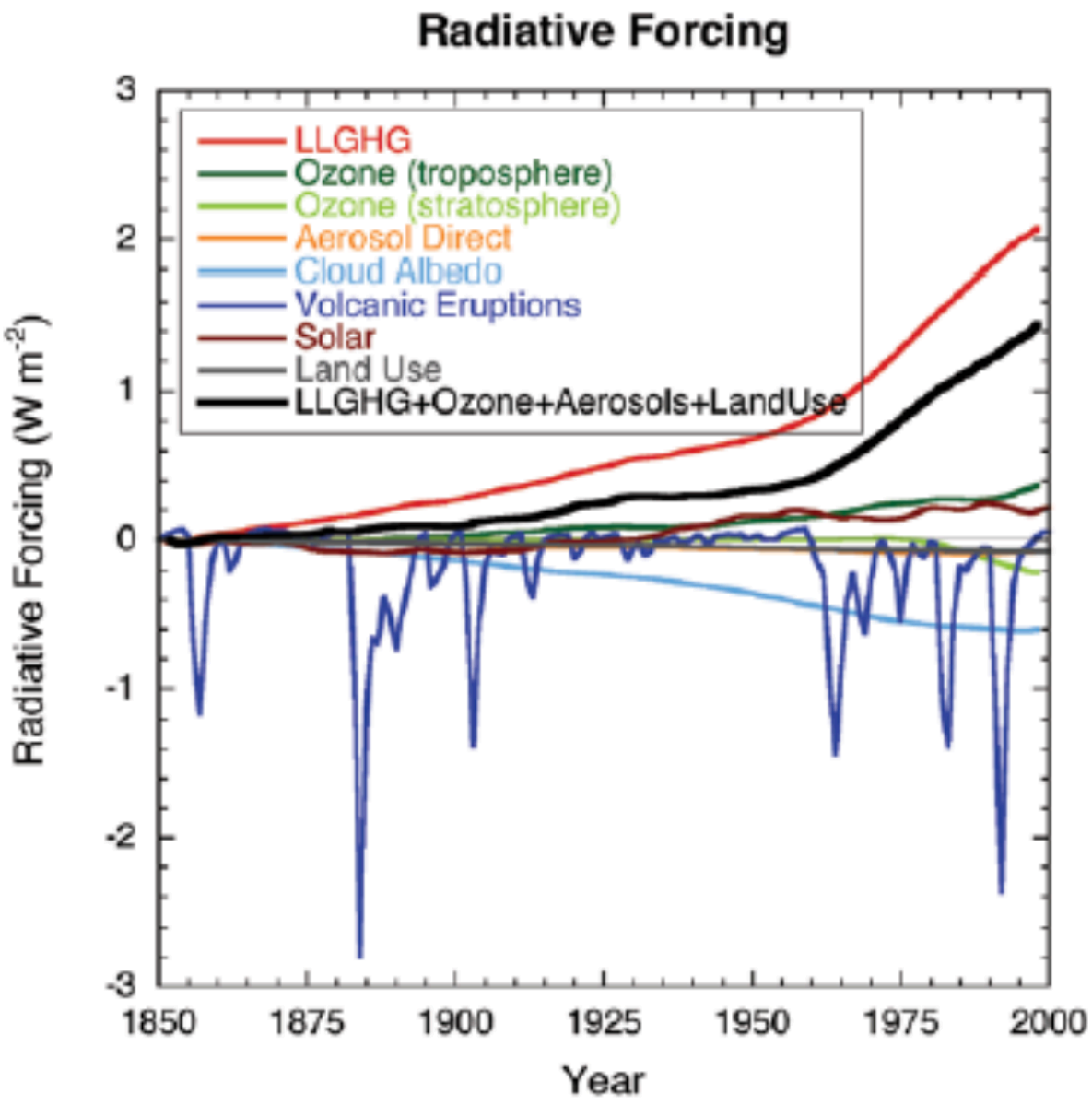


Figure 2.16. *Percentage change in monthly values of the total solar irradiance composites of Willson and Mordvinov (2003; WM2003, violet symbols and line) and Fröhlich and Lean (2004; FL2004, green solid line).*

Contributions to observed surface temperature change over the period 1951–2010




Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
Short lived gases and aerosols
Natural
CO2
CH4
Halo-carbons
N2O
CO
NMVOC
NOx
Aerosols and precursors (Mineral dust, SO2, NH3, Organic carbon and Black carbon)
CO2
CO2 H2Odir O3 CH4
O3 CFCs HCFCs
N2O
CO2 CH4 O3
CO2 CH4 O3
Nitrate CH4 O3
Mineral dust Sulphate Nitrate
Organic carbon Black carbon
Cloud adjustments due to aerosols
Albedo change due to land use
Changes in solar irradiance
1.68 [1.33 to 2.03]
0.97 [0.74 to 1.20]
0.18 [0.01 to 0.35]
0.17 [0.13 to 0.21]
0.23 [0.16 to 0.30]
0.10 [0.05 to 0.15]
-0.15 [-0.34 to 0.03]
-0.27 [-0.77 to 0.23]
-0.55 [-1.33 to -0.06]
-0.15 [-0.25 to -0.05]
0.05 [0.00 to 0.10]
VH
H
H
VH
M
M
M
H
L
M
M
Total anthropogenic RF relative to 1750
2011
1980
1950
2.29 [1.13 to 3.33]
1.25 [0.64 to 1.86]
0.57 [0.29 to 0.85]
H
H
M
−1
0
1
2
3
Radiative forcing relative to 1750 (W m−2)

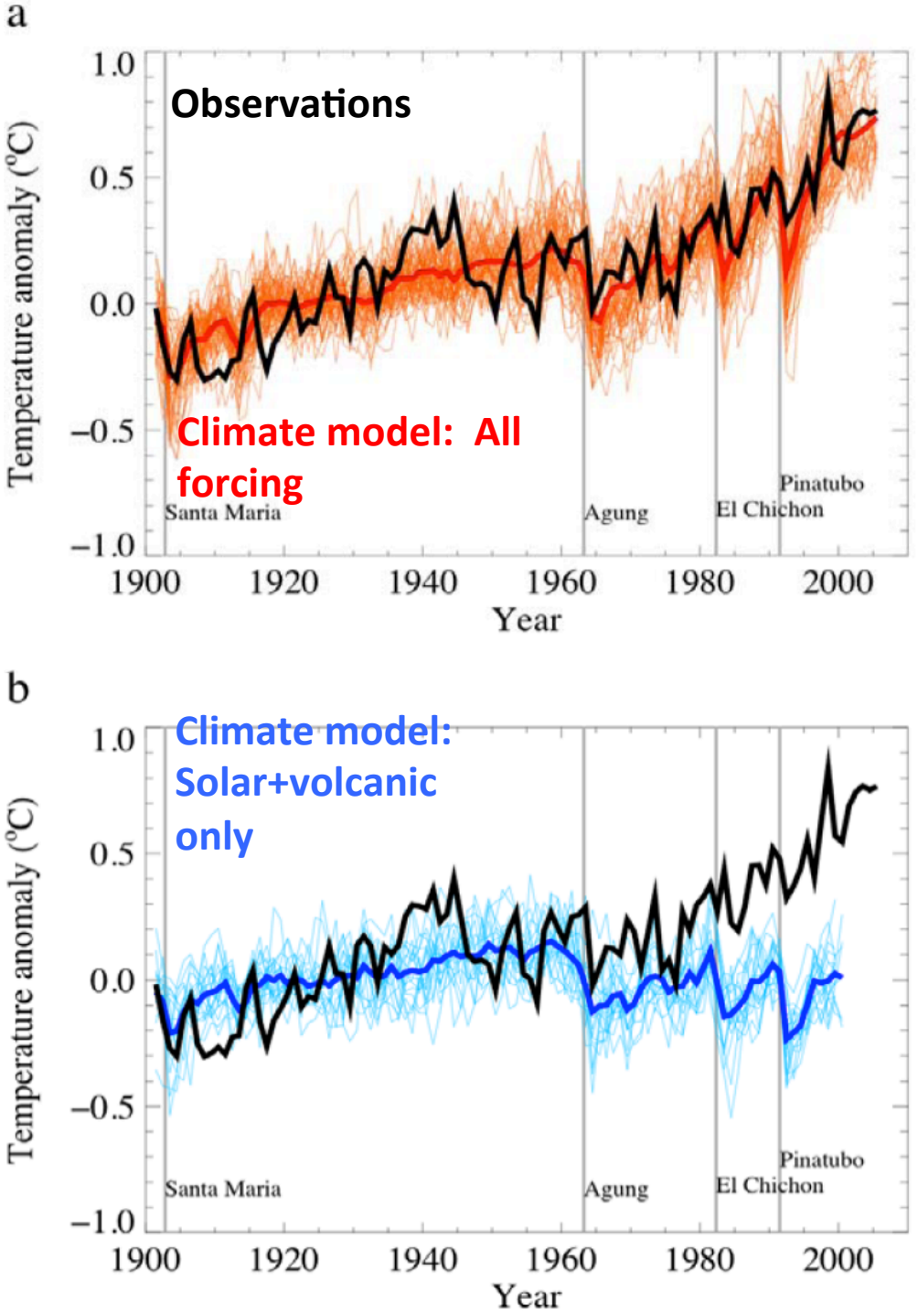

Radiative Forcing
LLGHG
Ozone (troposphere)
Ozone (stratosphere)
Aerosol Direct
Cloud Albedo
Volcanic Eruptions
Solar
Land Use
LLGHG+Ozone+Aerosols+LandUse
Radiative Forcing (W m-2)
3
2
1
0
-1
-2
-3
1850
1875
1900
1925
1950
1975
2000
Year

Attribution

- are observed changes consistent with

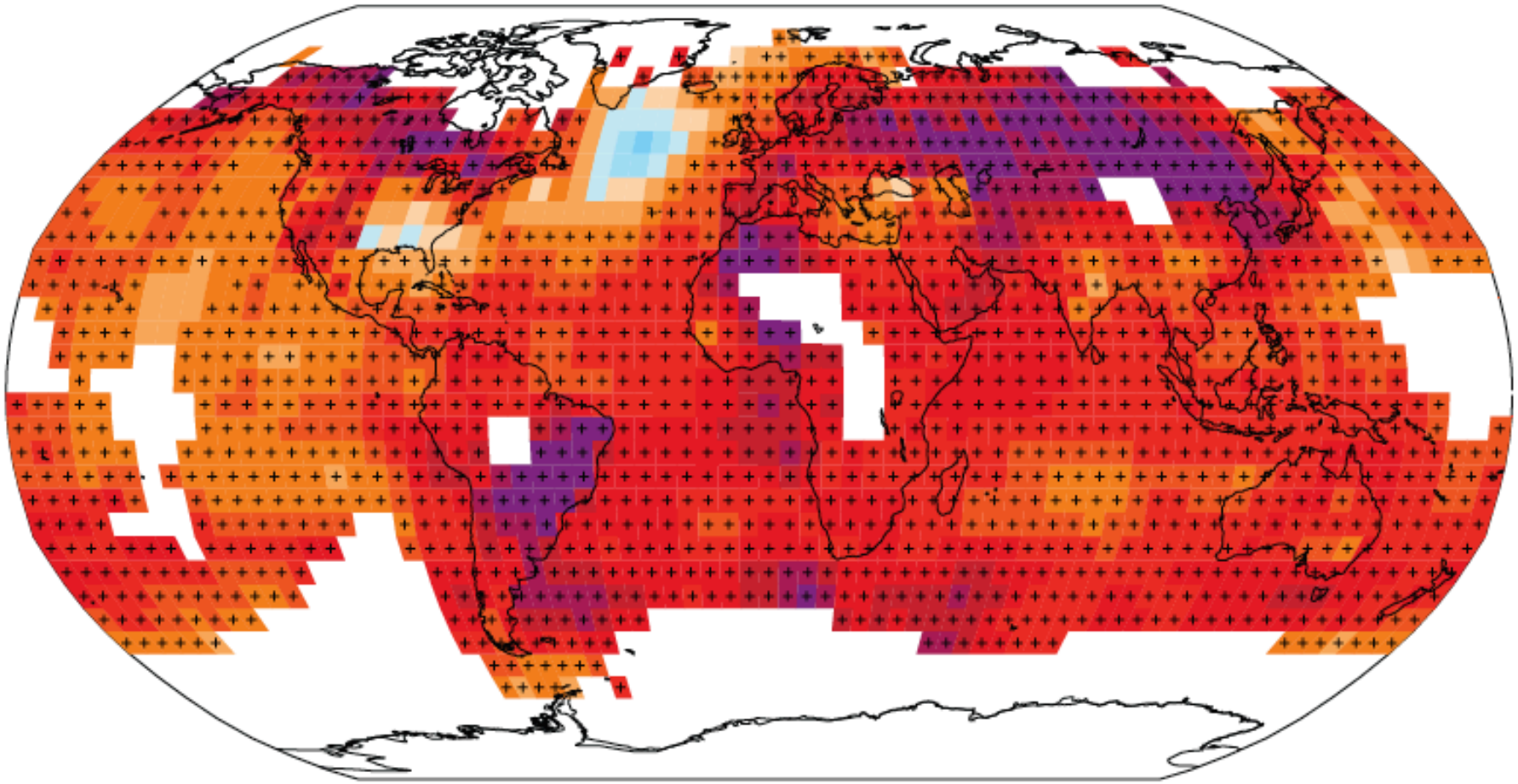
☑ expected responses to forcings

☒ inconsistent with alternative explanations



IPCC AR4

Observed change in surface temperature 1901–2012



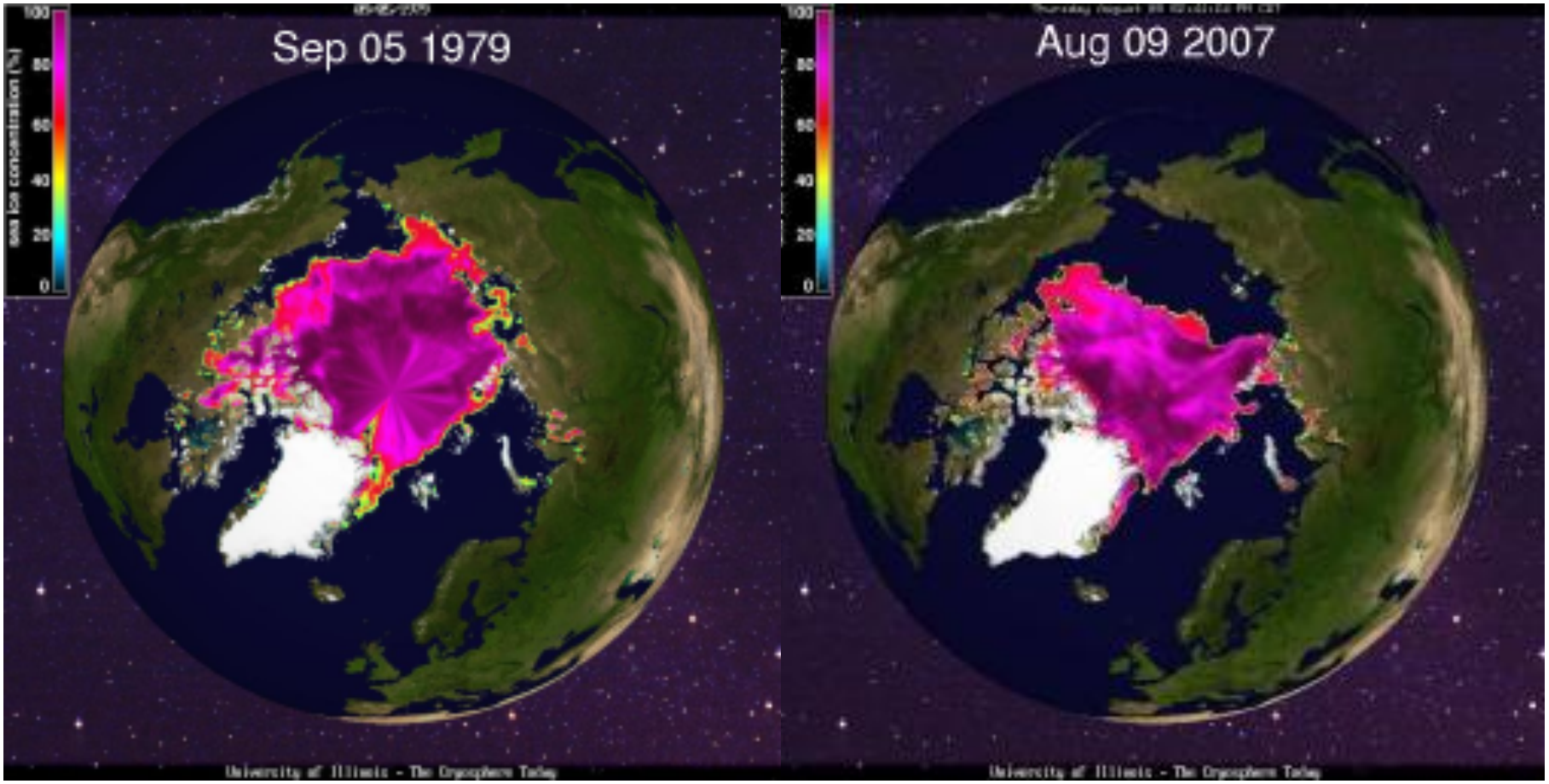
−0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1.0 1.25 1.5 1.75 2.5

(°C)

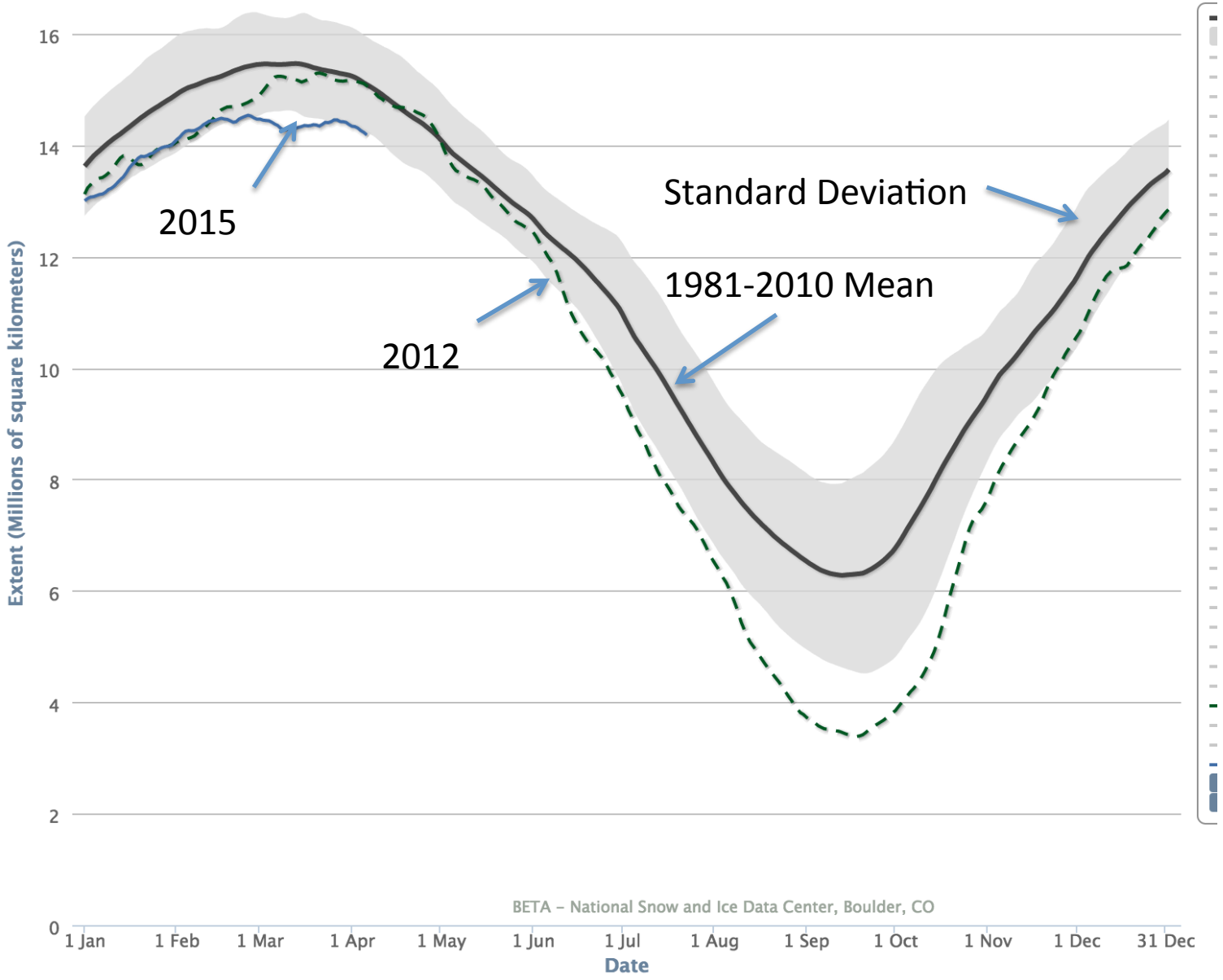
0.85
Global Mean

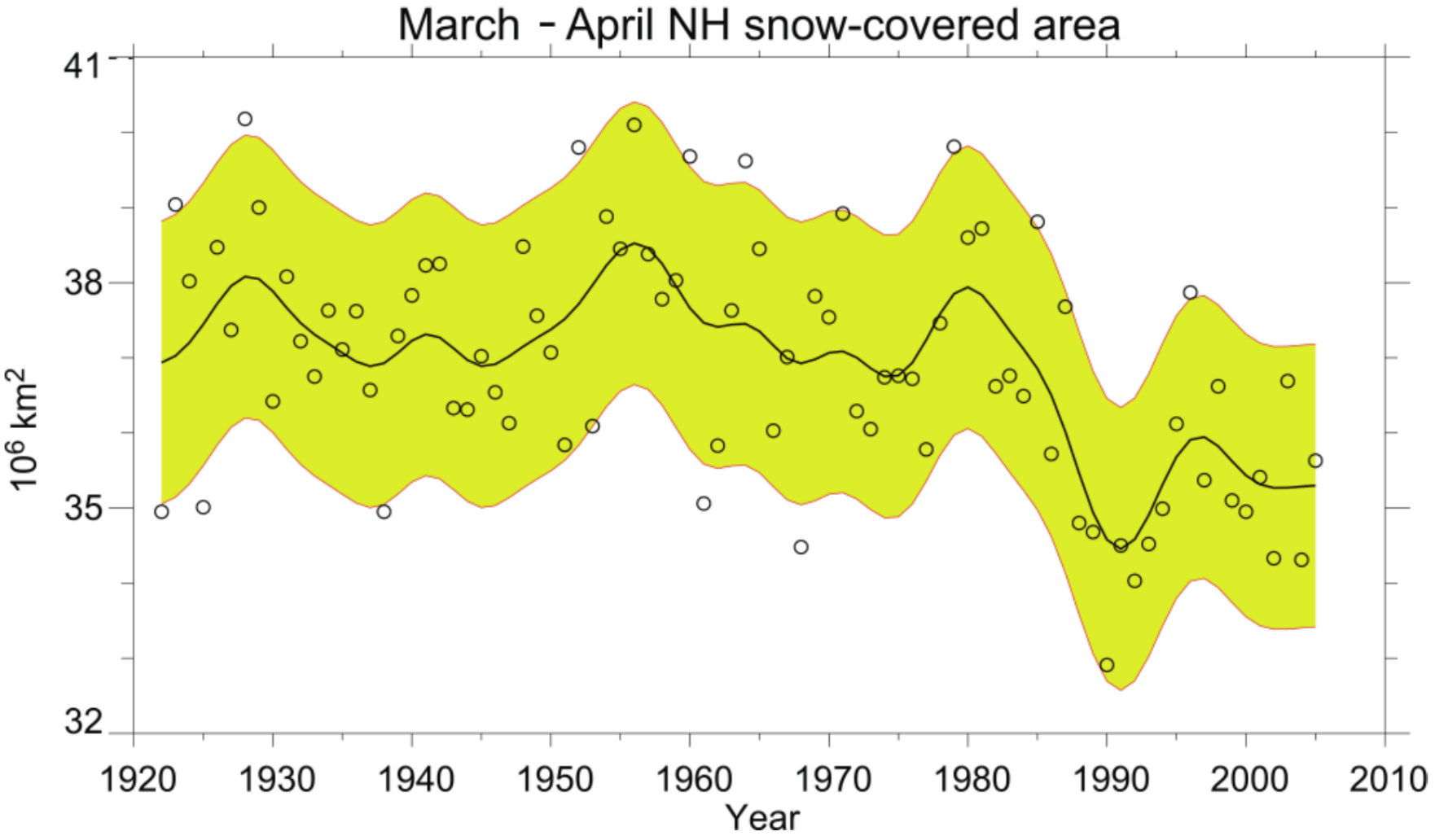
Arctic Sea Ice Reduction

This will Impact California!



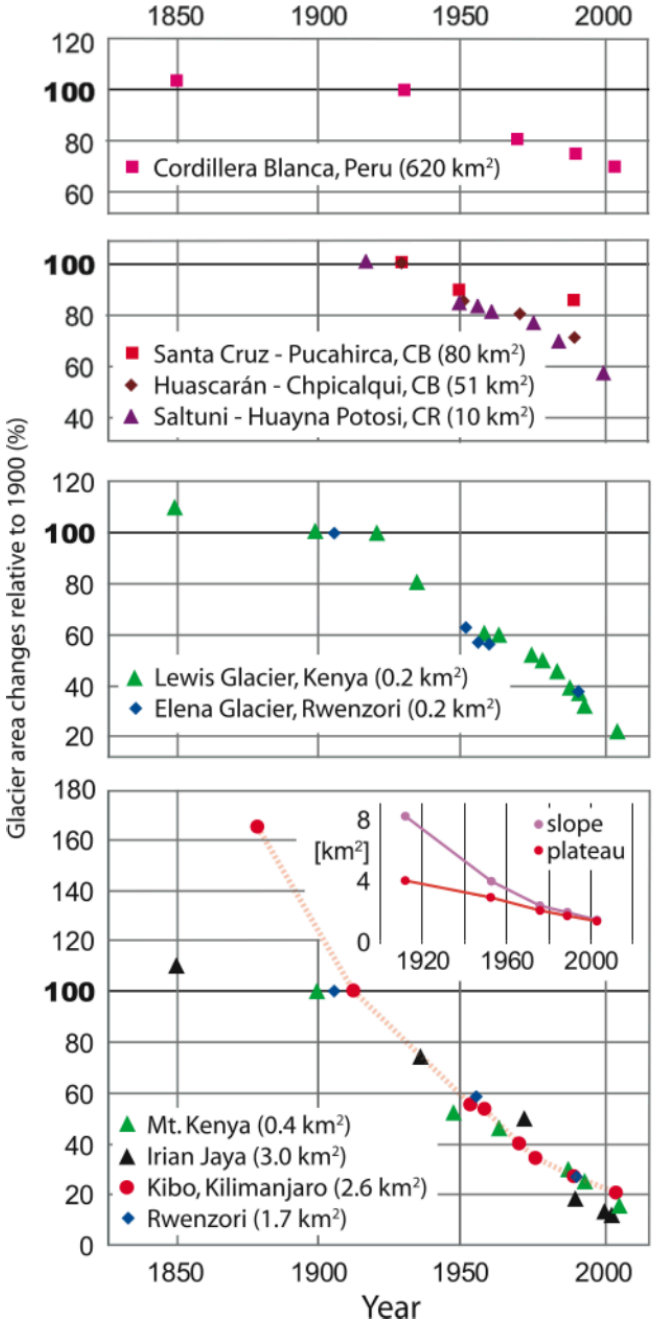
Minimum extent decreased by 40% between 1979 and 2012




March – April NH snow-covered area
41
38
35
32
10^6 km^2
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

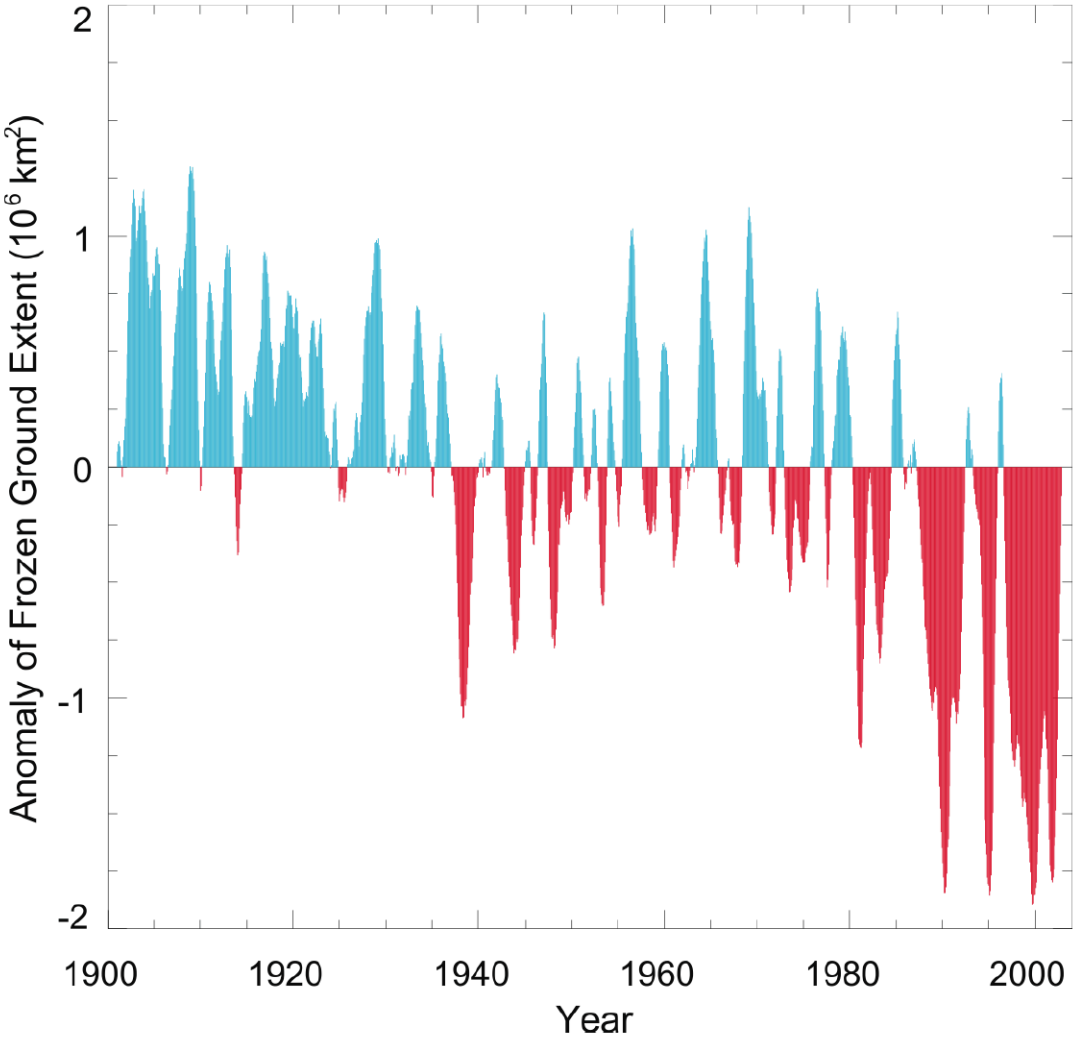
Tropical Glaciers are Shrinking

Changes in the surface area of tropical glaciers relative to their extent around 1900, grouped according to different glacier sizes.

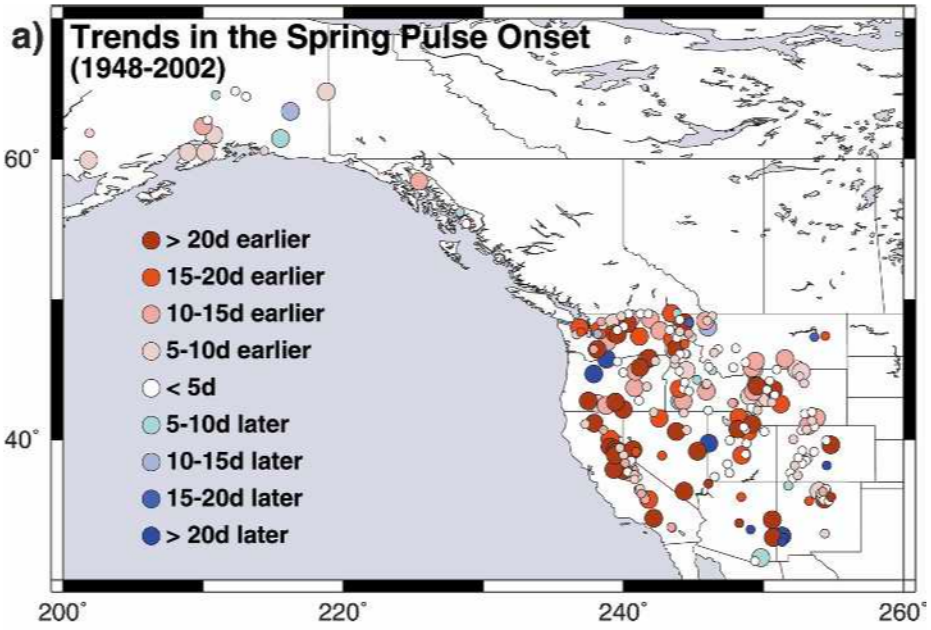


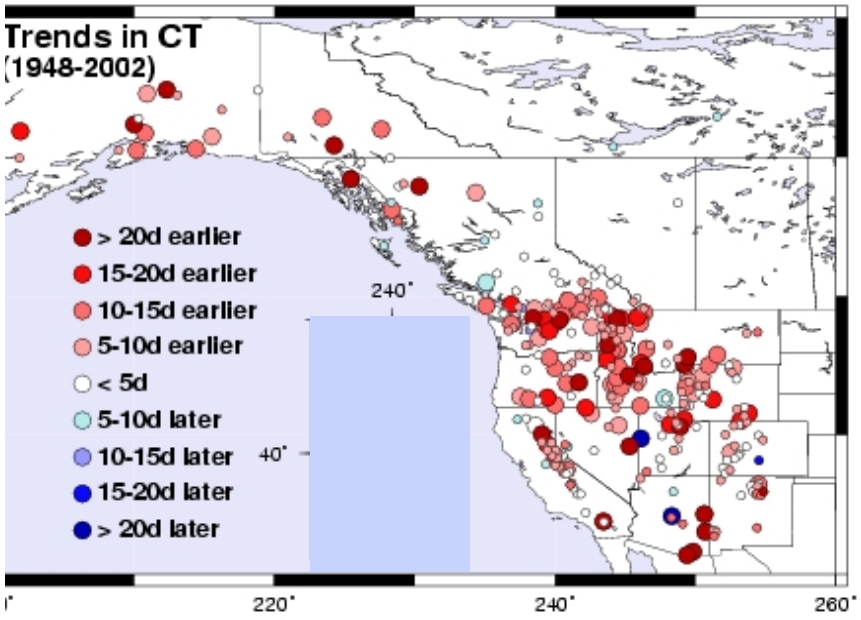
Frozen Ground Area is Decreasing

Historical variations in the monthly areal extent (10^6 km^2) of seasonally frozen ground (including the active layer over permafrost) for the period from 1901 through 2002 in the NH. The positive anomaly (blue) represents above-average monthly extent, while the negative anomaly (red) represents below-average extent.



Observed 20th Century Hydrologic Timing: Western US

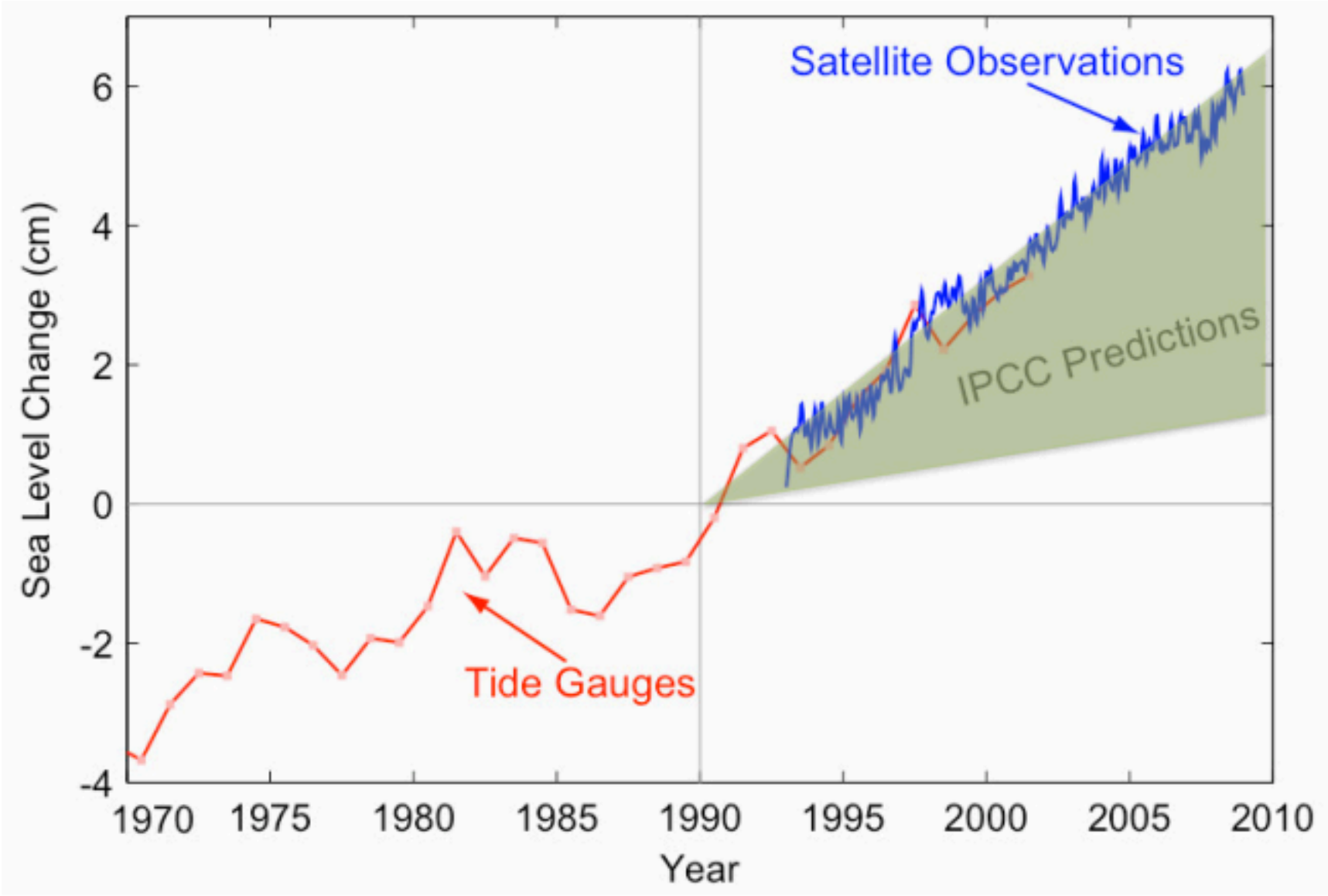




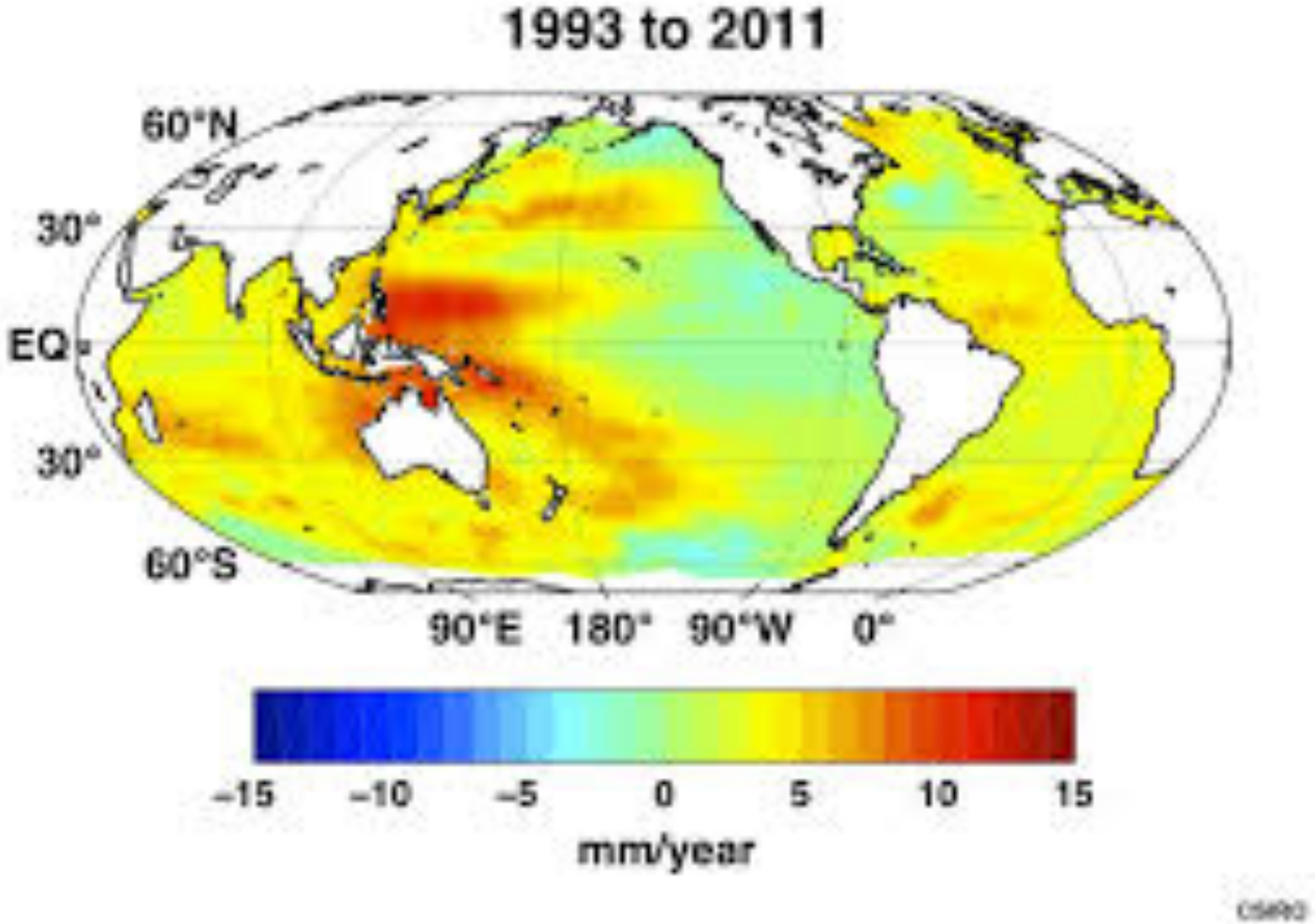
Stewart et al. 2005

- **Trends in stream flow timing shifted 1-3 weeks earlier over the past ~50 years.**
- **Timing shift dominated by changes in snowmelt-derived streamflow, partially attributed to warming.**

Global Mean Sea Level Rise

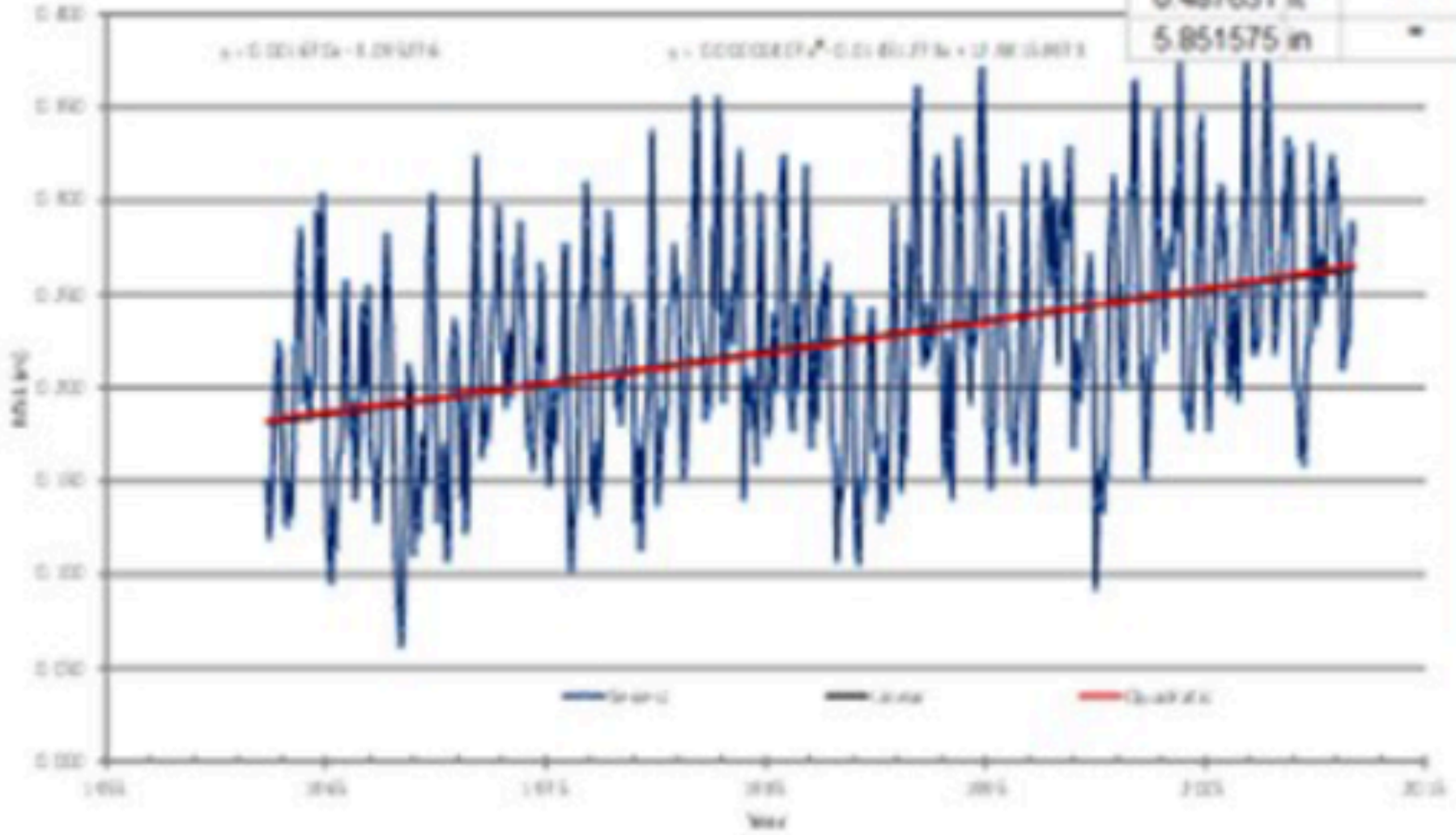


Change in Local Sea Level Rise



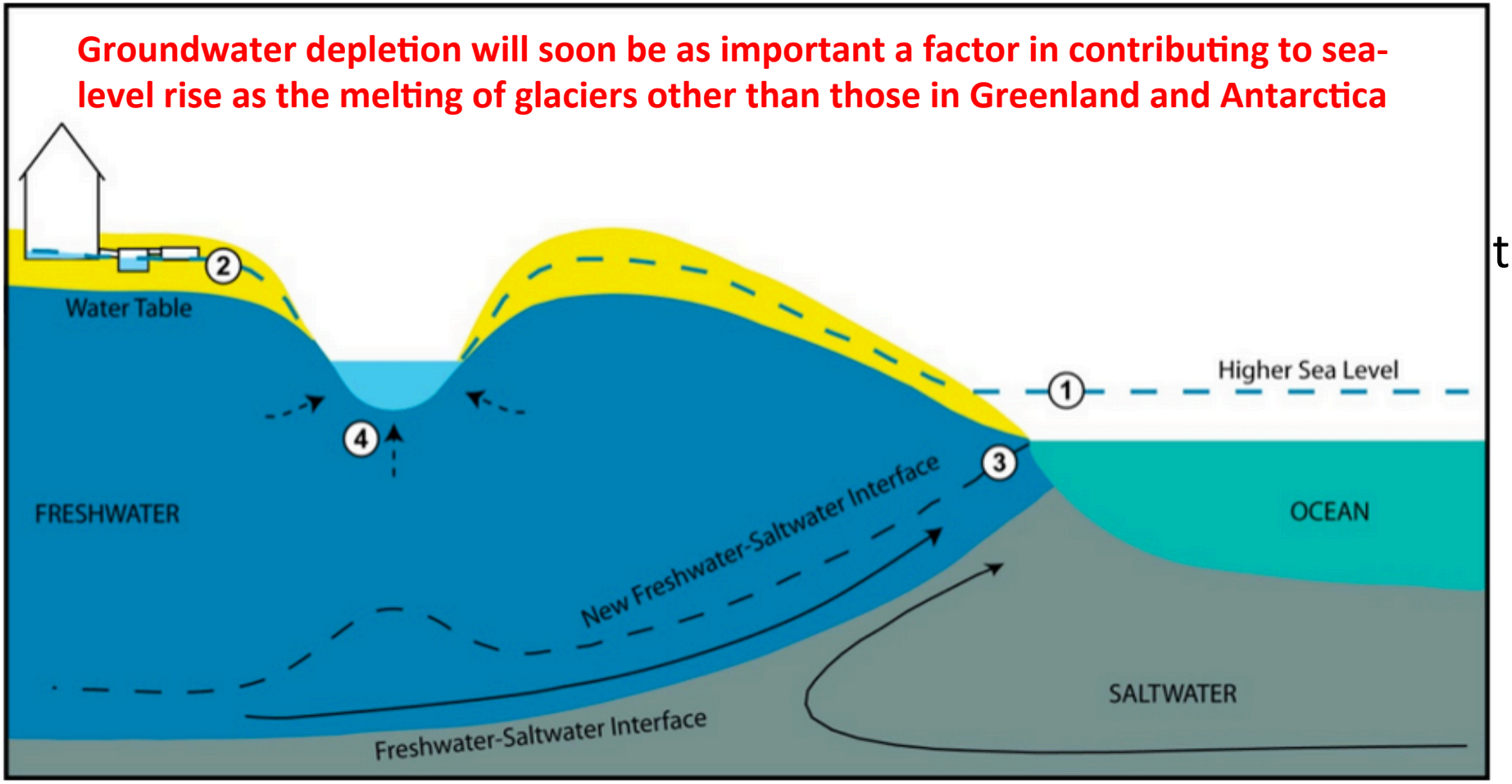
San Juan Sea Level Rise is Increasing

0.263094	m	2011
0.411724	m	2100
0.148630	m	increase
14.863000	cm	"
0.487631	ft	"
5.851575	in	"

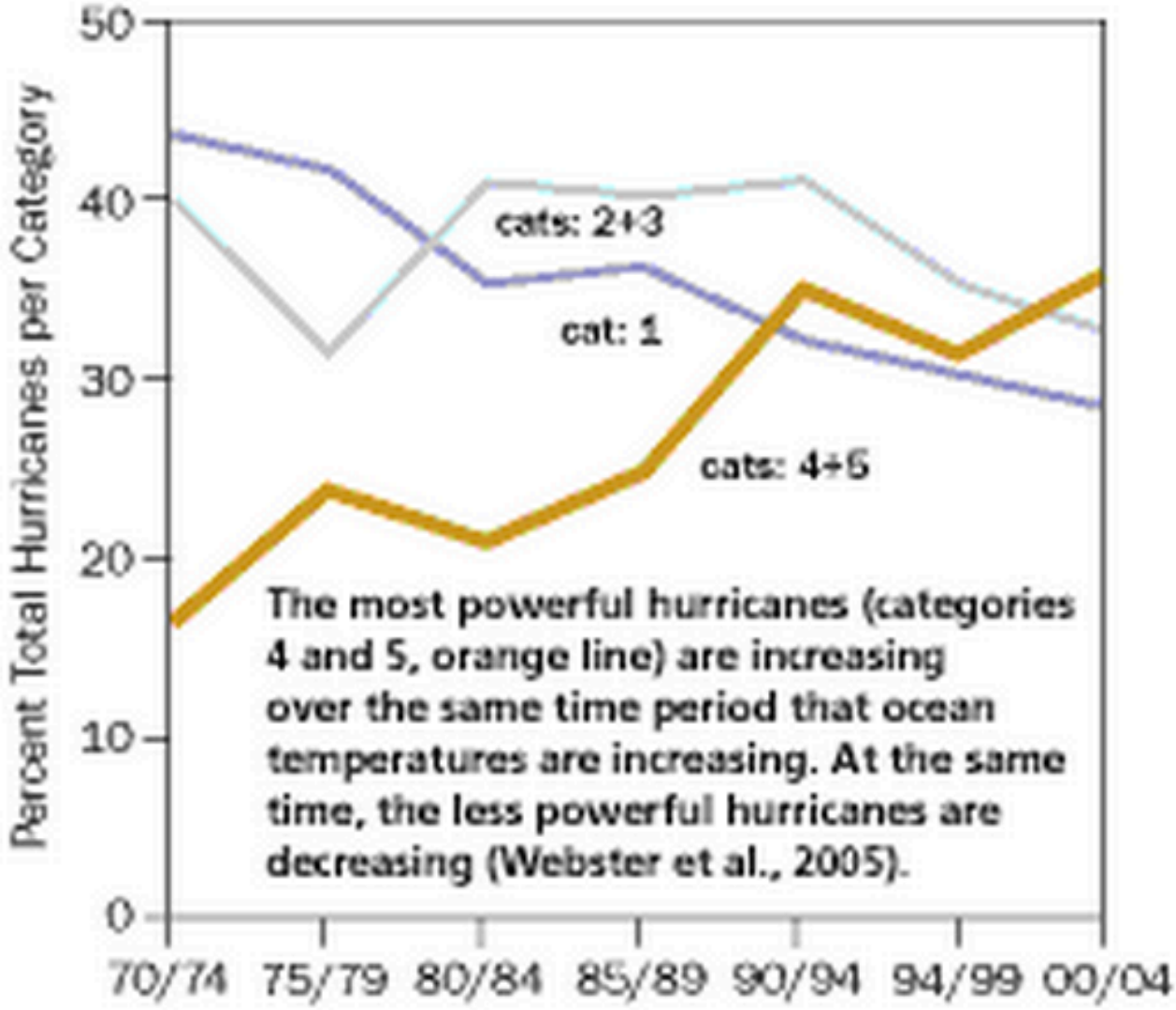


Sea Level Rise and Salt Water Intrusion

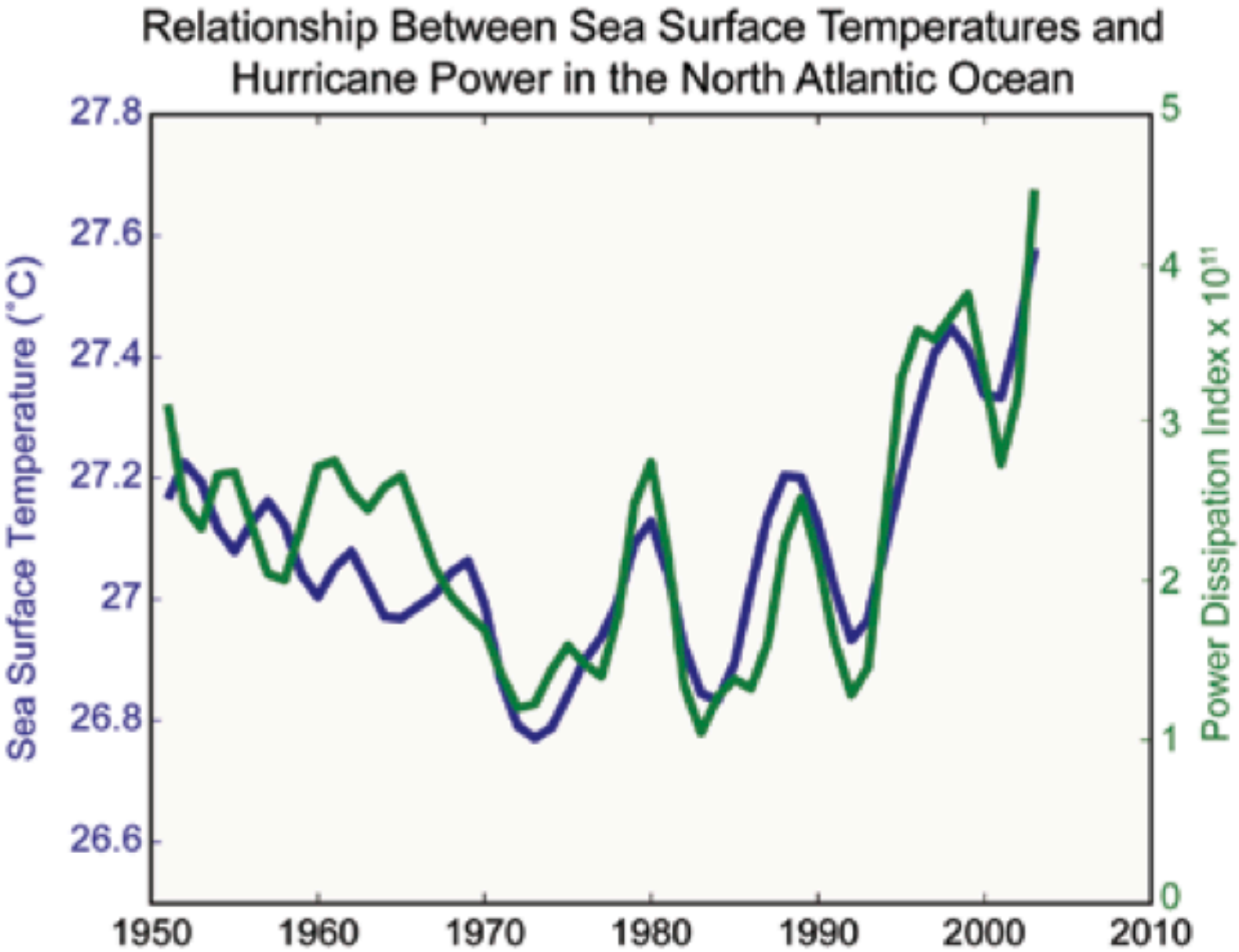
Sea Level Rise raises the water table and salt water intrudes coastal regions.



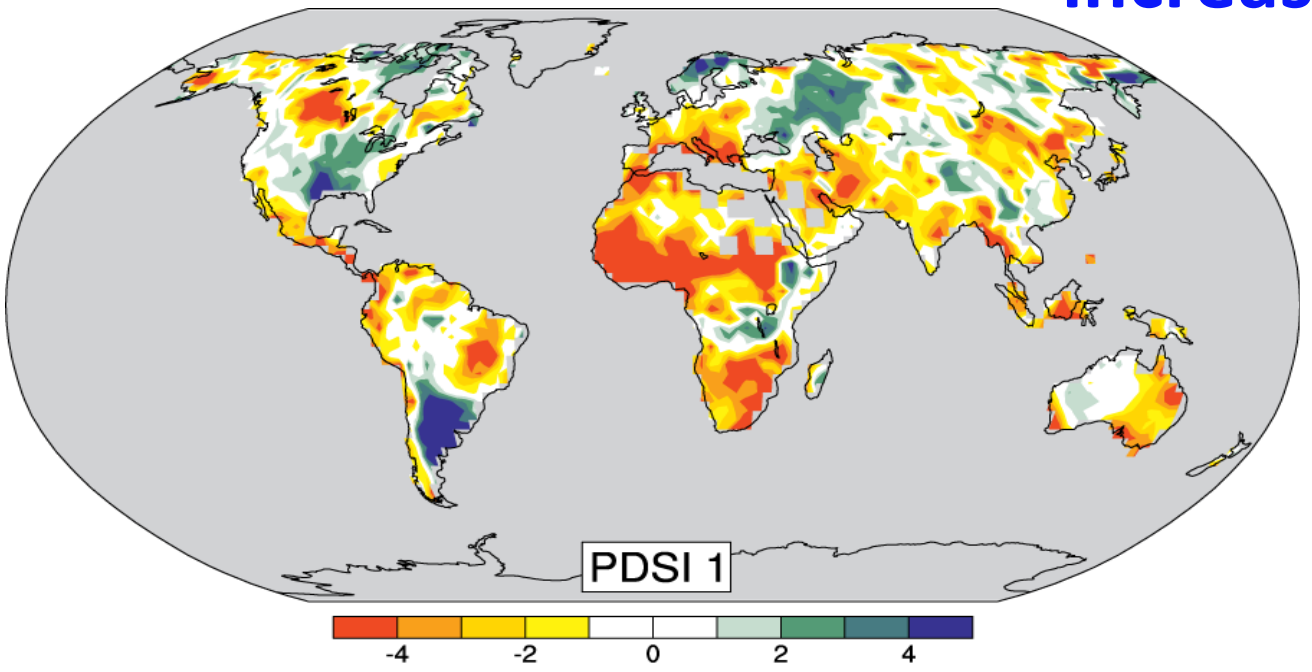
Higher Percent of Category 4 & 5 Hurricanes Worldwide

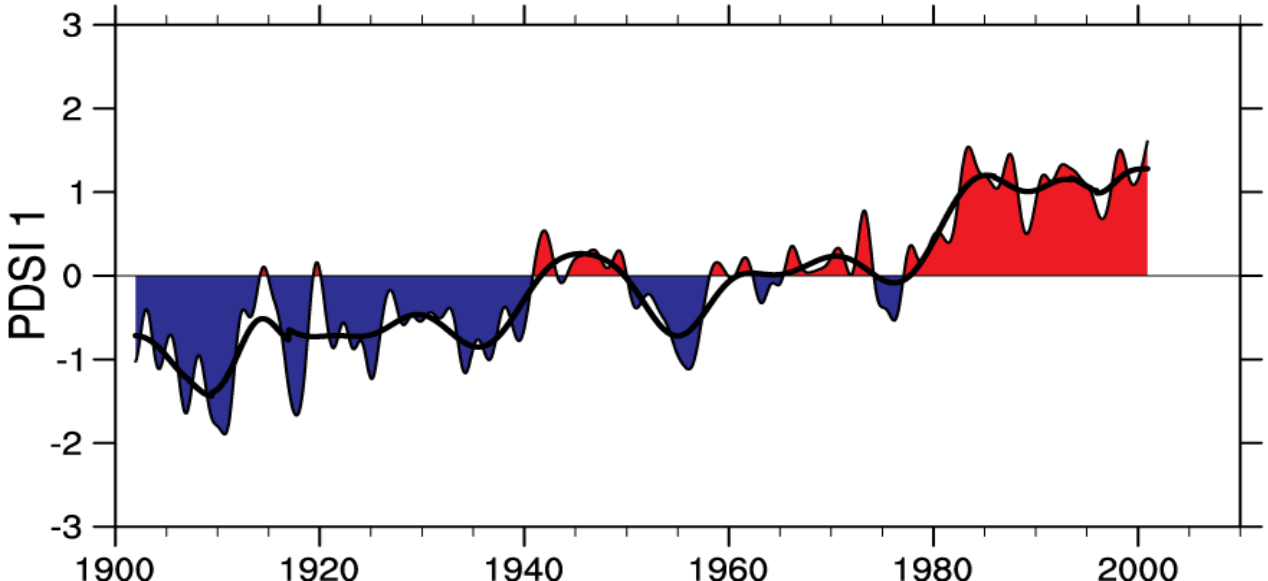


As Oceans Warm, Hurricane Intensity Increases



Drought is increasing most places, increased Evaporation





The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002.

The time series accounts for most of the trend in PDSI.

IPCC AR4

Definition of Drought

Meteorological, Hydrological, Agricultural, Socioeconomic

- **Meteorological Drought** - the degree of net precipitation dryness compared to the average amount and duration of the dry period.

- **Hydrological Drought** - periods of precipitation shortfall on surface or subsurface water supply, rather than with precipitation shortfalls directly.

- **Agricultural Drought** - meteorological and hydrological drought impacts on agriculture (precipitation shortages, soil water deficits, and reduced groundwater or reservoir levels).

- **Socioeconomic Drought** - the supply and demand of an economic good with elements of meteorological, hydrological, and agricultural drought (e.g. crop impacts).

Chinese Dynasties change during every major drought.

Anasazi Pueblo Collapse

Water Wars in the Mid-East

Mass migration in Sahel

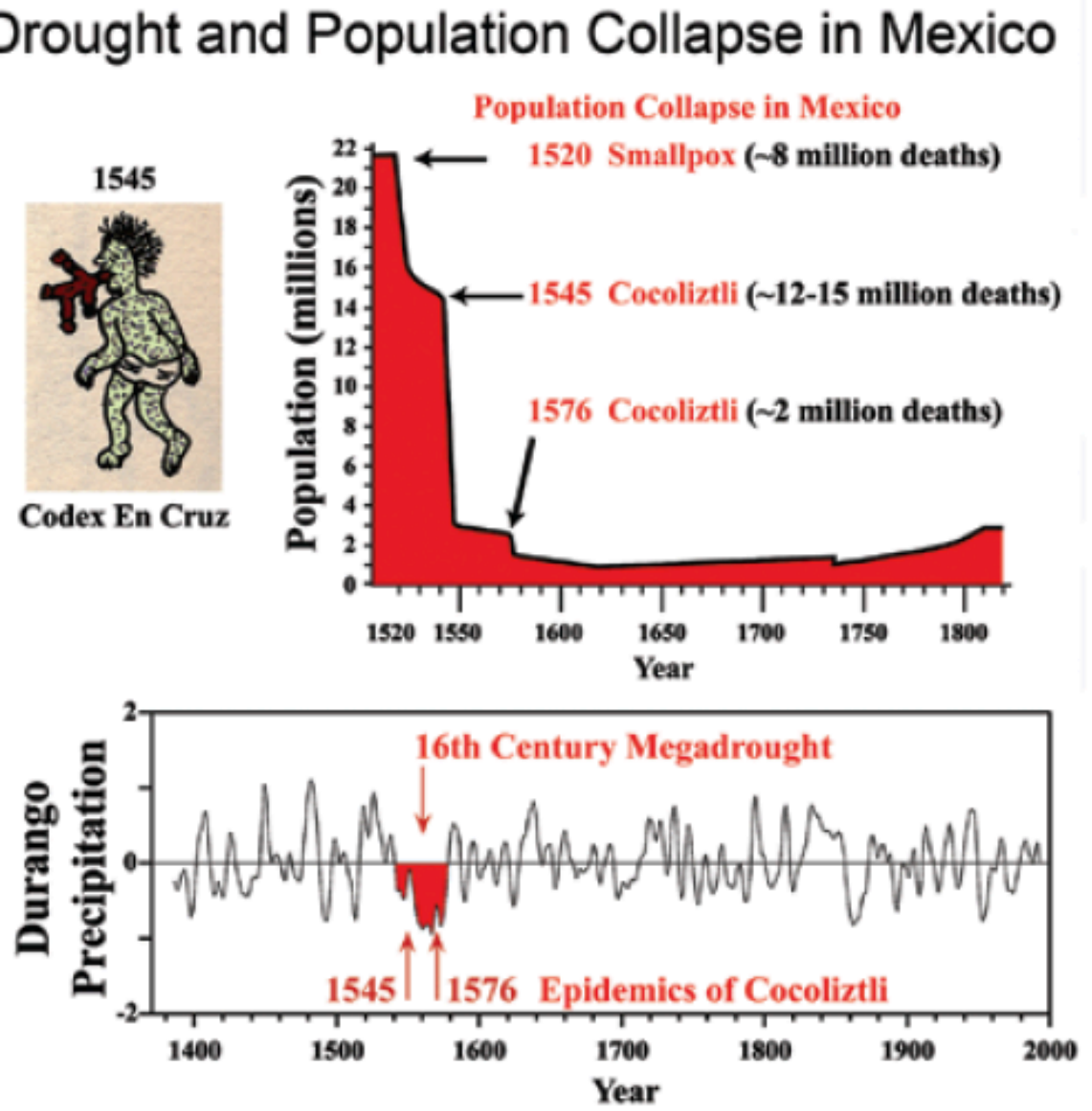
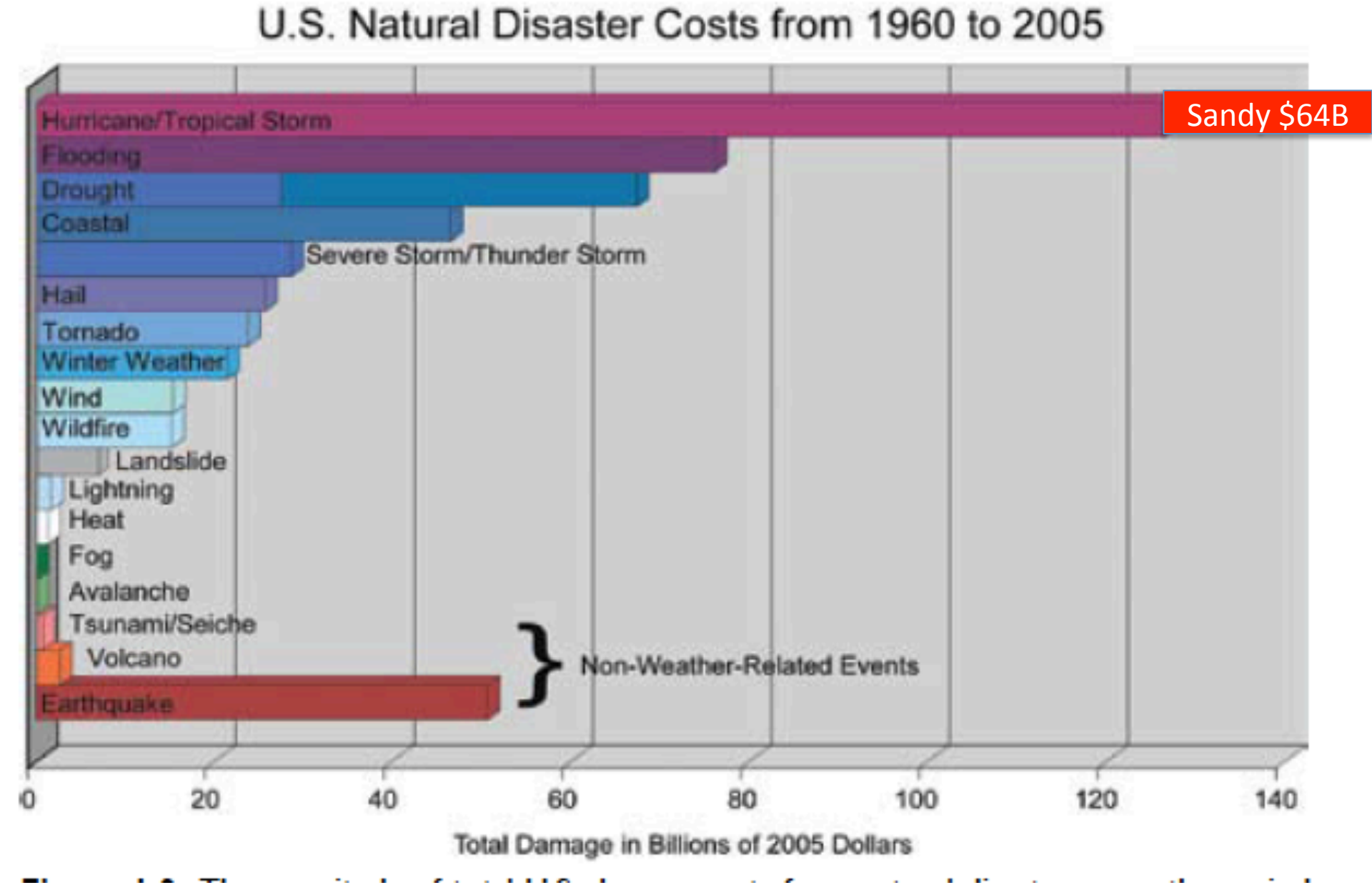
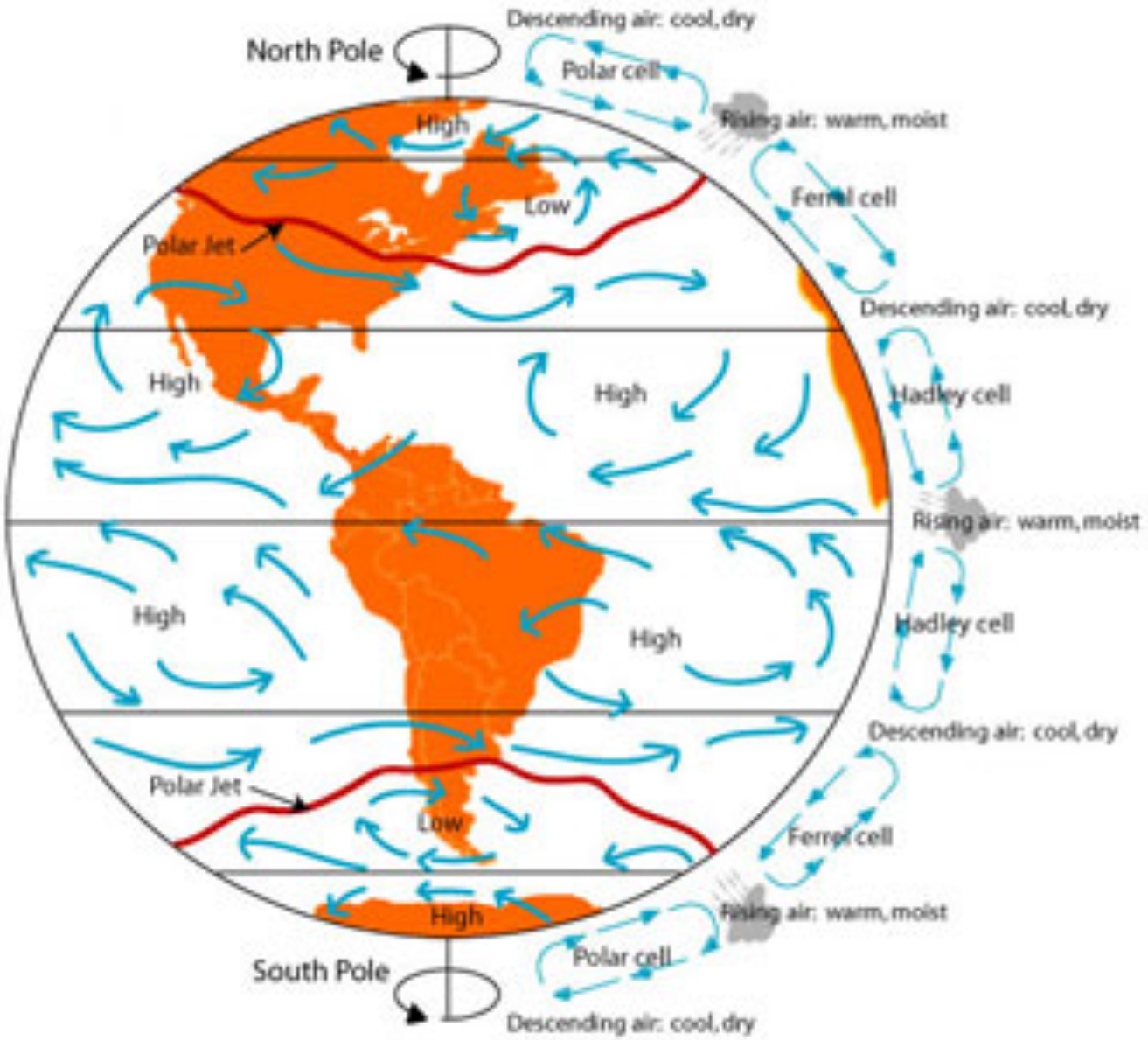


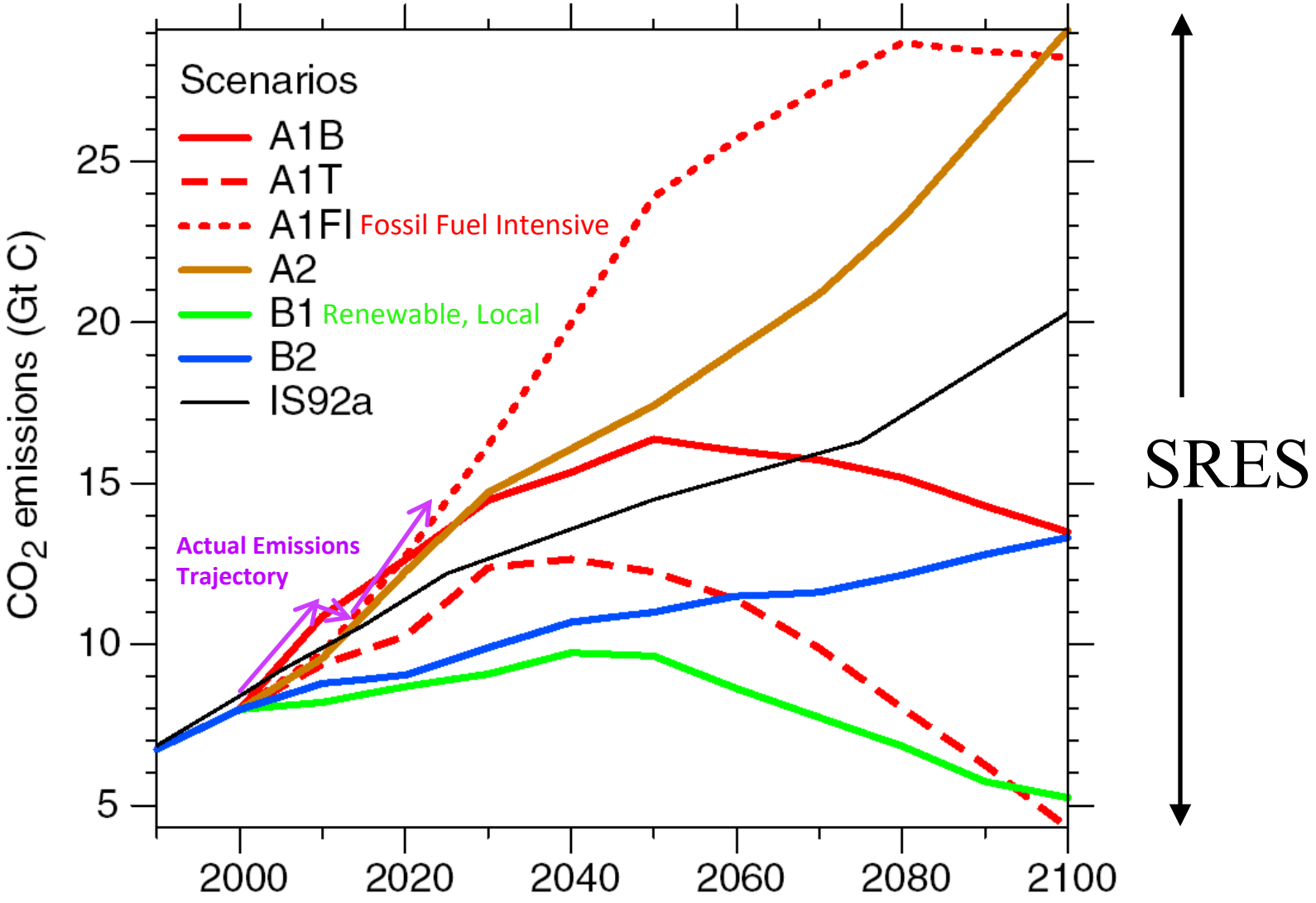
Figure 1.7 Megadrought and megadeath in 16th century Mexico. Four hundred years ago, the Mexican socioeconomic and natural systems were so sensitive to extremes that a megadrought in Mexico led to massive population declines (Acuna-Soto *et al.*, 2002). The 1545 Codex En Cruz depicts the effects of the cocoliztli epidemic, which has symptoms similar to rodent-borne hantavirus hemorrhagic fever.


U.S. Natural Disaster Costs from 1960 to 2005
Sandy $64B
Hurricane/Tropical Storm
Flooding
Drought
Coastal
Severe Storm/Thunder Storm
Hail
Tornado
Winter Weather
Wind
Wildfire
Landslide
Lightning
Heat
Fog
Avalanche
Tsunami/Seiche
Volcano
Earthquake
Non-Weather-Related Events
0
20
40
60
80
100
120
140
Total Damage in Billions of 2005 Dollars

Climate Change

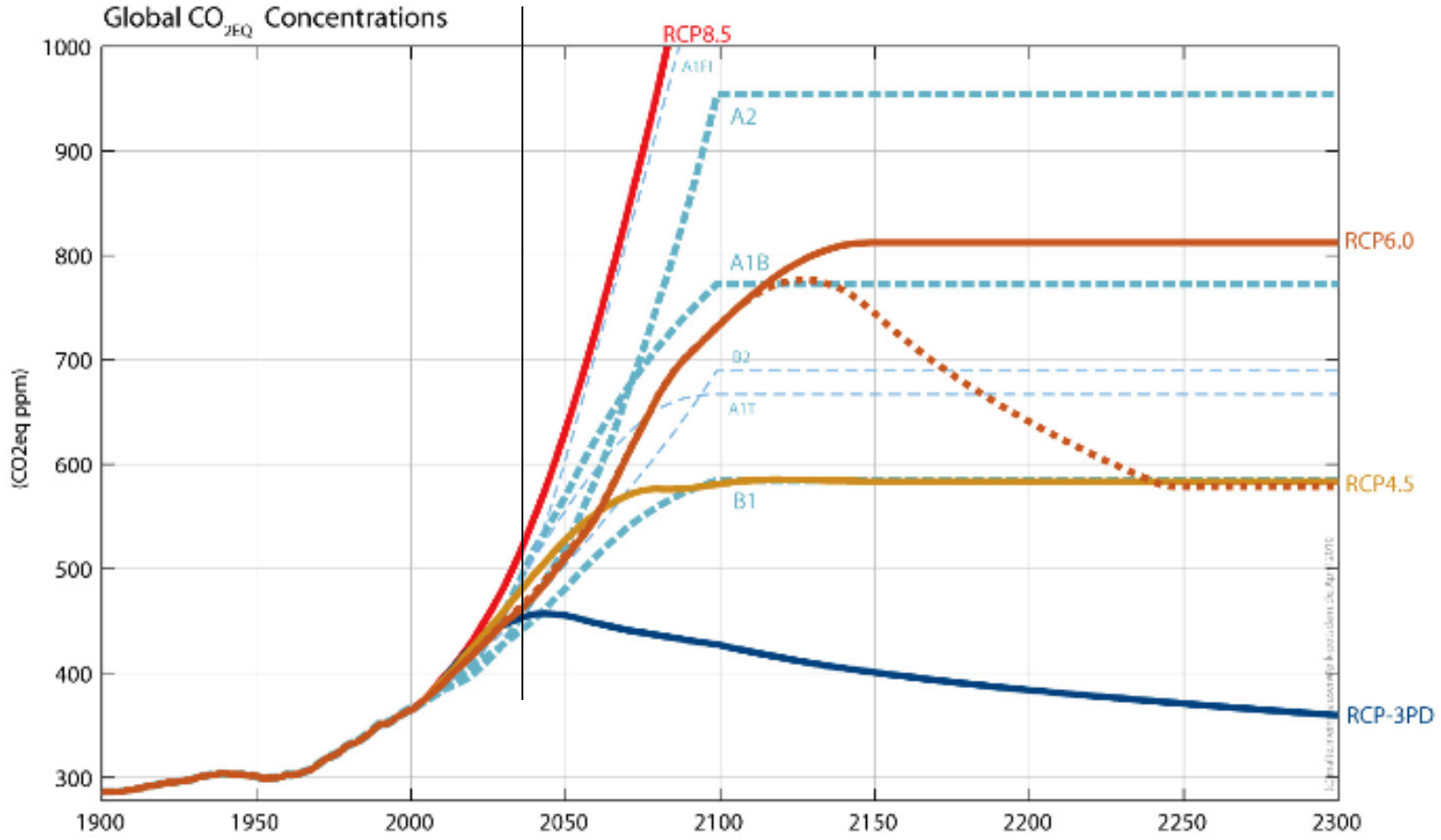


Intergovernmental Panel for Climate Change
Special Report on Emissions Scenarios



Representative Concentration Pathways replace SRES

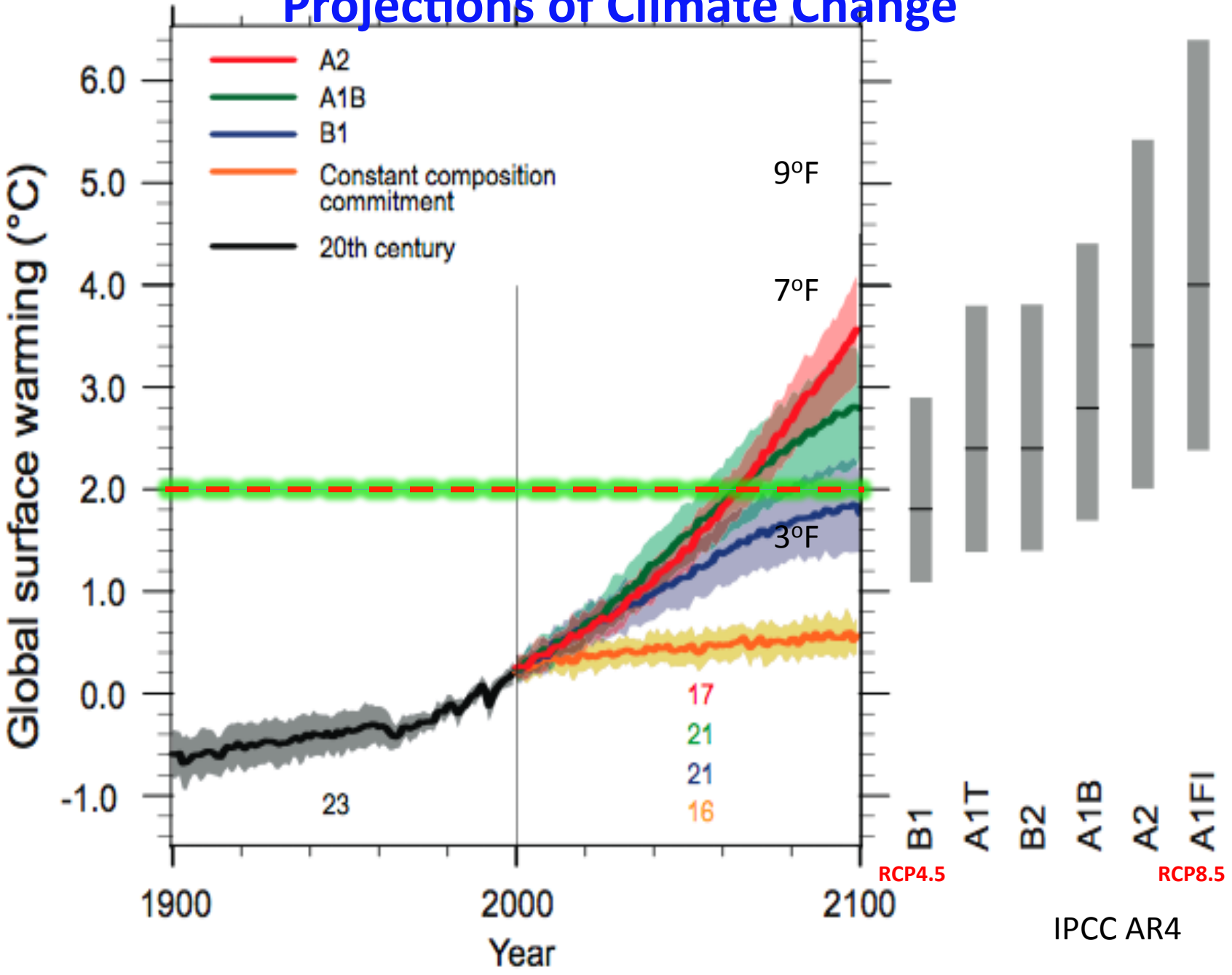
CO_2-eq Concentrations for the RCPs



From Malte Meinshausen

ipcc AR5
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Projections of Climate Change

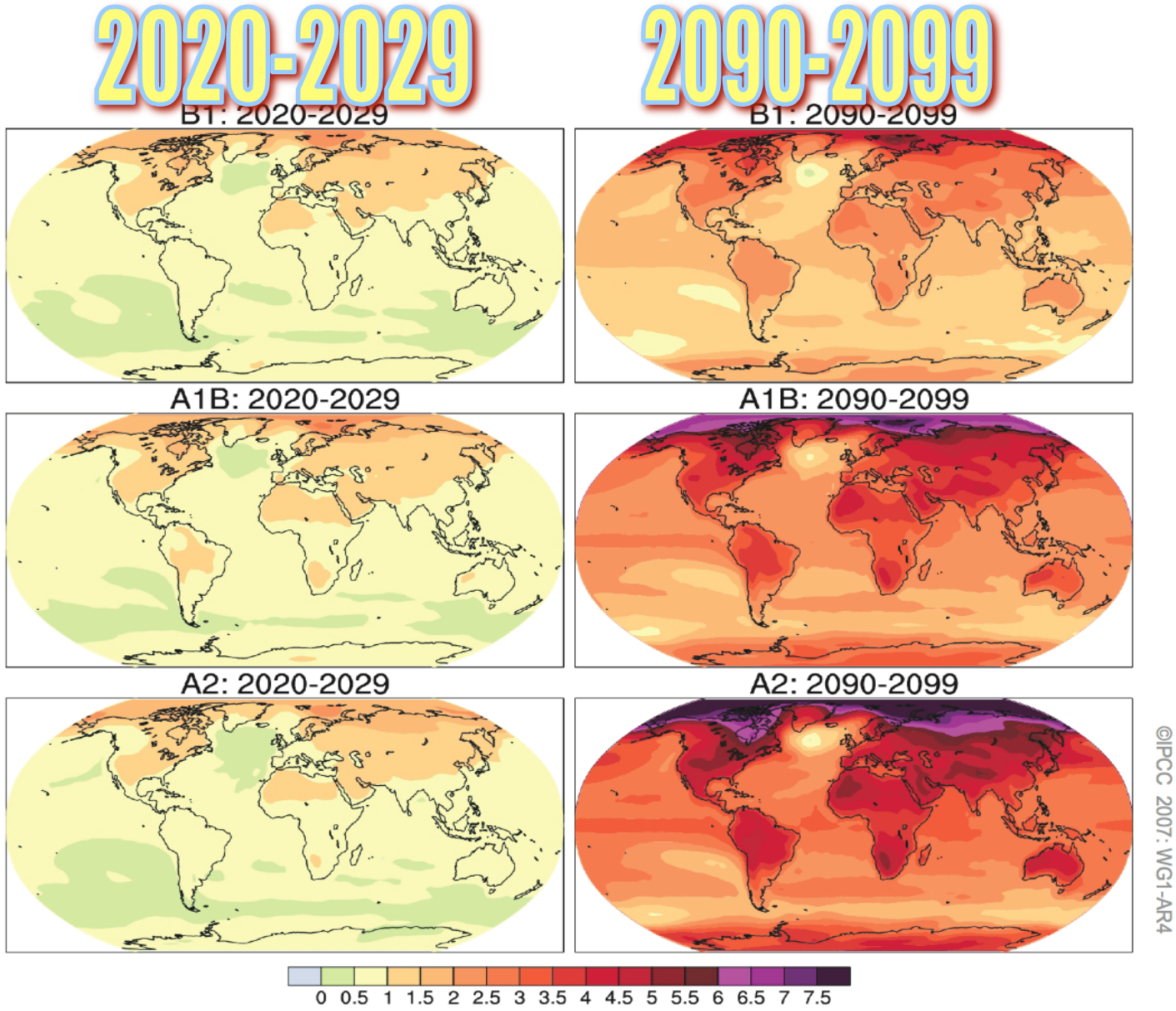


Projections of Climate Change

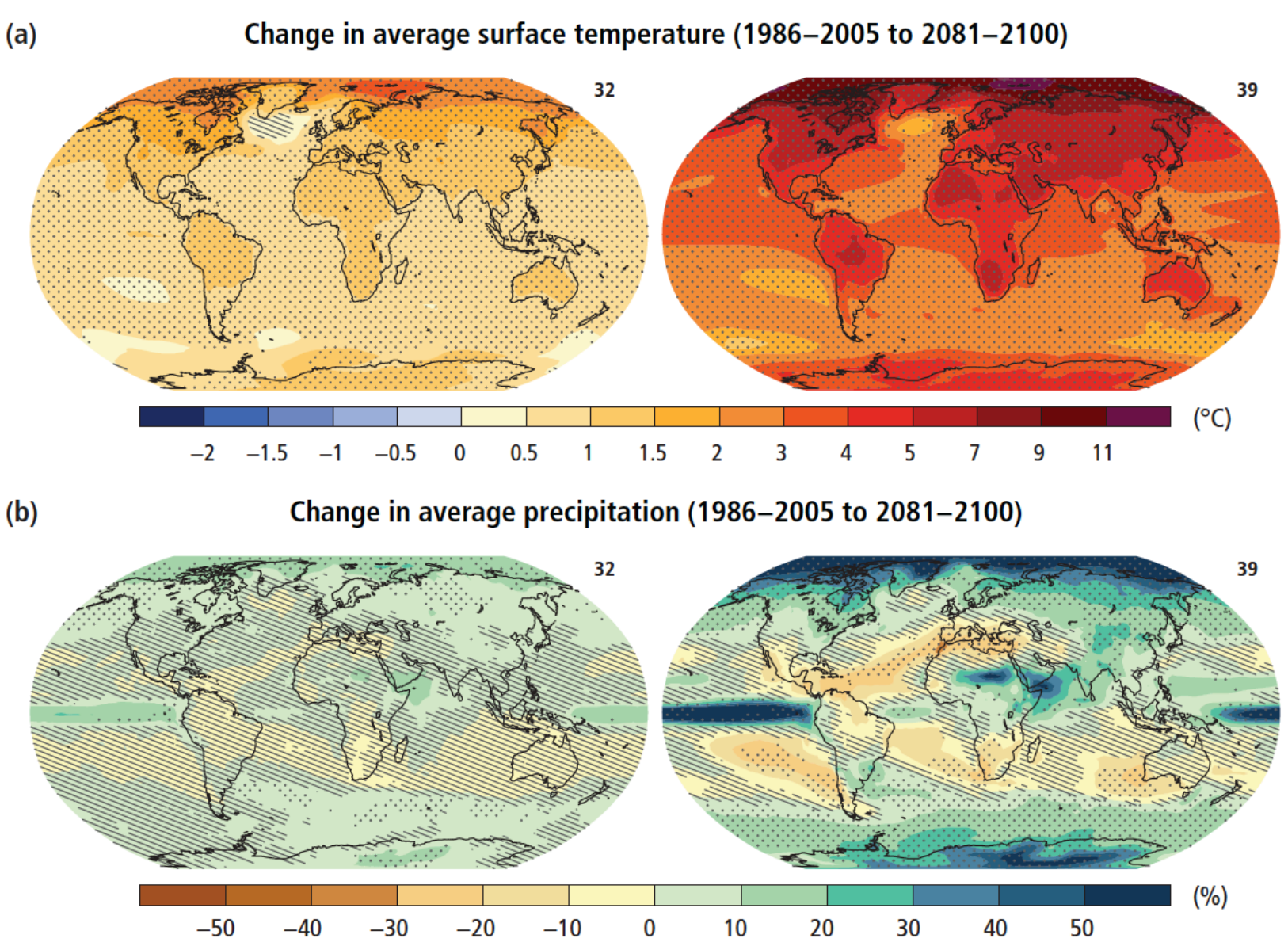
greatest over land &
at most high
Northern latitudes

and

least over the
Southern Ocean
& parts of the
North Atlantic



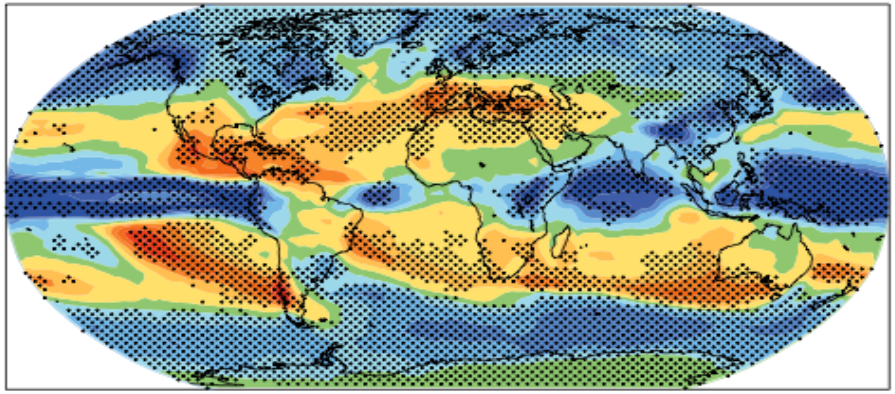
IPCC AR4


RCP2.6
RCP8.5
(a)
Change in average surface temperature (1986–2005 to 2081–2100)
32
39
(°C)
–2 –1.5 –1 –0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(b)
Change in average precipitation (1986–2005 to 2081–2100)
32
39
(%)
–50 –40 –30 –20 –10 0 10 20 30 40 50

As Warming Continues the Sub-Tropics and Mid-Latitudes Dry and Evaporation Increases Everywhere

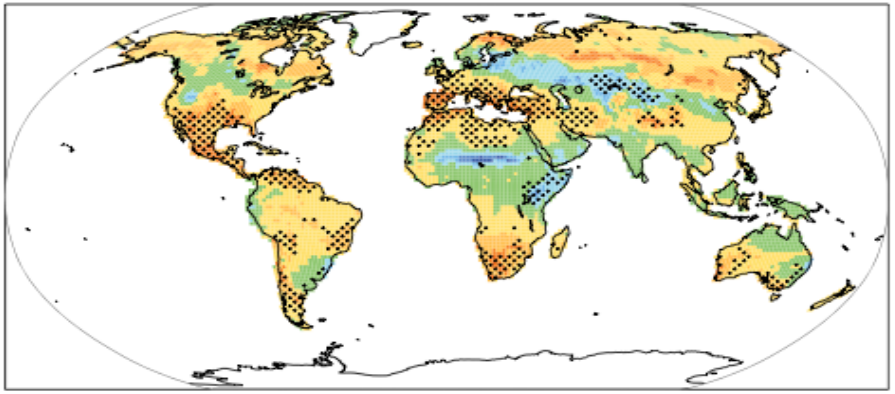
Stippled Regions are where 80% of IPCC Models Agree

a) Precipitation



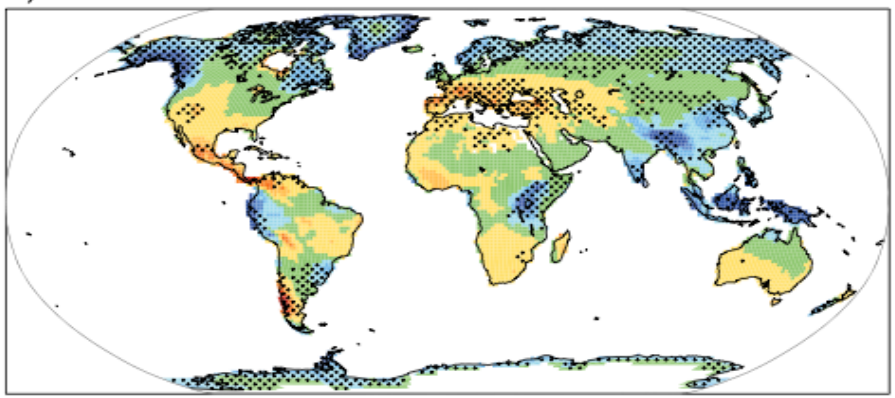
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 (mm day^{-1})

b) Soil moisture



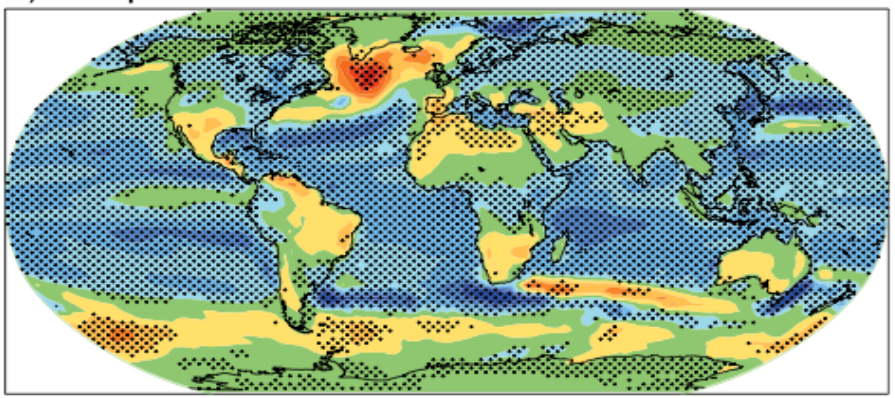
-25 -20 -15 -10 -5 0 5 10 15 20 25 (%)

c) Runoff



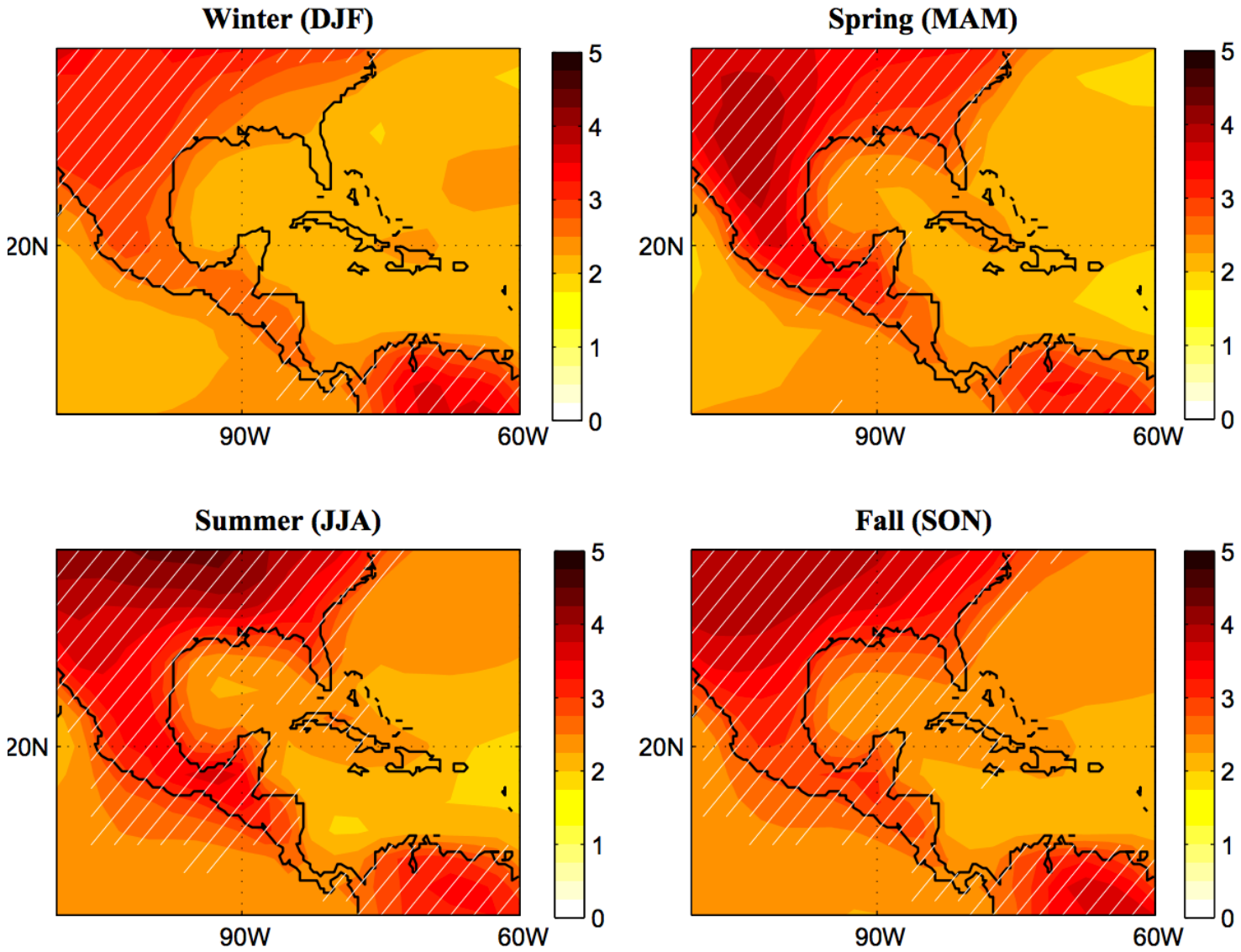
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 (mm day^{-1})

d) Evaporation



-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 (mm day^{-1})

Nine-Model Mean Temperature Change
A1B (2075-2099) minus 20C (1975-1999)
Puerto Rico ~ 2.5°C Increase

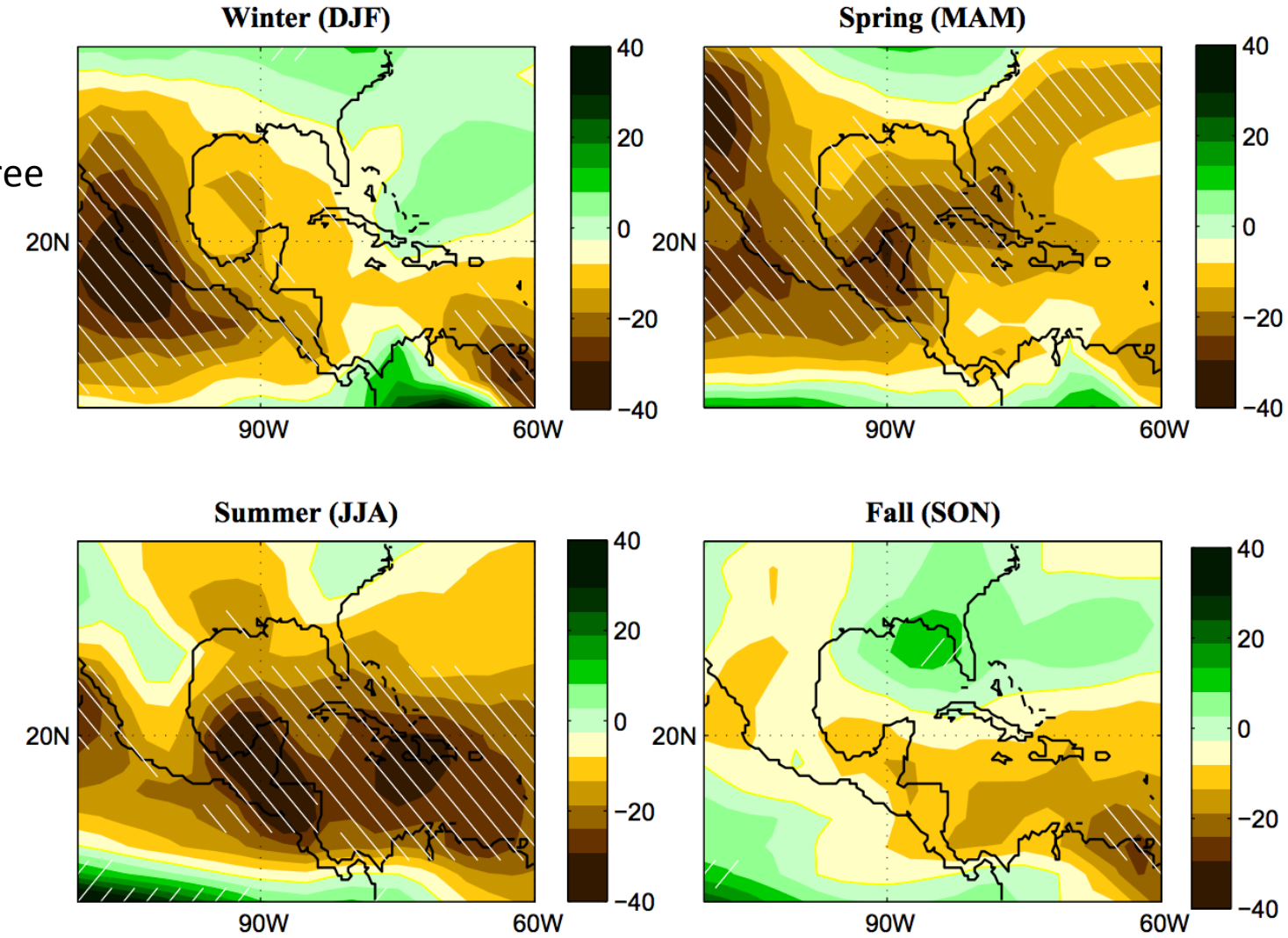


Nine-Model Mean Temperature Change

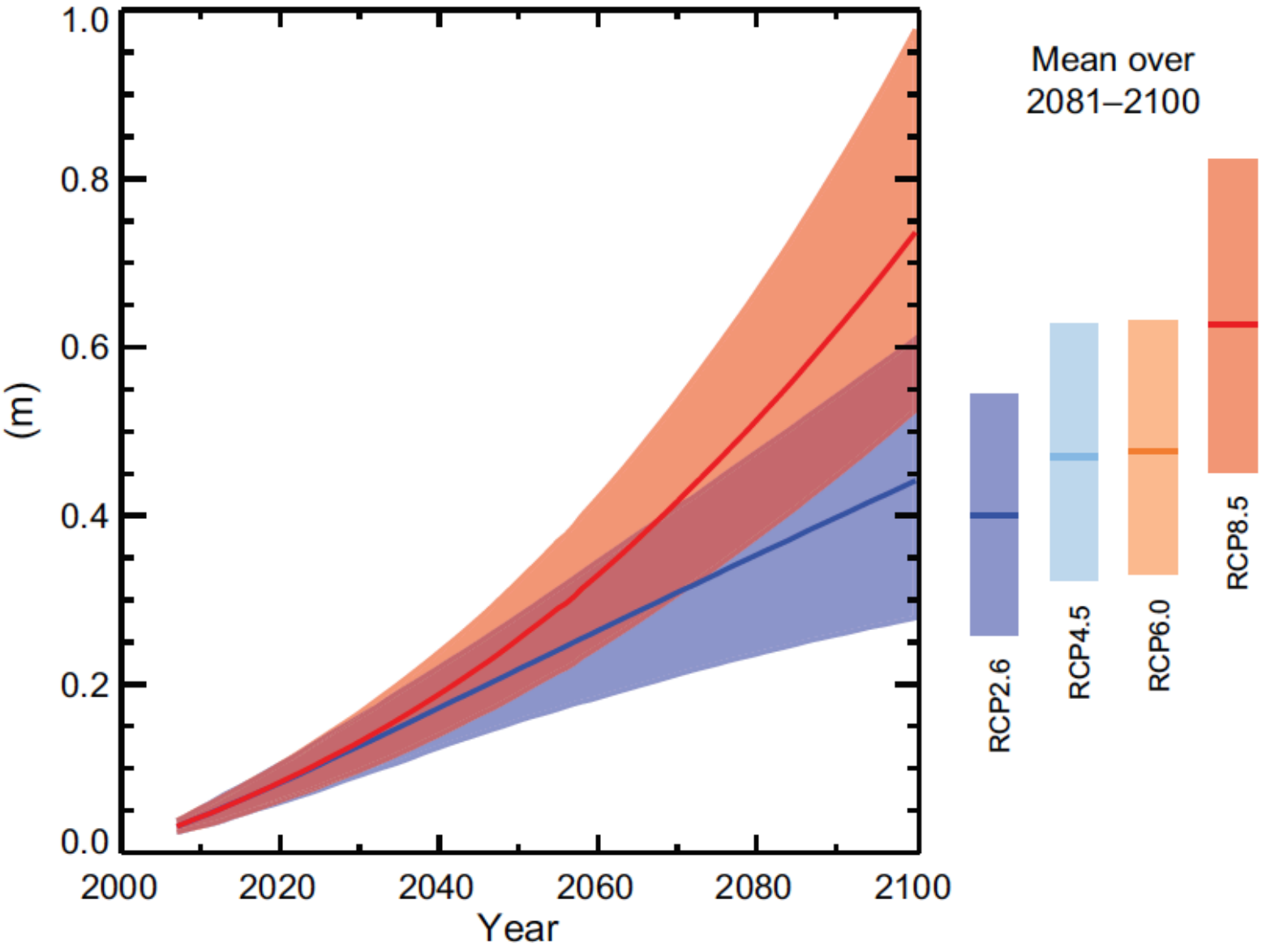
A1B (2075-2099) minus 20C (1975-1999)

Puerto Rico ~ 10-15% decrease

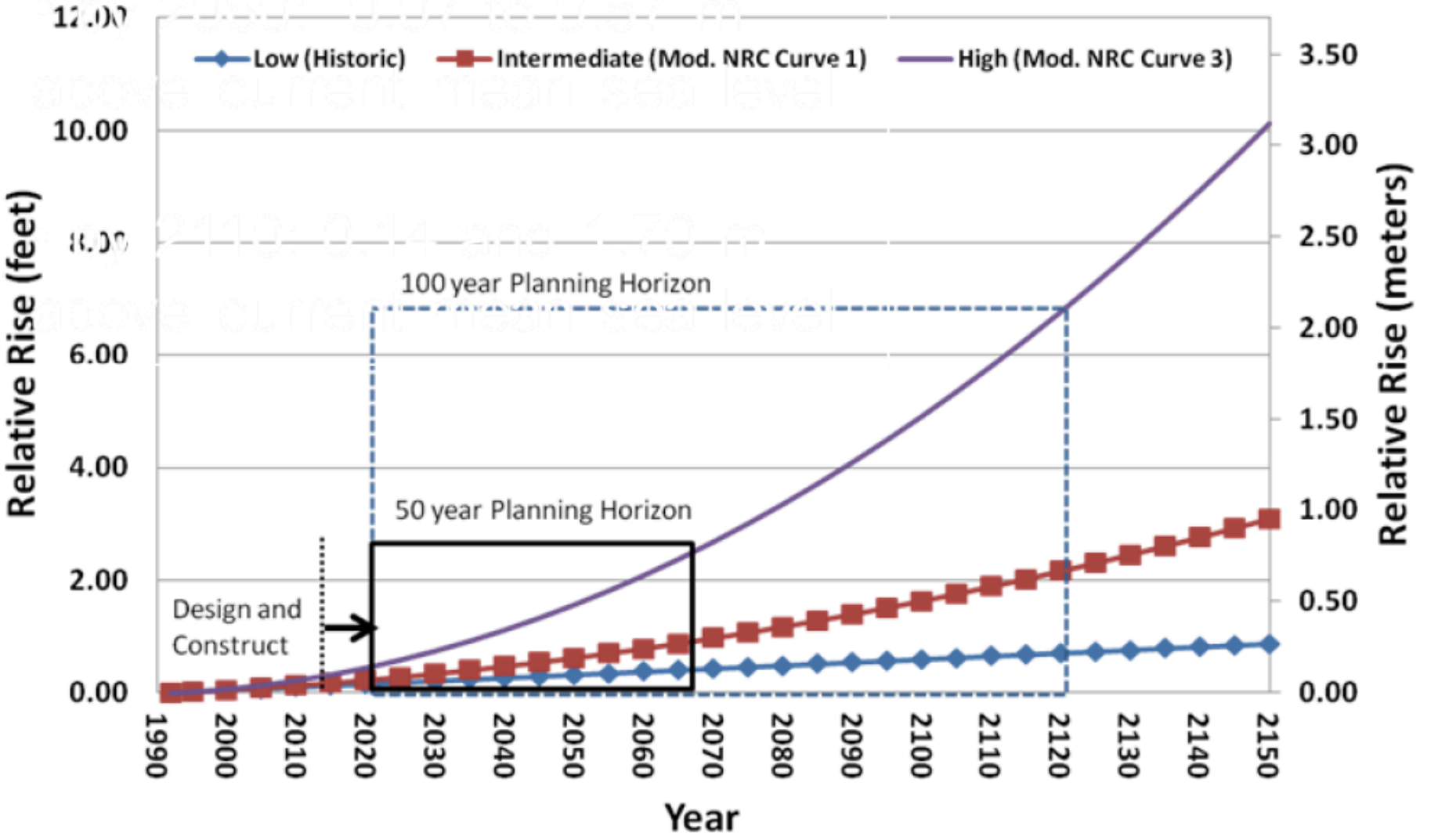
Hatching:
75% of
models agree



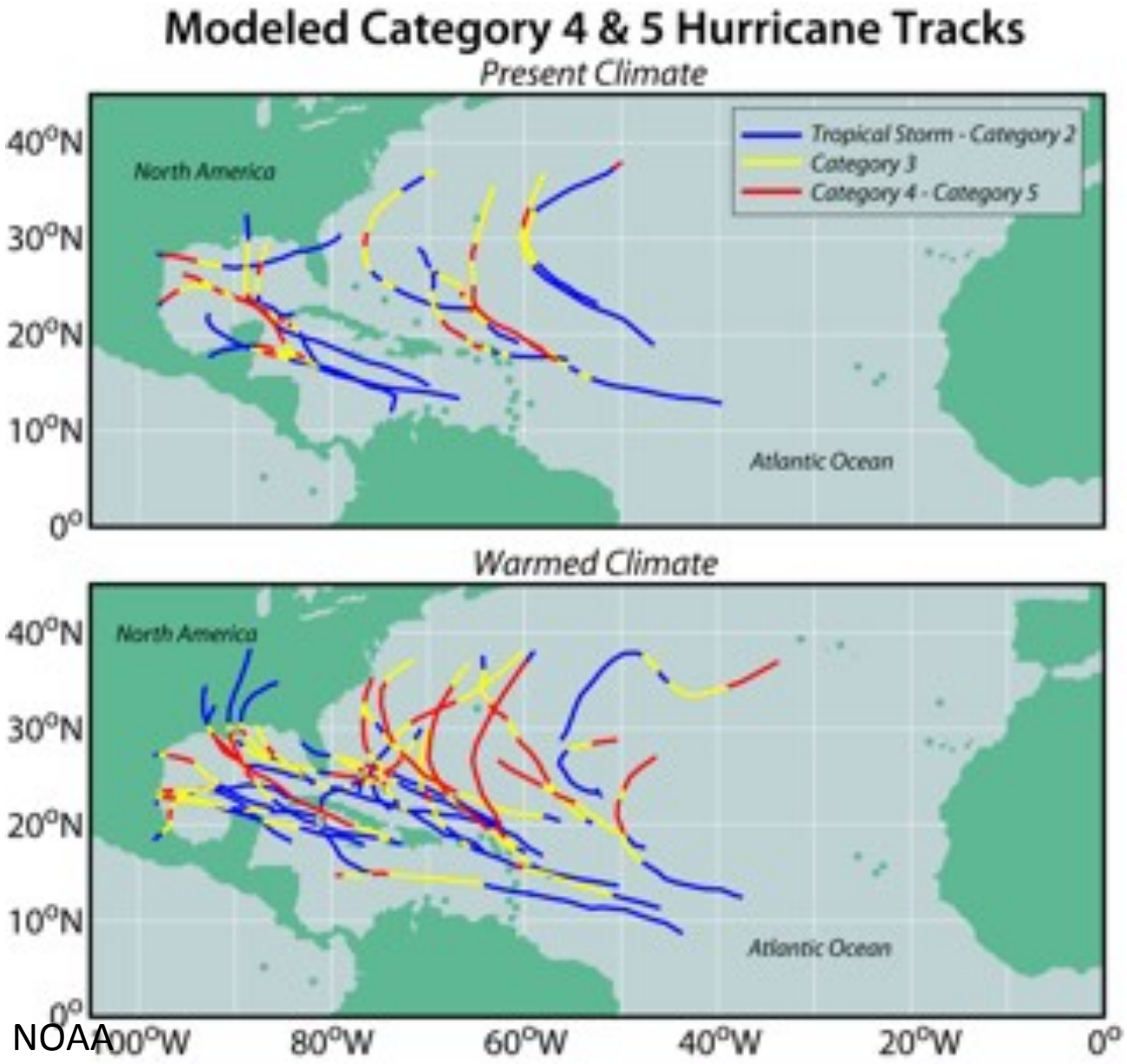
Global Mean Sea Level Rise
(Greenland and Antarctic Calving are not considered)



U.S. Army Corps of Engineers EC 1165-2-212
Relative Sea Level Rise Scenarios for San Juan, PR



There will be more Intense Hurricanes



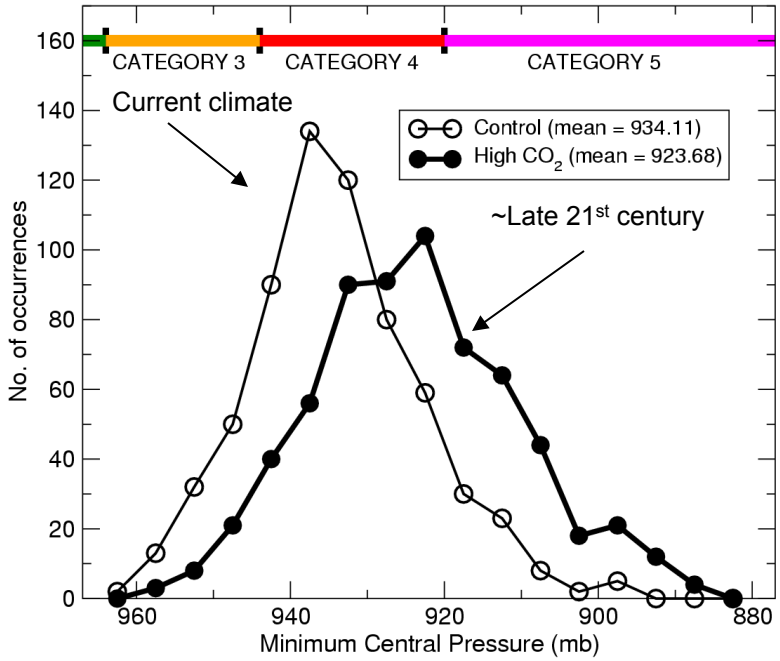
Source: NOAA

Hurricane models project increasing hurricane intensities and rainfall rates with climate warming…
…but the occurence of hurricanes may decrease.

Hurricane Intensity

Idealized hurricane simulations

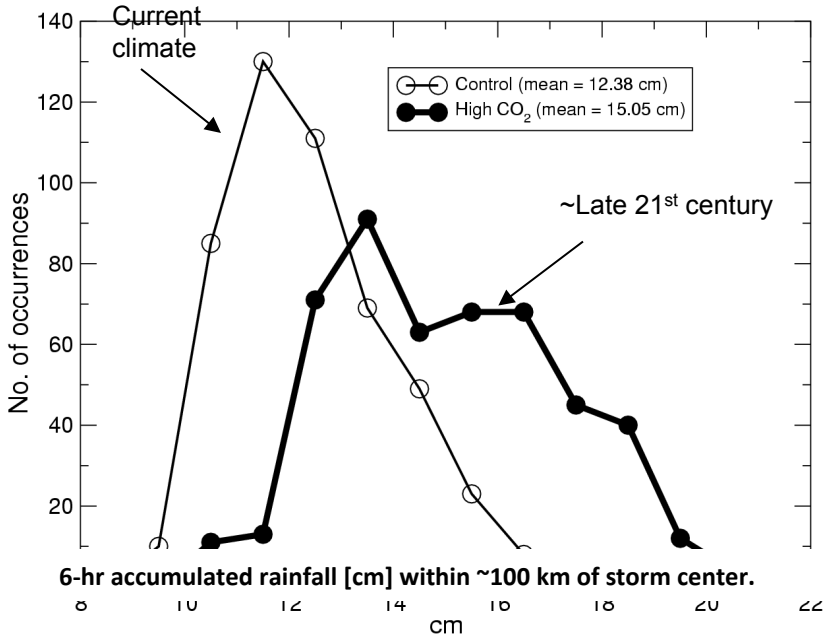
Aggregate results: 9 GCMs, 3 basins, 4 parameterizations, 6-member ensembles



Sensitivity: ~4% increase in wind speed per °C SST increase

Hurricane Rainfall Rates

6-hour accumulated near-storm rainfall

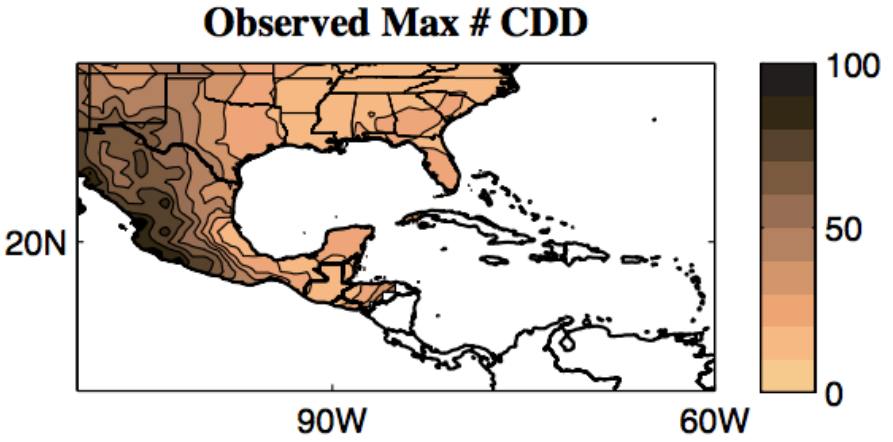


Sensitivity: ~12% increase in near-storm rainfall per °C SST increase

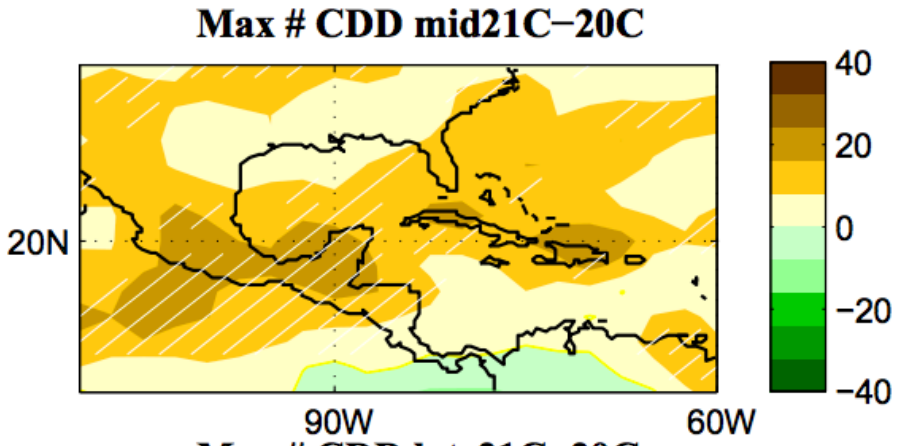
Sources: Knutson and Tuleya, *J. Climate*, 2004 (left); Knutson and Tuleya (2008) Cambridge Univ Press (right).
See also Bengtsson et al. (*Tellus* 2007) and Oouchi et (*J. Meteor. Soc. Japan,* 2006); Walsh et al. (2004) Stowasser et al. (2007).

More Dry Days

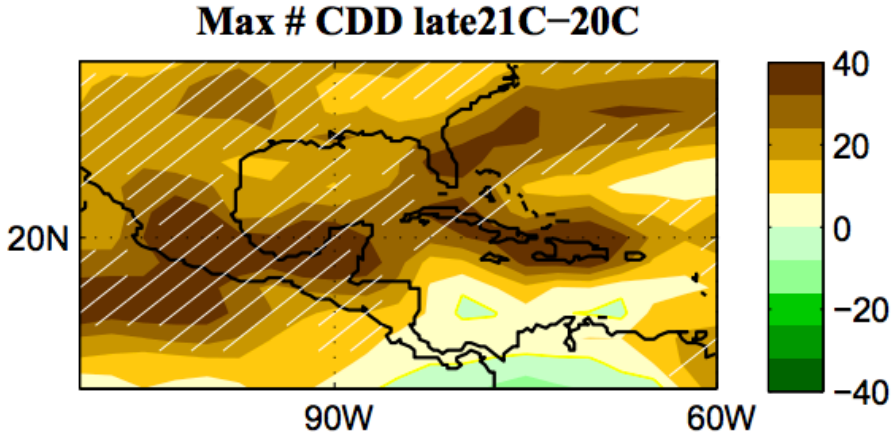
Observed number of dry days
1961-1990



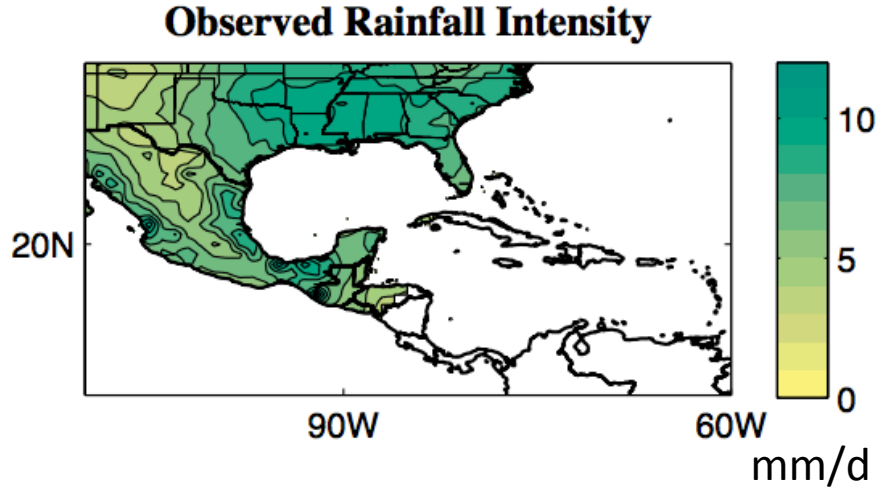
9-model mean projected dry days
2020-2049. ~20 day increase



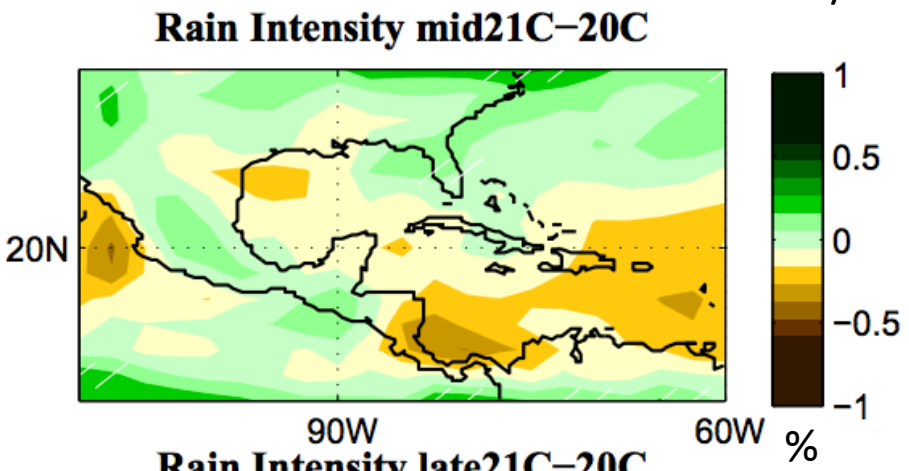
9-model mean projected dry days
2070-2099. ~30 day increase



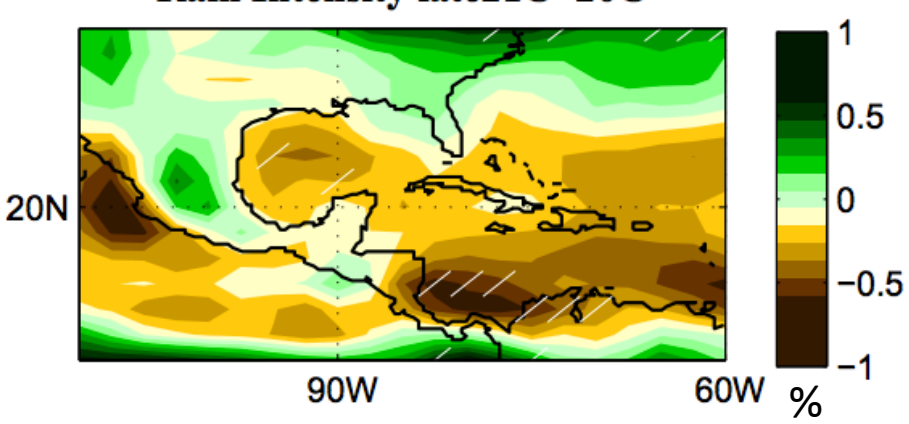
Observed and Model-Projected Rain Intensity



9-model mean projected dry days
2020-2049. PR decrease ~15%

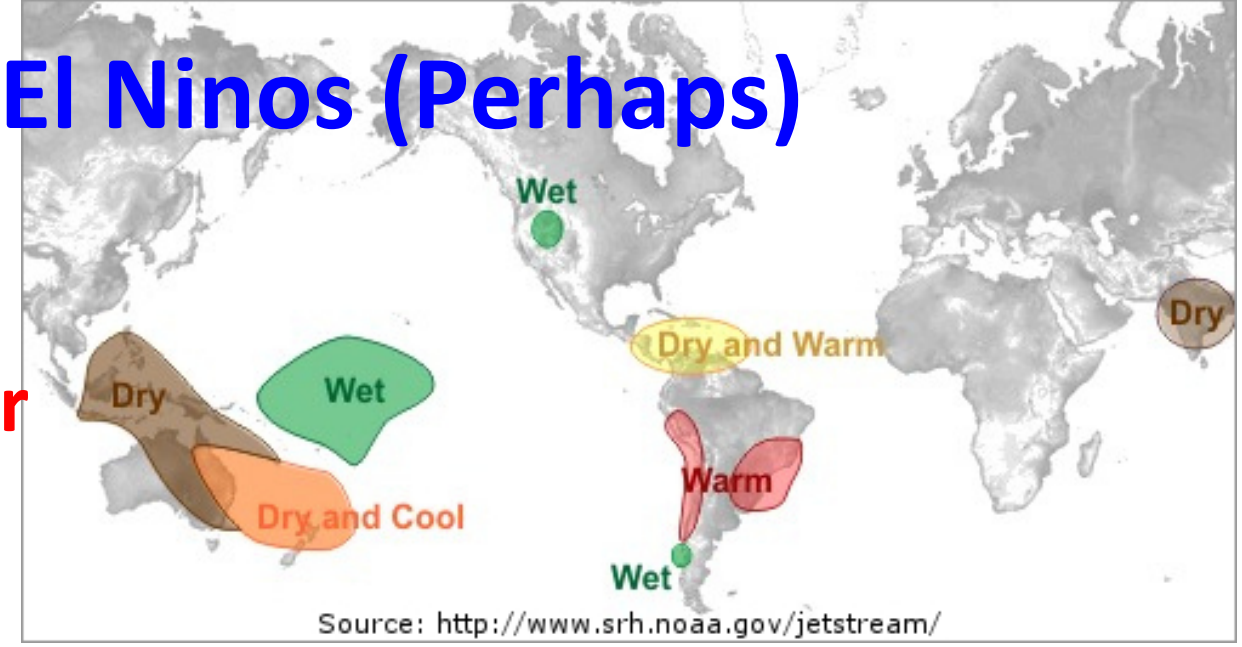


9-model mean projected dry days
2070-2099. PR decrease ~30%

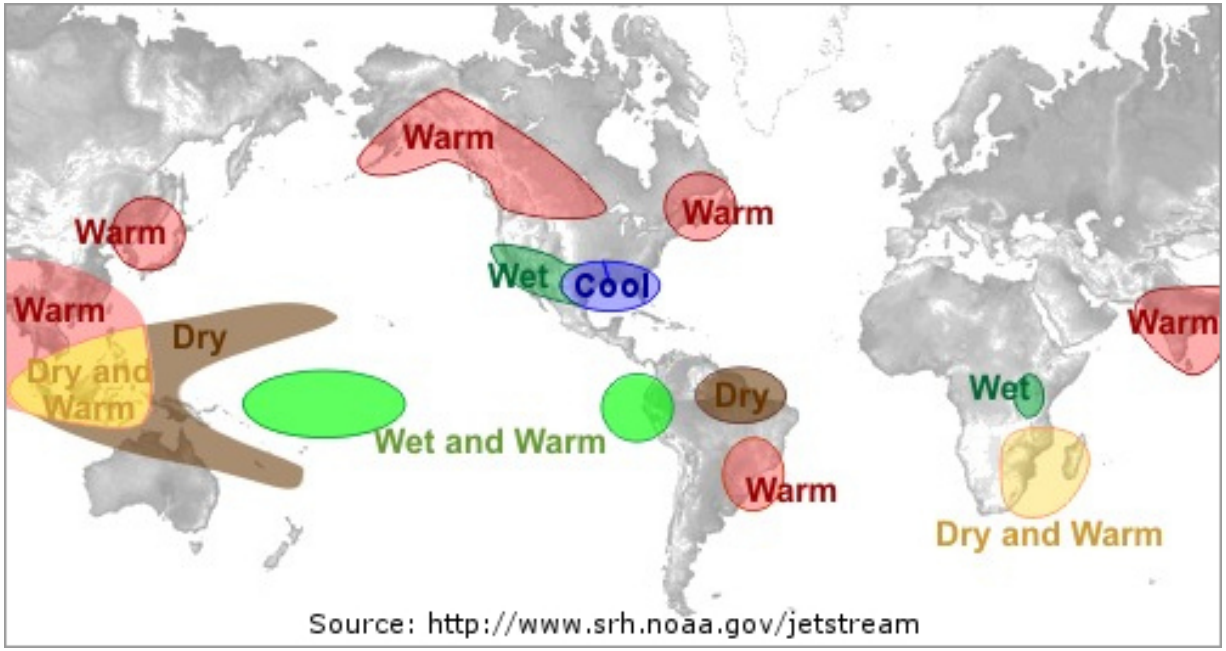


More El Ninos (Perhaps)

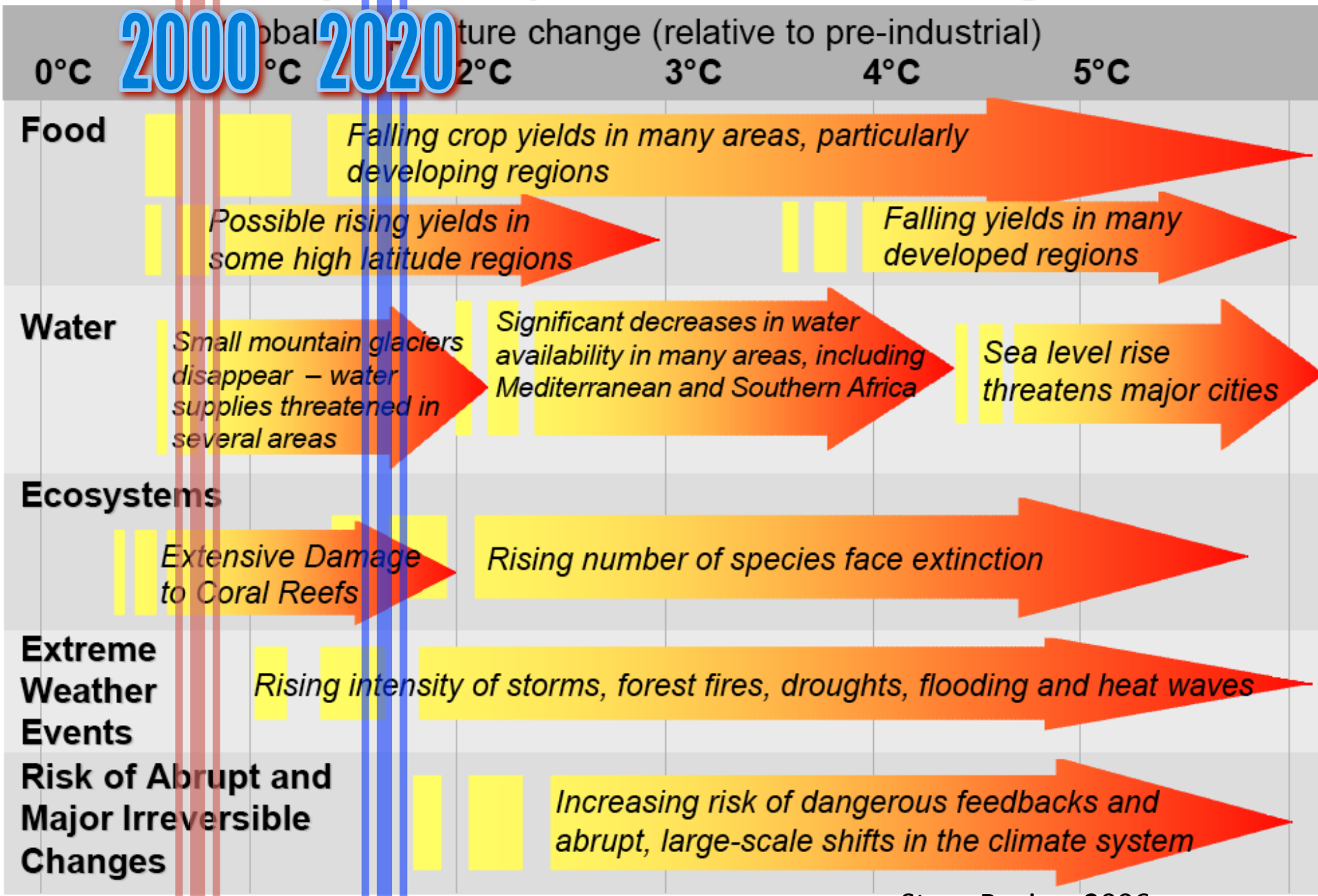
Summer



Winter



Projected Impacts of Climate Change



Stern Review 2006