Climate Science and Global Climate Change

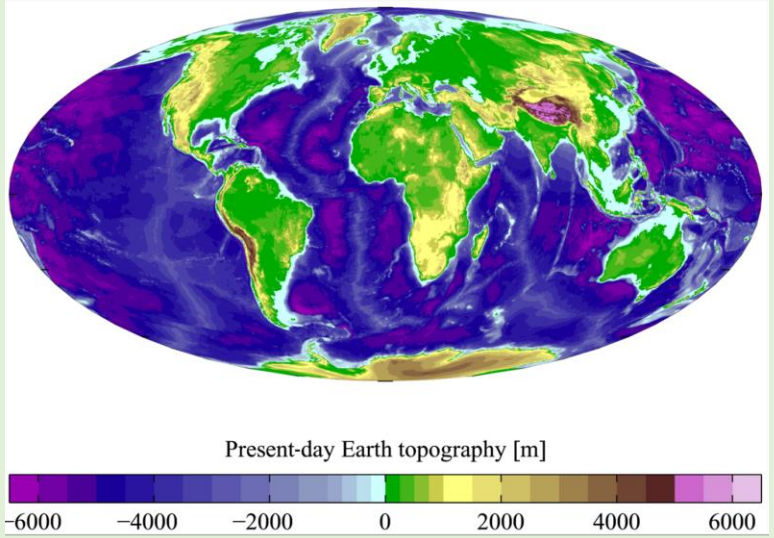
Session 4- *System Earth*

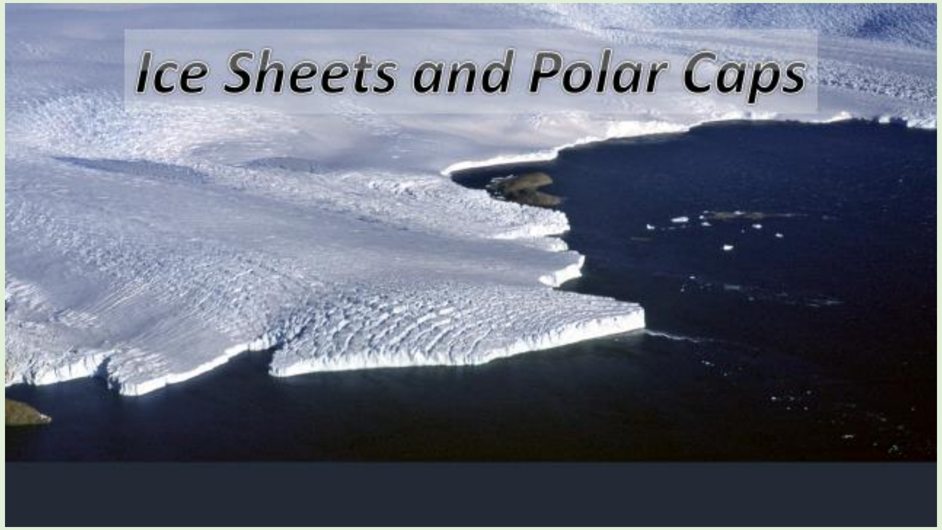
- The climate system
- Climate modeling
- Climate statistics
- *IPCC*
- Evidence of global warming
- *Future climate*

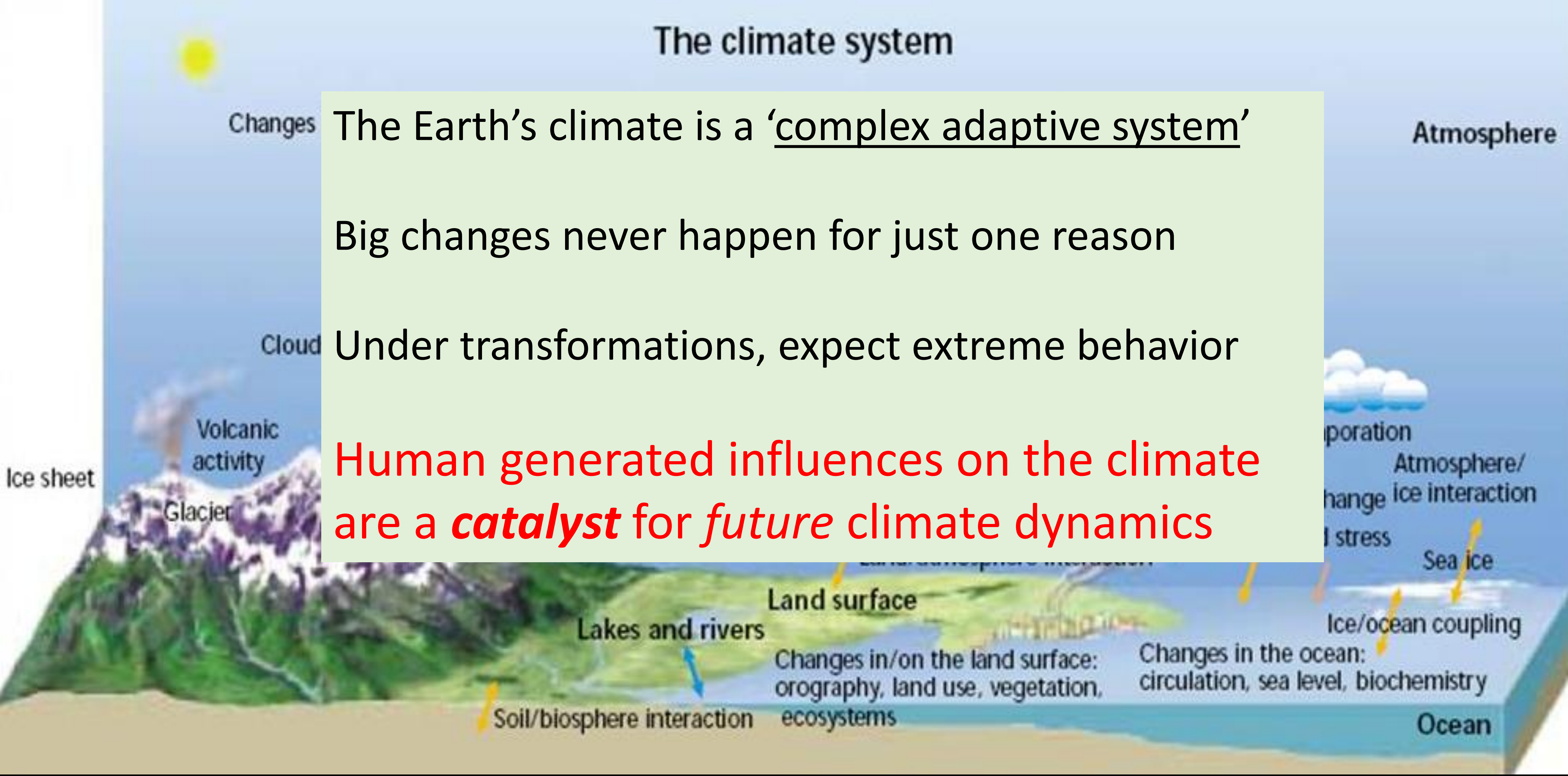
Spring 2018
Univ. of Arizona OLLI
Lockwood Carlson PhD

Our vision of a linear world

Earth's Landmasses





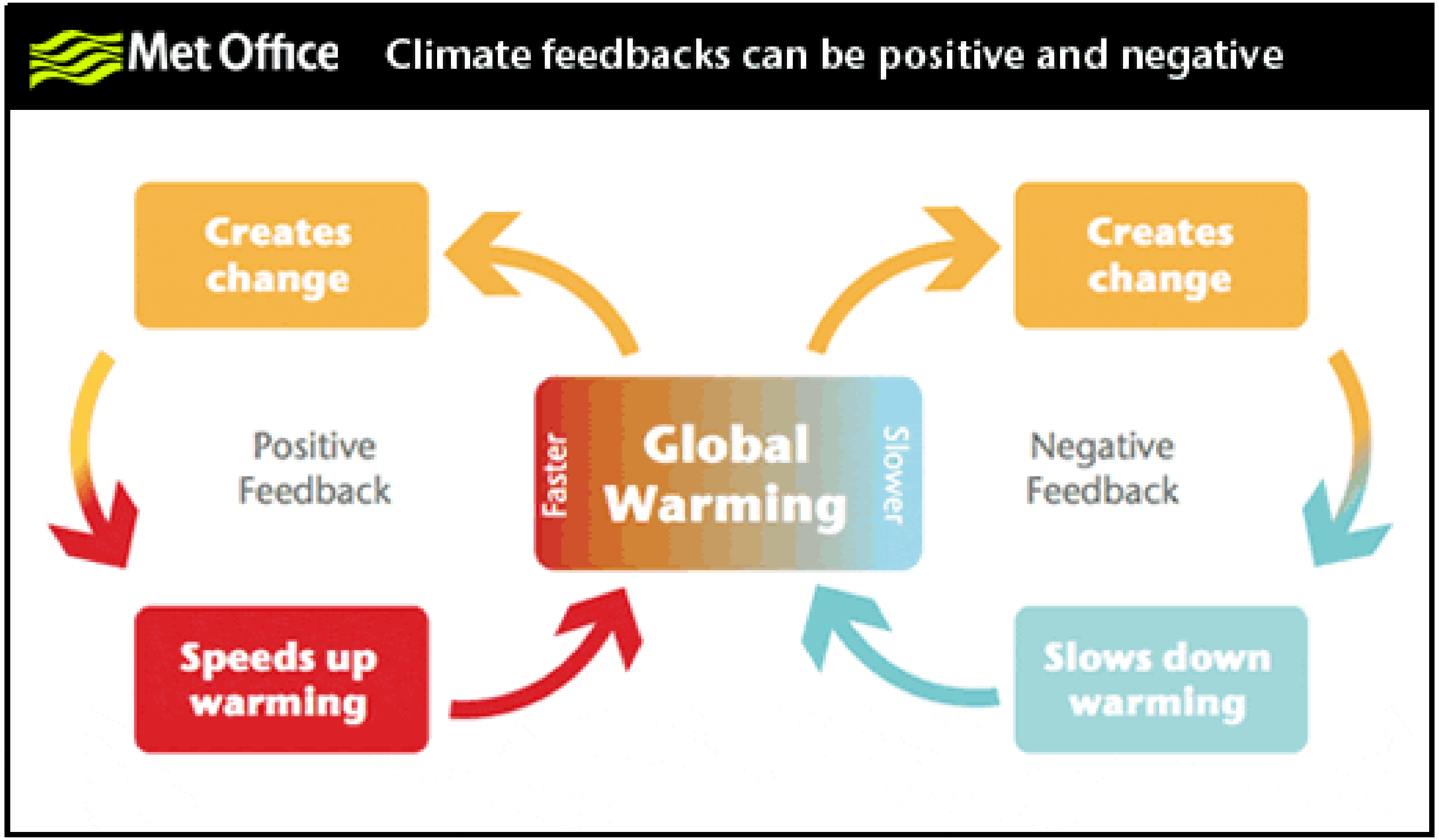


The Earth's climate is a 'complex adaptive system'

Big changes never happen for just one reason

Under transformations, expect extreme behavior

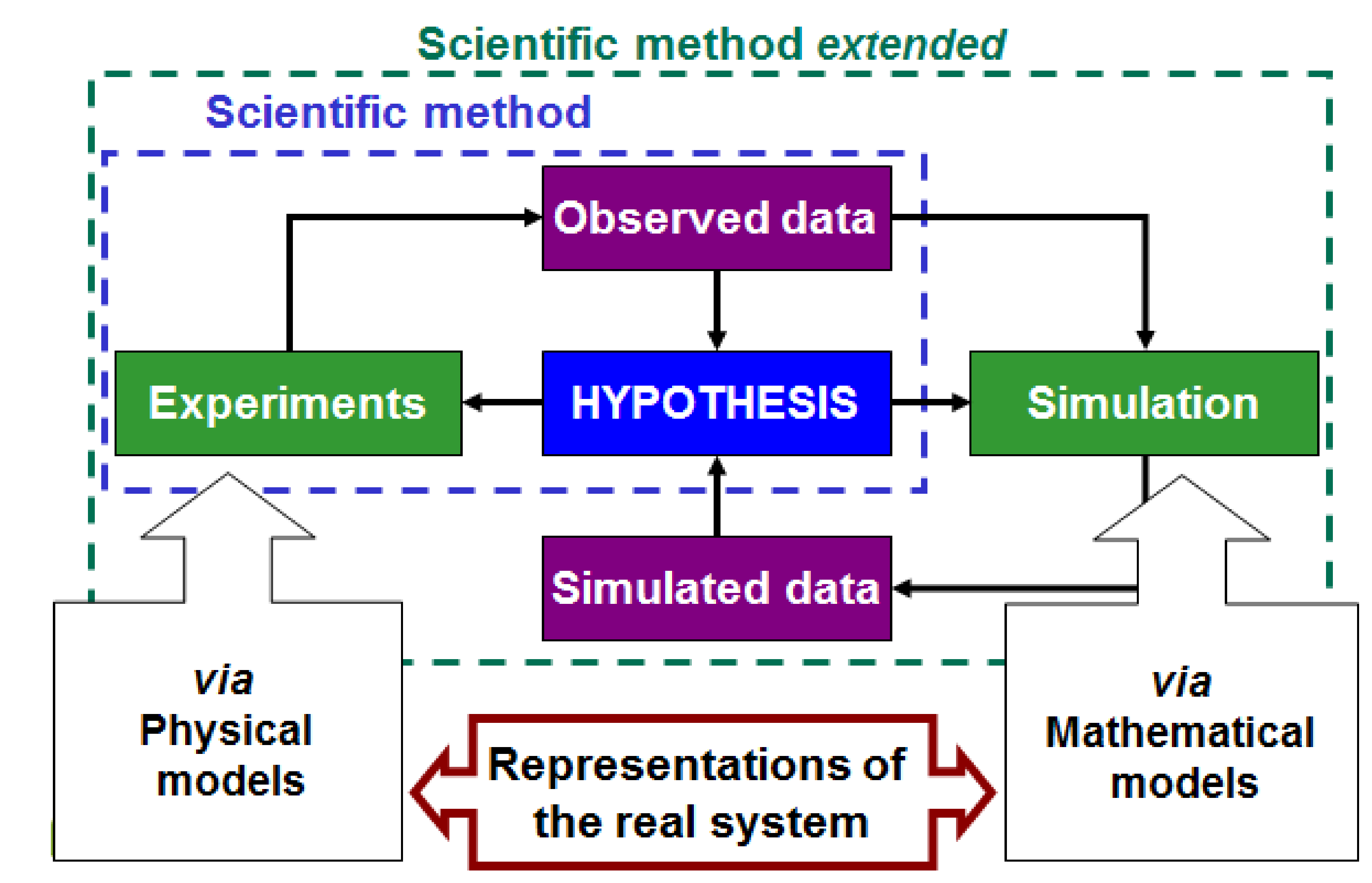
Human generated influences on the climate are a ***catalyst*** for *future* climate dynamics

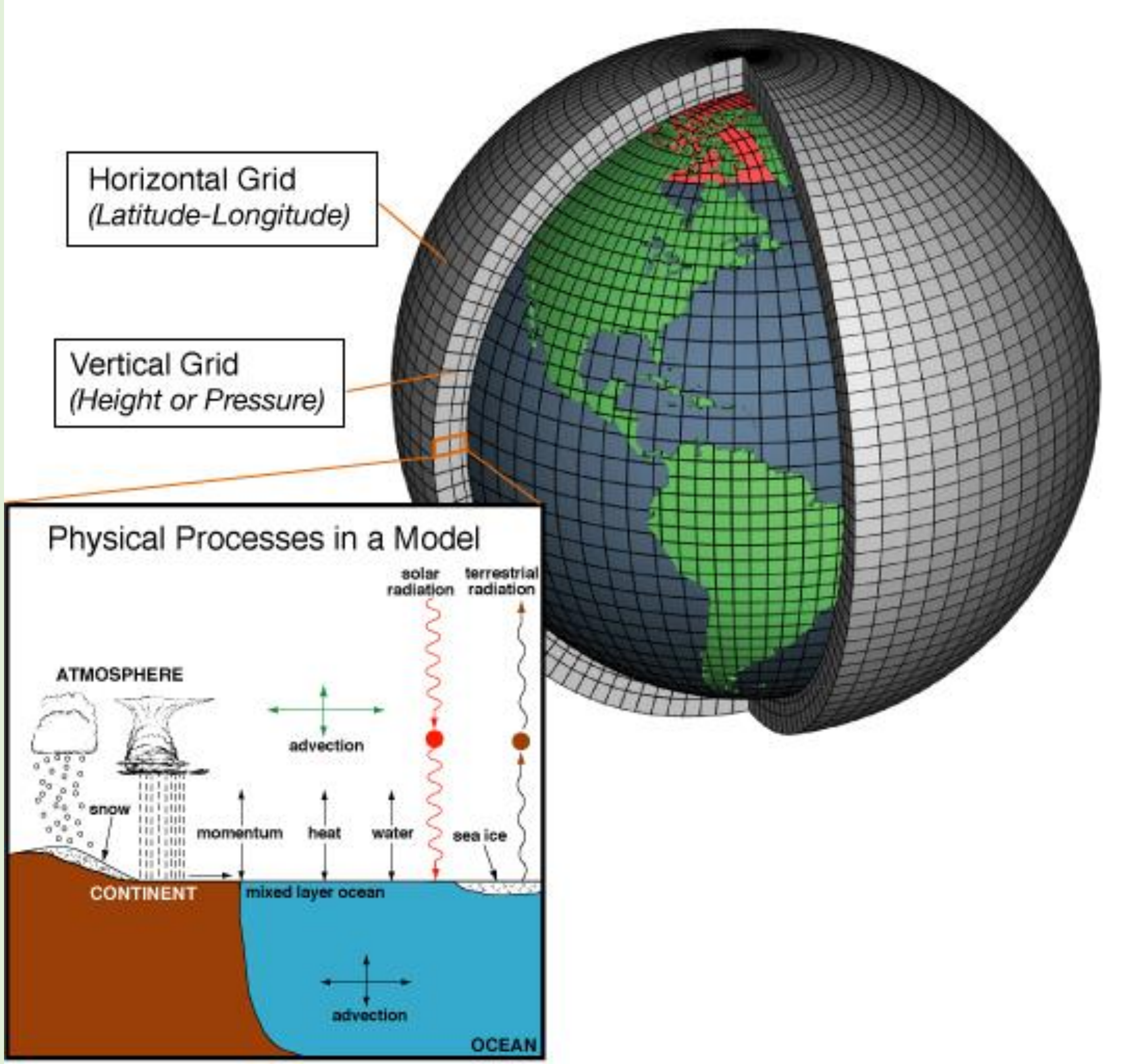


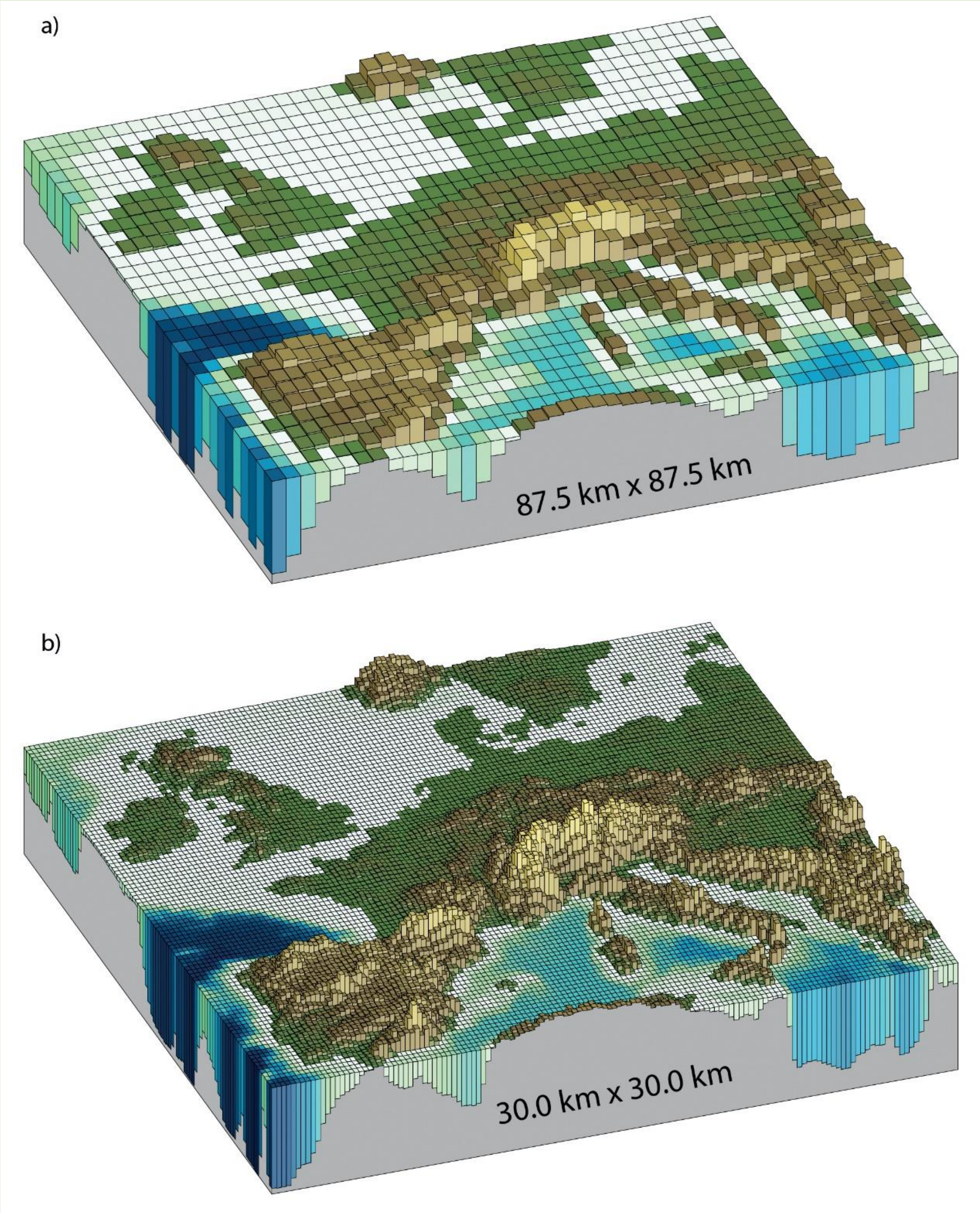
Cryosphere

Landmasses

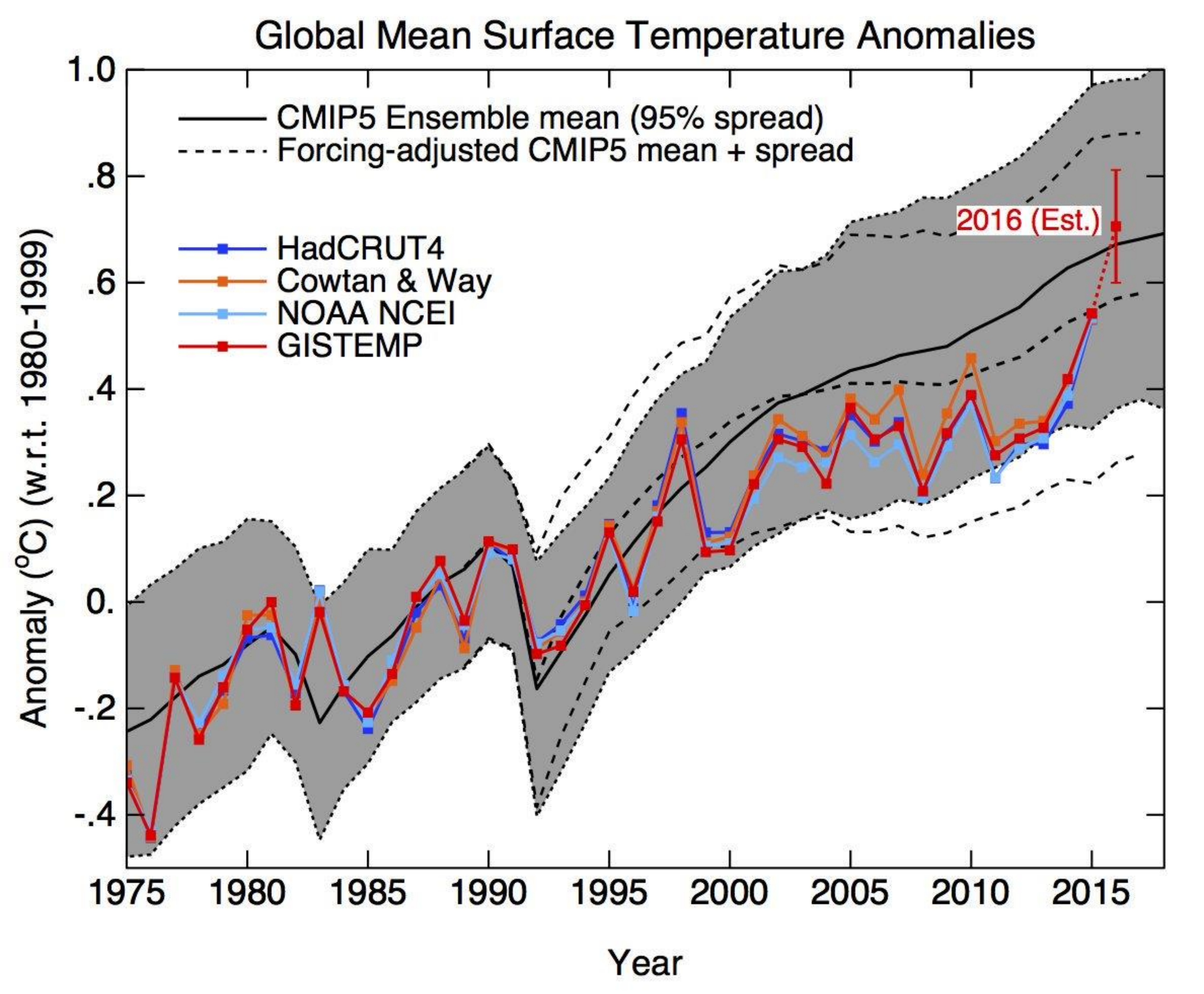
Computer modeling of Climate



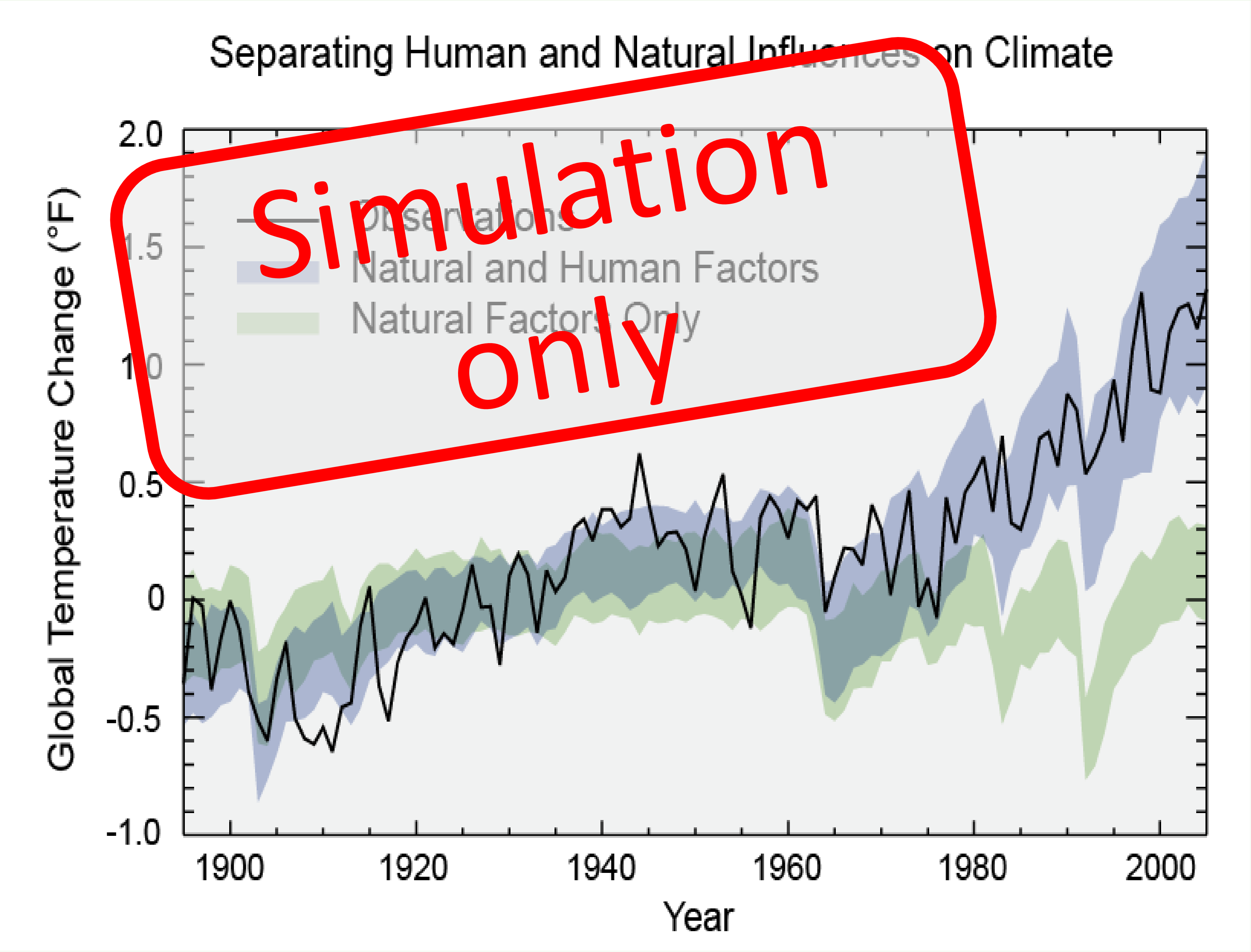

Horizontal Grid
(Latitude-Longitude)
Vertical Grid
(Height or Pressure)
Physical Processes in a Model
solar radiation
terrestrial radiation
ATMOSPHERE
advection
snow
momentum
heat
water
sea ice
CONTINENT
mixed layer ocean
advection
OCEAN



Current grid size 25 sq. km

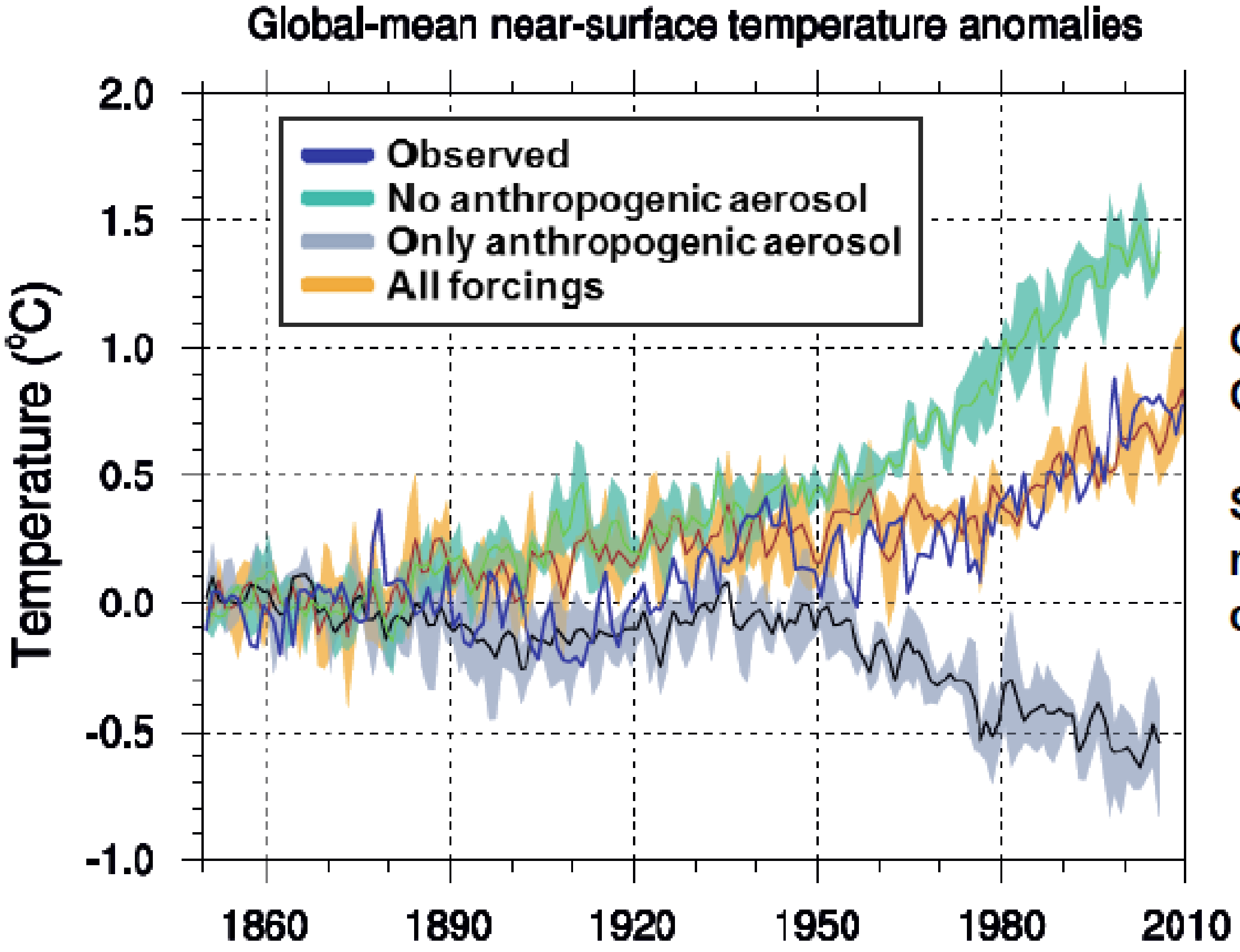


Global Mean Surface Temperature Anomalies
CMIP5 Ensemble mean (95% spread)
Forcing-adjusted CMIP5 mean + spread
HadCRUT4
Cowtan & Way
NOAA NCEI
GISTEMP
2016 (Est.)
1.0
.8
.6
.4
.2
0.
-.2
-.4
Anomaly (°C) (w.r.t. 1980-1999)
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year



Separating Human and Natural Influences on Climate
Observations
Natural and Human Factors
Natural Factors Only
Simulation only
Global Temperature Change (°F)
2.0
1.5
1.0
0.5
0
-0.5
-1.0
1900
1920
1940
1960
1980
2000
Year

Impact of all and anthropogenic aerosol forcings



One model (from CSIRO, Australia)

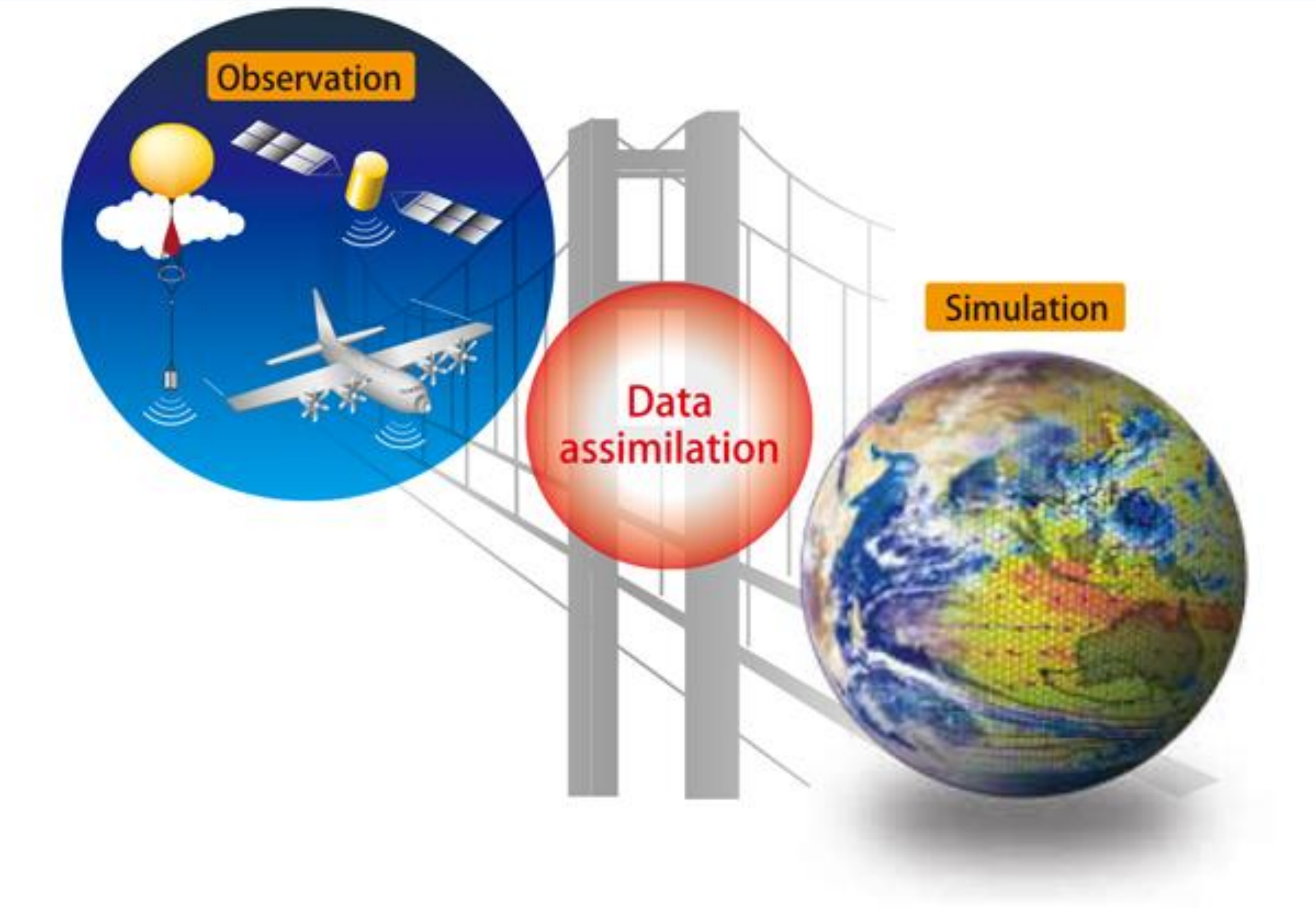
Spread of multiple realizations is denoted by shading

Boucher *et al.*, CLIVAR exchange, 2011

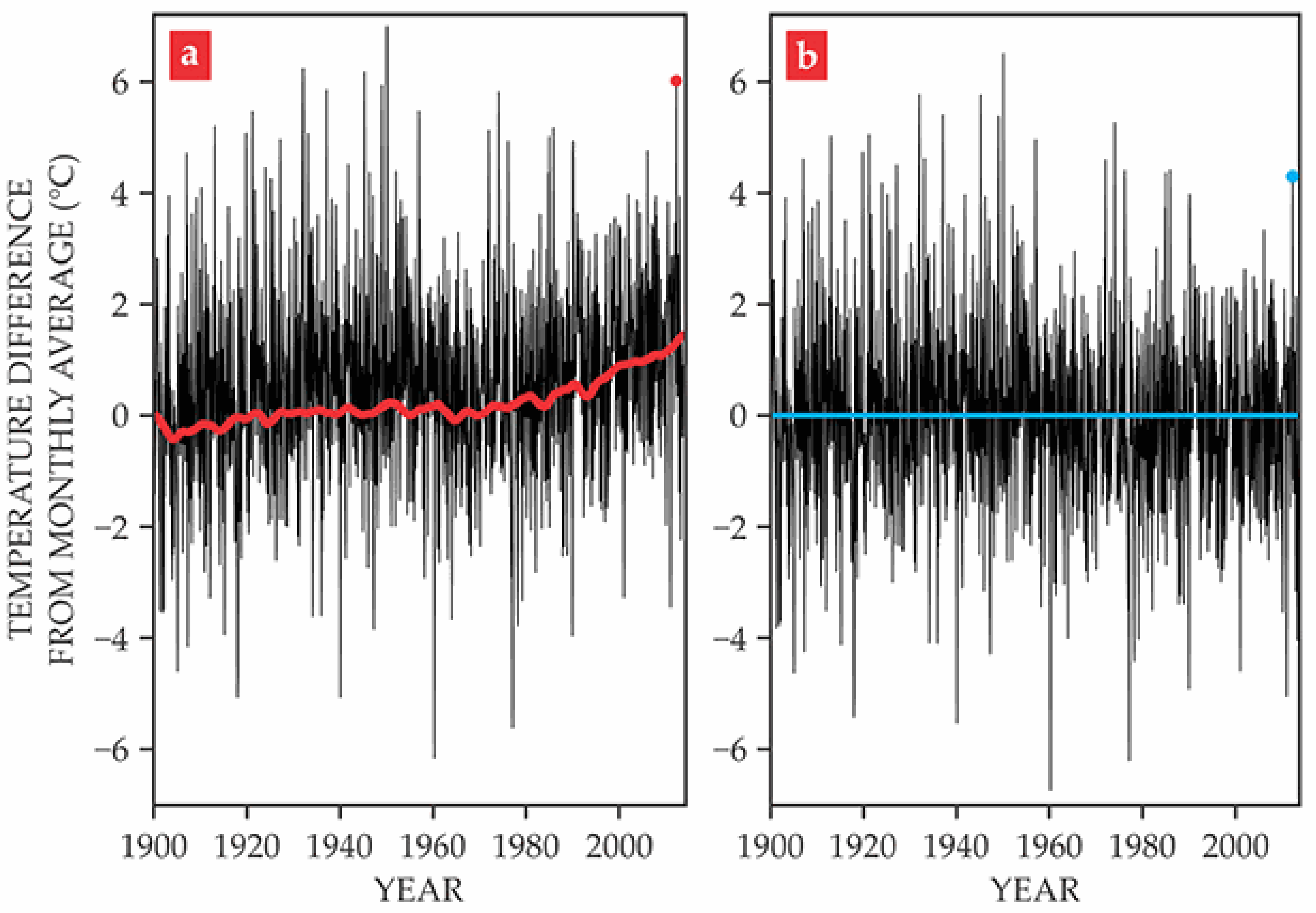
<u>Climate Science and Modeling challenges today</u>

- Clouds: convection and boundary layers
- Aerosols
- Oceans: water vapor ,vertical and horizontal mixing,
  convection
- Sea ice, glaciers
- Limitations in observational data sets

Data Assimilation: a new way of understanding the climate system

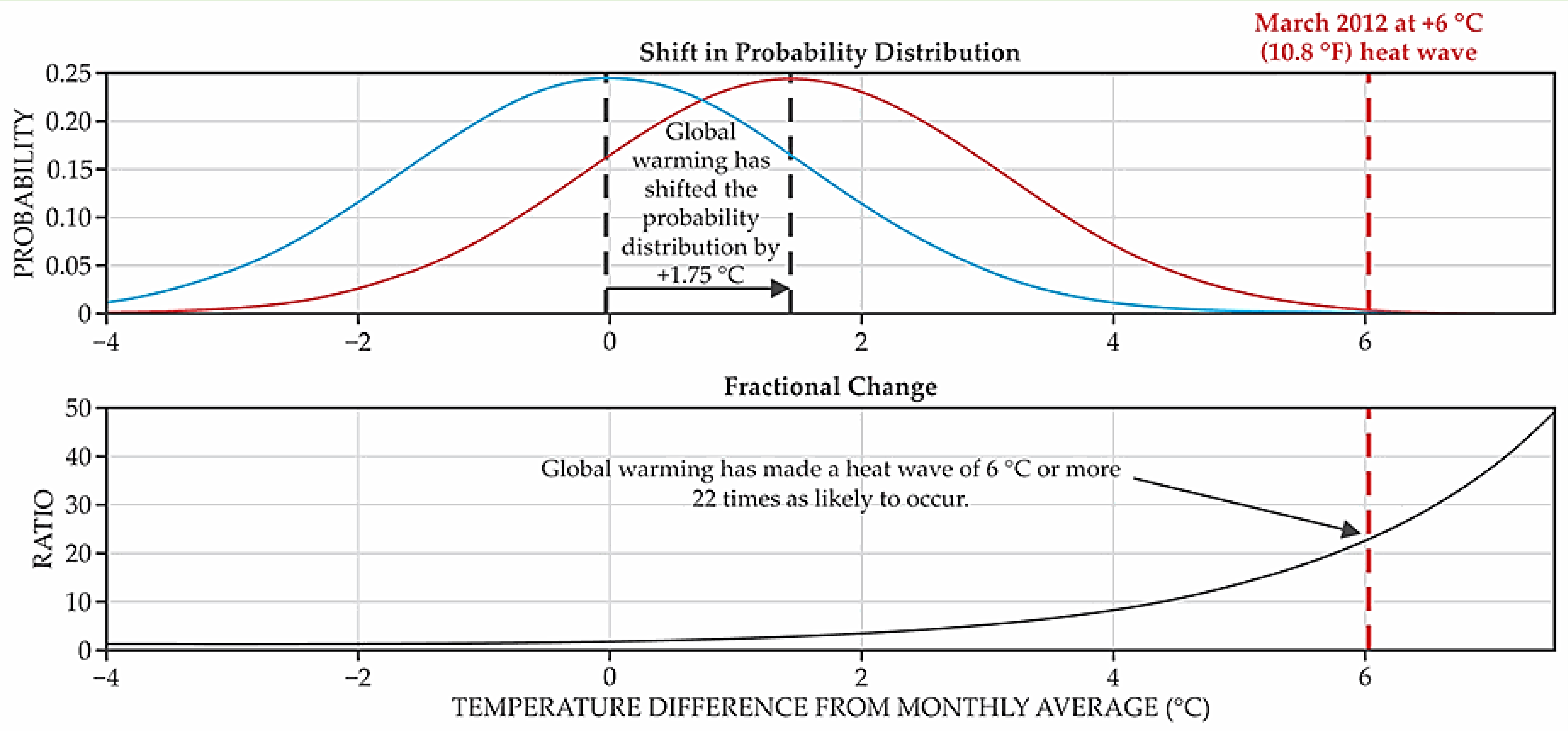


Climate statistics, trends, and future projections



Monthly temperature anomalies in Durham, North Carolina, with and without global warming, 1900–2013. The black data in the panels show the anomalies. **(a)** The red curve gives the contribution due to global warming, as estimated by climate models. **(b)** When the global warming contribution is subtracted out, the remaining anomalies show the effects of natural climate variability. The horizontal blue line corresponds to zero anomaly. In March 2012, the +6 °C total anomaly shown in panel a (red dot) received the +4.25 °C natural contribution displayed in panel b (blue dot) and a +1.75 °C contribution from global warming.

Citation: Phys. Today **69**, 10, 10 (2016)



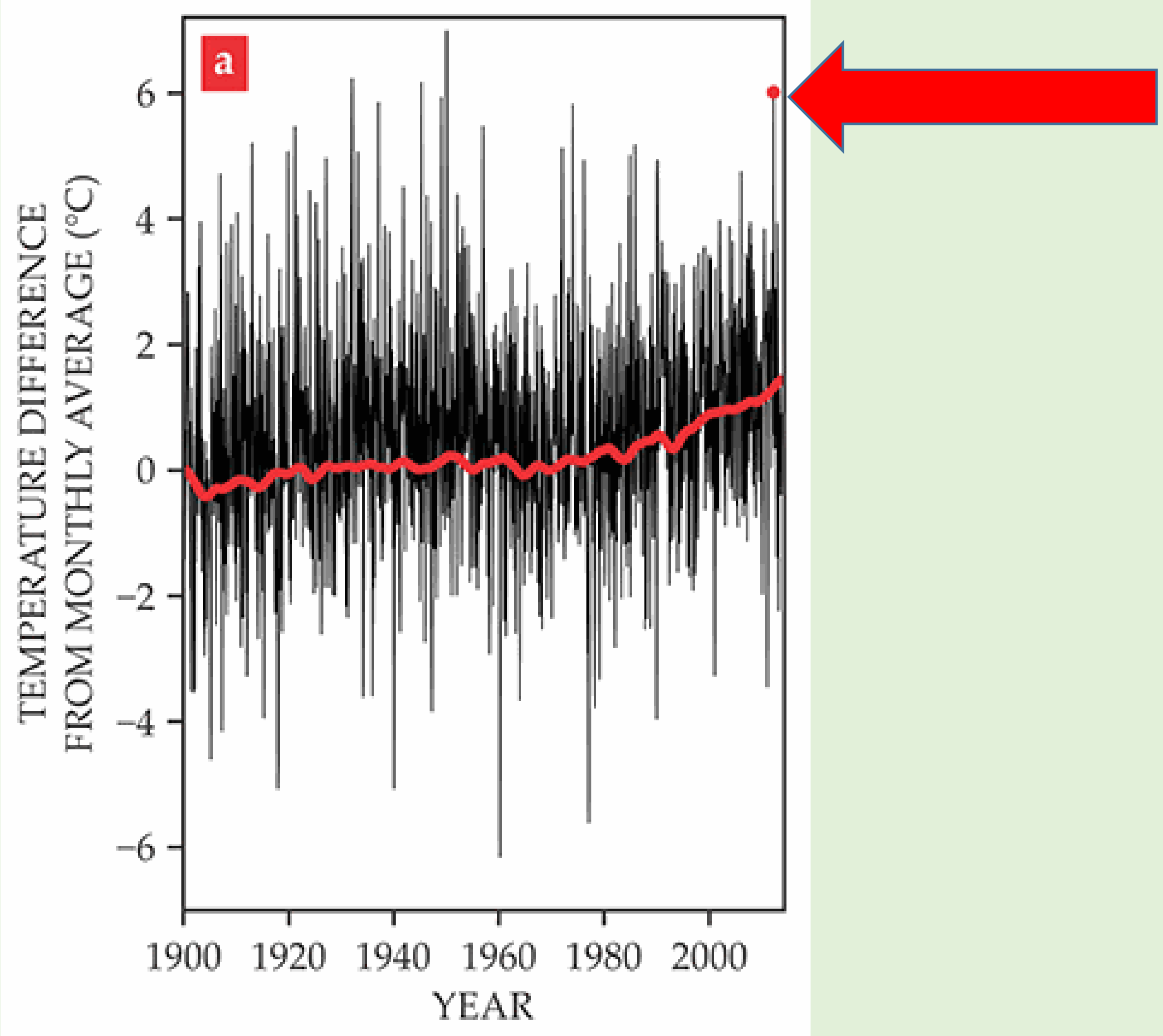
Normal distribution of monthly temperature anomalies in Durham, North Carolina, without global warming (blue) and with global warming (red). The shift due to global warming produces a small change in the absolute probability of a large temperature anomaly (top) but a big relative change (bottom).

Citation: Phys. Today **69**, 10, 10 (2016)

Recent heat wave was due 71% to natural variability and 29% to global warming.

Global warming increased the odds of the recent heat wave by only 0.25%.

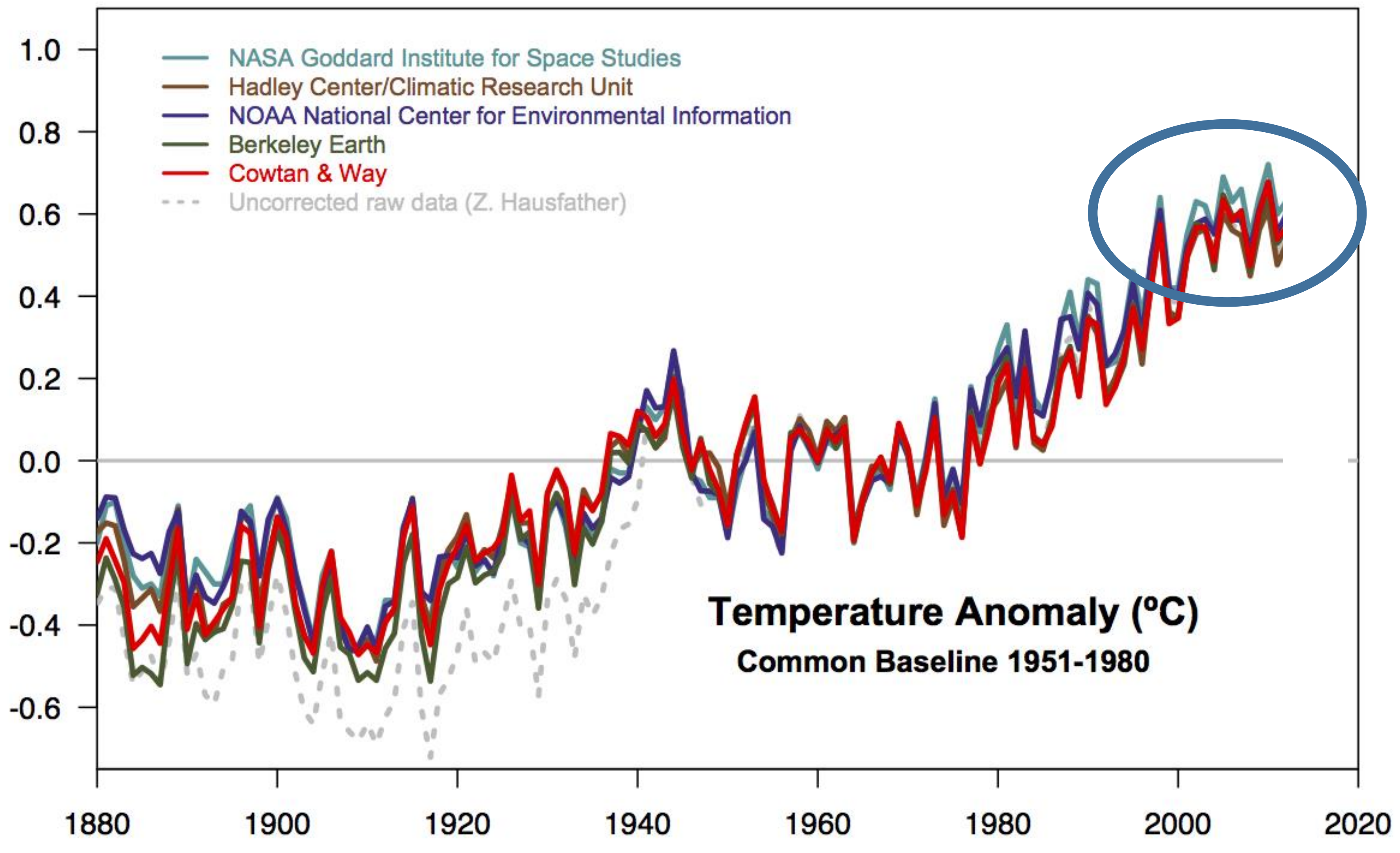
Global warming has made heat waves like the recent one occur 22 times as often as they would have otherwise.



- ~~This heat event was caused by global warming~~
- The probability of this event was increased by global warming
- This event's high temperature was increased by global warming
- A single event is not attributable to global warming ?

Don’t be a climate ‘day-trader’.

A case study in statistical estimating: the recent ‘hiatus’ in global average surface temperatures



NASA Goddard Institute for Space Studies
Hadley Center/Climatic Research Unit
NOAA National Center for Environmental Information
Berkeley Earth
Cowtan & Way
Uncorrected raw data (Z. Hausfather)
Temperature Anomaly (ºC)
Common Baseline 1951-1980
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1880
1900
1920
1940
1960
1980
2000
2020

CLIMATE CHANGE

Possible artifacts of data biases in the recent global surface warming hiatus

Thomas R. Karl,[1*] Anthony Arguez,[1] Boyin Huang,[1] Jay H. Lawrimore,[1]
James R. McMahon,[2] Matthew J. Menne,[1] Thomas C. Peterson,[1]
Russell S. Vose,[1] Huai-Min Zhang[1]

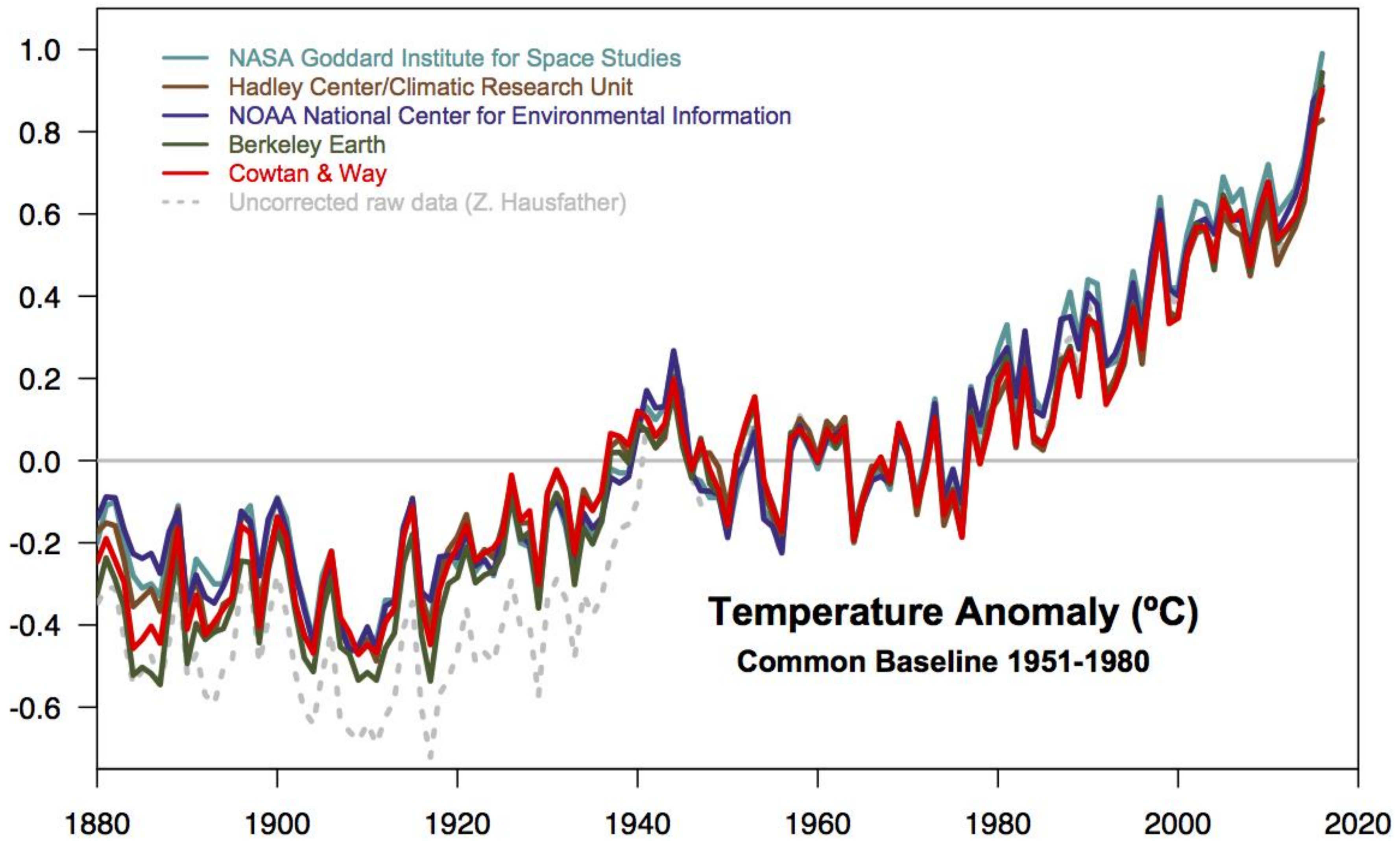
Much study has been devoted to the possible causes of an apparent decrease in the upward trend of global surface temperatures since 1998, a phenomenon that has been dubbed the global warming "hiatus." Here, we present an updated global surface temperature analysis that reveals that global trends are higher than those reported by the Intergovernmental Panel on Climate Change, especially in recent decades, and that the central estimate for the rate of warming during the first 15 years of the 21st century is at least as great as the last half of the 20th century. These results do not support the notion of a "slowdown" in the increase of global surface temperature.

T.R. Karl, A. Arguez, B. Huang, J.H. Lawrimore, J.R. McMahon, M.J. Menne, T.C. Peterson, R.S. Vose, and H. Zhang, "Possible artifacts of data biases in the recent global surface warming hiatus", *Science*, vol. 348, pp. 1469-1472, 2015. http://dx.doi.org/10.1126/science.aaa5632

House Science Committee Chairman Lamar Smith, R-Texas. Photograph: Scott J. Ferrell/Congressional Quarterly

… Smith has used new subpoena powers to threaten the leadership of NOAA, demanding that the federal climate and weather agency hand over all internal correspondence between scientists to find out if there has been a grand conspiracy to alter or misrepresent the data.

"It was inconvenient for this administration that climate data has clearly showed no warming for the past two decades," Smith said last month.


NASA Goddard Institute for Space Studies
Hadley Center/Climatic Research Unit
NOAA National Center for Environmental Information
Berkeley Earth
Cowtan & Way
Uncorrected raw data (Z. Hausfather)
Temperature Anomaly (ºC)
Common Baseline 1951-1980
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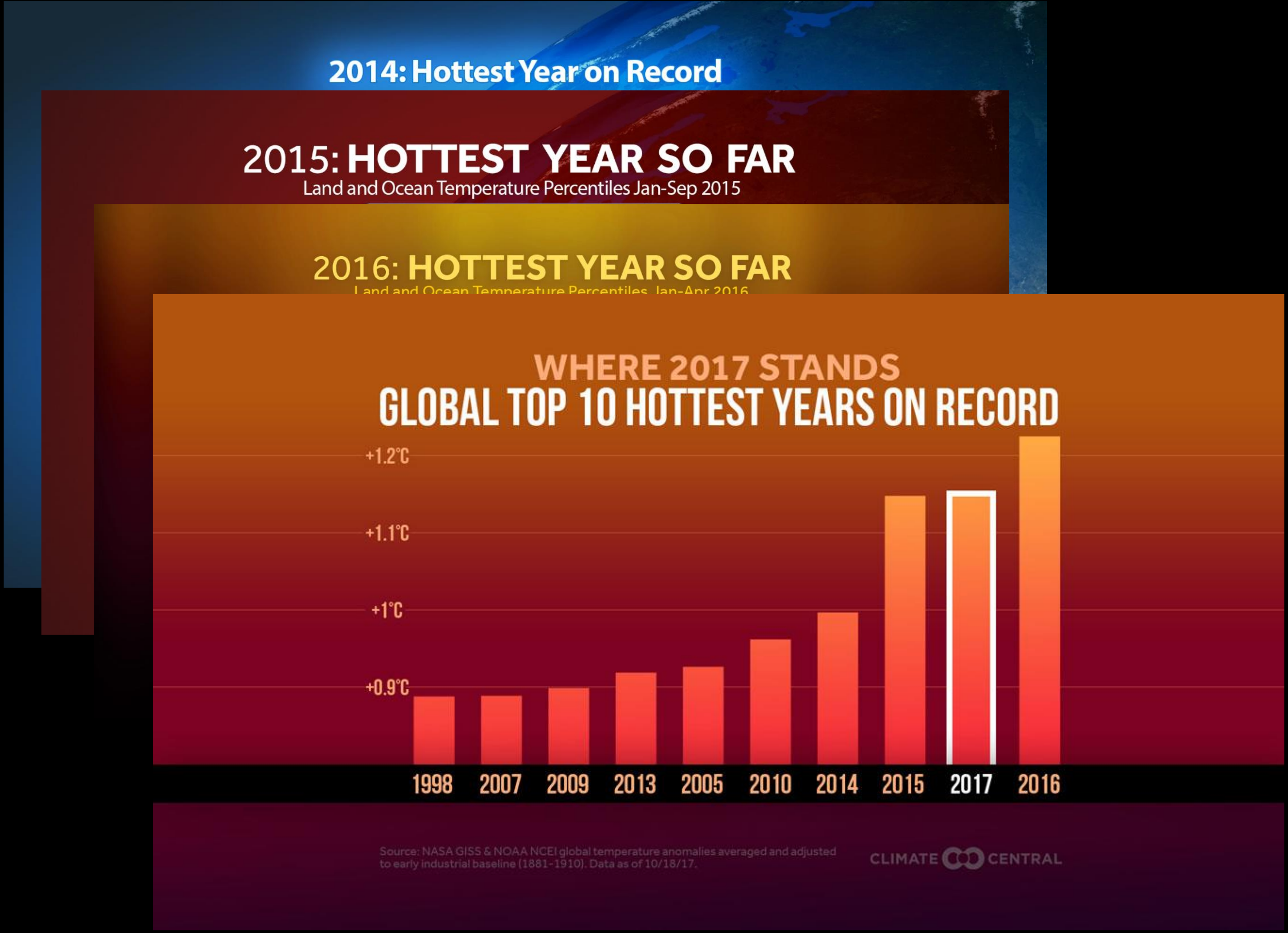
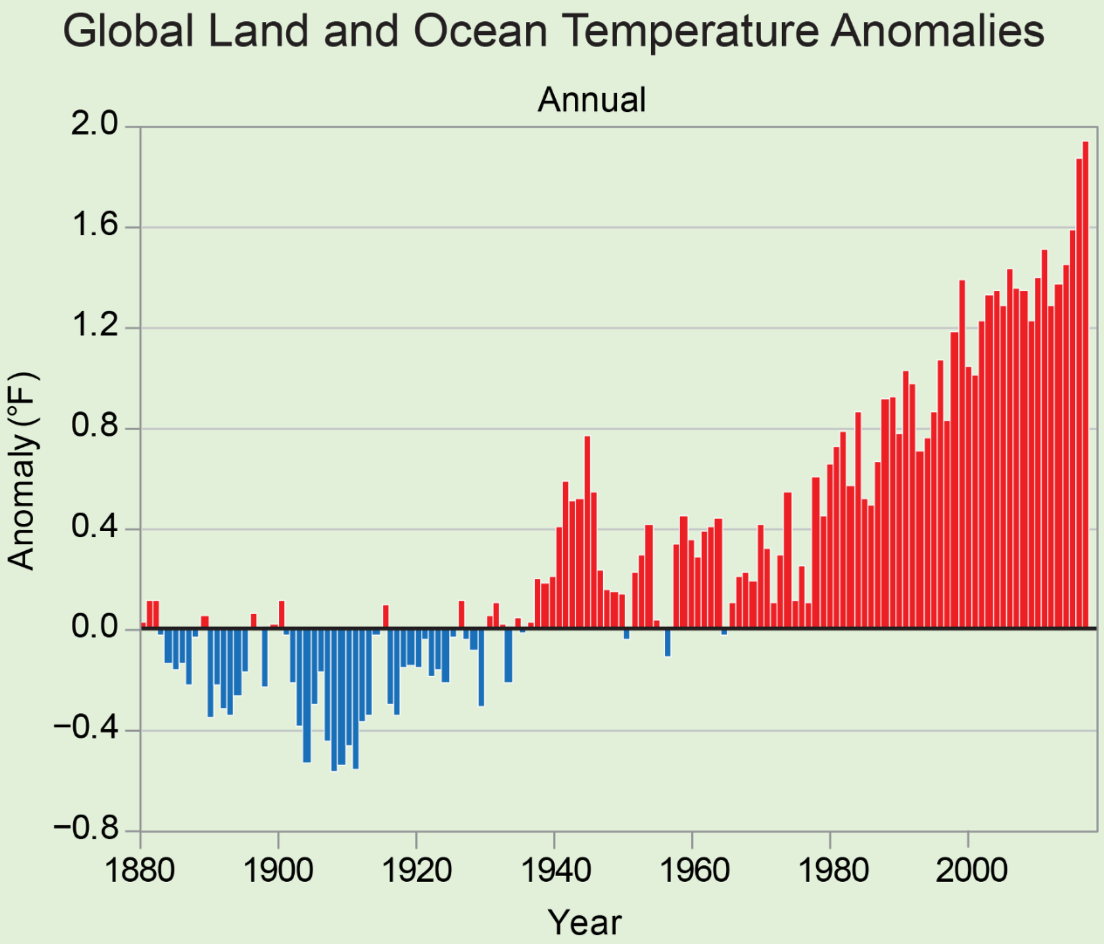
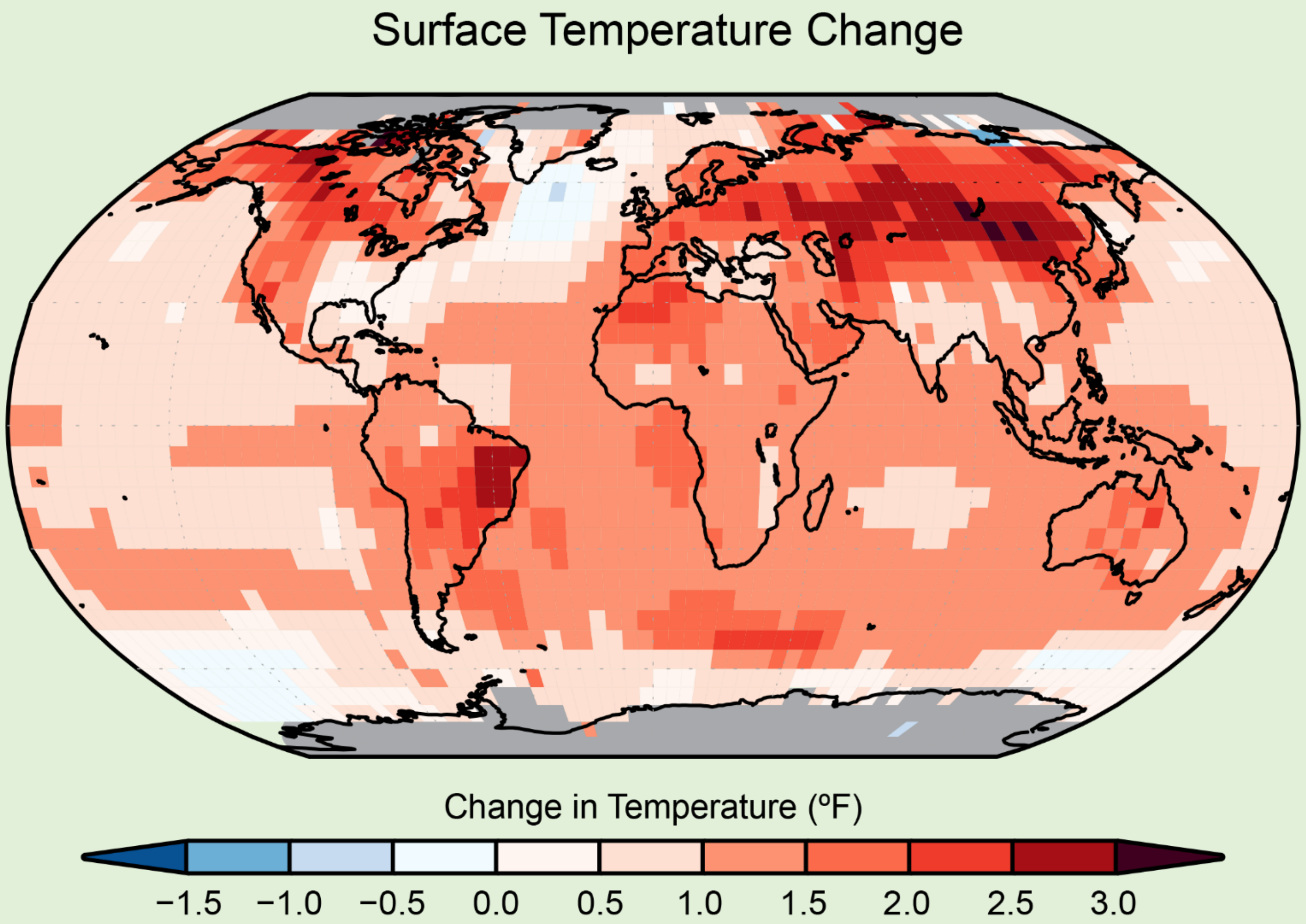
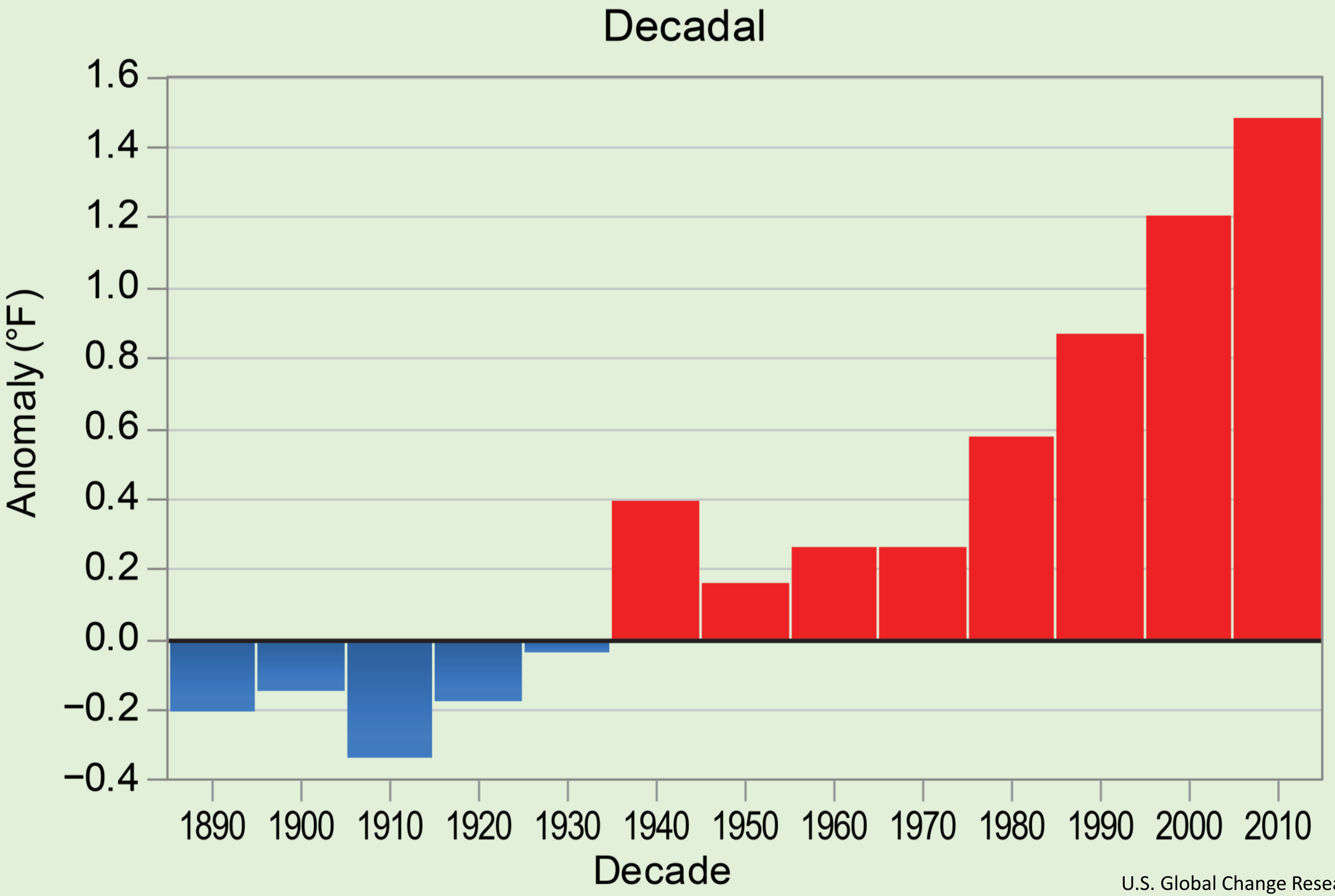
0.4
0.2
0.0
-0.2
-0.4
-0.6
1880
1900
1920
1940
1960
1980
2000
2020


2014: Hottest Year on Record
2015: HOTTEST YEAR SO FAR
Land and Ocean Temperature Percentiles Jan-Sep 2015
2016: HOTTEST YEAR SO FAR
Land and Ocean Temperature Percentiles Jan-Apr 2016
WHERE 2017 STANDS
GLOBAL TOP 10 HOTTEST YEARS ON RECORD
+1.2°C
+1.1°C
+1°C
+0.9°C
1998
2007
2009
2013
2005
2010
2014
2015
2017
2016
Source: NASA GISS & NOAA NCEI global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910). Data as of 10/18/17.
CLIMATE CENTRAL



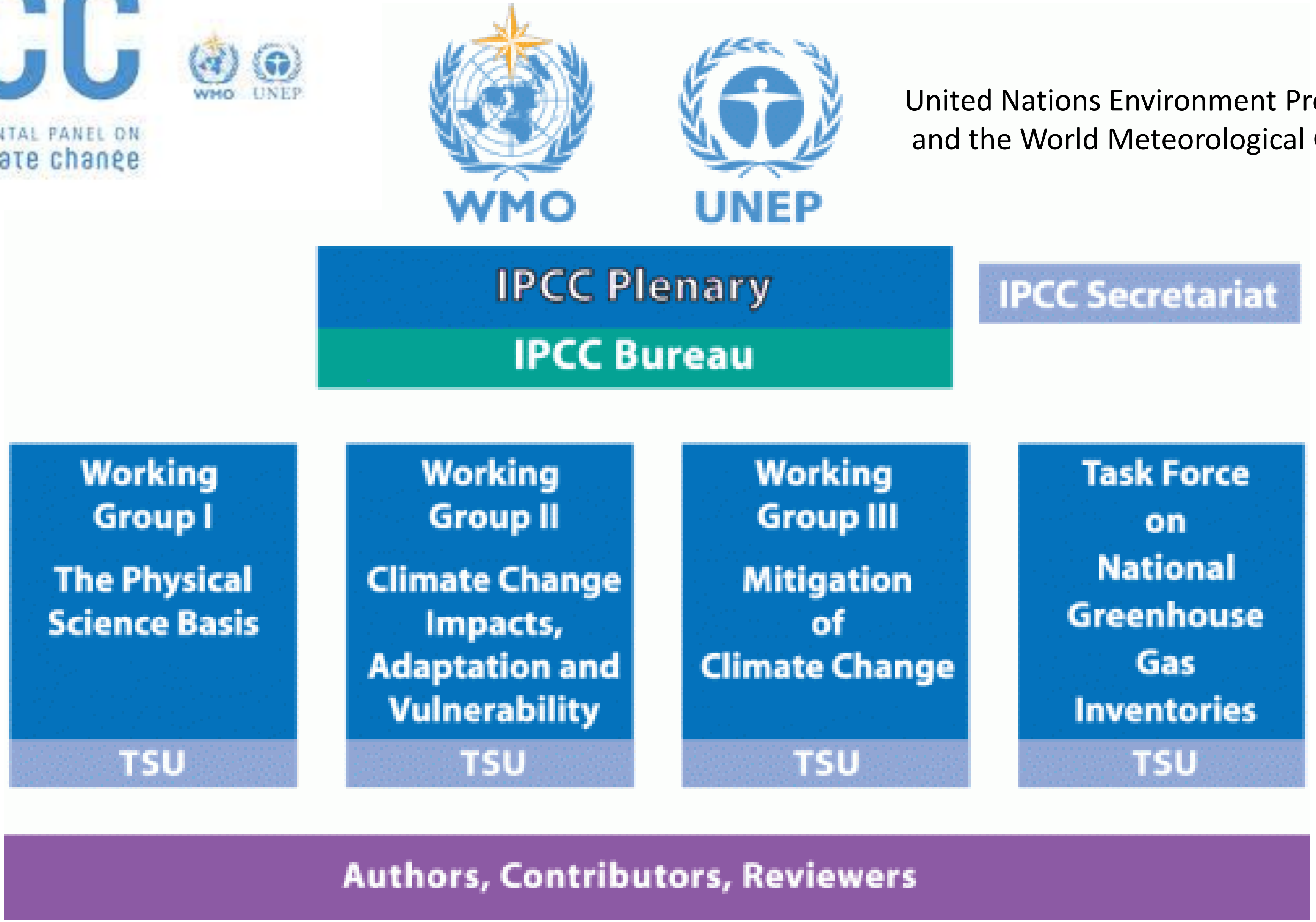


U.S. Global Change Research Program
Climate Science Special Report 2017

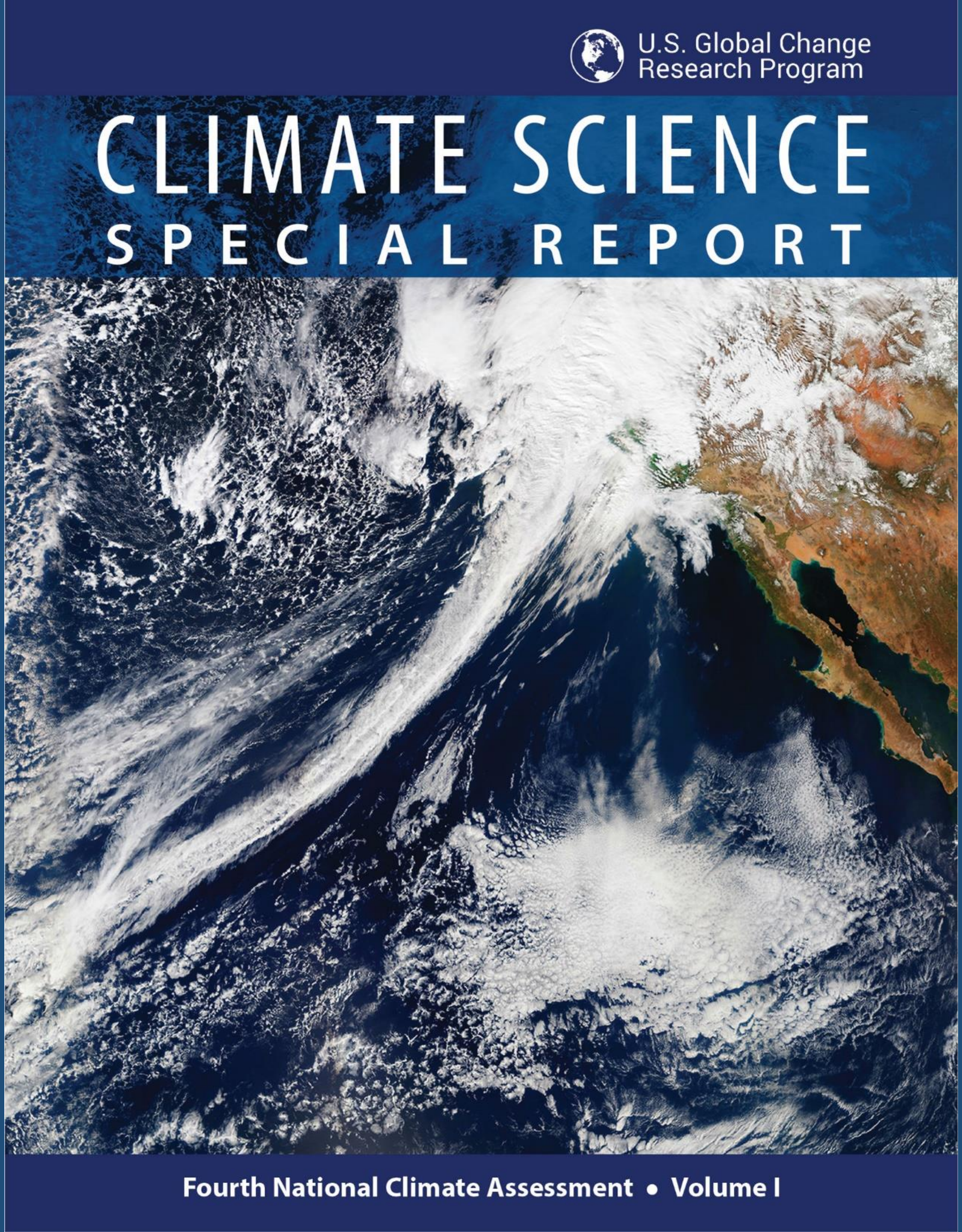


U.S. Global Change Research Program
Climate Science Special Report 2017

United Nations Environment Programme (UNEP)
and the World Meteorological Organisation (WMO)

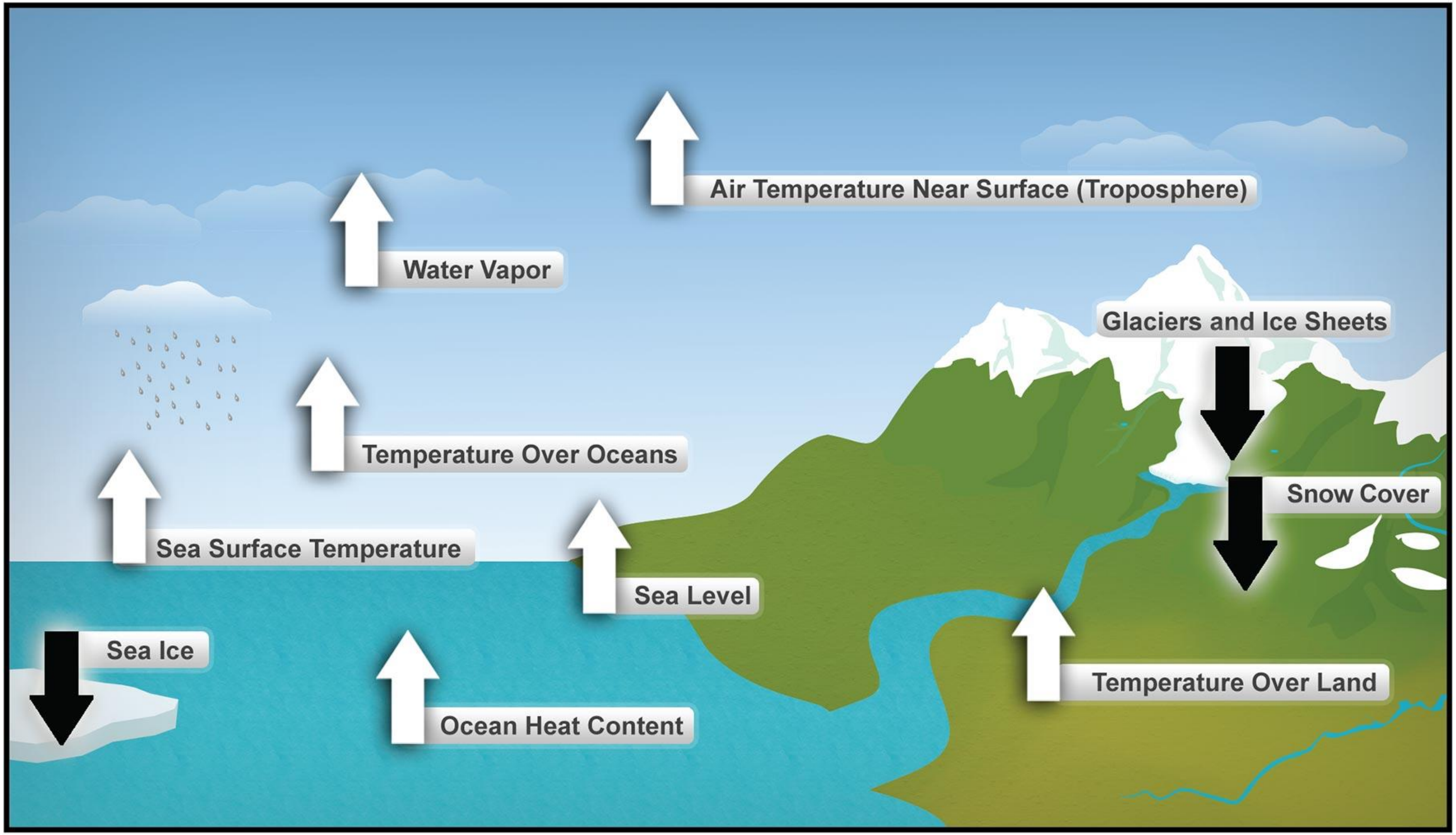


2017

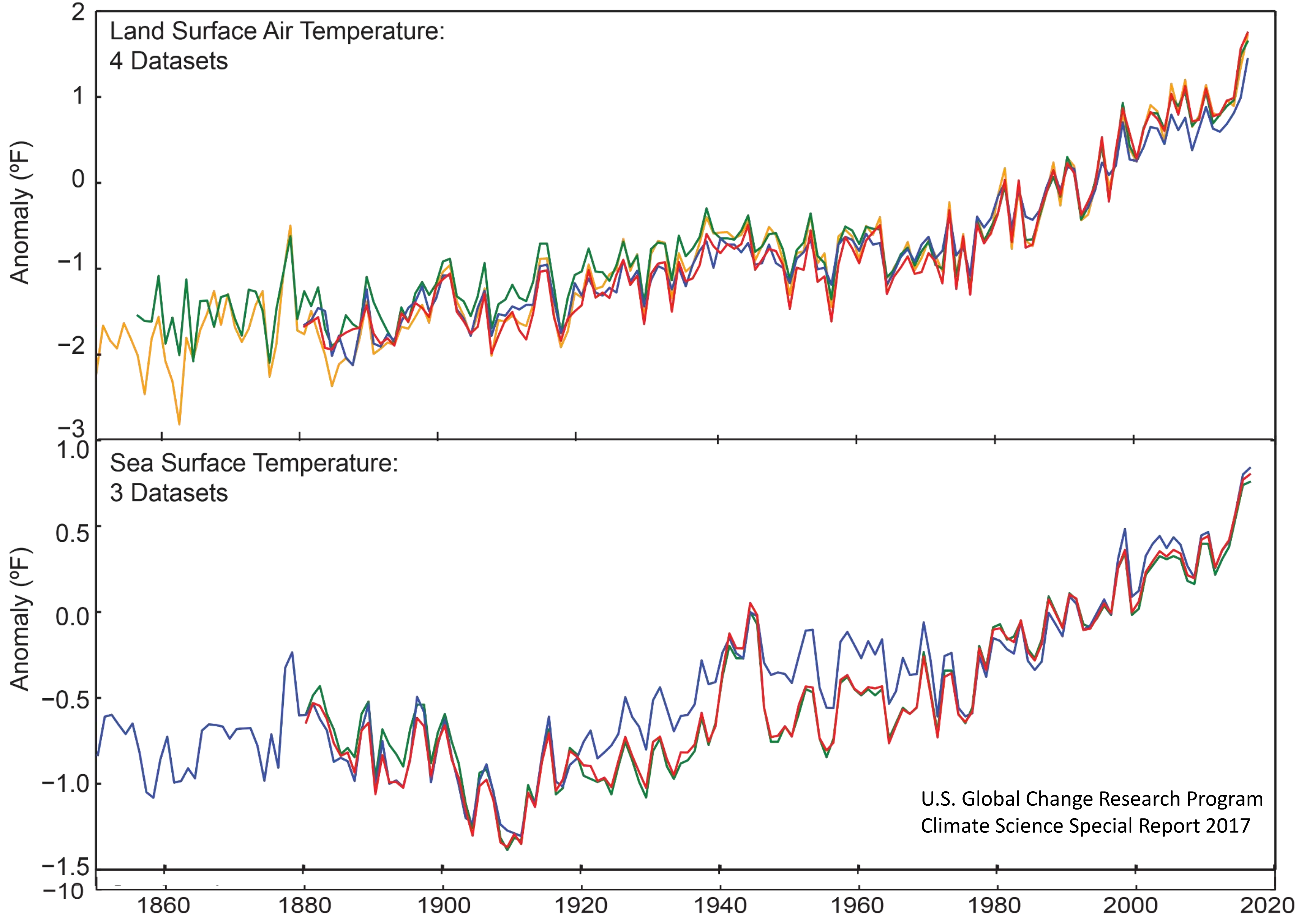

U.S. Global Change
Research Program
CLIMATE SCIENCE
SPECIAL REPORT
Fourth National Climate Assessment • Volume I

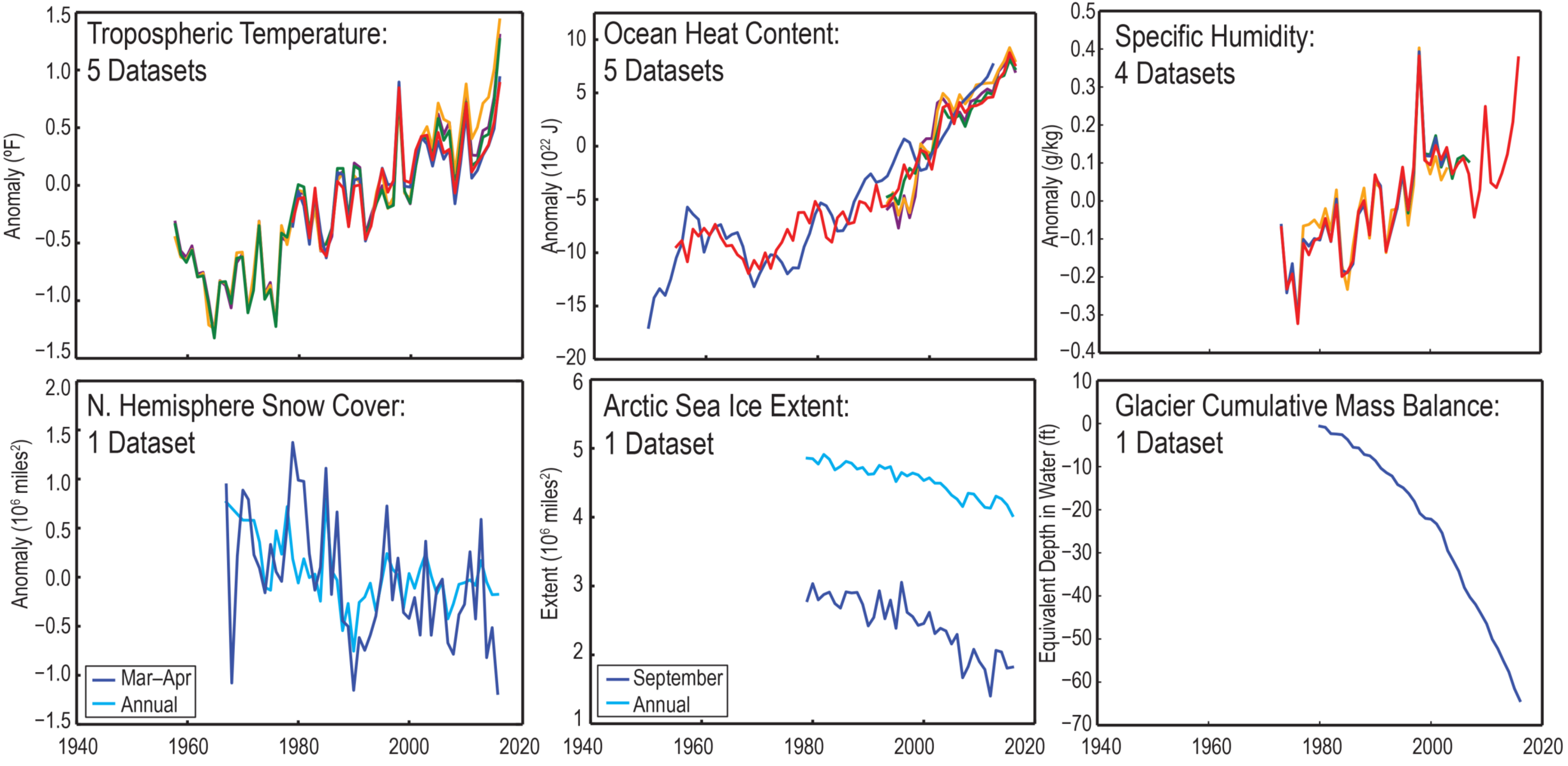
How do we know the climate is warming?

Ten Indicators of a Warming World

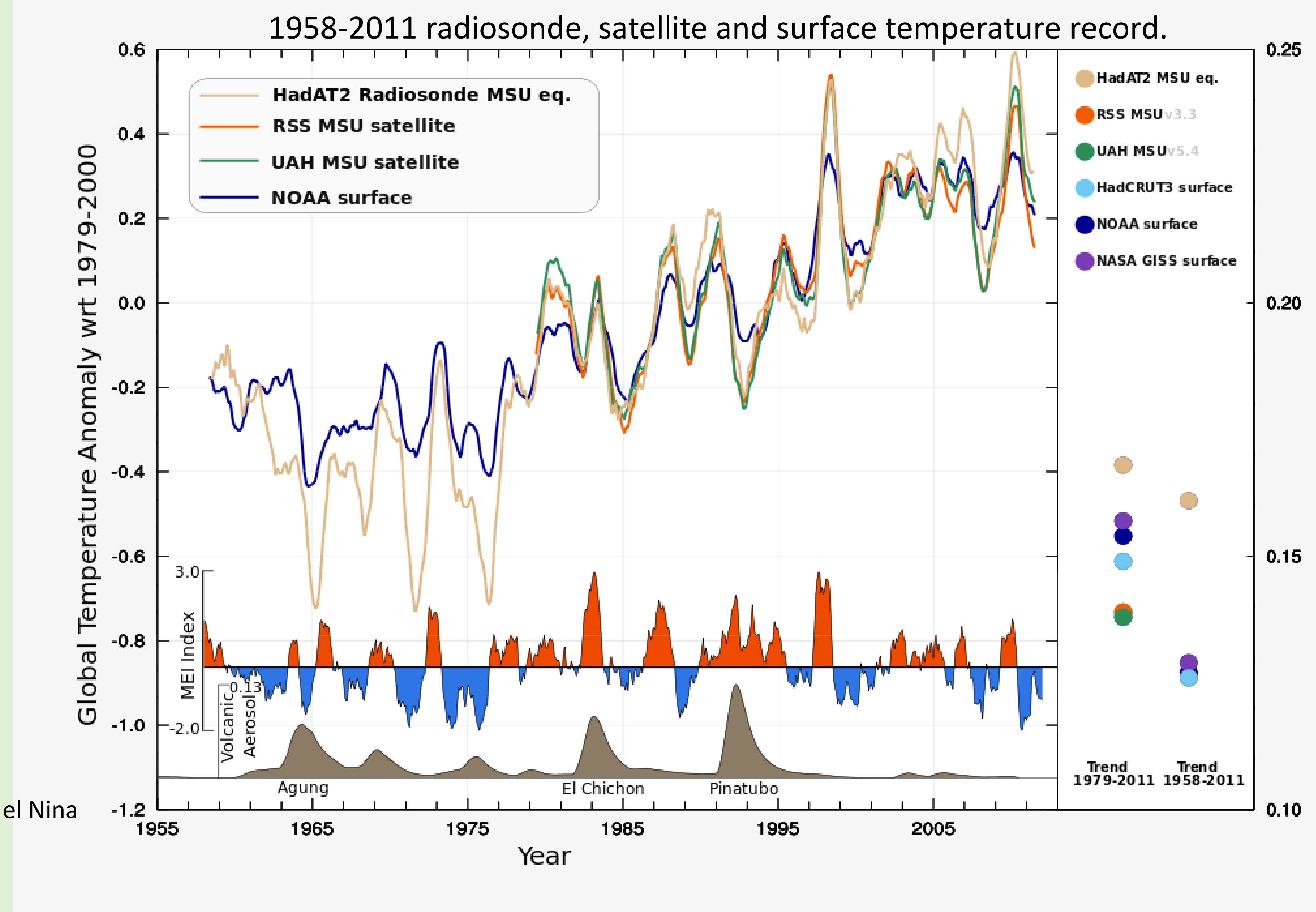


Indicators of Warming from Multiple Datasets



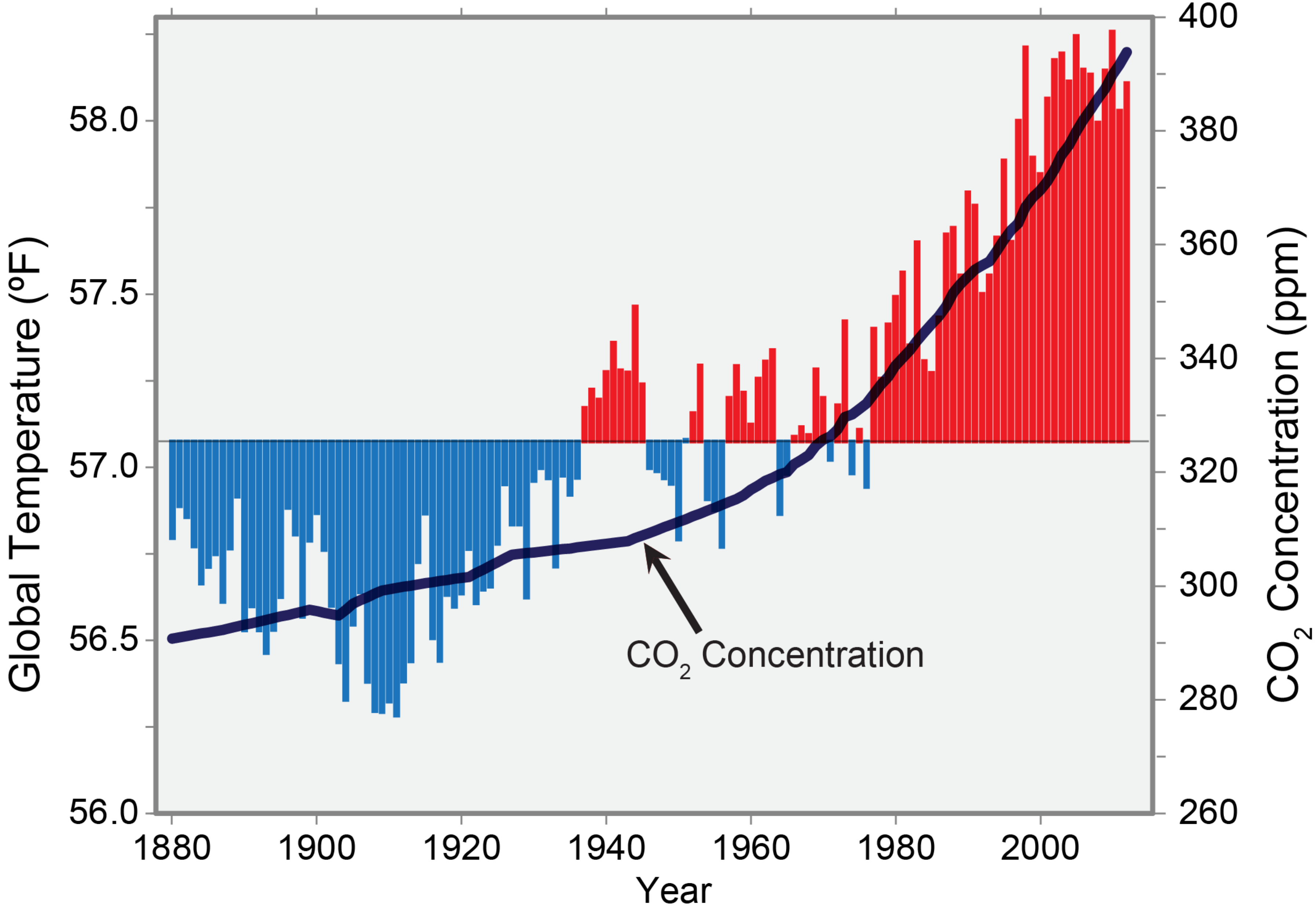


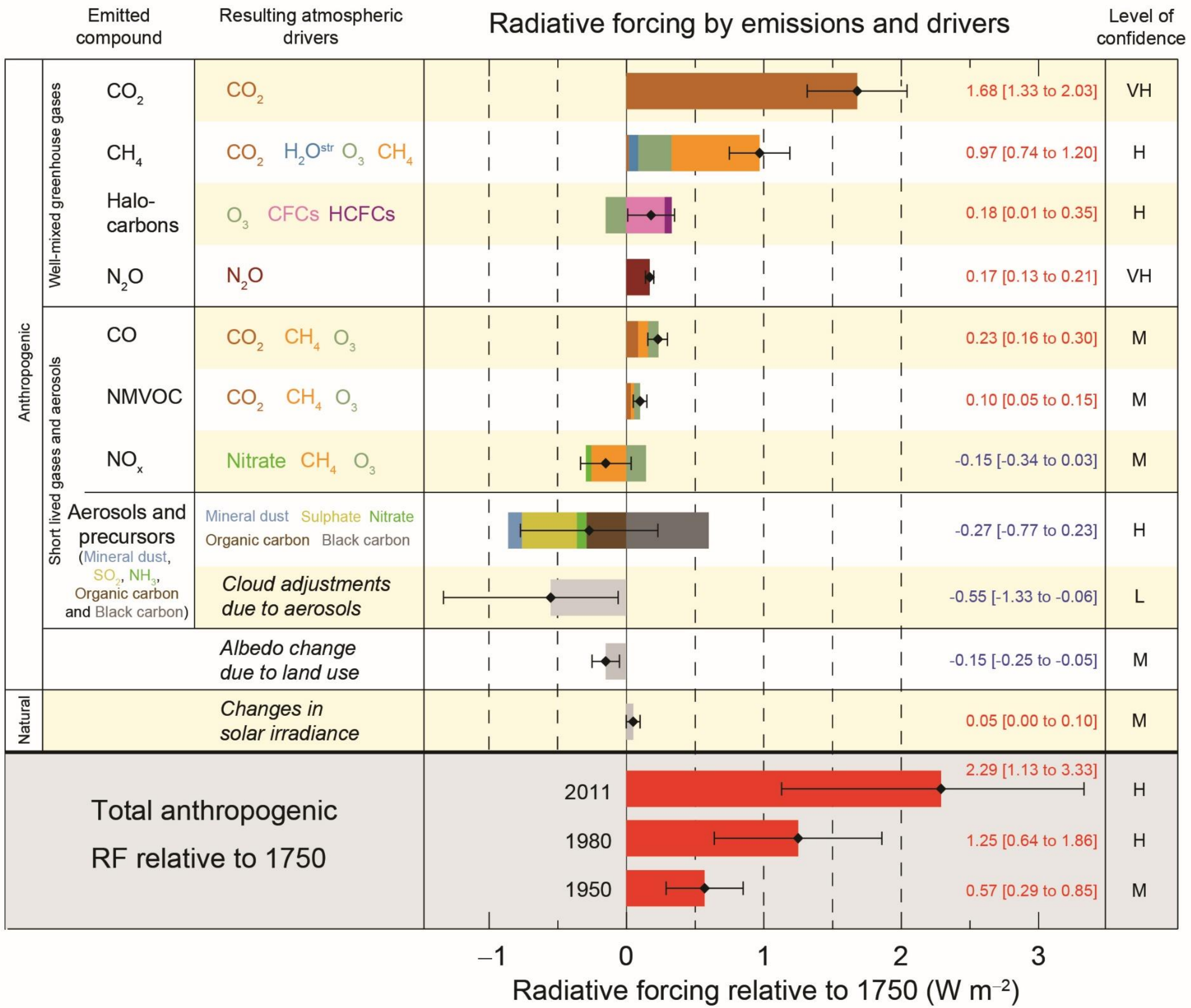
U.S. Global Change Research Program
Climate Science Special Report 2017



MEI index: el Nino vs. el Nina composite metric

Global Temperature and Carbon Dioxide





Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
CO_2
CO_2
1.68 [1.33 to 2.03]
VH
CH_4
CO_2 H_2O^{str} O_3 CH_4
0.97 [0.74 to 1.20]
H
Halo-carbons
O_3 CFCs HCFCs
0.18 [0.01 to 0.35]
H
N_2O
N_2O
0.17 [0.13 to 0.21]
VH
Short lived gases and aerosols
CO
CO_2 CH_4 O_3
0.23 [0.16 to 0.30]
M
NMVOC
CO_2 CH_4 O_3
0.10 [0.05 to 0.15]
M
NO_x
Nitrate CH_4 O_3
-0.15 [-0.34 to 0.03]
M
Aerosols and precursors (Mineral dust, SO_2, NH_3, Organic carbon and Black carbon)
Mineral dust Sulphate Nitrate Organic carbon Black carbon
-0.27 [-0.77 to 0.23]
H
Cloud adjustments due to aerosols
-0.55 [-1.33 to -0.06]
L
Albedo change due to land use
-0.15 [-0.25 to -0.05]
M
Natural
Changes in solar irradiance
0.05 [0.00 to 0.10]
M
Total anthropogenic RF relative to 1750
2011
2.29 [1.13 to 3.33]
H
1980
1.25 [0.64 to 1.86]
H
1950
0.57 [0.29 to 0.85]
M
–1
0
1
2
3
Radiative forcing relative to 1750 (W m^{-2})

Global climate change- the human factor

Projections for the *21st Century*

Future climate projections

Possible scenarios for global GHG emissions up to year 2100

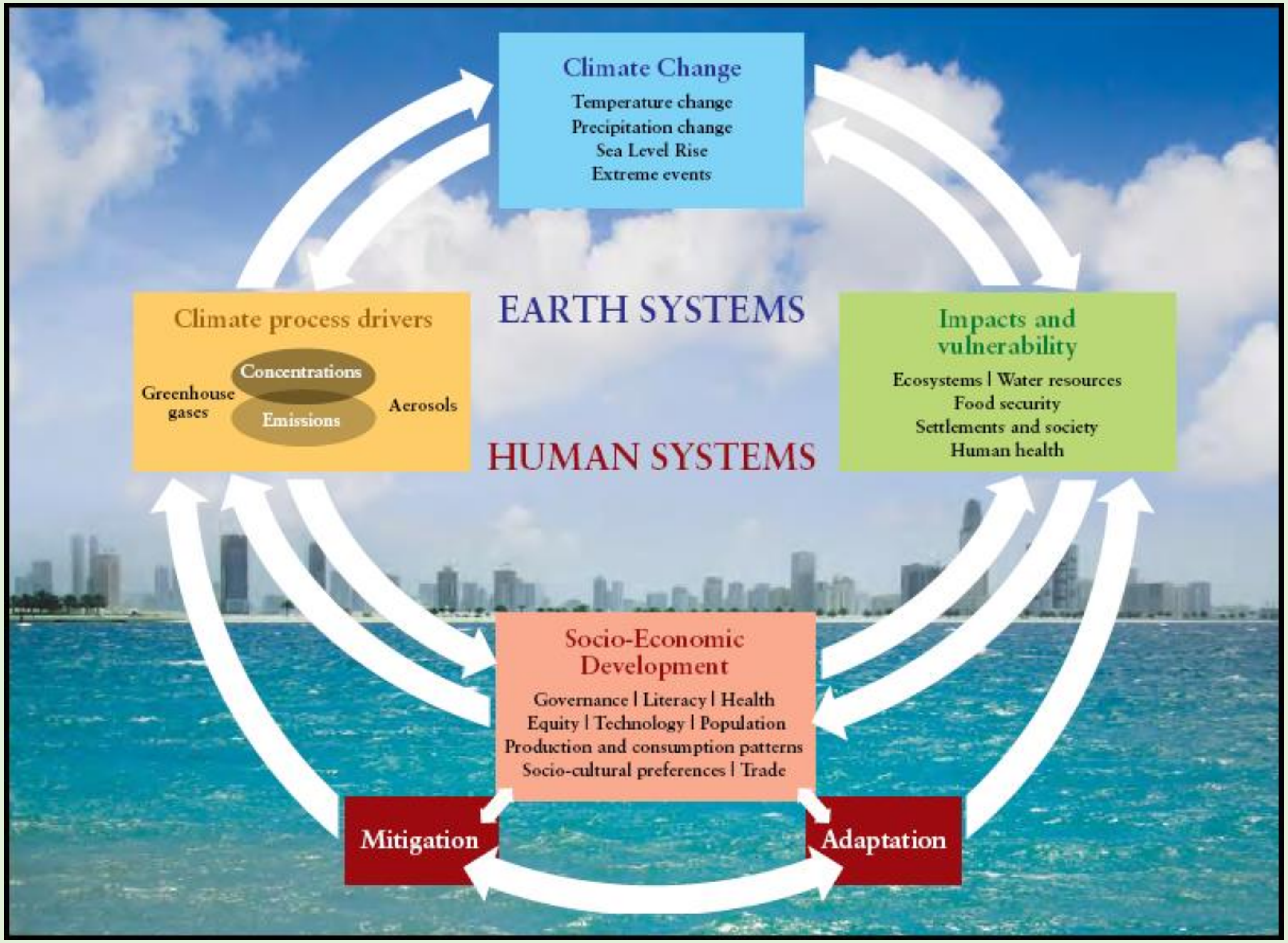
How does the climate depend on atmospheric CO2 concentrations?

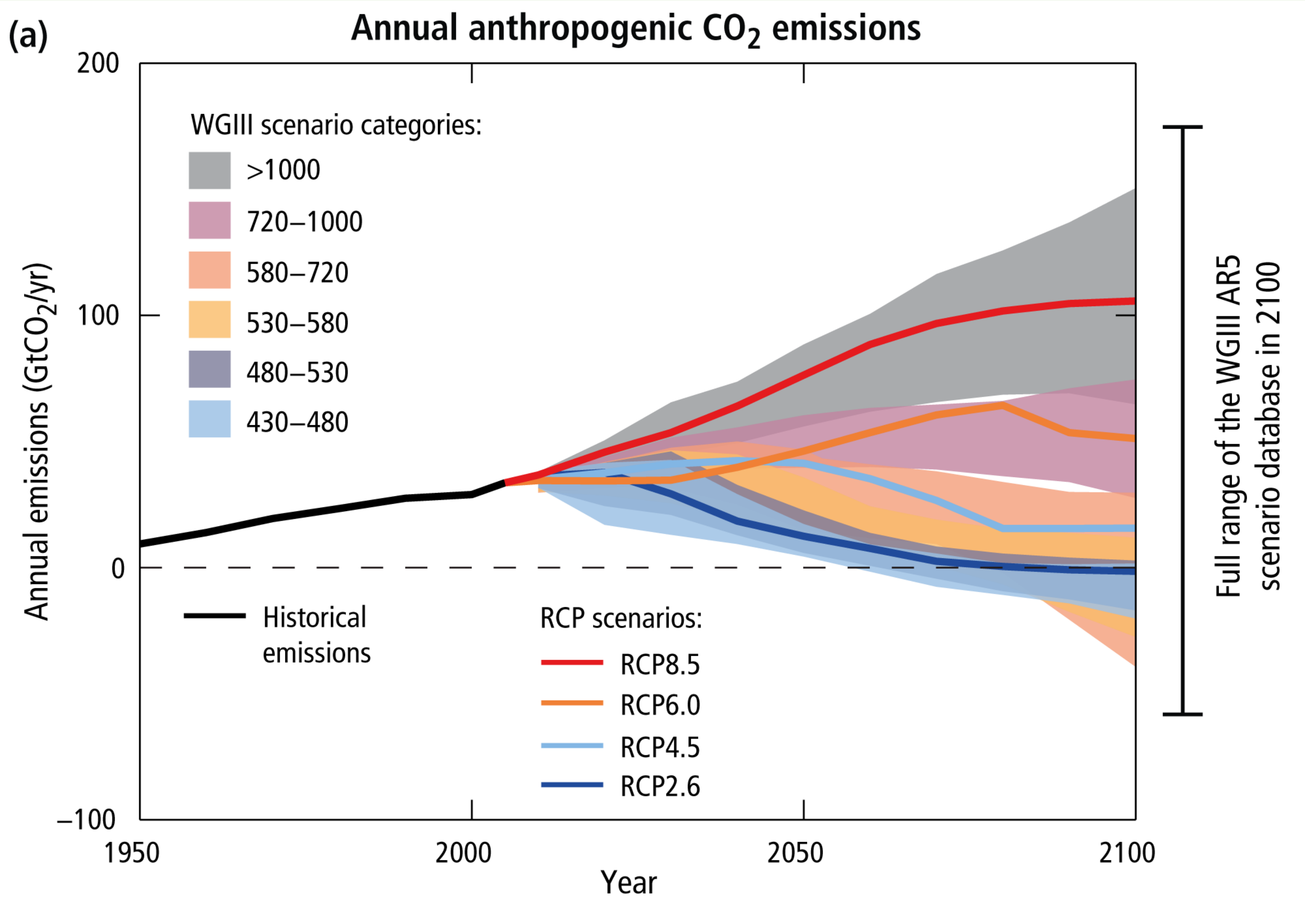
Climate impacts:

- Global surface temp.
- Sea surface temp.
- Sea level rise, sea ice extent
- Ocean pH
- Precipitation
- Regional climate change

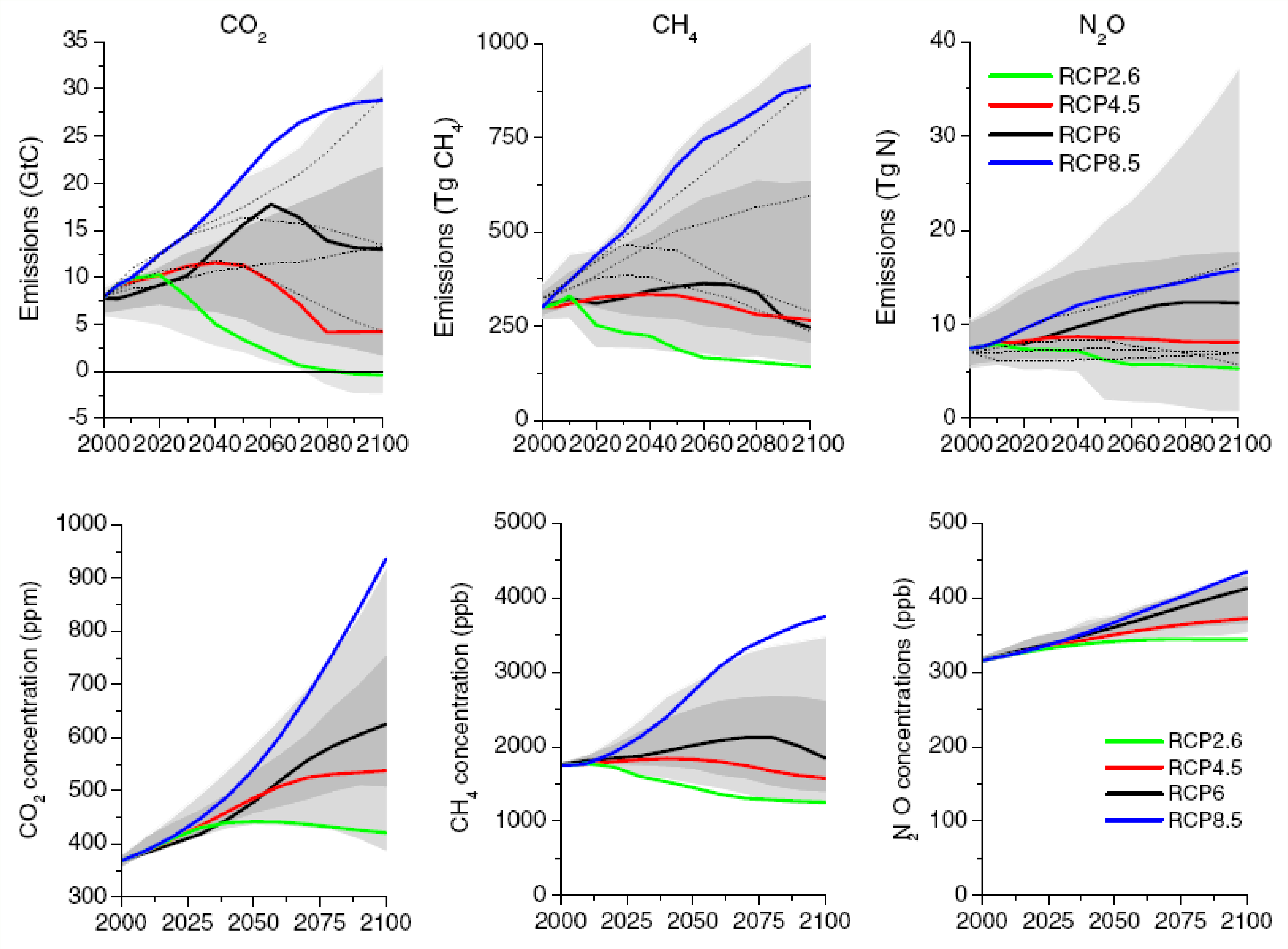
Factors driving choice of future GHG scenarios (*IPCC*)

Possible scenarios for global GHG emissions up to year 2100





Representative Concentration Pathways (RCPs)



Representative Concentration Pathways (RCPs) for major greenhouse gasses

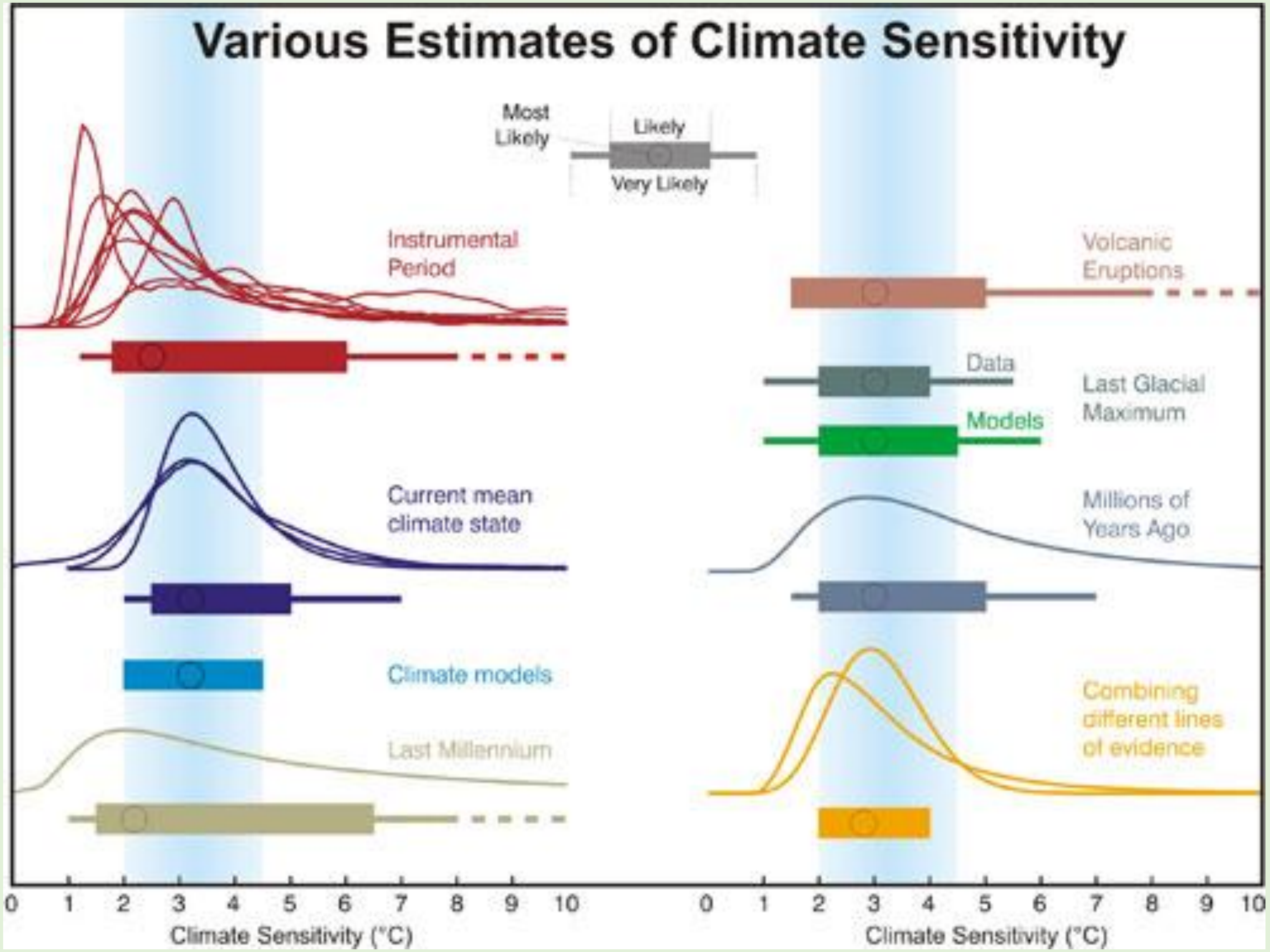
How does the climate depend on atmospheric CO_2 concentrations?

‘Climate Sensitivity’: a standard metric for future global temperature estimates

Climate Sensitivity = global surface temperature change induced by a <u>doubling of atmospheric CO_2 concentrations</u>.

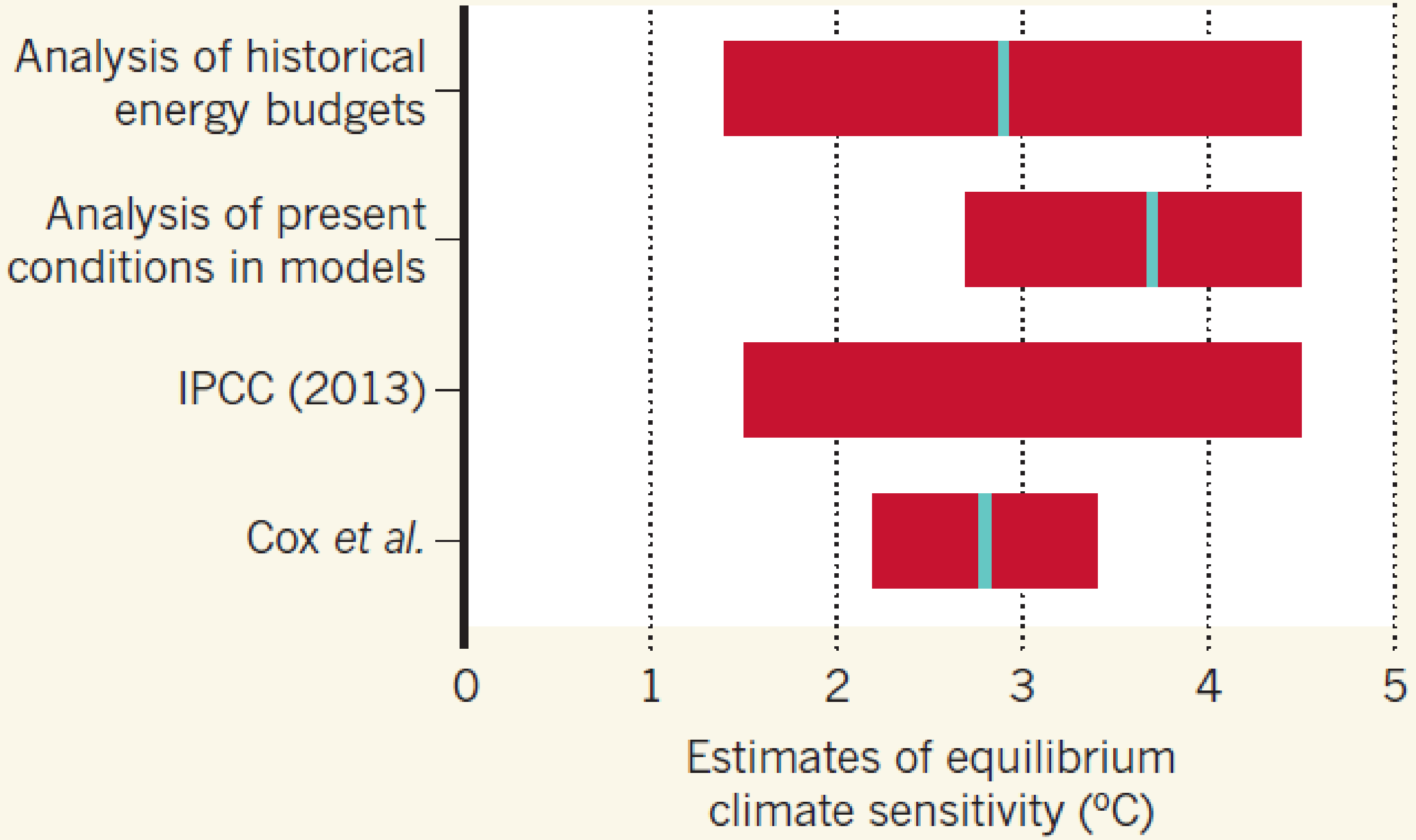
Example: 1850 conc. 280 x 2 = 560 ppm (expected in 30-70 years)
Example: 2017 conc. 406 x 2 = 812 ppm

‘Climate Sensitivity’: a standard metric for future global temperature estimates



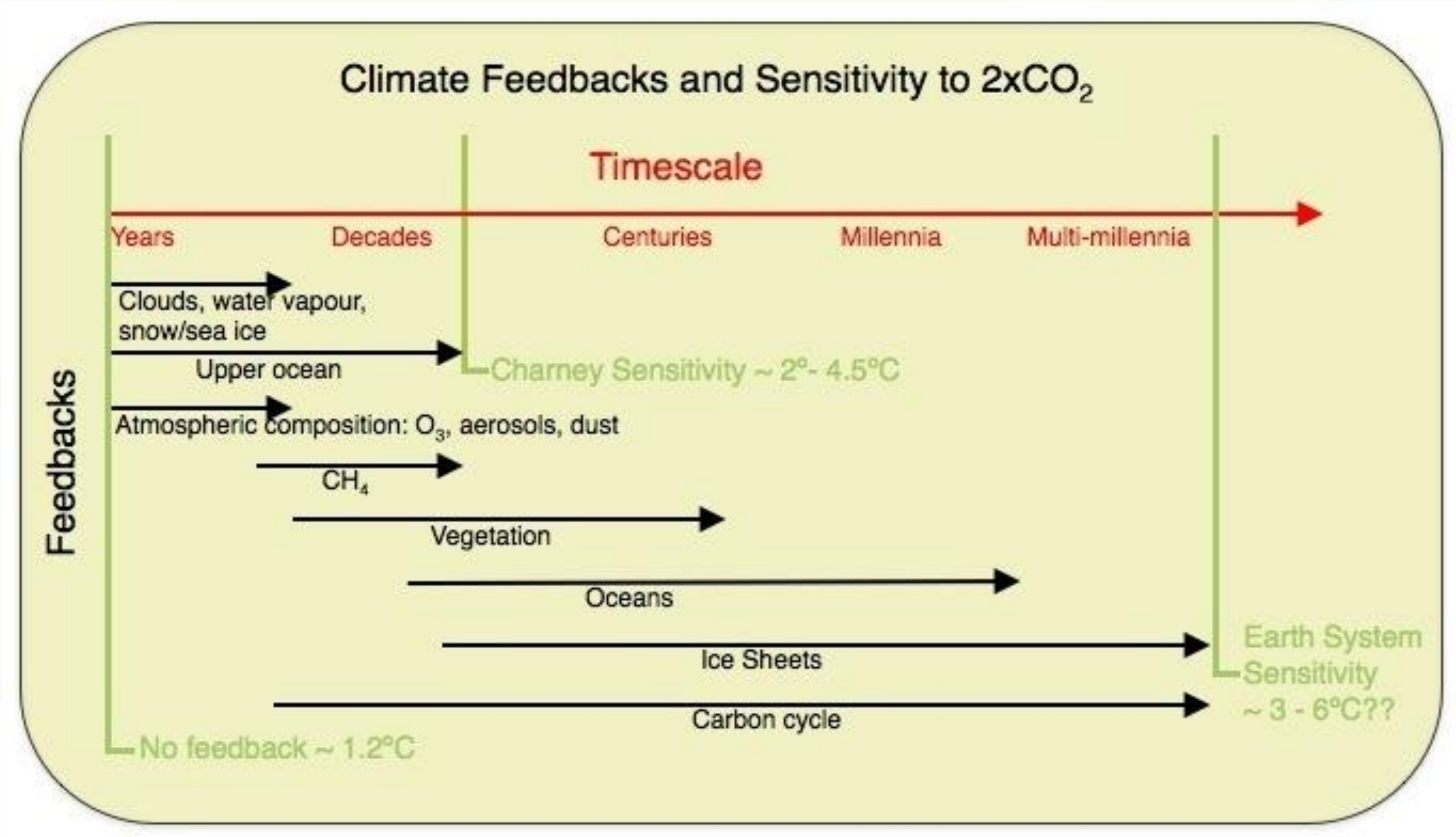
Climate Sensitivity- recent estimates

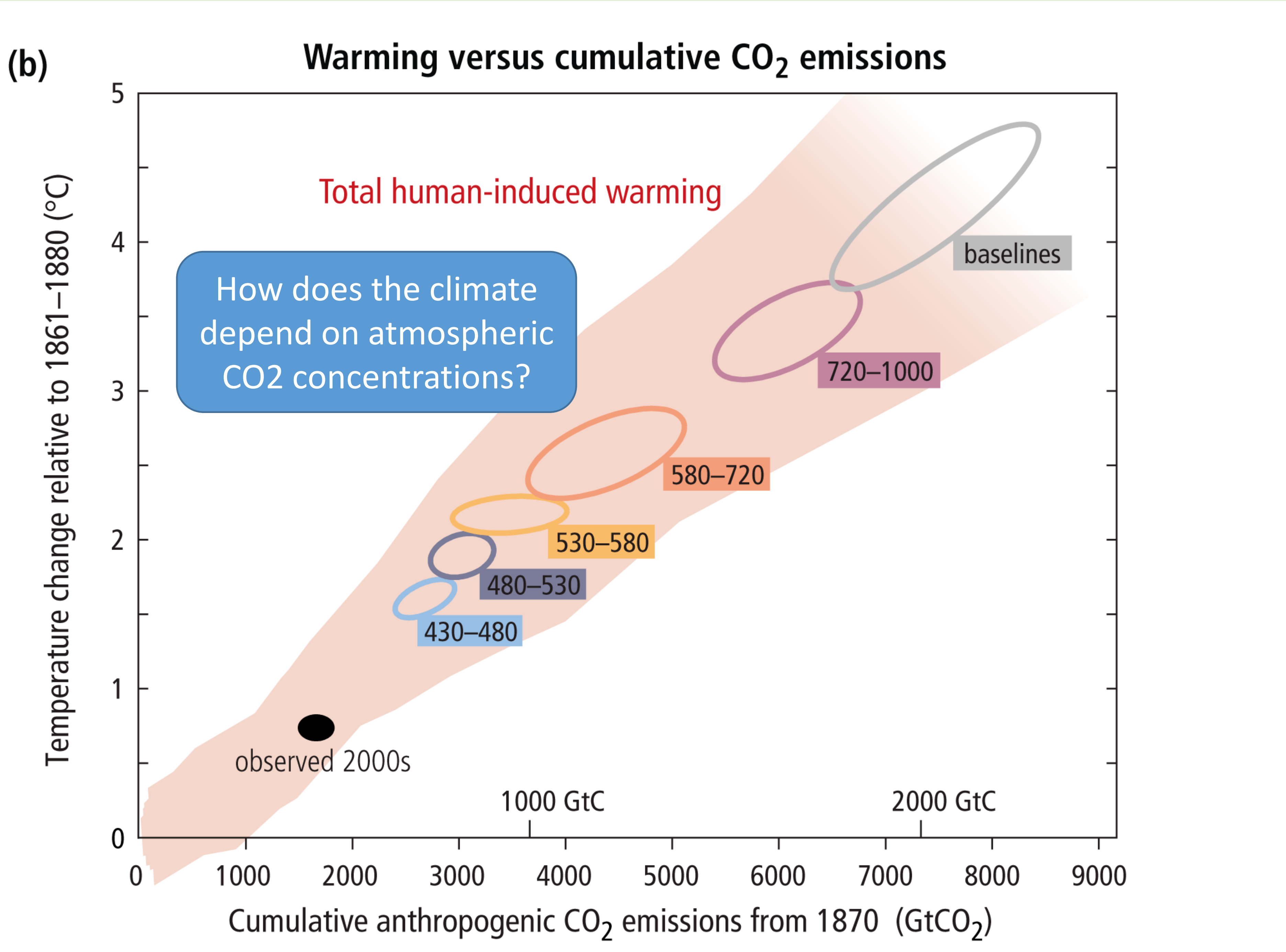
Estimates of equilibrium climate sensitivity (ECS). ECS quantifies the increase in Earth's average surface temperature that would occur if atmospheric carbon dioxide levels were doubled and the climate system was allowed to reach an equilibrium state. Estimates of ECS vary depending on the evidence used (such as records of Earth's energy budget[9] and analyses[4] of present climate conditions produced by models). The estimate[1] from the Intergovernmental Panel on Climate Change (IPCC) published in 2013 is based on several lines of evidence. Cox *et al.*[5] now report estimates based on an analysis of surface-temperature variation predicted by climate models. Their analysis rules out high estimates of ECS. Bars depict ranges for which there is a 66% likelihood of the value being correct; for the top two bars, these ranges have been inferred from the data in references 4 and 9. Best estimates of ECS for each range, if available, are indicated by a blue line.



https://www.nature.com/articles/d41586-018-00480-0

What are the timescales for feedbacks?




(b)
Warming versus cumulative CO2 emissions
Total human-induced warming
How does the climate depend on atmospheric CO2 concentrations?
baselines
720–1000
580–720
530–580
480–530
430–480
observed 2000s
1000 GtC
2000 GtC
Temperature change relative to 1861–1880 (°C)
0
1
2
3
4
5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Cumulative anthropogenic CO2 emissions from 1870 (GtCO2)

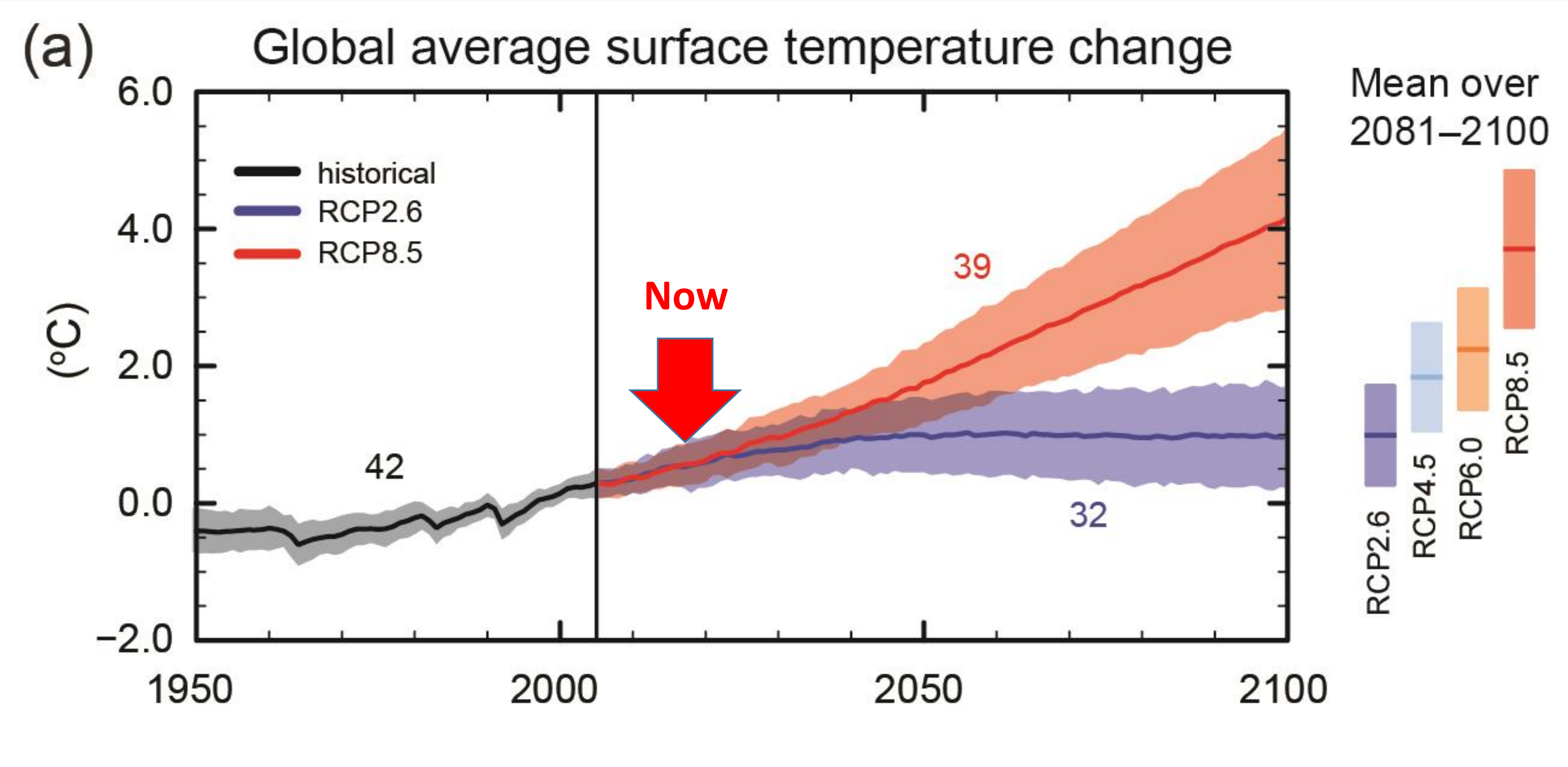
Future climate projections

Possible scenarios for global GHG emissions up to year 2100

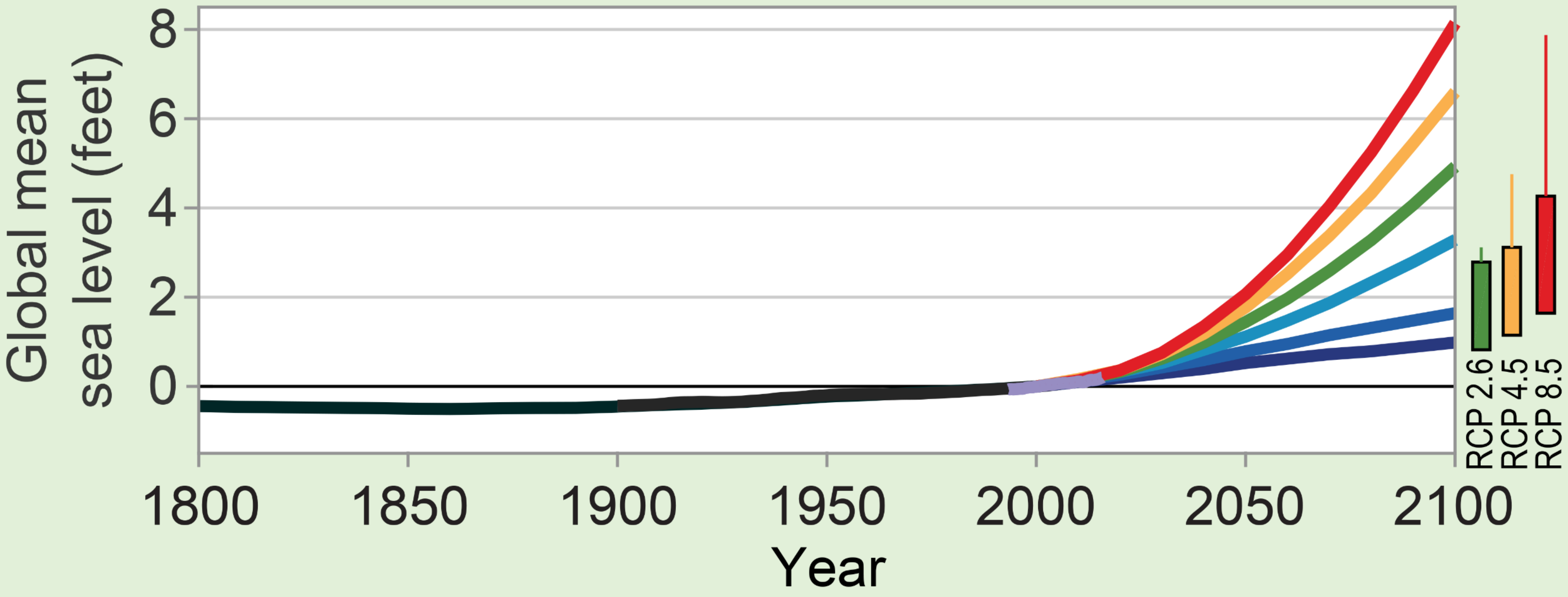
How does the climate depend on atmospheric CO2 concentrations?

Climate impacts:

- Global surface temp.
- Sea surface temp.
- Sea level rise, sea ice extent
- Ocean pH
- Precipitation
- Regional climate change

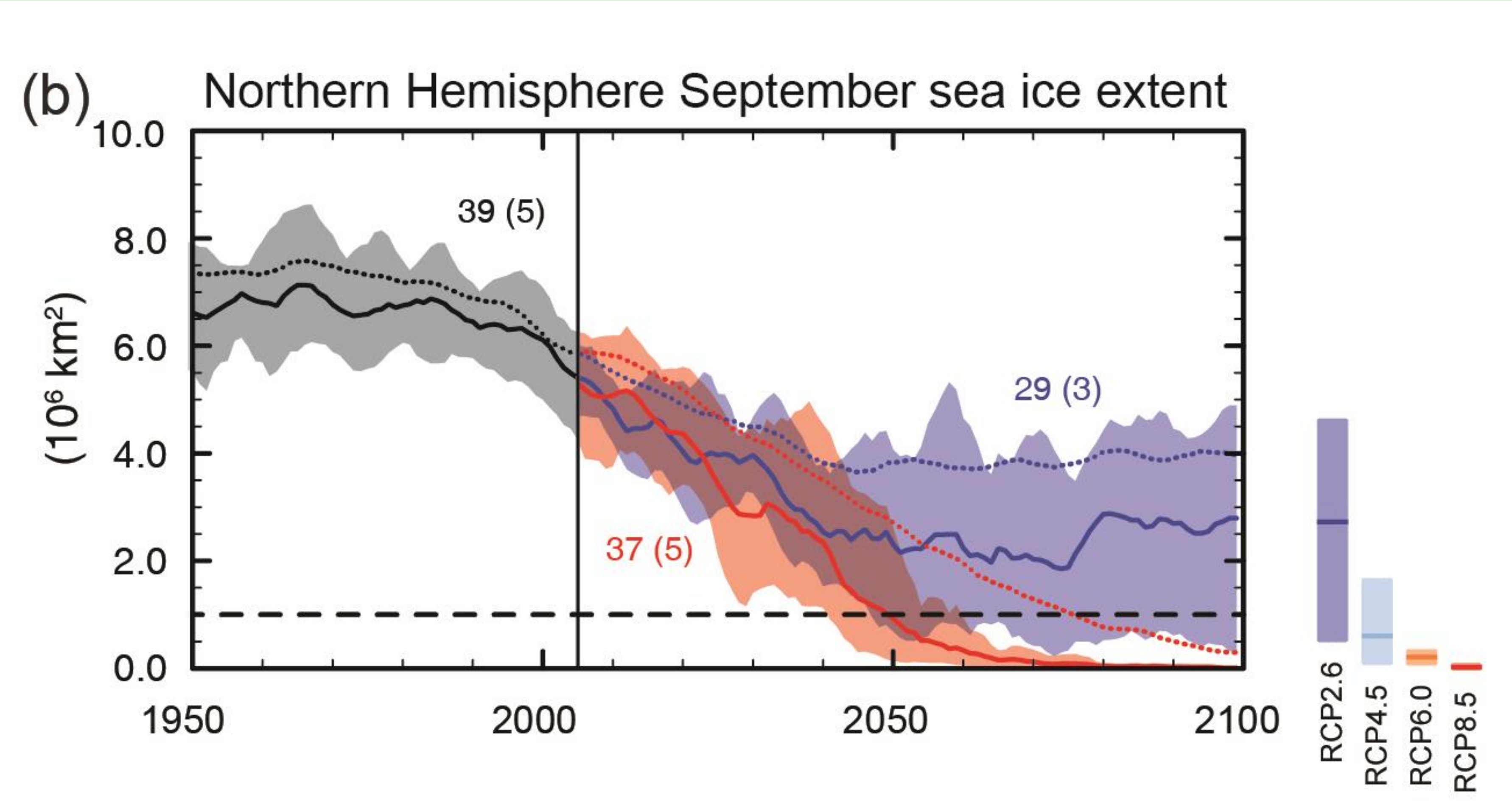

(a)
Global average surface temperature change
Mean over
2081–2100
6.0
4.0
2.0
0.0
−2.0
(ºC)
historical
RCP2.6
RCP8.5
Now
39
42
32
1950
2000
2050
2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5

(a)



Global mean sea level (feet)
8
6
4
2
0
1800
1850
1900
1950
2000
2050
2100
Year
RCP 2.6
RCP 4.5
RCP 8.5

CSSR
2018


(b)
Northern Hemisphere September sea ice extent
10.0
8.0
6.0
4.0
2.0
0.0
(10⁶ km²)
1950
2000
2050
2100
39 (5)
29 (3)
37 (5)
RCP2.6
RCP4.5
RCP6.0
RCP8.5

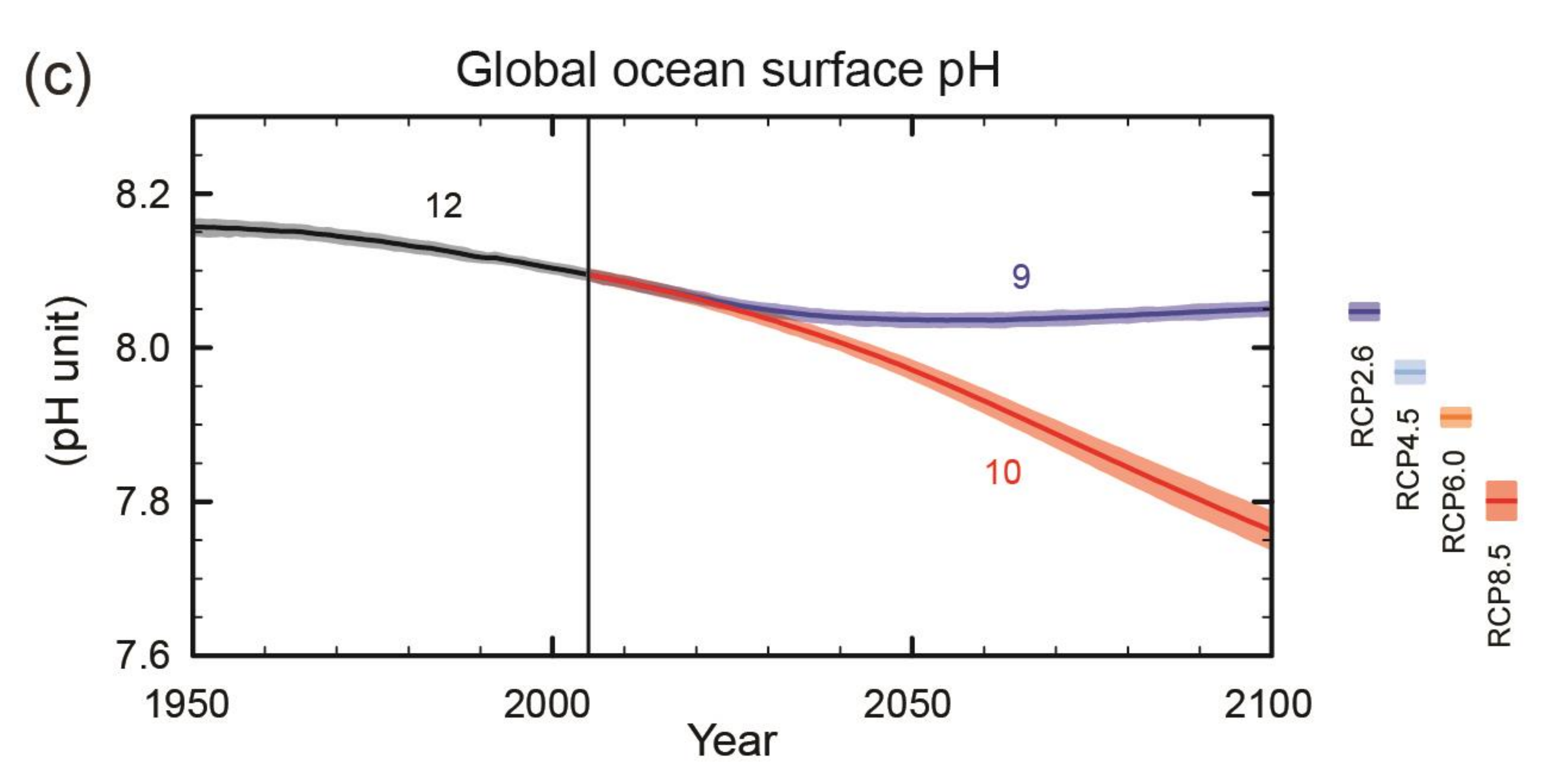
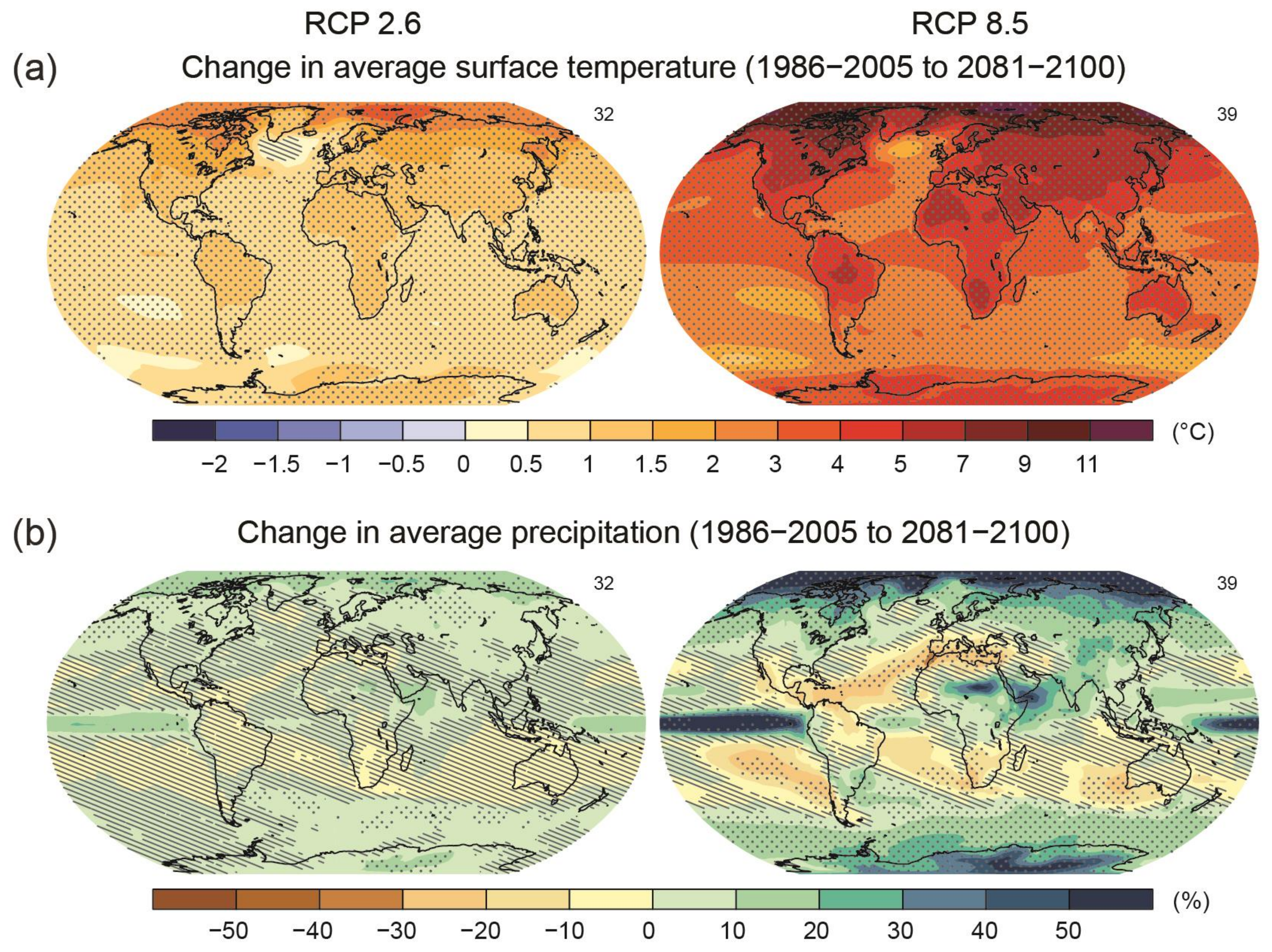


Figure SPM.7 | CMIP5 multi-model simulated time series from 1950 to 2100 for (a) change in global annual mean surface temperature relative to 1986–2005, (b) Northern Hemisphere September sea ice extent (5-year running mean), and (c) global mean ocean surface pH. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081−2100 are given for all RCP scenarios as colored vertical bars. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. For sea ice extent (b), the projected mean and uncertainty (minimum-maximum range) of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice is given (number of models given in brackets). For completeness, the CMIP5 multi-model mean is also indicated with dotted lines. The dashed line represents nearly ice-free conditions (i.e., when sea ice extent is less than 106 km2 for at least five consecutive years). For further technical details see the Technical Summary Supplementary Material {Figures 6.28, 12.5, and 12.28–12.31; Figures TS.15, TS.17, and TS.20}


RCP 2.6
RCP 8.5
(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

Future Surface Warming with ZERO emissions after 2050

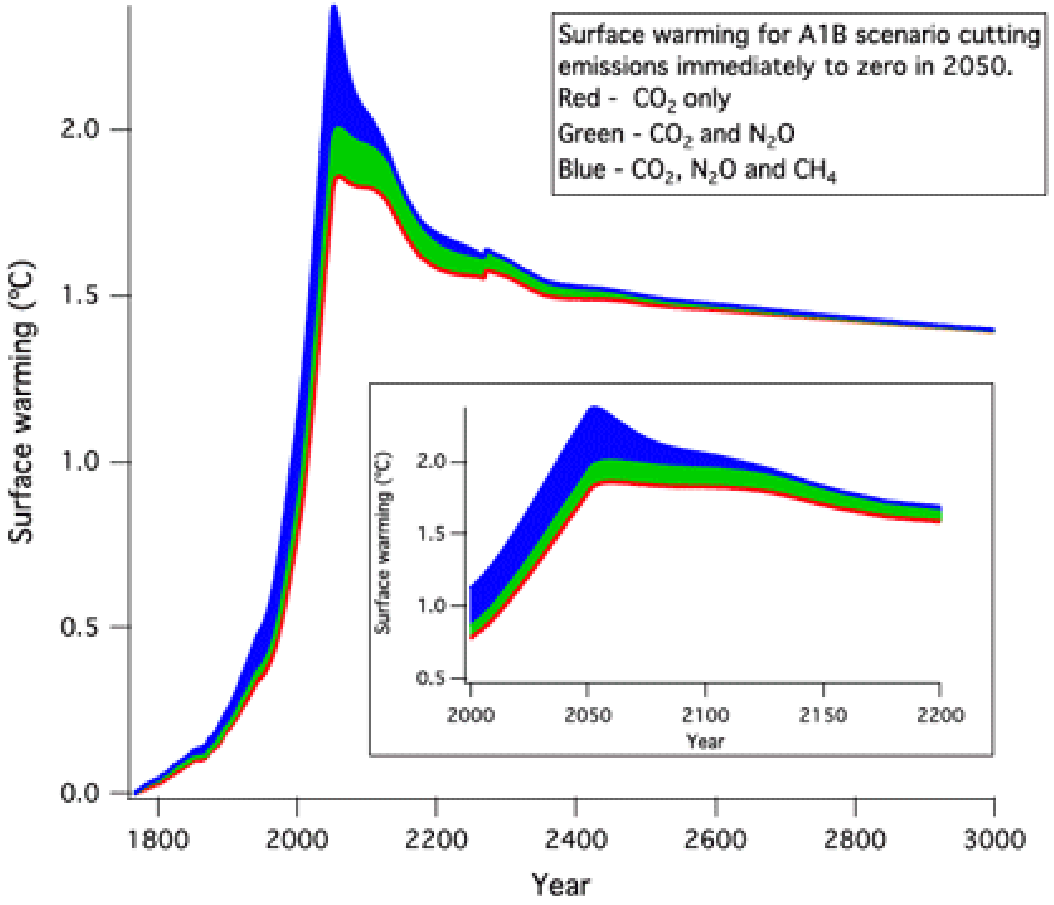
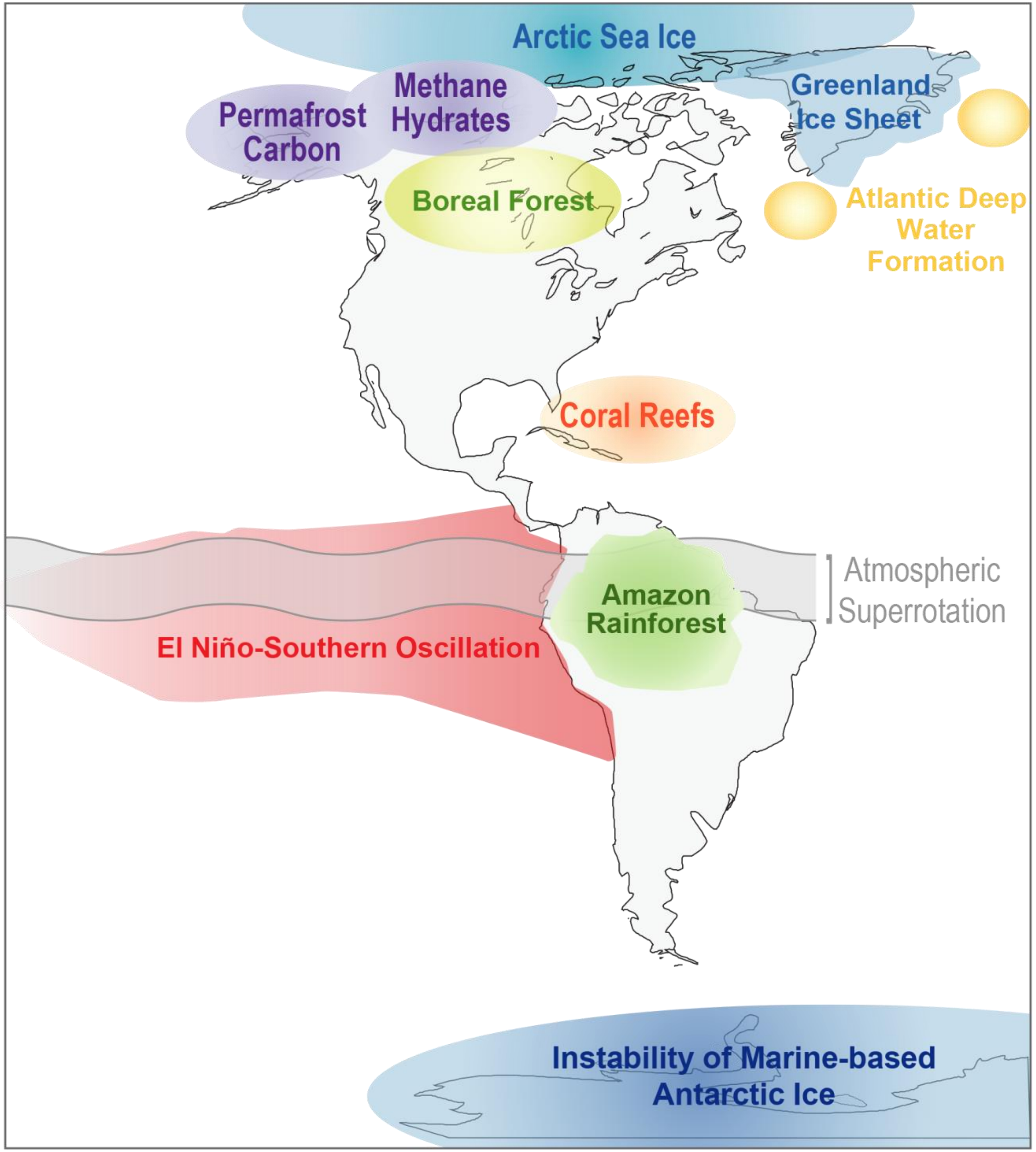


Fig. 1. Computed surface warming obtained in the Bern 2.5CC model due to CO_2, CH_4, and N_2O emission increases to 2050 following a "midrange" scenario (called A1B; see ref. 23) followed by zero anthropogenic emissions thereafter. The gases are changed sequentially in this calculation in order to explicitly separate the contributions of each. The bumps shown in the calculated warming are due to changes in ocean circulation, as in previous studies (5, 26, 39). The main panel shows the contributions to warming due to CO_2, N_2O, and CH_4. The inset shows an expanded view of the warming from year 2000 to 2200.

Solomon et al.
Proc. NAS 2010

Tipping points, non-linear processes, exponential events:

disaster, catastrophe, end-of-the-world, "OMG", the sky is Glowing

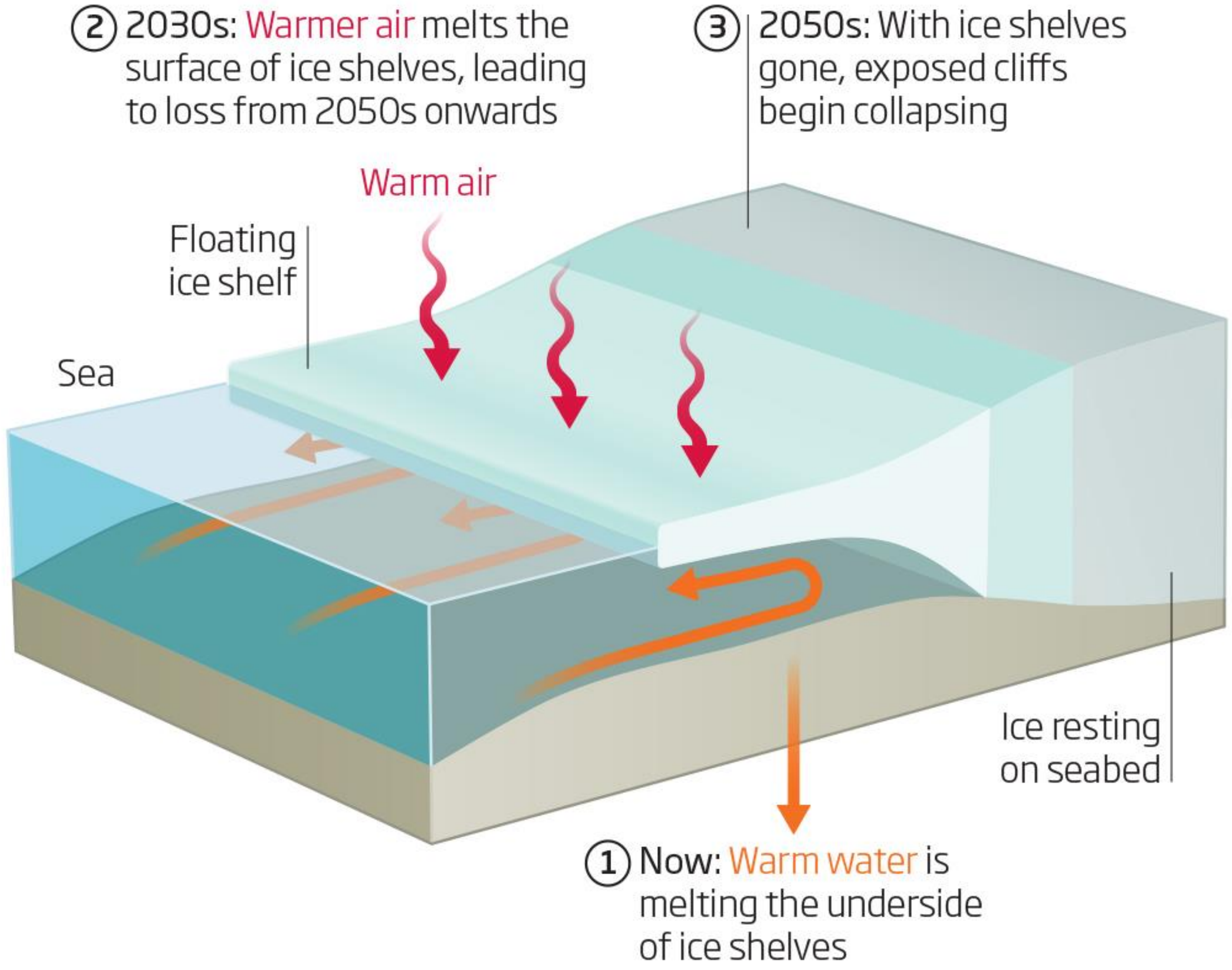


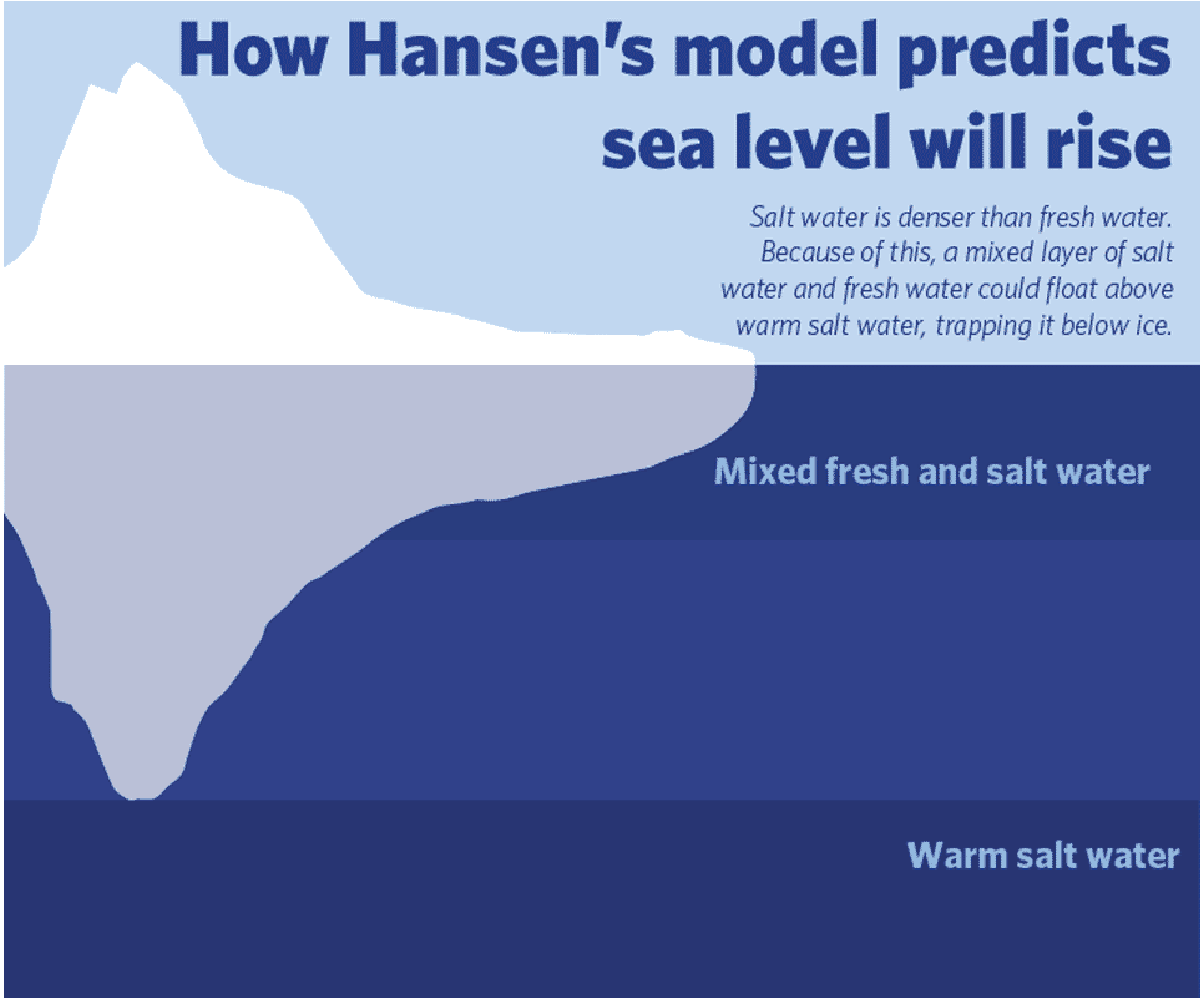
Potential climatic tipping elements affecting the Americas

U.S. Global Change Research Program
https://science2017.globalchange.gov/chapter/15/

Double whammy

Warmer air and cliff collapse could lead to rapid sea level rise




How Hansen's model predicts sea level will rise
Salt water is denser than fresh water. Because of this, a mixed layer of salt water and fresh water could float above warm salt water, trapping it below ice.
Mixed fresh and salt water
Warm salt water

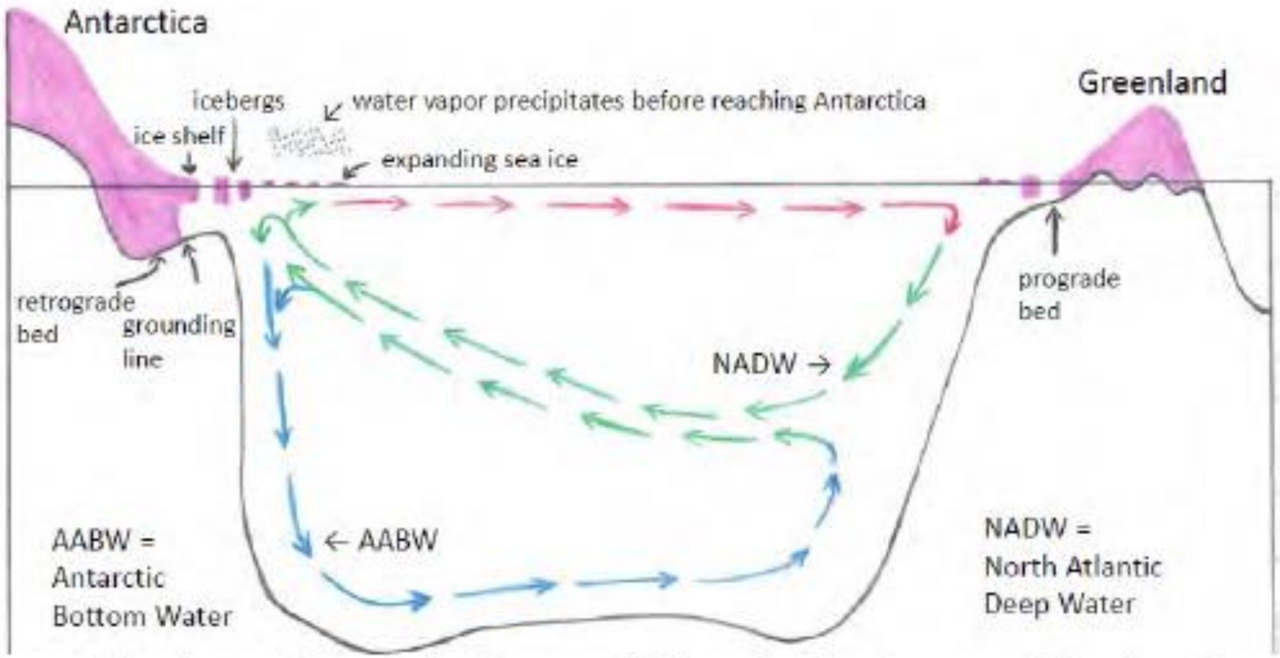


Fig. 18. Schematic of stratification and precipitation amplifying feedbacks. Stratification: increased freshwater flux reduces surface water density, thus reducing AABW formation, trapping NADW heat, and increasing ice shelf melt. Precipitation: increased freshwater flux cools ocean mixed layer, increases sea ice area, causing precipitation to fall before it reaches Antarctica, reducing ice sheet growth and increasing ocean surface freshening. Ice in West Antarctica and the Wilkes Basin, East Antarctica is most vulnerable because of the instability of retrograde beds.

Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Dangerous, preprint 2016

Southwest US Climate Change

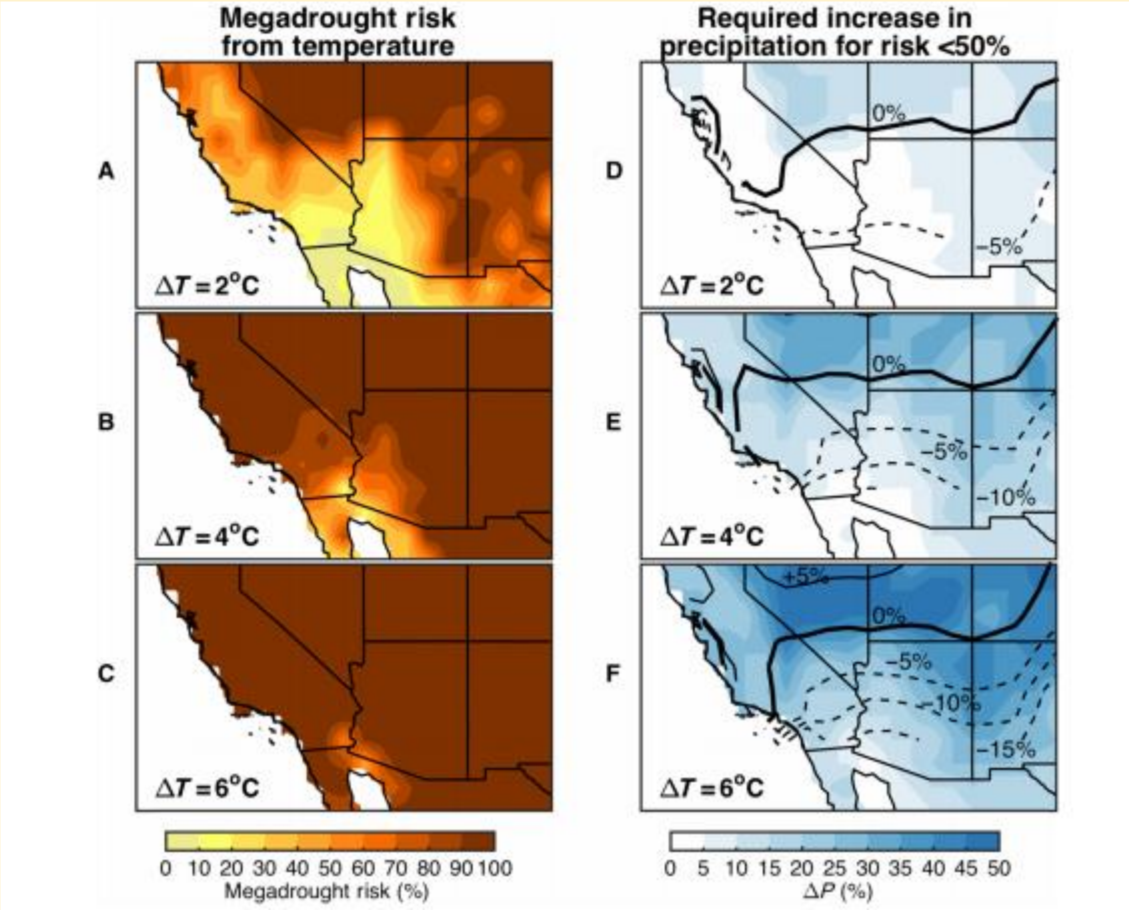
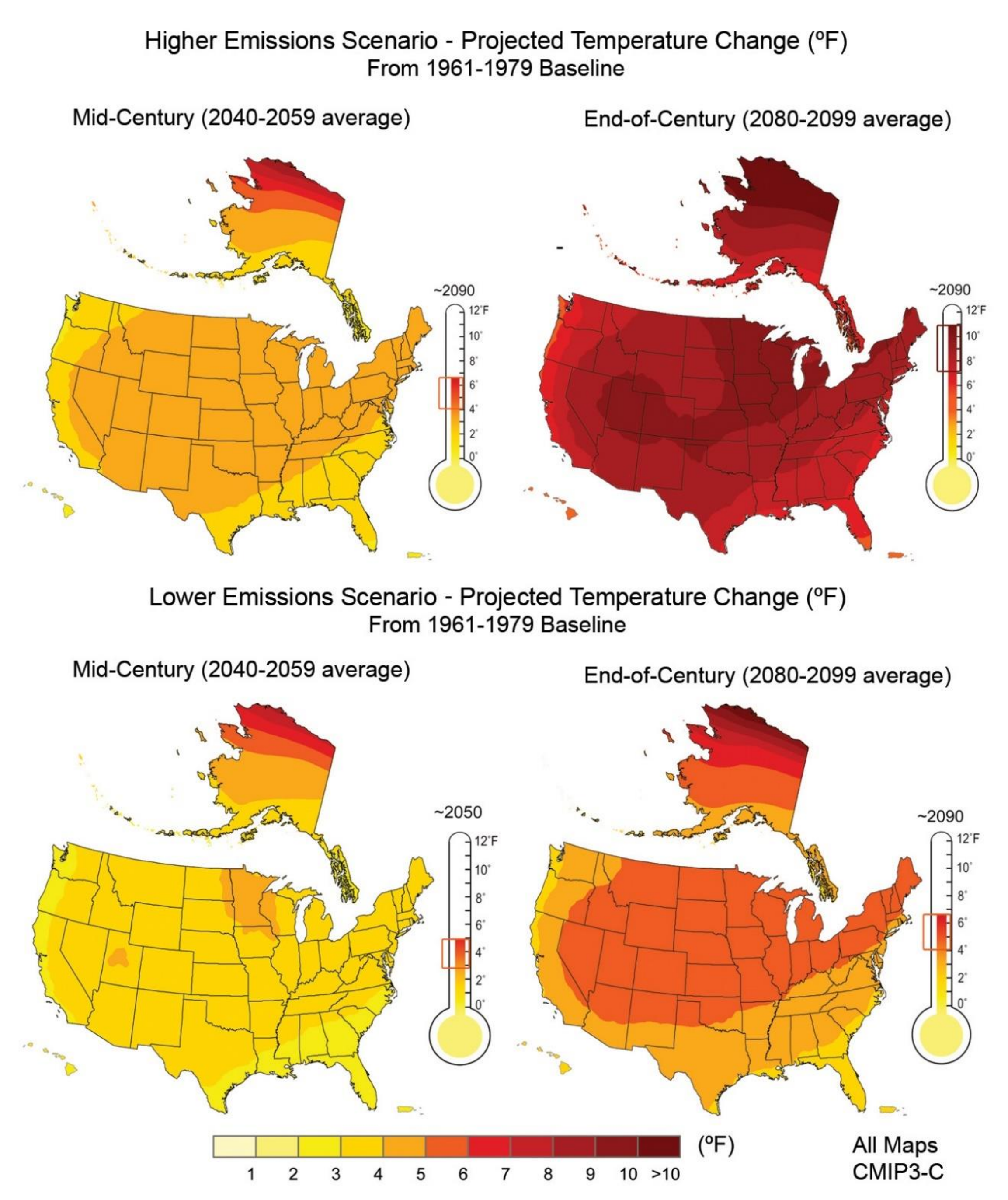


Fig. 4. Maps of megadrought risk for the American Southwest under different levels of warming, and the required increase in precipitation to compensate for that warming. (**A** to **C**) Maps of megadrought risk for the entire American Southwest domain at constant (historical) precipitation climatology ($\Delta P = 0\%$) and various levels of warming. These estimates are based on the Monte Carlo procedure of observational and reanalysis data, not on CMIP5 (see Materials and Methods). (**D** to **F**) Increases in precipitation (blue shading) needed to maintain megadrought risks below 50% for different levels of regional warming. Contours map the projected changes in precipitation derived from the multimodel CMIP5 mean and are shown for reference at each level of temperature change.

Megadrought Risk: Ault et al., Sci. Adv. 2016;2: e1600873 5 October 2016

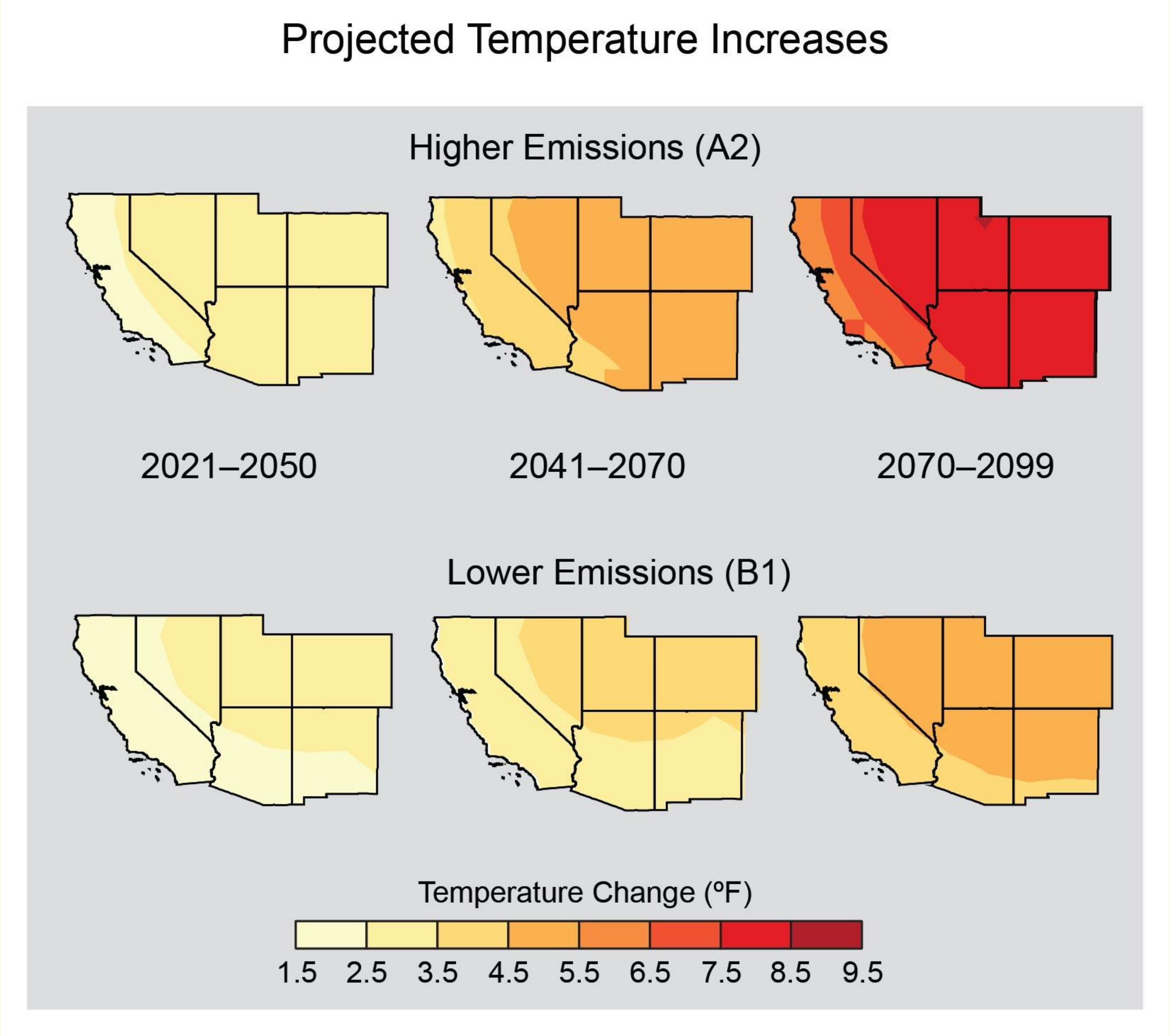
Arizona
+5 F

+4 F



+9 F

+5 F



http://nca2014.globalchange.gov/report/regions/southwest

Climate Science and Global Climate Change

Session 5

- Consequences of global warming
- COP21 Paris Agreement
- Adaptation and Mitigation
- Challenges and Positive Trends

Spring 2018
Univ. of Arizona OLLI
Lockwood Carlson PhD