Climate Change Projections

Alexandra Jahn

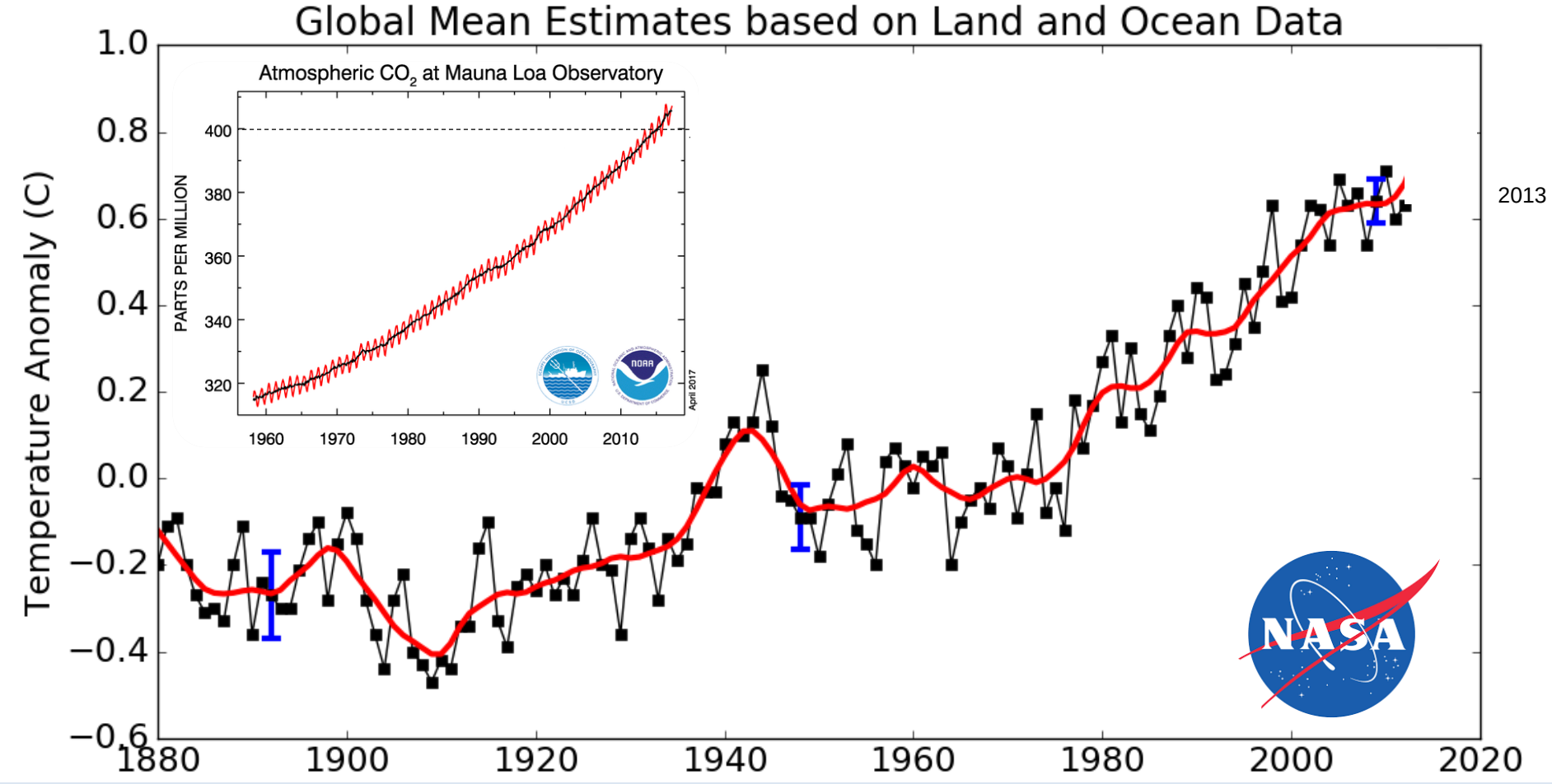
Atmospheric and Oceanic Sciences and Institute for Arctic and Alpine Research at CU Boulder

Scientists at CU Boulder are doing lots of climate research

- Scientists in several departments at CU Boulder are doing climate related research (Atmospheric and Oceanic Sciences, Geography, Geological Sciences, ATOC, INSTAAR, CIRES, Aerospace Engineering, ….)
- Many focus on historical climate change and paleo climate, building the foundation of our understanding of how climate reacts to perturbations
- Several groups focus on projections of future climate change

→ the focus of this presentation is on climate projections and future climate change

How is the climate changing?



NASA News & Feature Releases

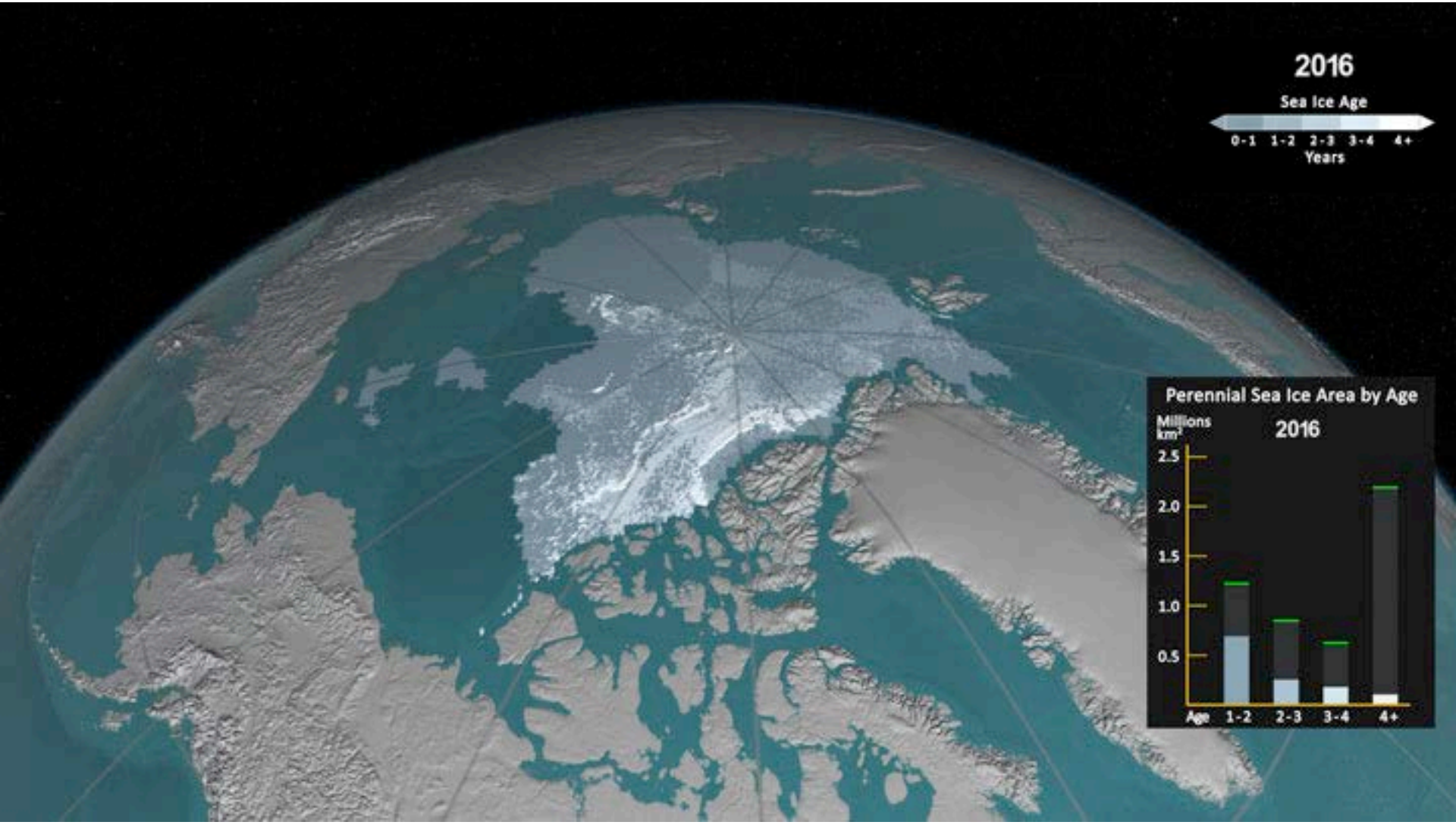
NASA, NOAA Data Show 2016 Warmest Year on Record Globally

Posted Jan. 18, 2017

Earth's 2016 surface temperatures were the warmest since modern recordkeeping began in 1880, according to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA).

Globally-averaged temperatures in 2016 were 1.78 degrees Fahrenheit (0.99 degrees Celsius) warmer than the mid-20th century mean. This makes 2016 the third year in a row to set a new record for global average surface temperatures.

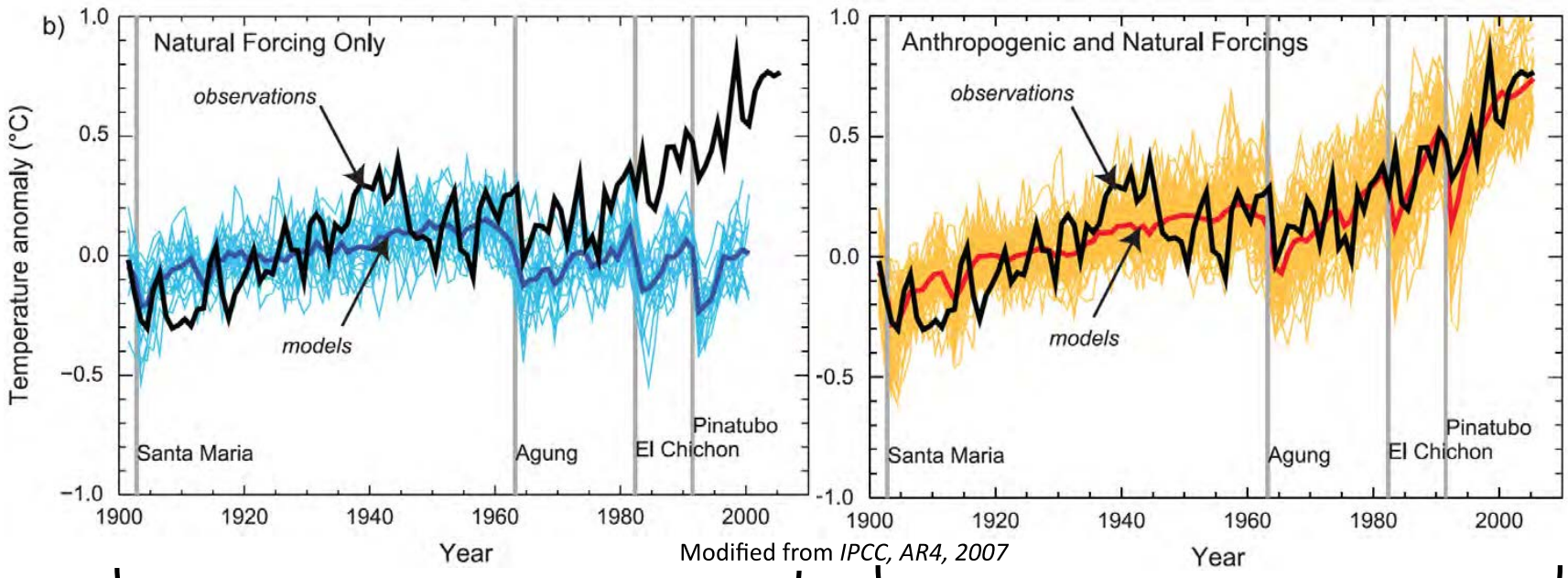
September sea ice cover and age in the Arctic



The area of summer sea ice lost since the 1980s is as large as 40 percent of the continental U.S

Source: NASA Earth Observatory

Global warming attribution with climate models



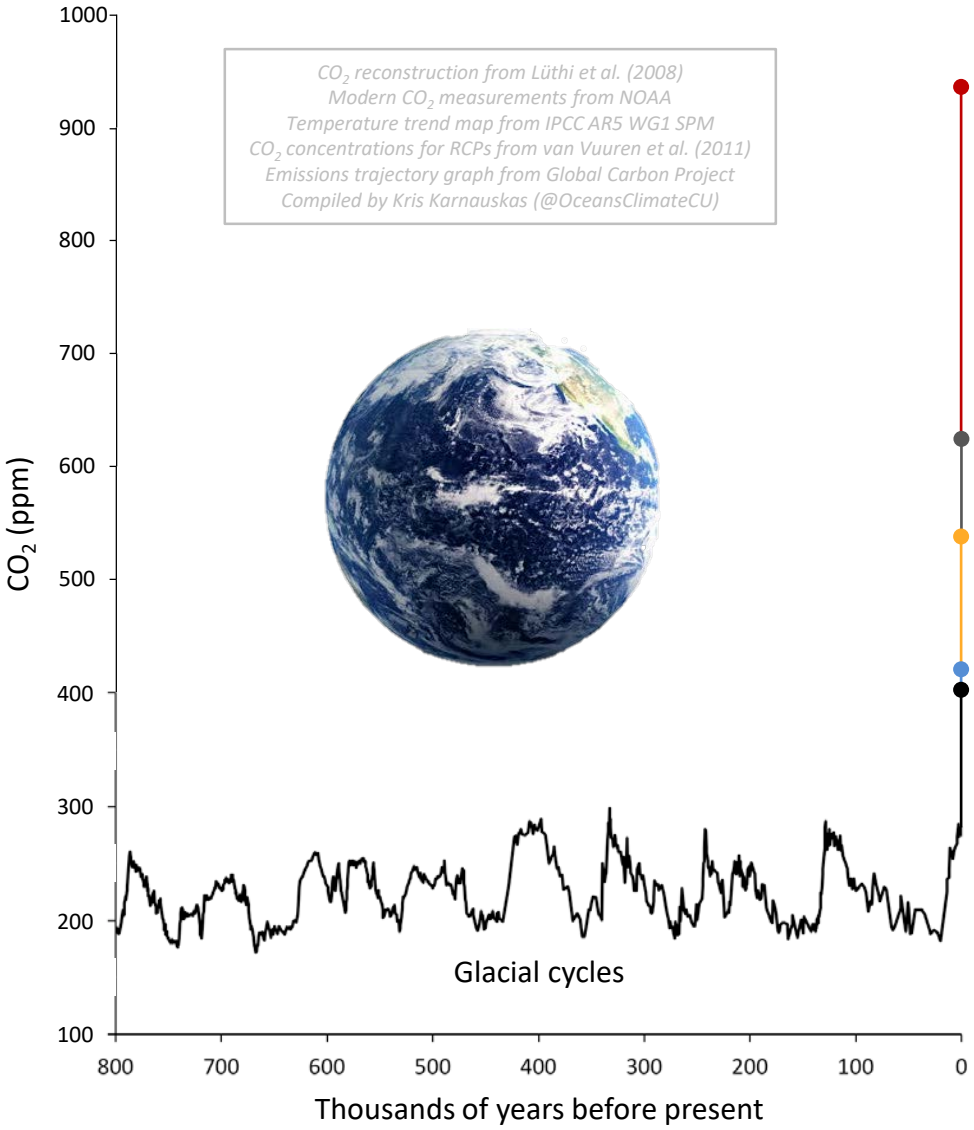
Modified from *IPCC, AR4, 2007*

Without Human Emissions

With Human Emissions

IPCC, 2007

An unprecedented global experiment is underway



930 in 2100 RCP8.5

RCP8.5: our emissions trajectory so far

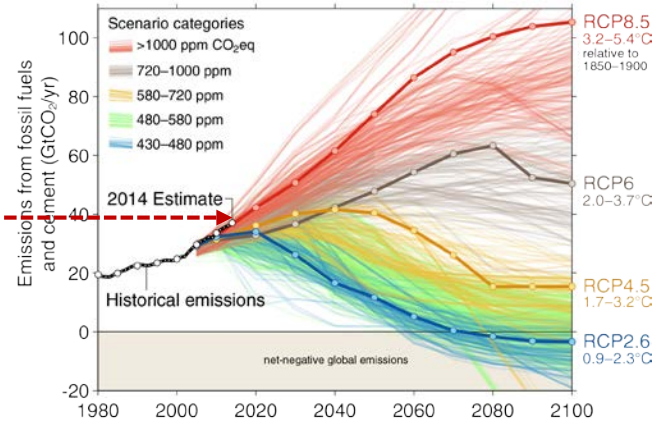
625 in 2100 RCP6

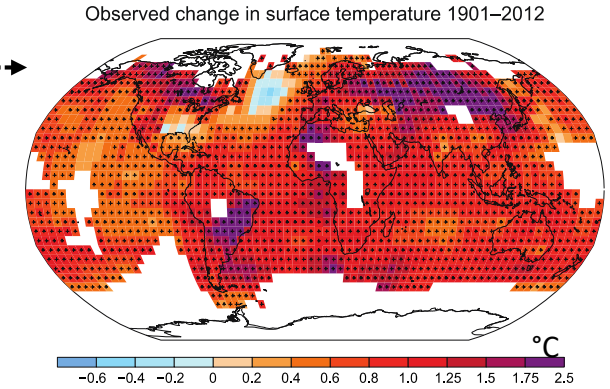
540 in 2100 RCP4.5

420 in 2100 RCP2.6

407 in 2016

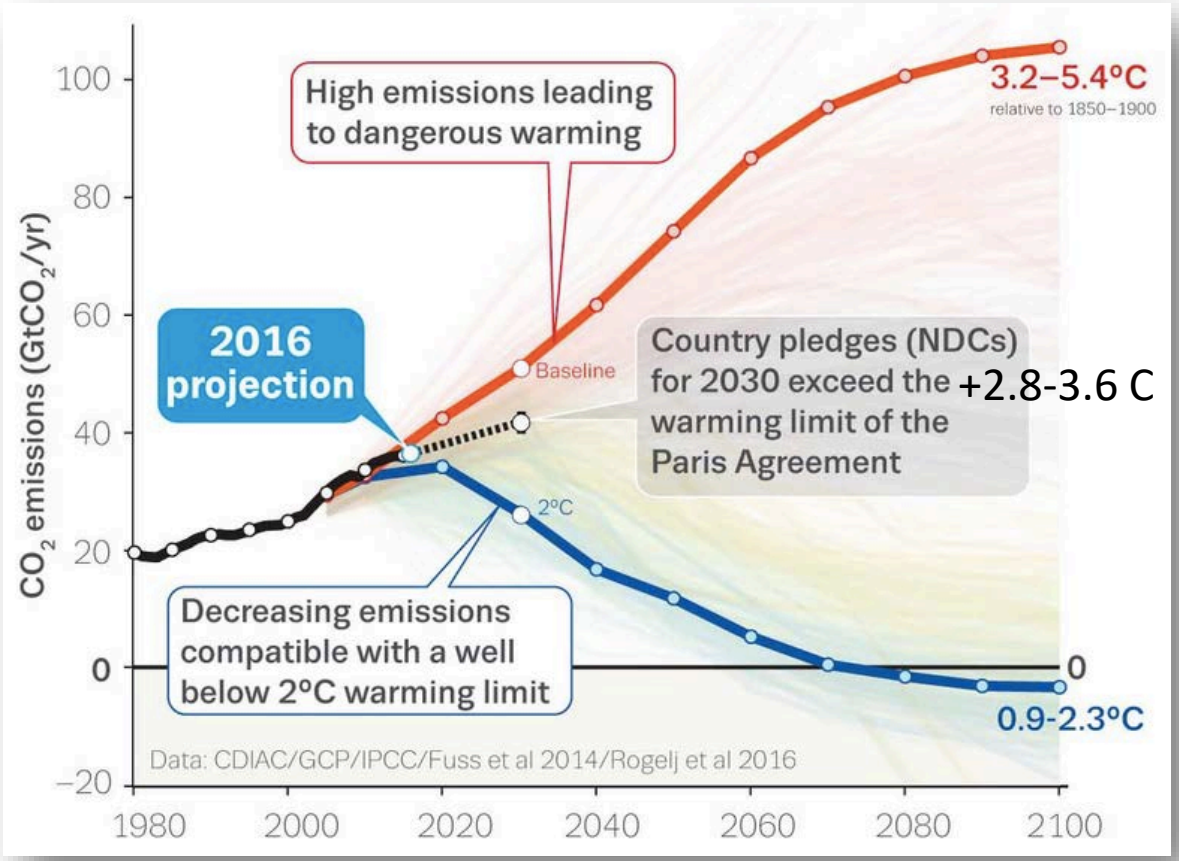
280 in 1813

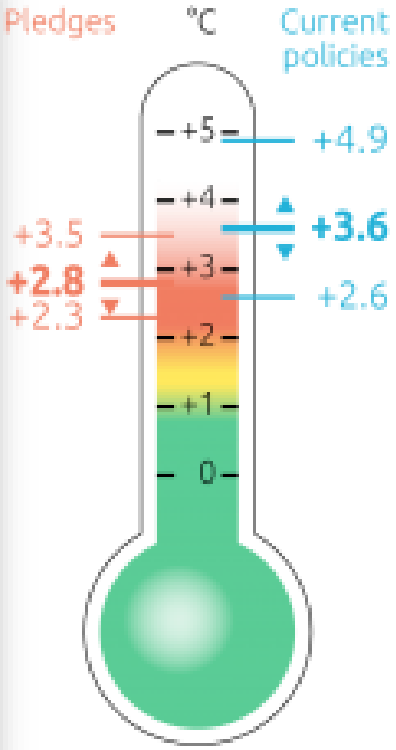




Slide courtesy of K. Karnauskas

An unprecedented global experiment is underway





Global Carbon Budget 2016 (www.globalcarbonproject.org)

To assess how the climate will change in response to the different possible future CO2 emission, we use climate models

Slide courtesy of K. Karnauskas

What is a global climate model?

$$u = -\frac{1}{f\rho}\frac{\partial p}{\partial y}; \qquad v = \frac{1}{f\rho}\frac{\partial p}{\partial x}$$

$$w_E(0) = -\mathrm{curl}_z\left(\frac{T}{\rho f}\right)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$T = \rho_a C_D U_{10}^2$$

$$\frac{D}{Dt}\left(\frac{\zeta + f}{H}\right) = 0$$

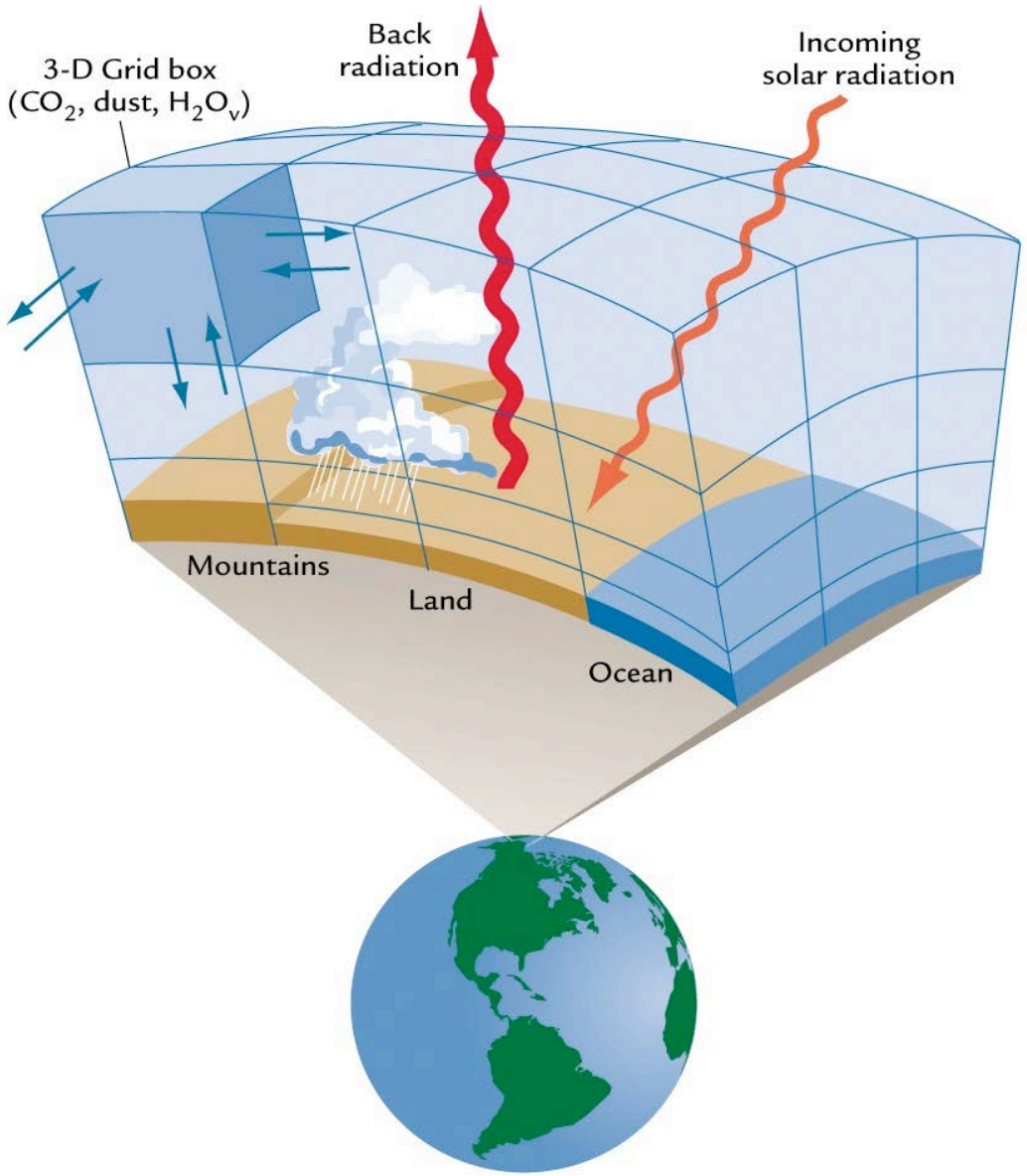
$$\frac{Dv}{Dt} = -\frac{1}{\rho}\nabla p - 2\Omega \times v + g + F_r$$

$$\beta M_y = \mathrm{curl}_z(T)$$

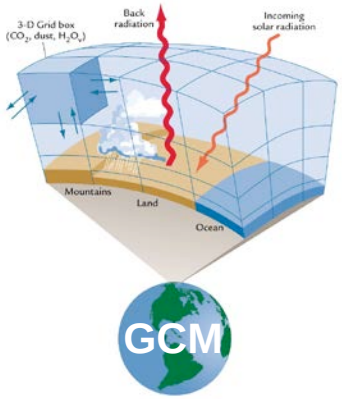
$$A_H \nabla^4 \Psi - \beta\frac{\partial \Psi}{\partial x} = -\mathrm{curl}_z T$$

What is a global climate model?

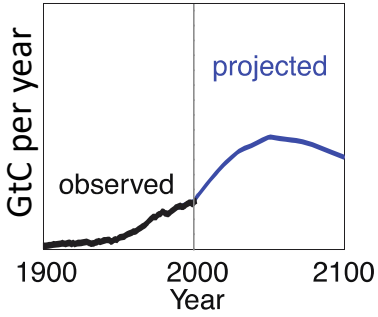
All of that stuff calculated at EVERY grid point on the planet!

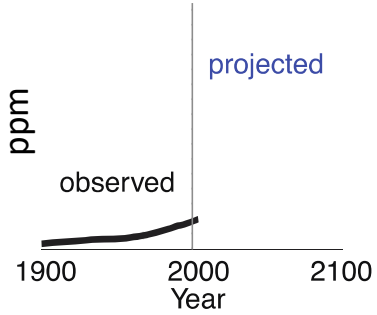


From emissions to climate response

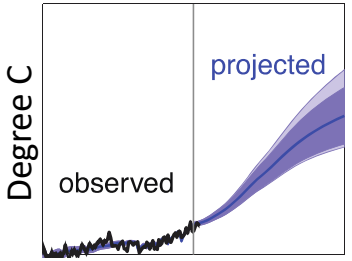


EMISSIONS → CONCENTRATIONS OF RADIATIVELY ACTIVE SPECIES → RADIATIVE FORCING → CLIMATE RESPONSE





W/m^2



Sources of Uncertainty of Climate Projections

Uncertainty in climate models projections is due to:

1) Scientific uncertainty
2) Societal uncertainty
3) Chaotic system uncertainty

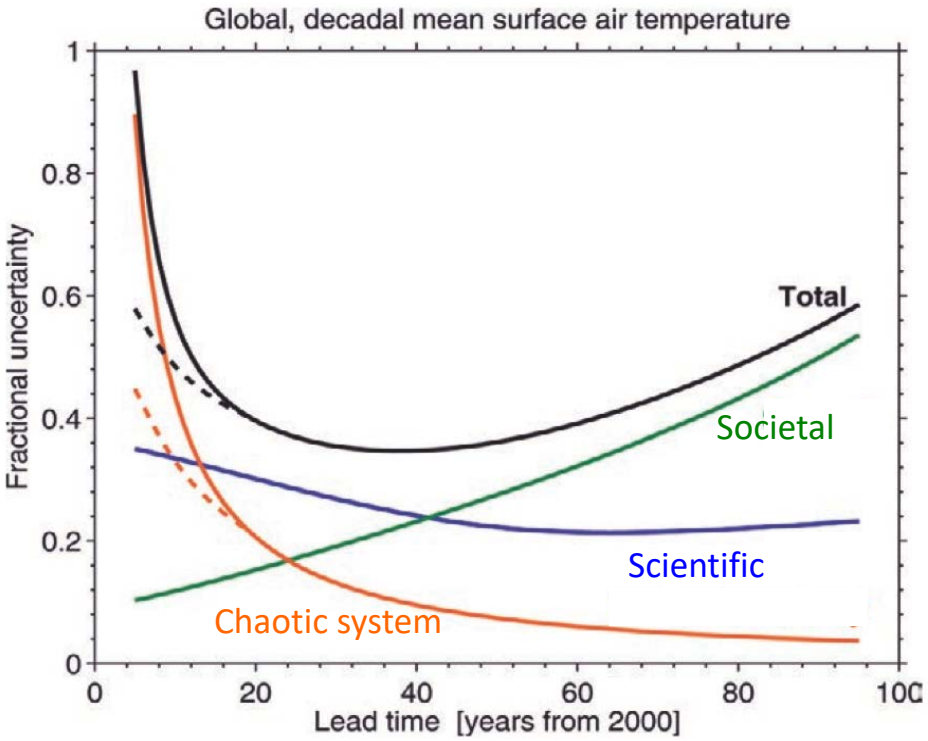
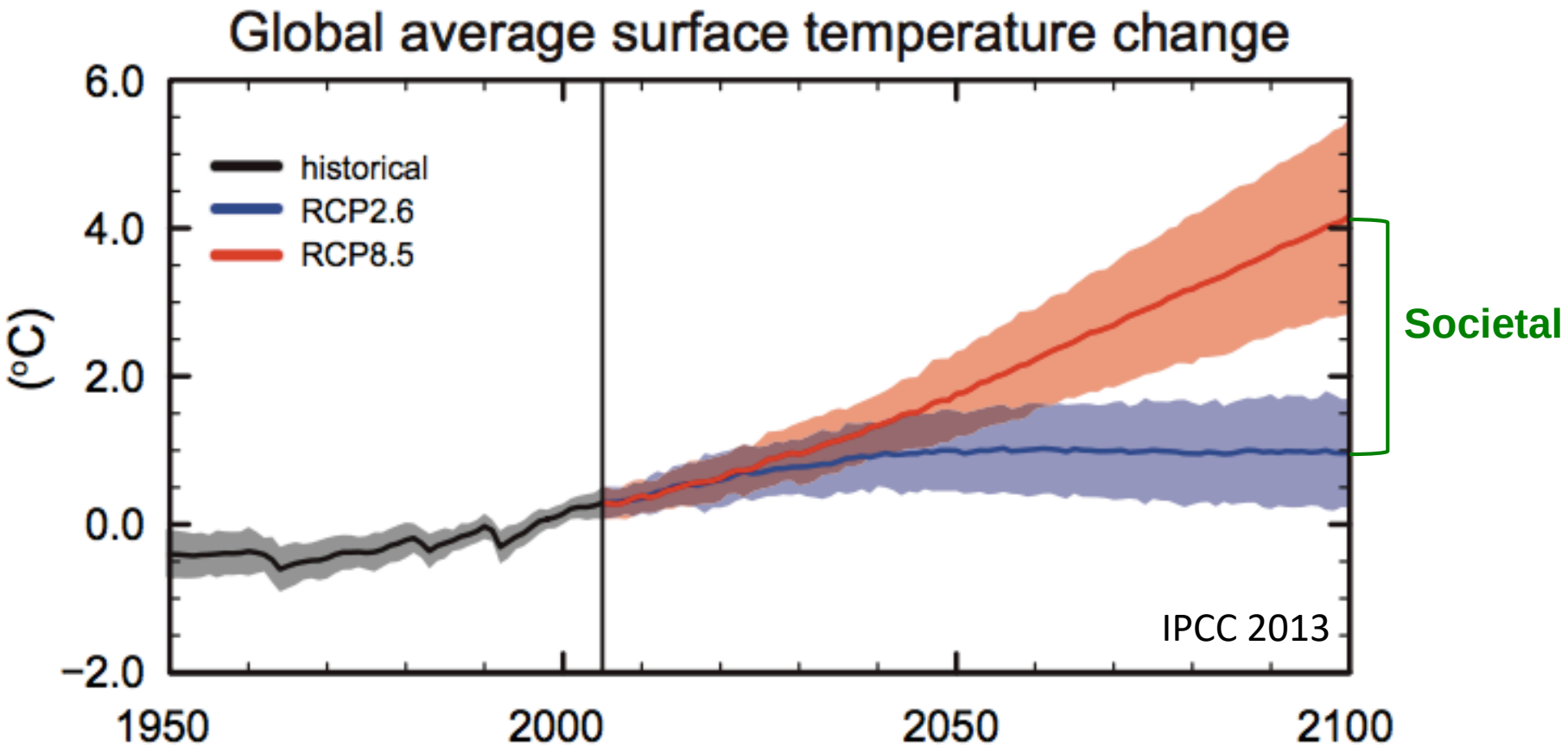


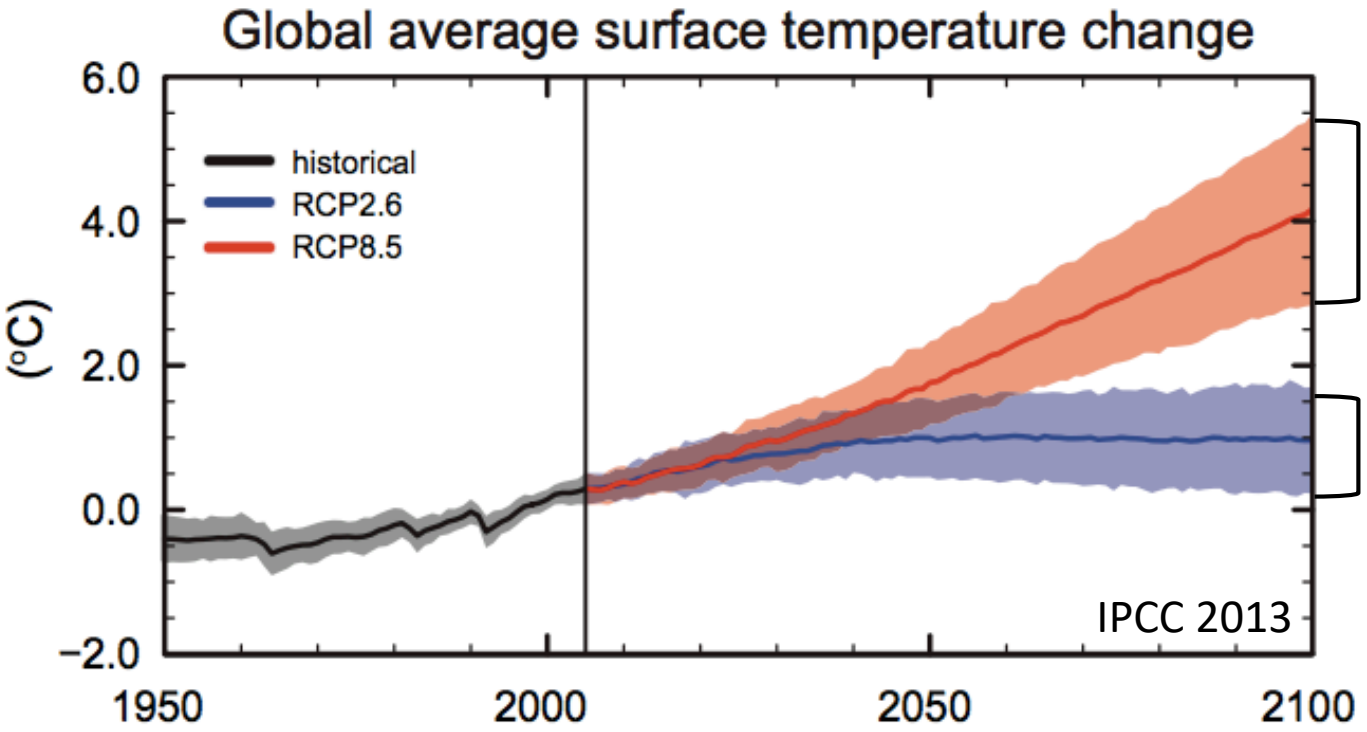
Figure from Hawkins and Sutton 2009

Sources of Uncertainty of Climate Projections



<u>Societal uncertainty:</u> how much uncertainty is there due to the fact that we don't know how human emissions will change over the course of this century?

Sources of Uncertainty of Climate Projections



Scientific and chaotic system uncertainty

<u>Scientific uncertainty:</u> how much uncertainty is there due to the fact that we have imperfect models?

<u>Chaotic system uncertainty:</u> how much uncertainty is there due to the fact that the climate system is a chaotic system that has inherent predictability limits?

Chaotic System uncertainty

One model, same forcing, difference between simulations (=uncertainty) due to chaotic system

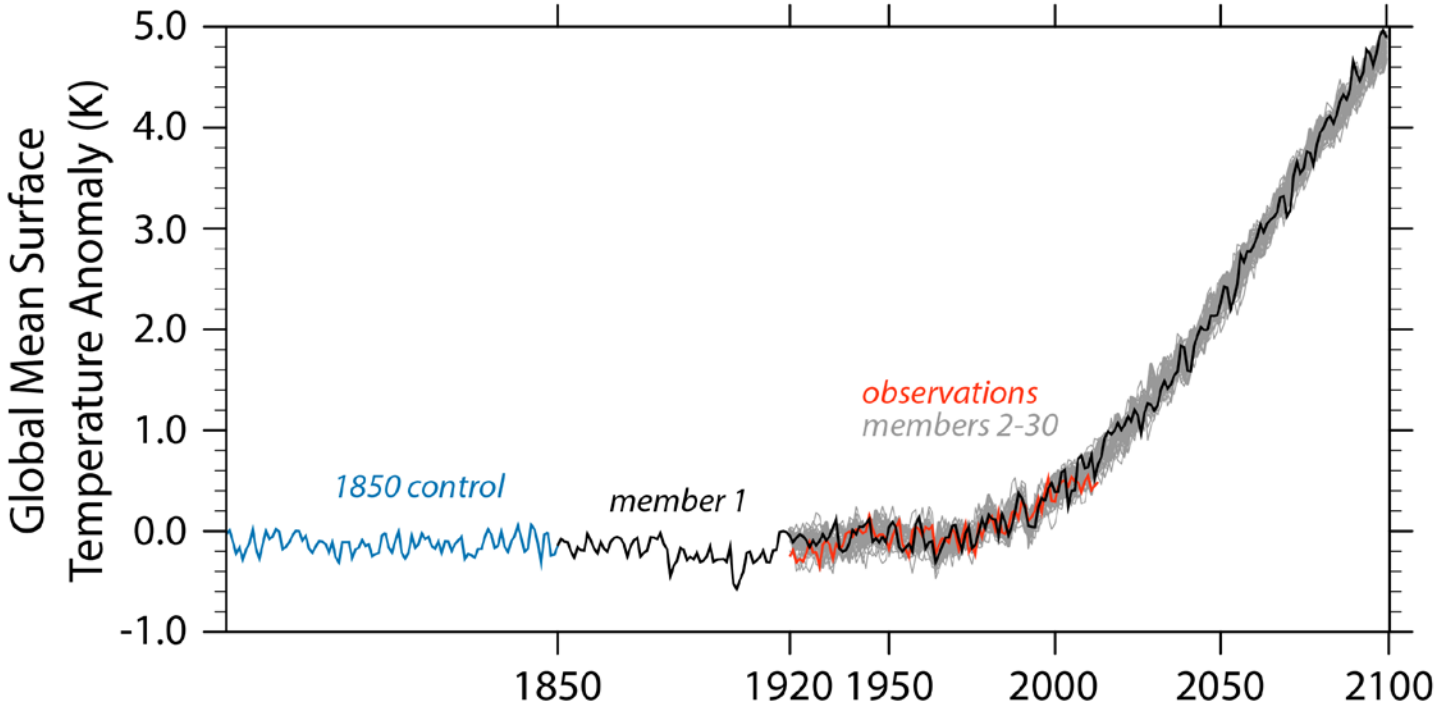
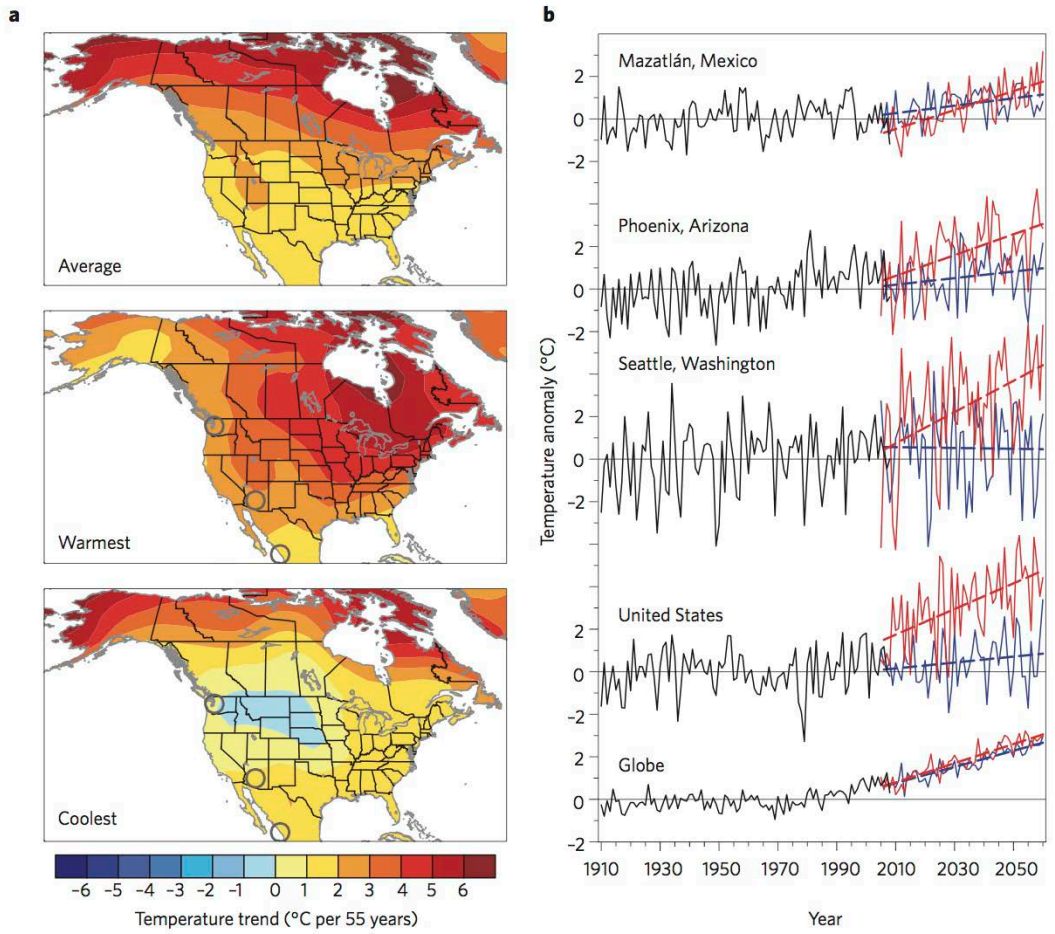


Figure from Kay et al. 2015

- Differences in projections due to chaotic nature of the system (not part of scientific uncertainty!)
- Chaotic system uncertainty can not be reduced (just like accurate weather forecasts for Dec. 25th on May 9th will never be possible)

Jennifer Kay, ATOC and CIRES Assistant Professor

Chaotic System uncertainty



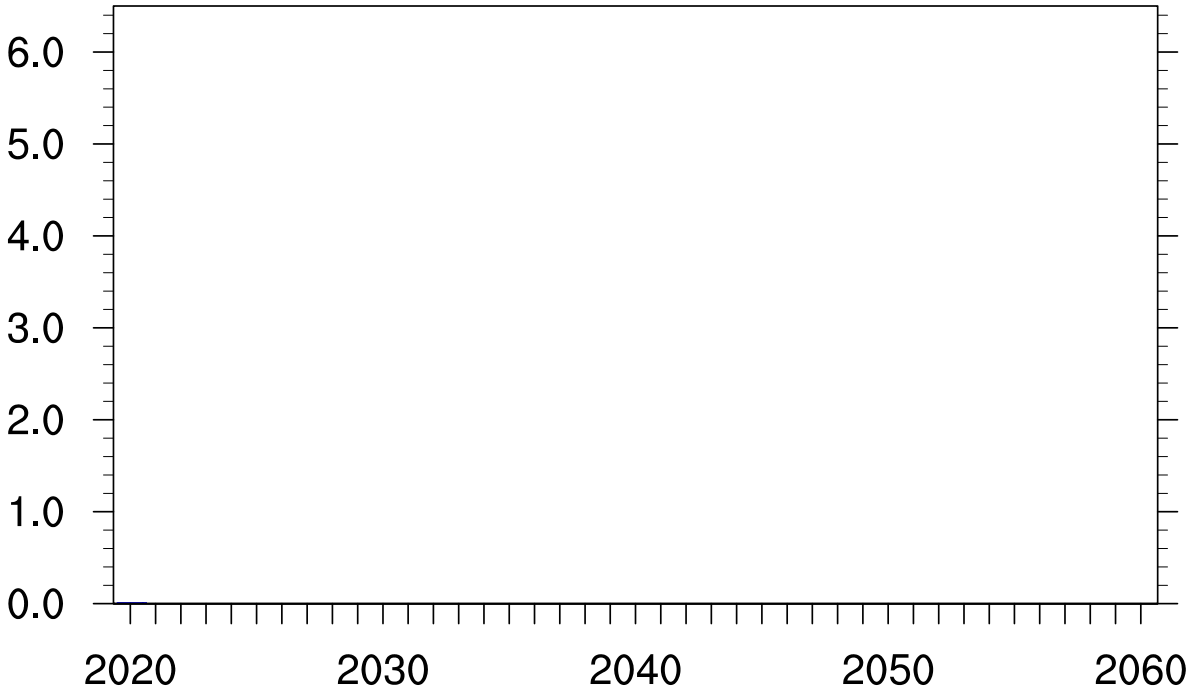
Deser et al., 2012

- ***Important sources of uncertainty in climate projections on regional spatial scales and on short to medium (several decades) timescales.***
- Less important on global scales and for long periods (>50 years)

Chaotic System uncertainty

Influence of chaotic system on sea ice projections of the first occurrence of an ice-free Arctic

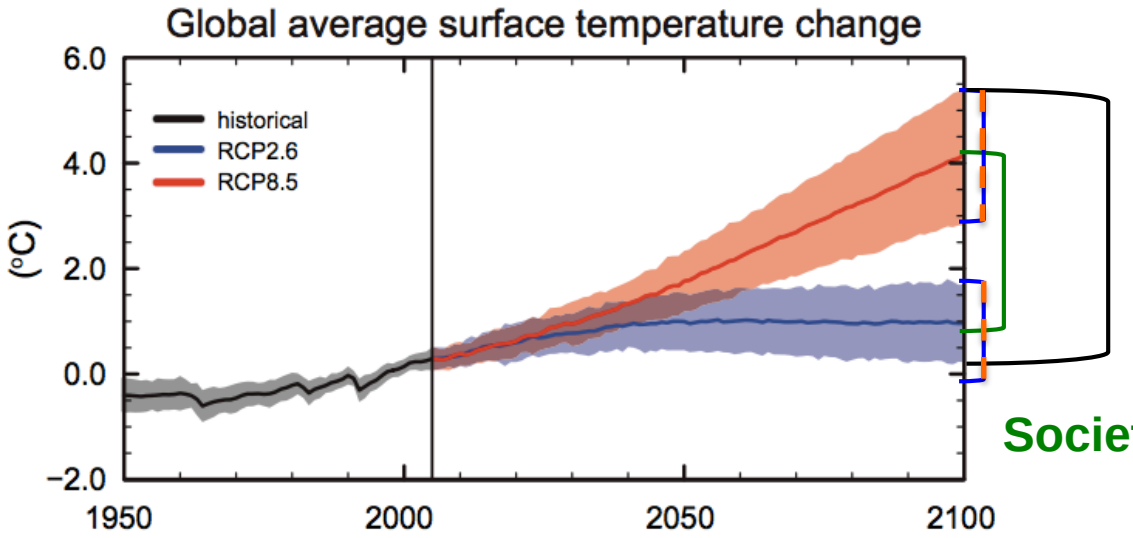
Within one model and one scenario, large projection uncertainty due to the chaotic climate system



Alexandra Jahn, ATOC & INSTAAR

Jahn et al., 2016, GRL

Climate Projections Uncertainty



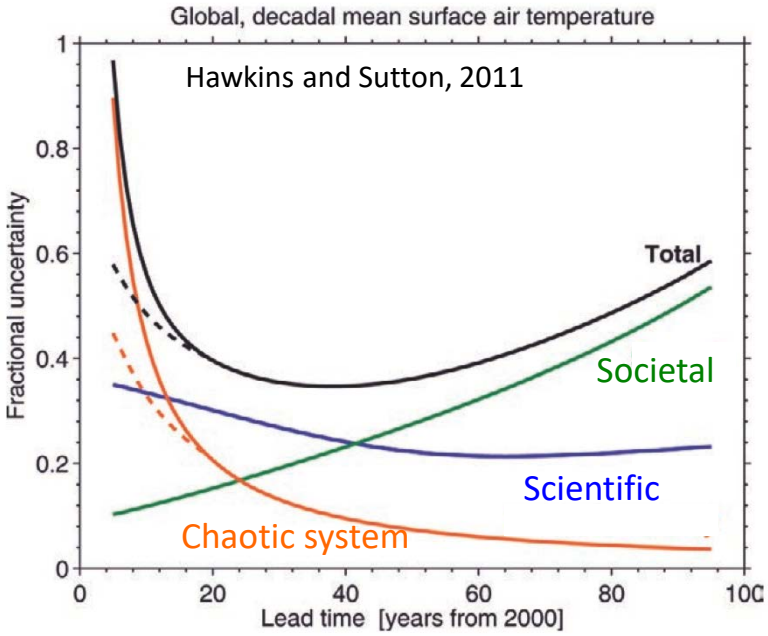
Scientific & chaotic system

Combined projection uncertainty

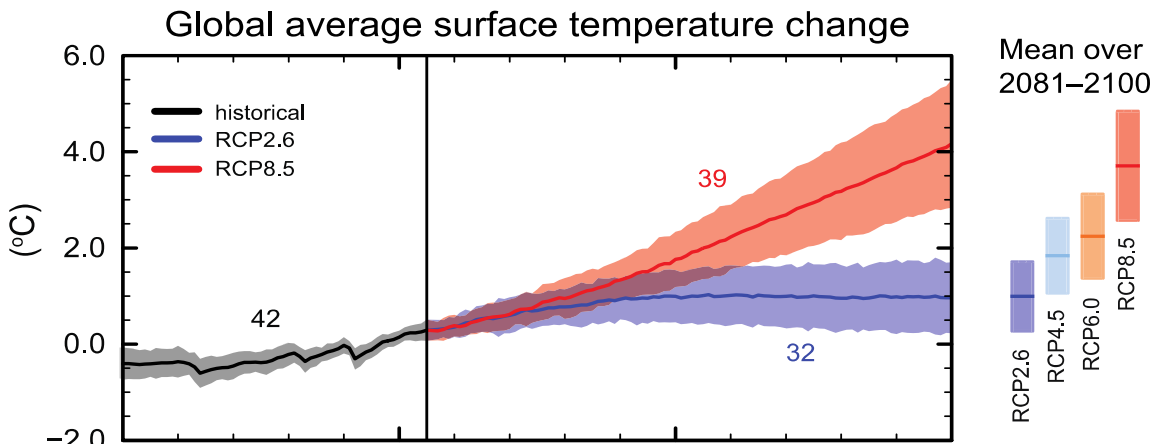
Societal

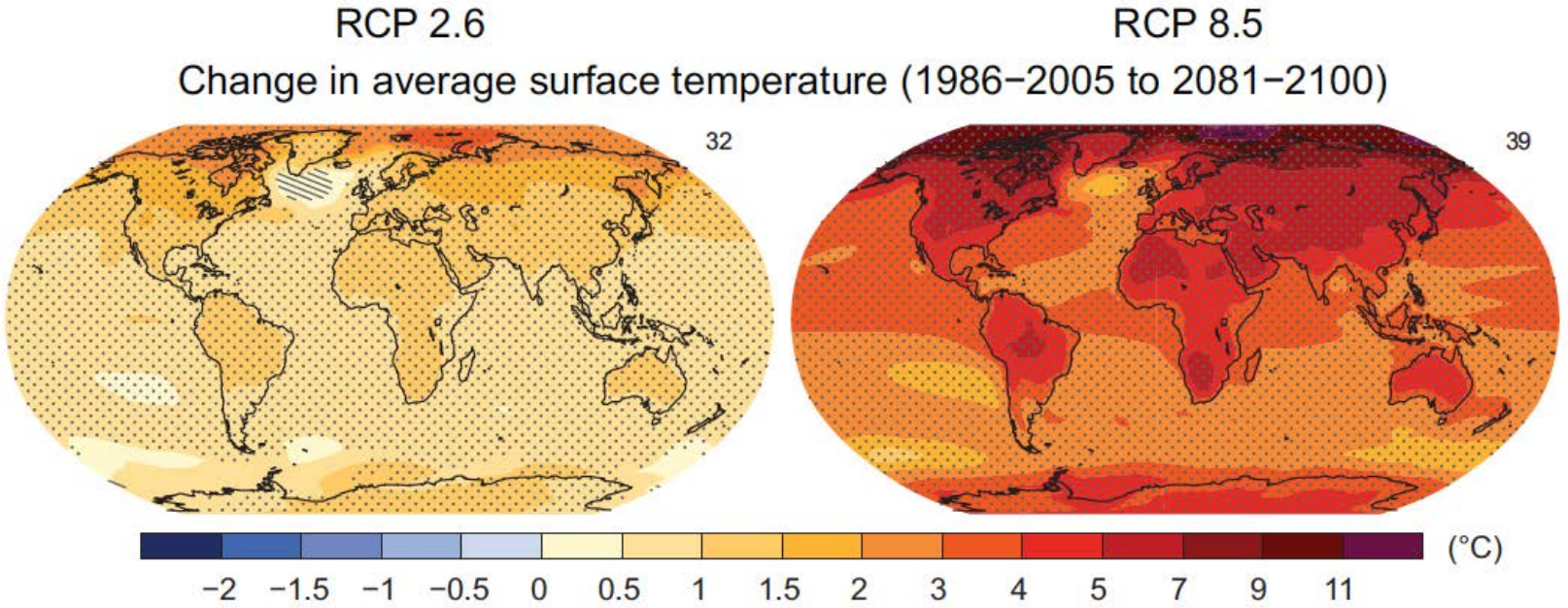
<u>Climate projection uncertainty:</u> We have three different sources of uncertainty to consider, which vary in when and where they are most important

→ Climate projections are always probabilistic



Climate Projections of average surface air temperature

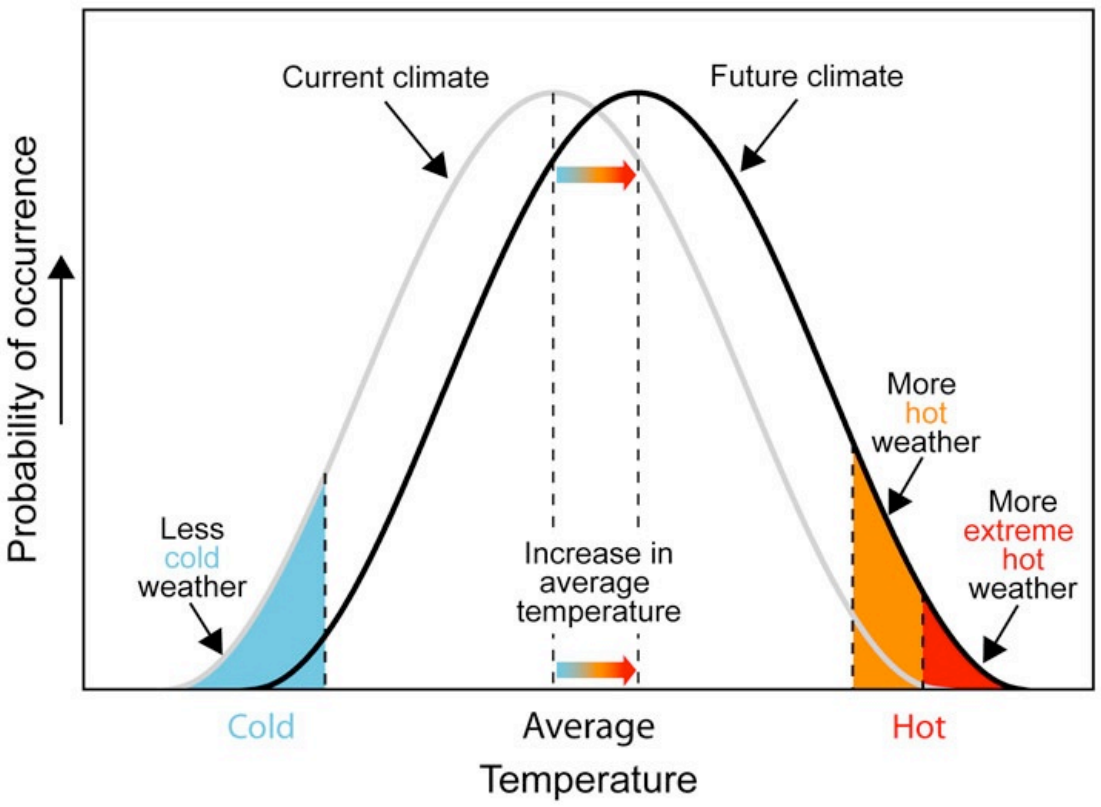




Source: IPCC WG1 2013

Climate Projections of temperature extremes

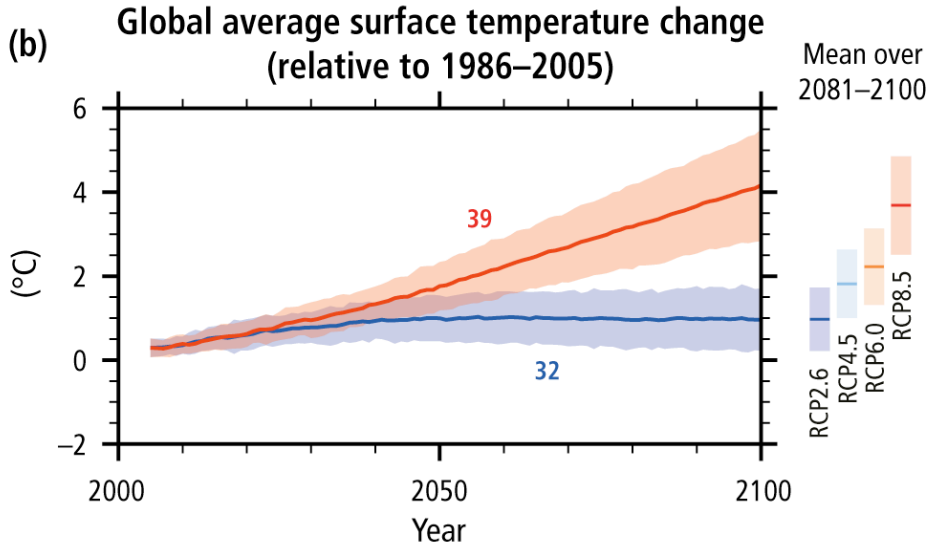
As a result of a shift in the mean, the probability of extreme events changes

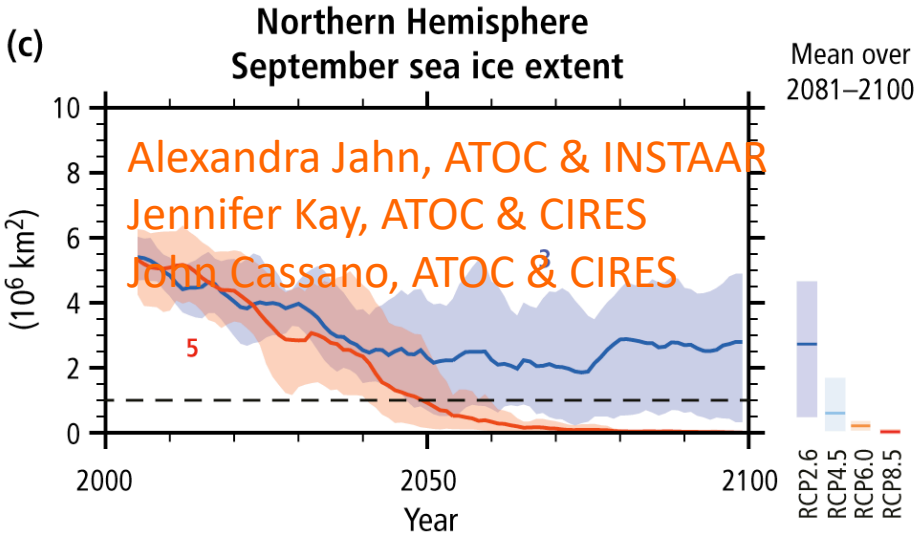


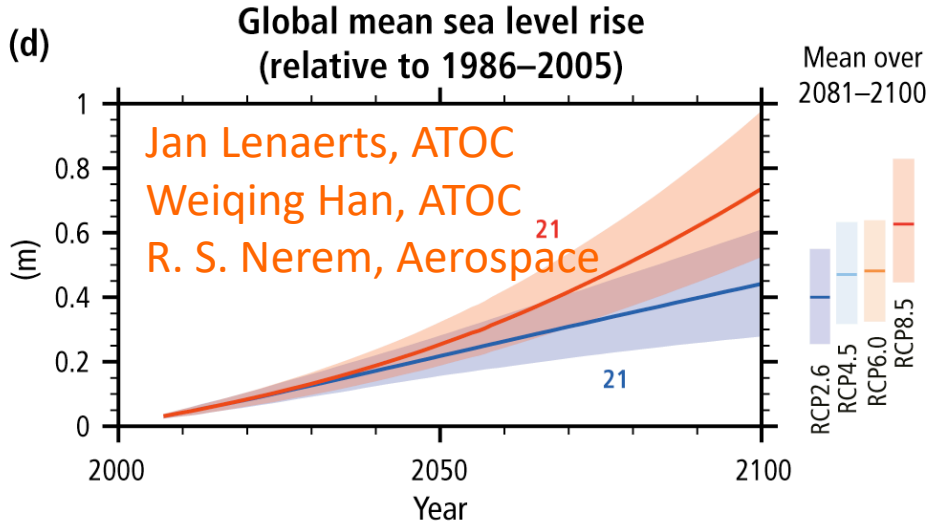
- The average temperature will increase
- Higher frequency of previously extreme hot weather
- New extreme hot weather that hasn't been seen before can be expected
- We will still have cold weather
- But, extreme cold weather is less likely in the future

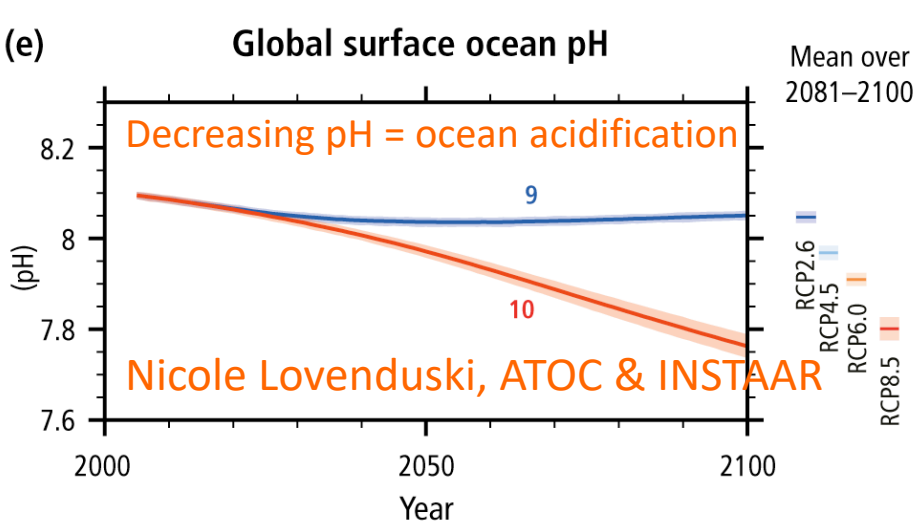
Source: IPCC WG1 2013

Climate Projections of other variables



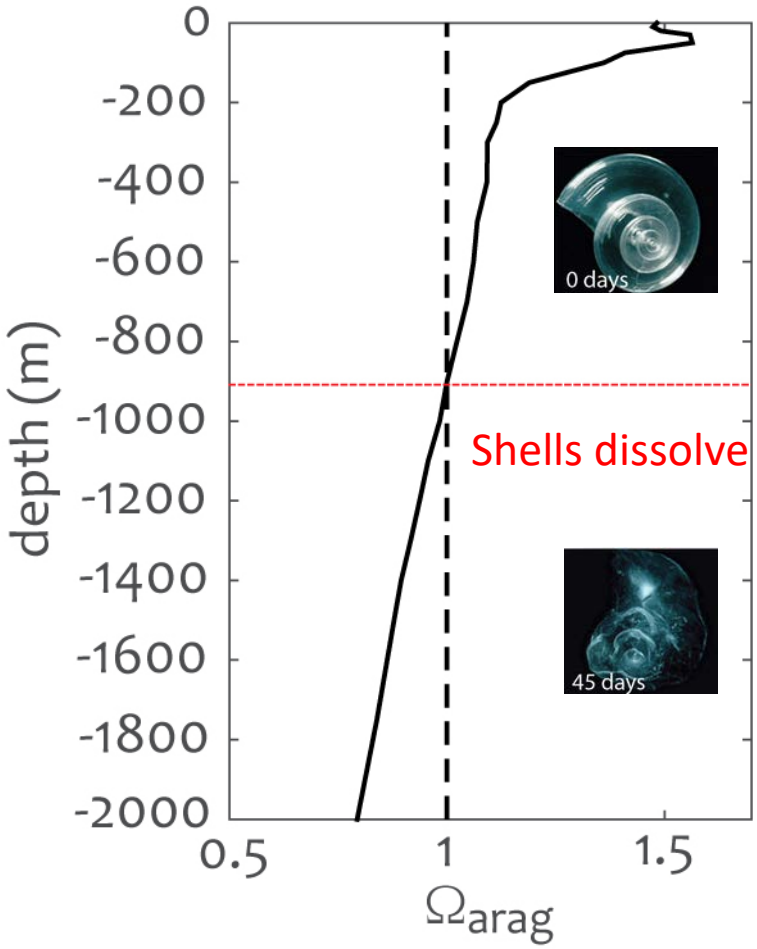


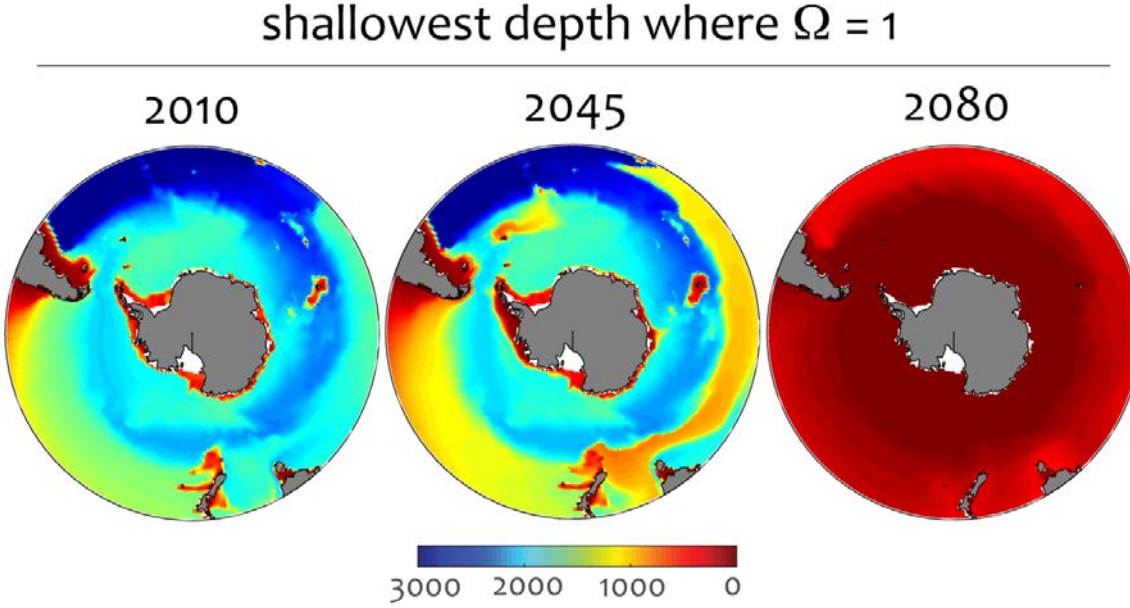




Source: IPCC WG1 2013

Ocean acidification





By 2080, the saturation horizon is projected to be within 500 m of the surface. This is very concerning for the health of ocean plankton and fisheries in the Southern Ocean

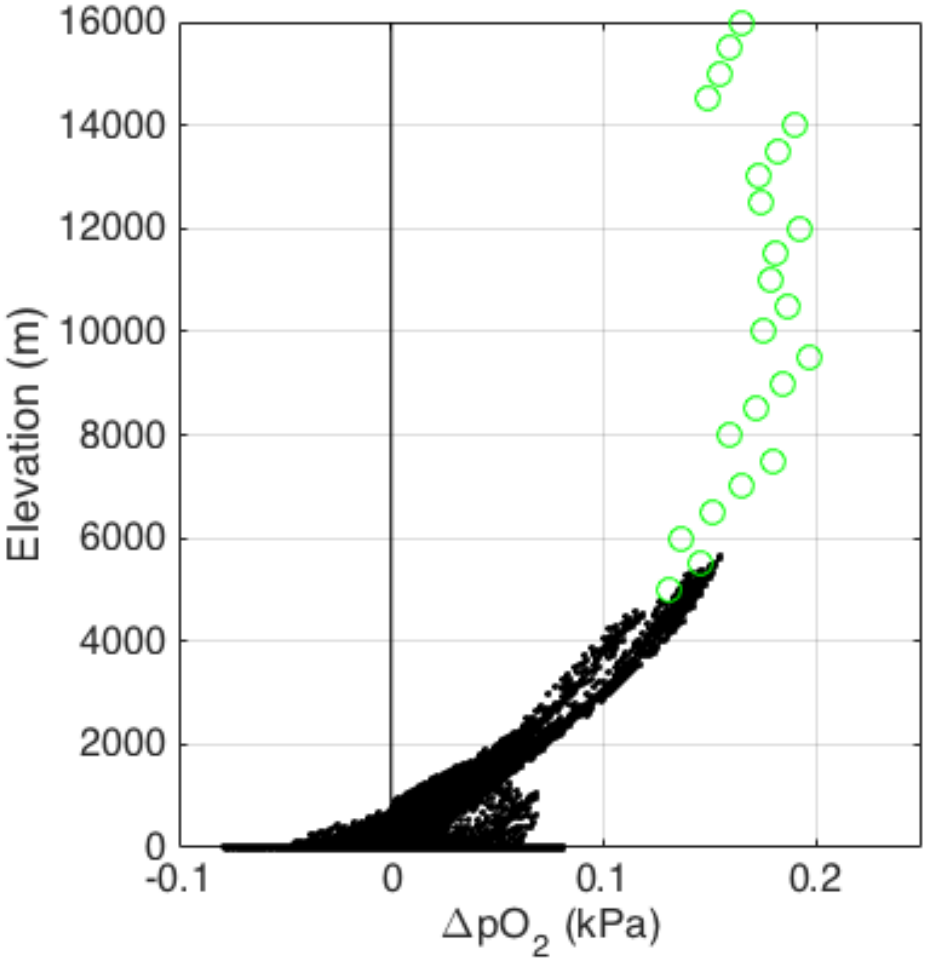
Nicole Lovenduski (ATOC / INSTAAR)

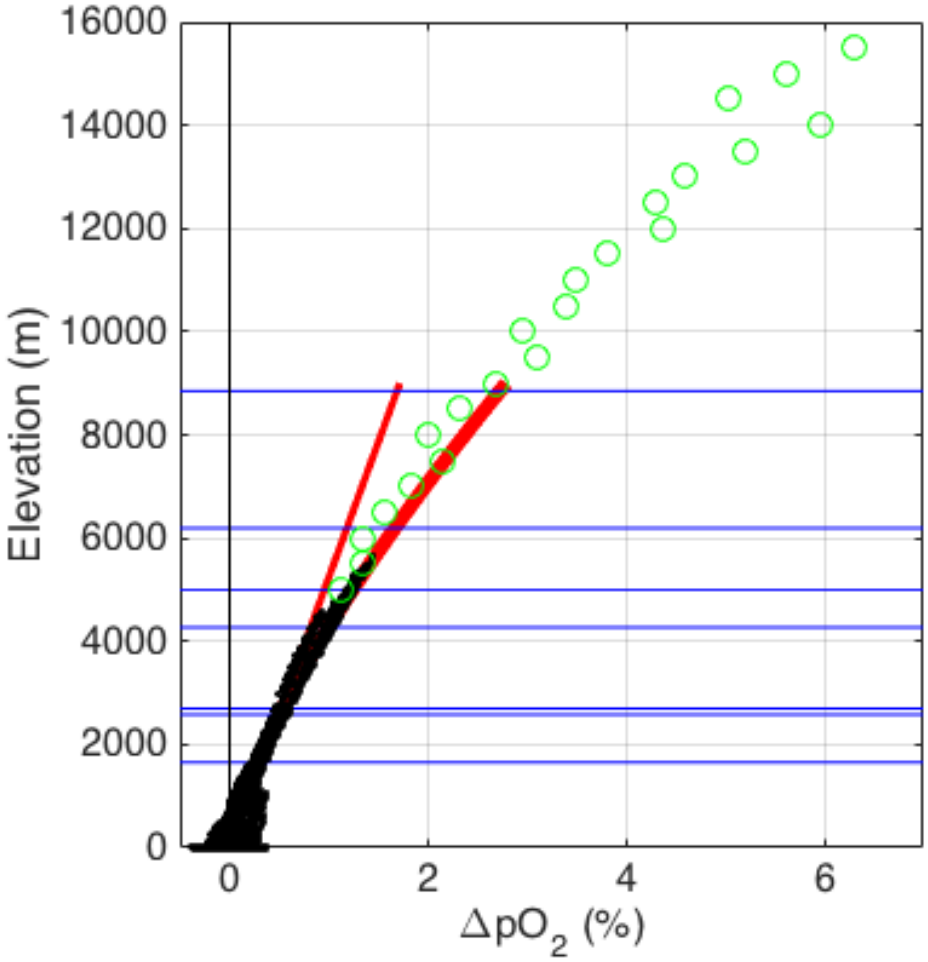
The effect of climate variability and change on **global altitude sickness**

- Variations in global climate, both natural cycles and long-term (anthropogenic) trends, can alter the geographic distribution of surface air pressure.
- Air pressure is directly related to the partial pressure of oxygen, to which the human body is sensitive—especially at high altitude.
- What does this mean for altitude sickness in the future?

Kristopher Karnauskas, Ph.D. (University of Colorado Boulder)
Jay Lemery, M.D. (University of Colorado School of Medicine)
Elaine Reno, M.D. (University of Colorado School of Medicine)
Benjamin Honigman, M.D. (University of Colorado School of Medicine)
Iñigo San Millán, Ph.D. (University of Colorado Boulder)
Peter Hackett, M.D. (Institute for Altitude Medicine)

Kris Karnauskas, ATOC & CIRES



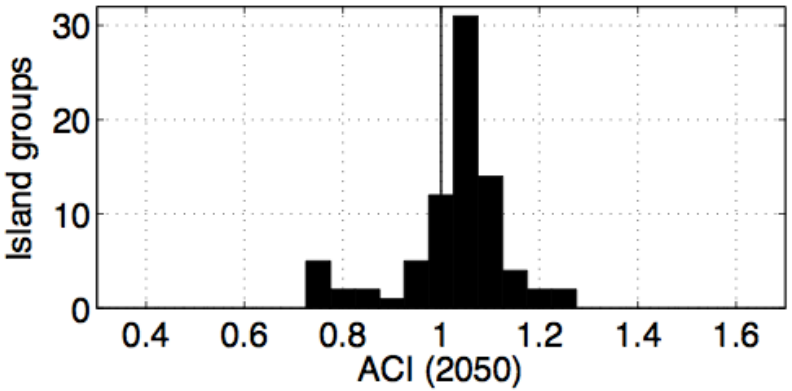


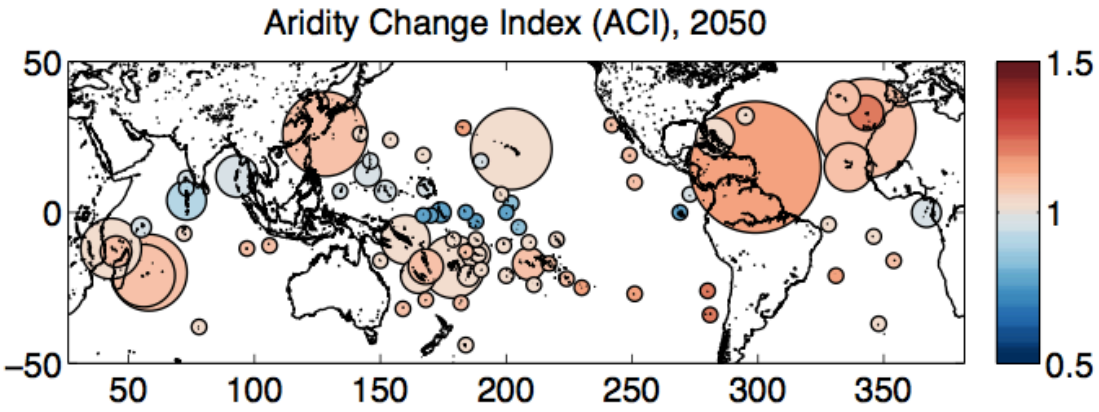
Changes in the partial pressure of oxygen (expressed in kPa on the left, and % change on the right) as a function of altitude. The blue horizontal lines on the right indicate a few notable elevations: **Boulder**, **Bear Peak**, **Ethiopian Highlands**, **14ers**, **Tibetan Plateau**, **Denali**, and **Everest**.

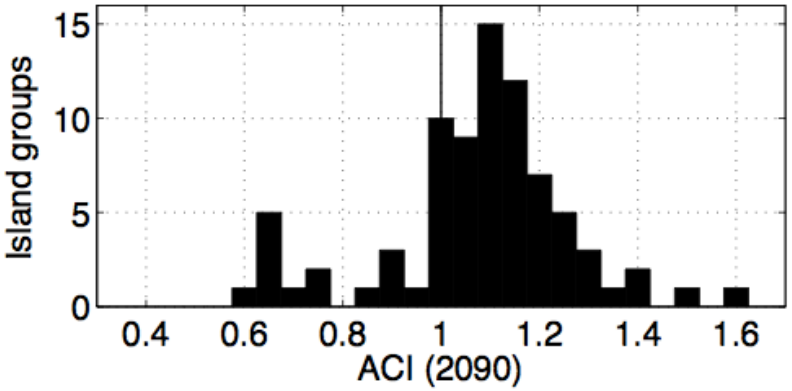
These results indicate that by the end of this century, there will be ~3% greater pO_2 at the summit of Mt. Everest

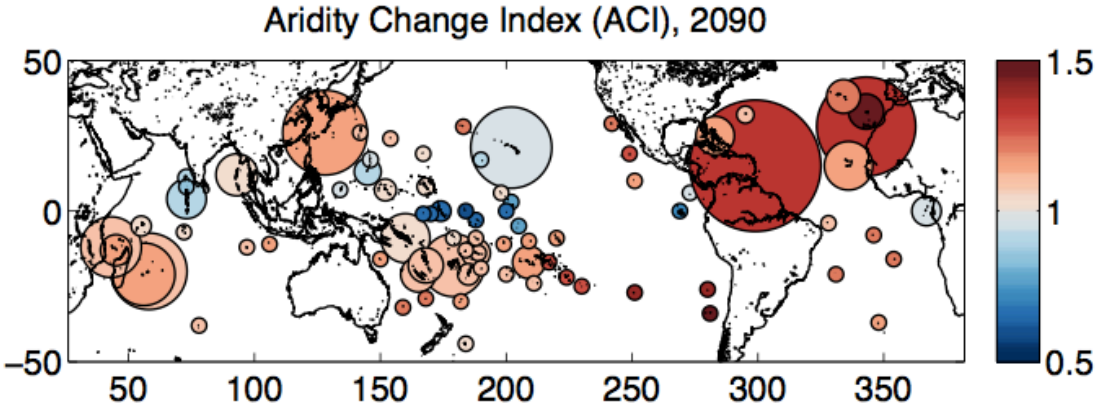
Future freshwater stress for island populations

Kris Karnauskas (ATOC & CIRES)

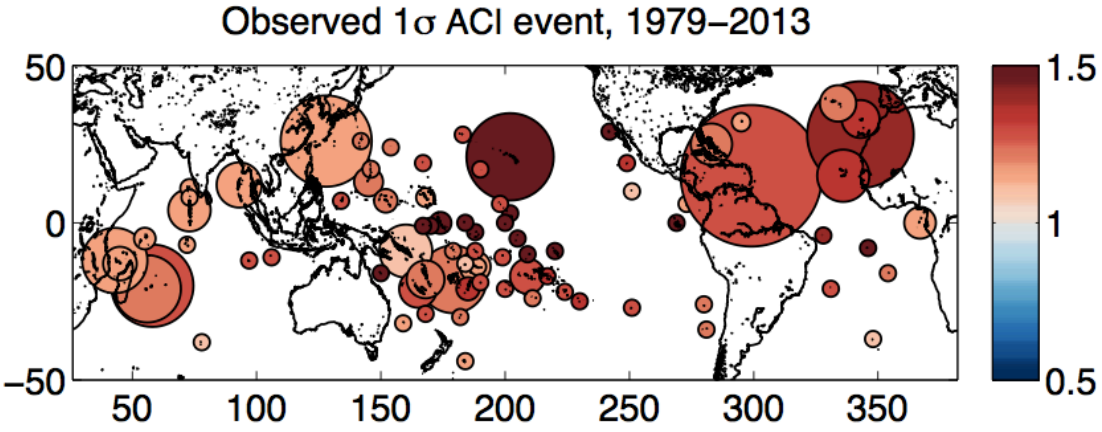








$$\mathrm{ACI} = \frac{PE_F}{PE_H} \Big/ \frac{P_F}{P_H}$$



Kris Karnauskas (ATOC & CIRES)

Karnauskas, K. B., J. P. Donnelly, and K. J. Anchukaitis, 2016: Future Freshwater Stress for Island Populations. *Nature Climate Change*, **6**, 720–725.

Some of the climate projection expertise at CU Boulder

Sea level rise:

- Weiqing Han (ATOC)
- R. S. Nerem (Aerospace)
- Jan Lenaerts (ATOC)

Polar climate:

- Alexandra Jahn (ATOC & INSTAAR)
- Jennifer Kay (ATOC & CIRES)
- John Cassano (ATOC & CIRES)
- Mark Serreze (Geology & CIRES & NSIDC)

Ocean biogeochemistry

- Nicole Lovenduski (ATOC & INSTAAR)

Monsoon changes

- Balaji Rajagopalan (CIRES and Civil Environmental, and Architectural Engineering)
- Kris Karnauskas (ATOC & CIRES)

Temperature extremes:

- Thomas N. Chase (Civil, Environmental, and Architectural Engineering & CIRES)
- Balaji Rajagopalan (CIRES and Civil Environmental, and Architectural Engineering)
- Noah P. Molotch (INSTAAR and Geography)

Drought prediction and impacts:

- Ben Livneh (Civil, Environmental, and Architectural Engineering & CIRES)

Climate adaptation

- William Travis (geography)

Climate and health

- Colleen Reid (wildfires and human health)
- Kris Karnauskas (altitude sickness and climate change; freshwater stress on island populations)
- Balaji Rajagopalan (climate change & kidney disease)

Global climate model development/CMIP6

- Alexandra Jahn (ATOC & INSTAAR)
- Jennifer Kay (ATOC & CIRES)
- Jan Lenaerts (ATOC)