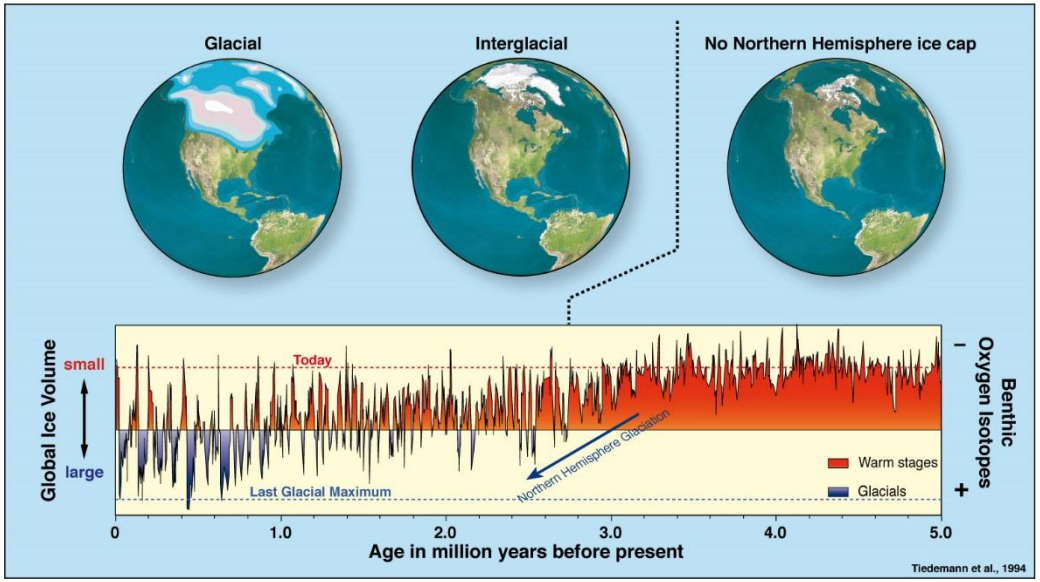
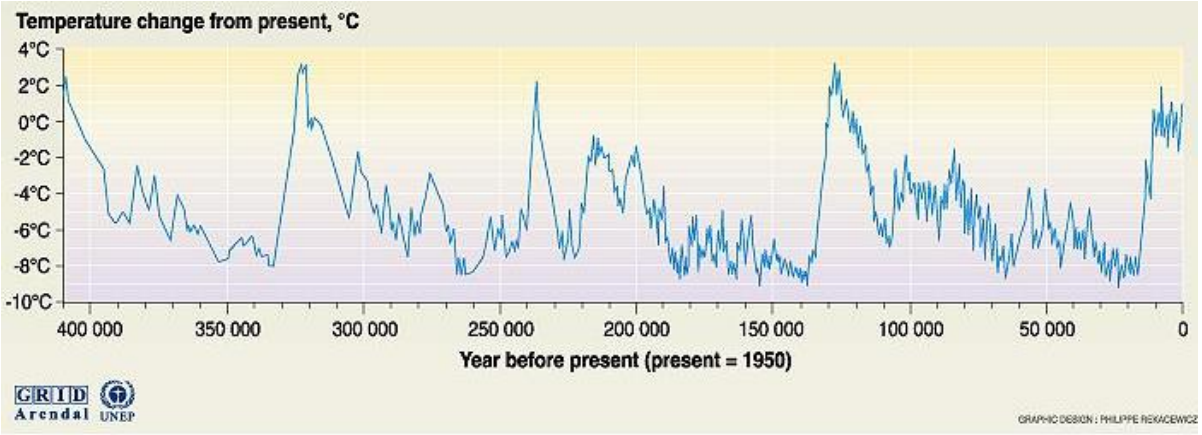
Global Climate Change

Earth, 1972, Apollo 17,
29,000 km into space.

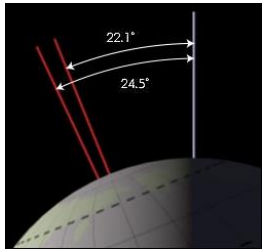
Natural Variation in Climate

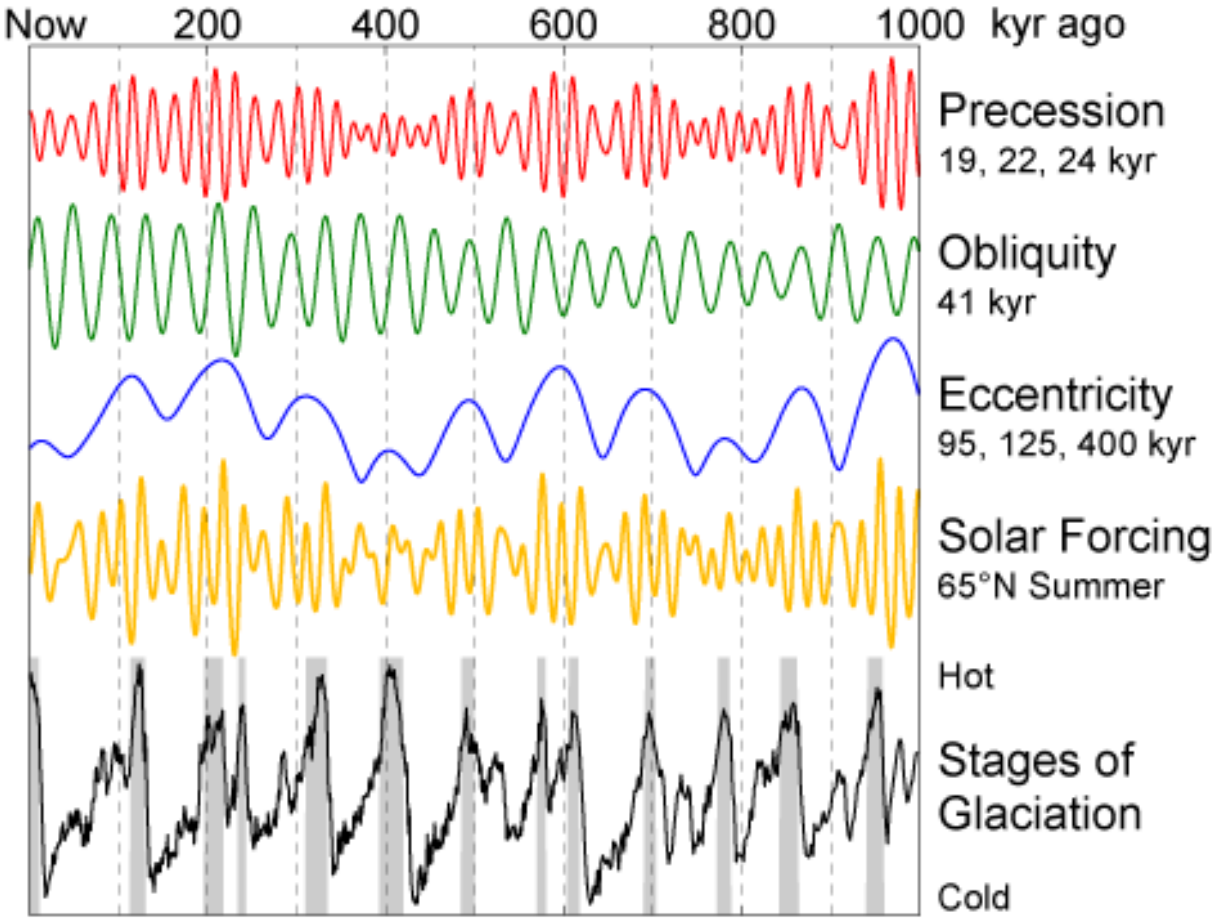


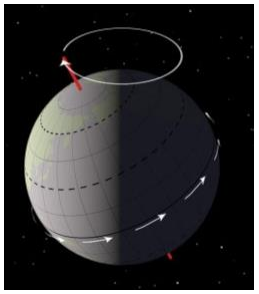


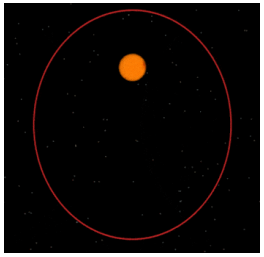
Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

Natural Variation in Climate









Precession - change in the orientation of the rotational axis of a rotating body.
Obliquity – change in the Earth's axial tilt.
Eccentricity – variation in earth's orbit around the sun.

Natural Variation in Climate
Wet/Dry Periods

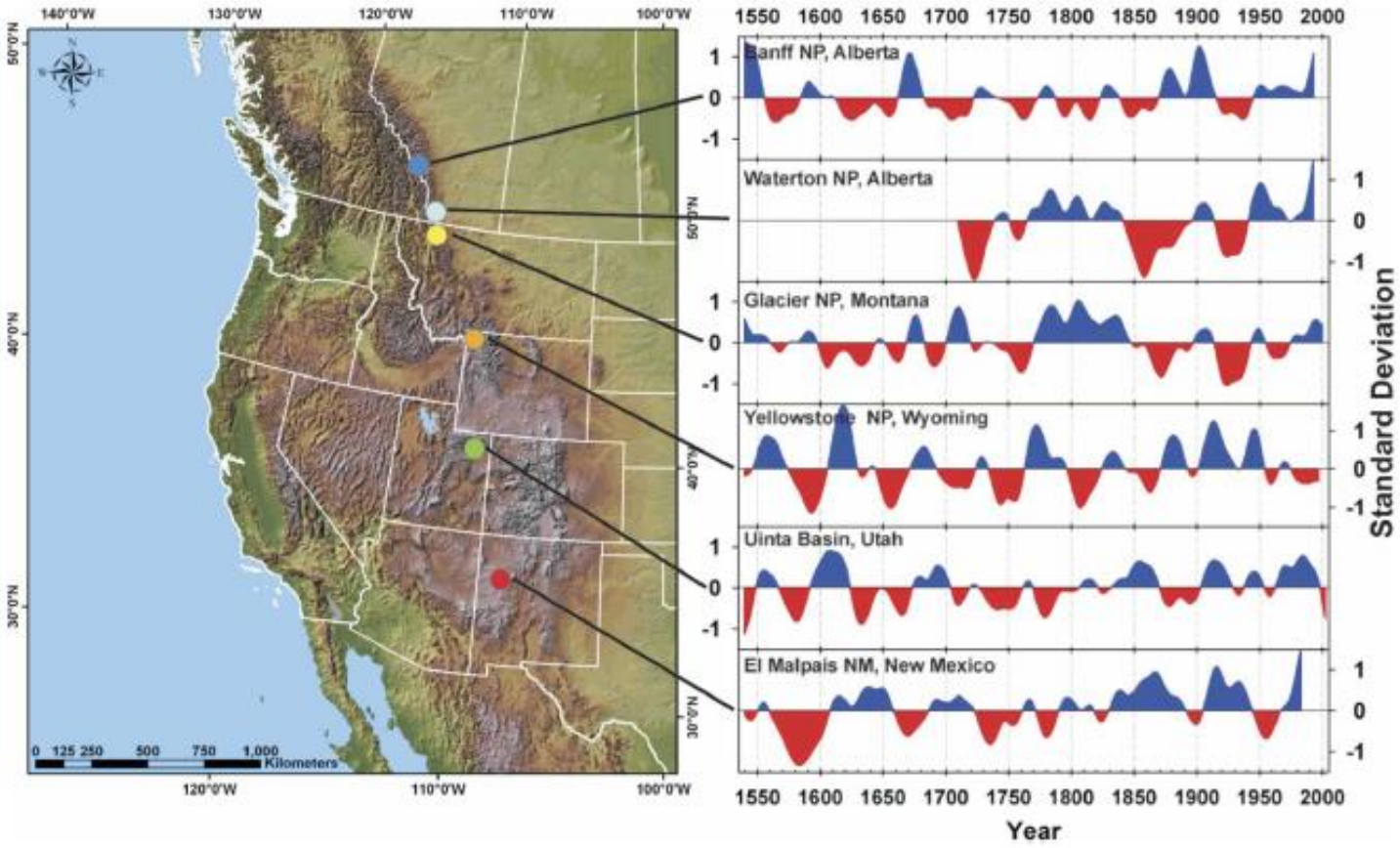


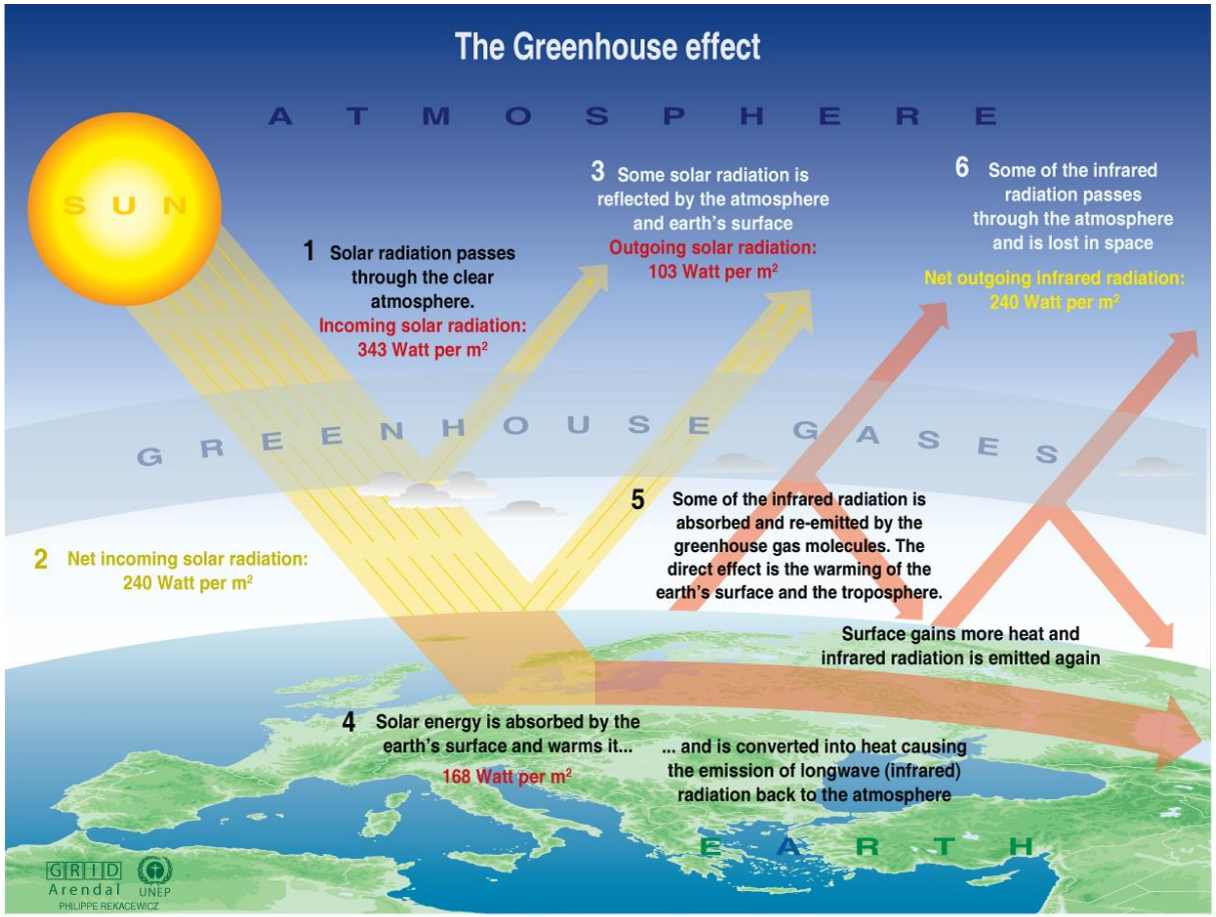
Figure 5. (left) Location of tree-ring-based precipitation and drought reconstructions used in comparison of moisture conditions along a north–south Rocky Mountain transect. (right) Tree-ring-based reconstructions of moisture anomalies. Each series has been normalized and smoothed using a 25-yr cubic spline to highlight the prominent 20–30-yr frequencies identified by MTM spectral analysis (Mann and Lees 1996).

Pederson et al. 2005

Human Impacts on Climate

Irish chemist Sir John Tyndall discovered in 1859 that CO_2 absorbs infrared energy as a radiatively active constituent in Earth's atmosphere.

Svante Arrhenius, a Swedish chemist born, speculated in 1890 that fossil fuel burning would elevate CO2 in the atmosphere and result in climatic warming.



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Human Impacts on Climate

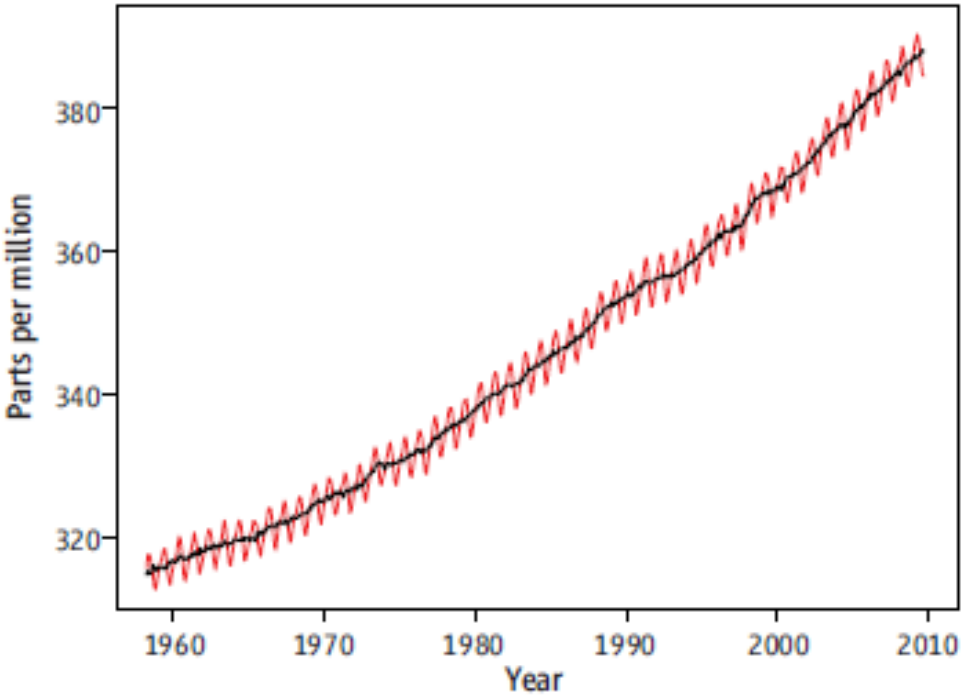
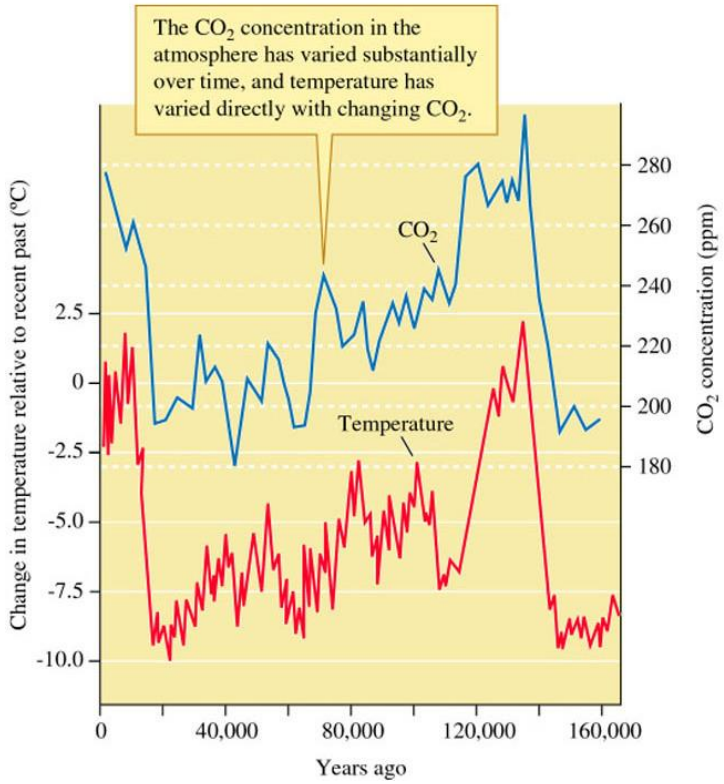


Fig. 1. Keeling curve for atmospheric CO_2. Monthly mean atmospheric CO_2 at Mauna Loa Observatory, Hawaii.

McCarthy 2009.

Human Impacts on Climate

A test of GHE comes from the paleo record of the earth.



Human Impacts on Climate

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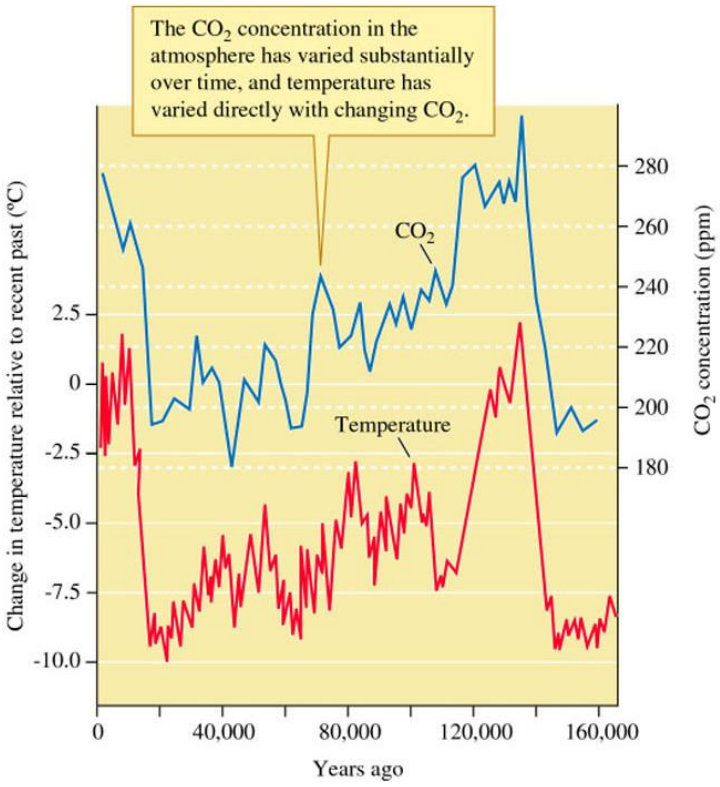
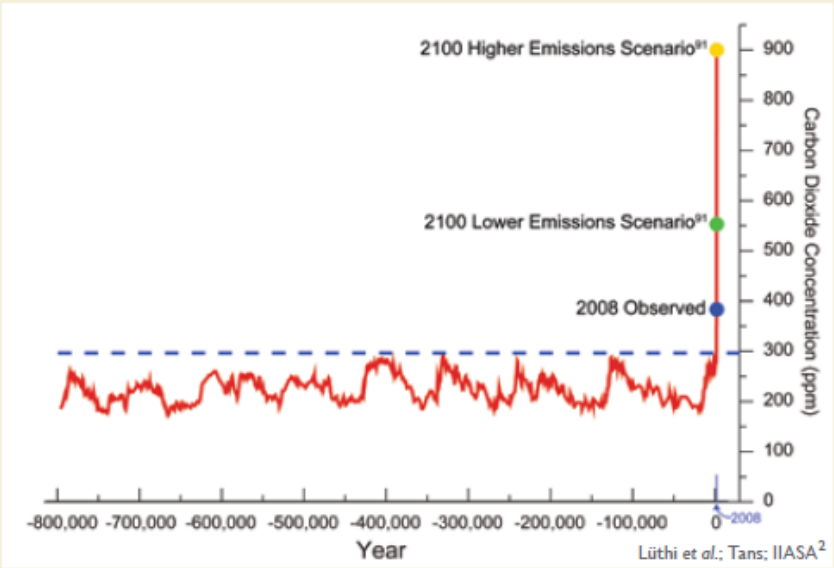


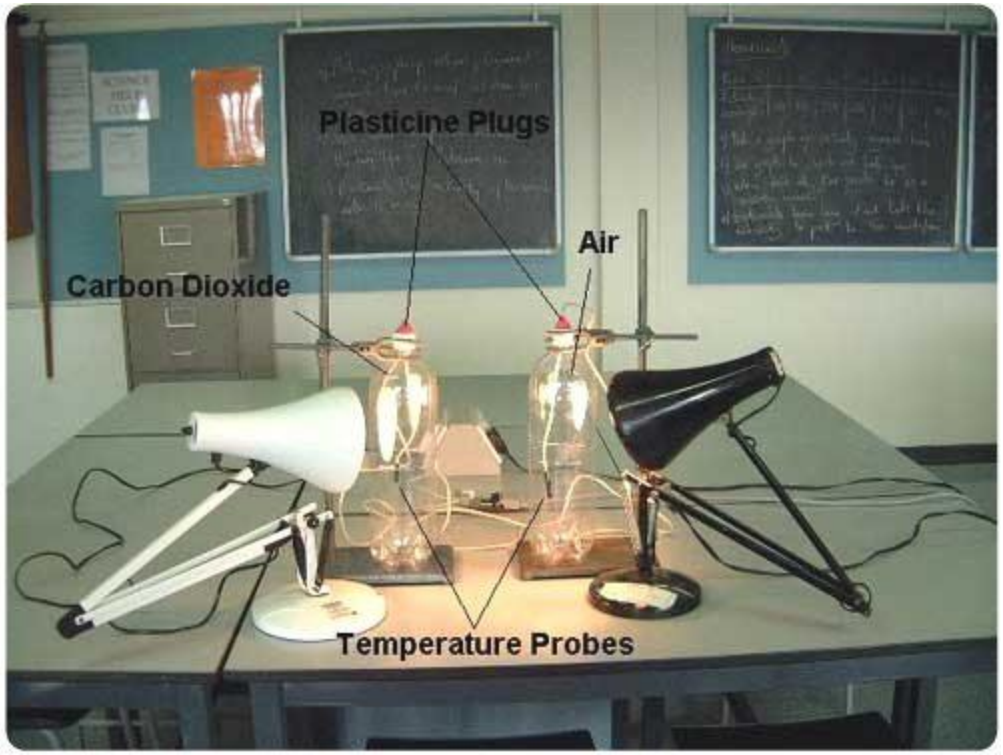


Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. Over this long period, natural factors have caused the atmospheric carbon dioxide concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in the carbon dioxide concentration increasing to a level that is roughly 2 to 3 times the highest level occurring over the glacial-interglacial era that spans the last 800,000 or more years.

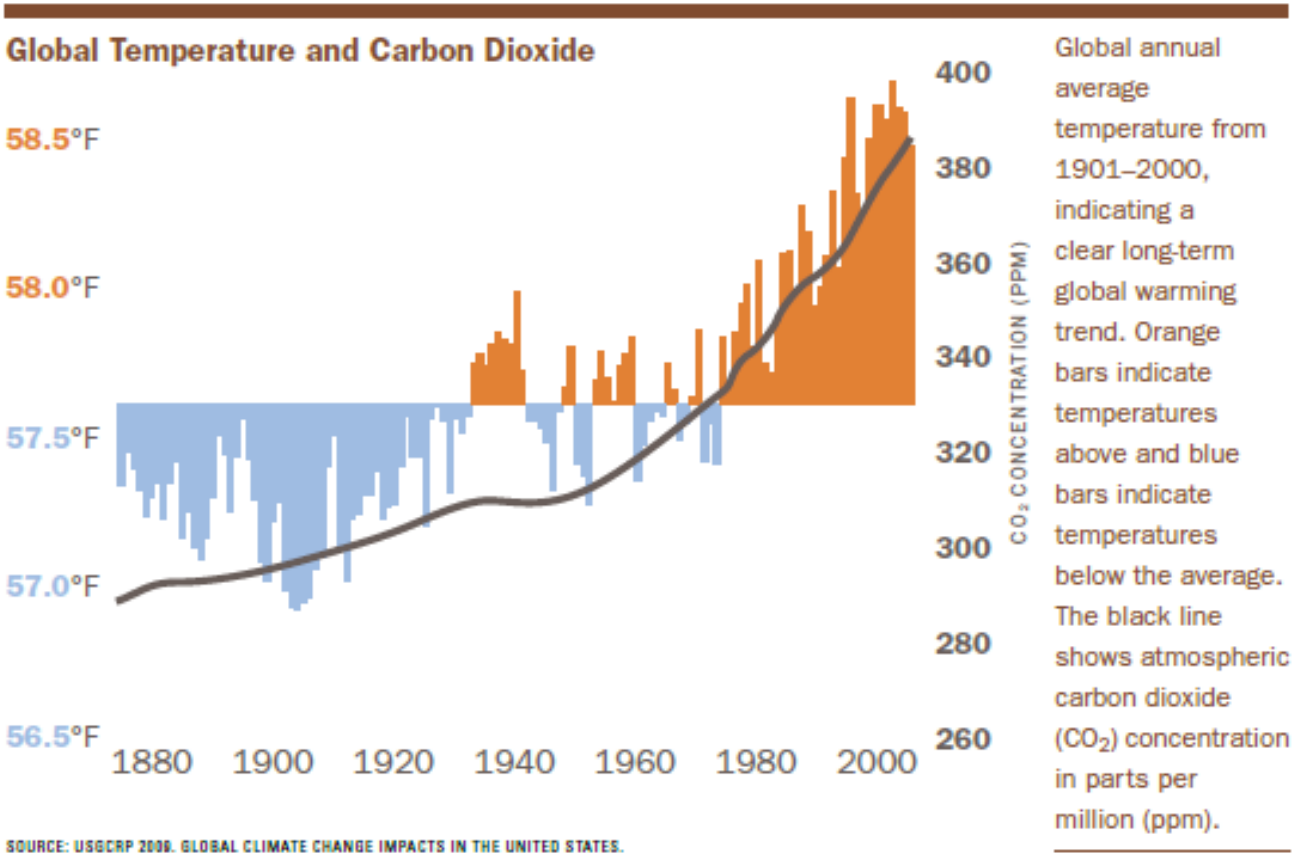
Global Change Impacts 2009.

Human Impacts on Climate

Greenhouse effect easily tested in a classroom experiment.



Has Climate Changed as Predicted?



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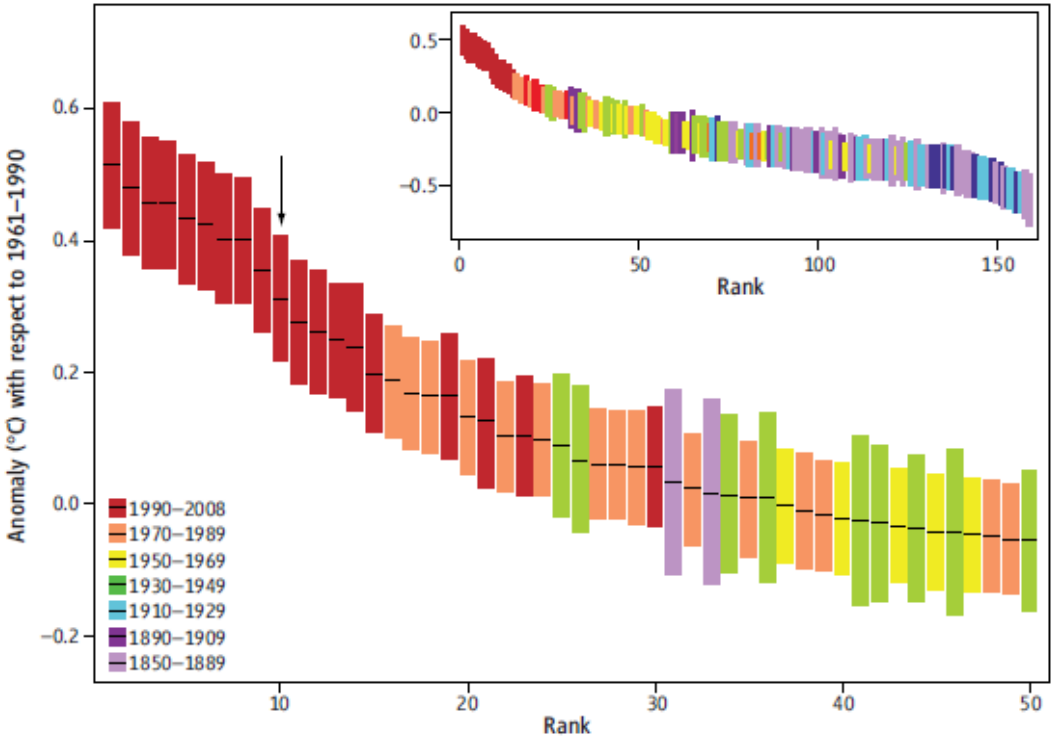
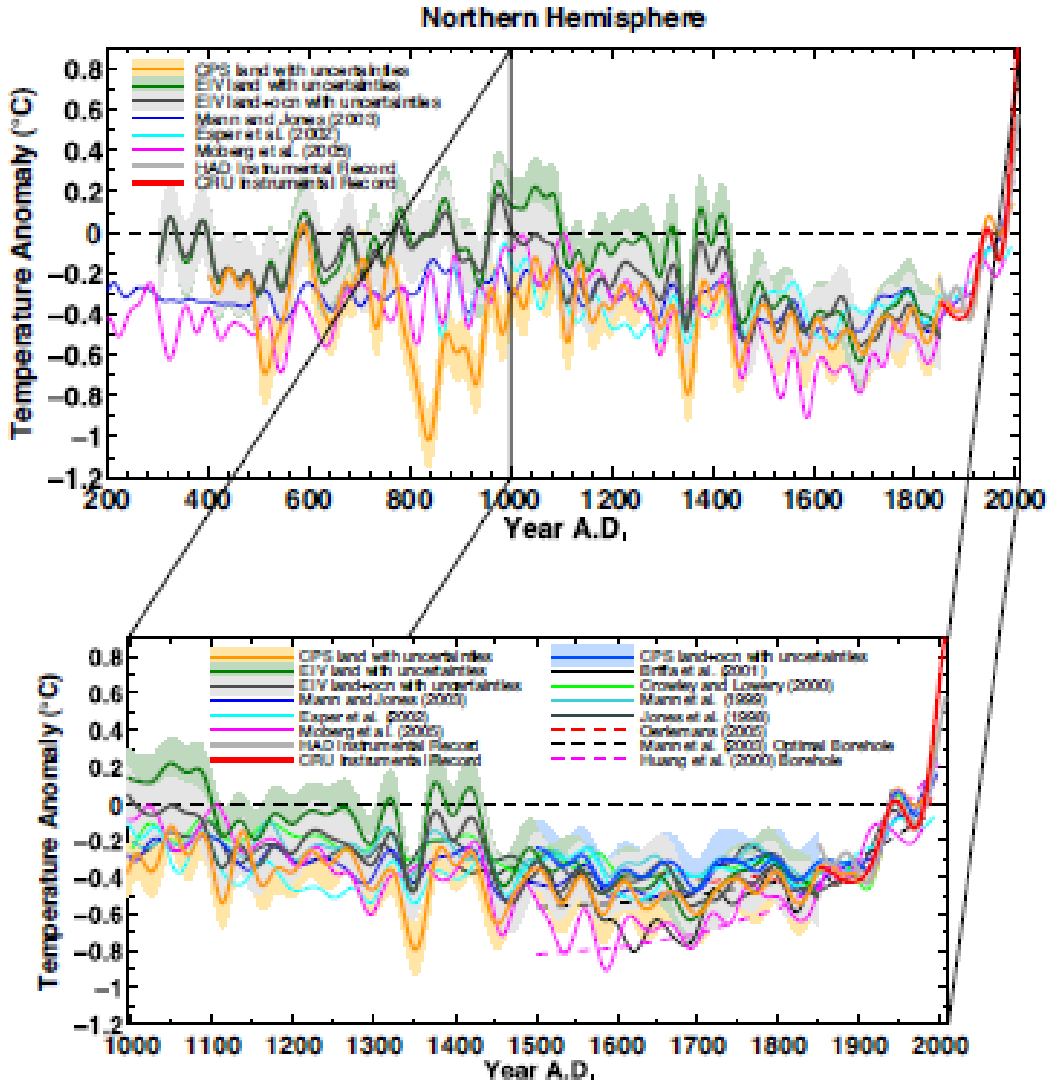


McCarthy 2009.

Fig. 6. Global surface temperature. Global ranked surface temperatures for the warmest 50 years. The inset shows global ranked surface temperatures from 1850. The size of the bars indicates the 95% confidence limits associated with each year. The source data are blended land-surface air temperature and sea surface temperature from the HadCRUT3 series. Values are simple area-weighted averages for the whole year (*28*).

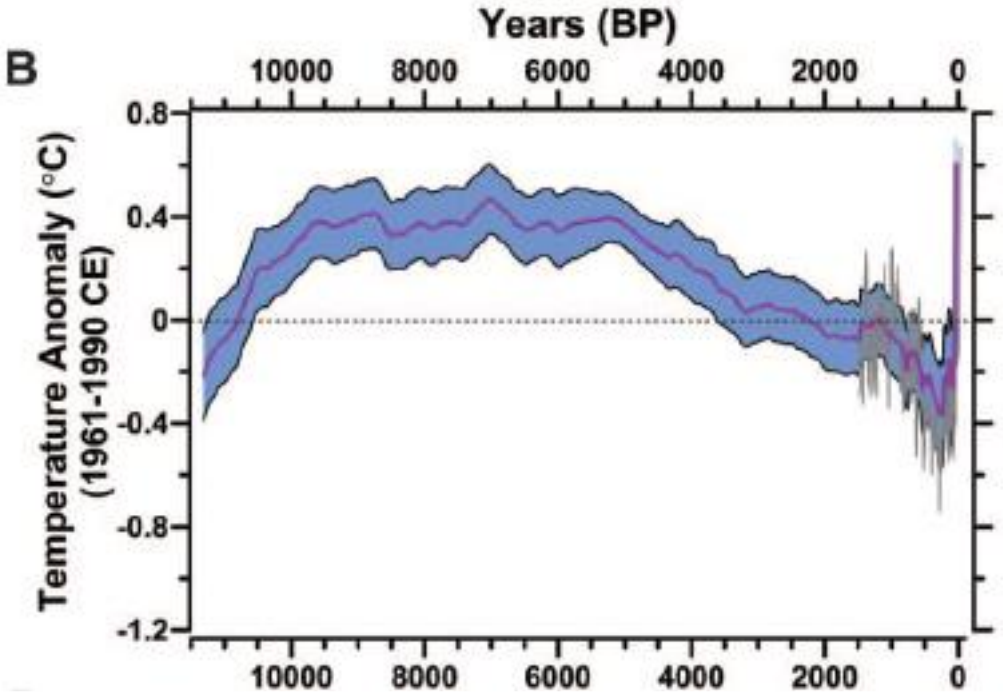
Has Climate Changed as Predicted?



Mann et al. 2008

Fig. 3. Composite CPS and EIV NH land and land plus ocean temperature reconstructions and estimated 95% confidence intervals. Shown for comparison are published NH reconstructions, centered to have the same mean as the overlapping segment of the CRU instrumental NH land surface temperature record 1850–2006 that, with the exception of the borehole-based reconstructions, have been scaled to have the same decadal variance as the CRU series during the overlap interval (alternative scaling approaches for attempting to match the amplitude of signal in the reconstructed and instrumental series are examined in *SI Text*). All series have been smoothed with a 40-year low-pass filter as in ref 33. Confidence intervals have been reduced to account for smoothing.

Has Climate Changed as Predicted?



Marcott et al. 2013

Is this Warming Due to Human Activities?

McCarthy 2009.

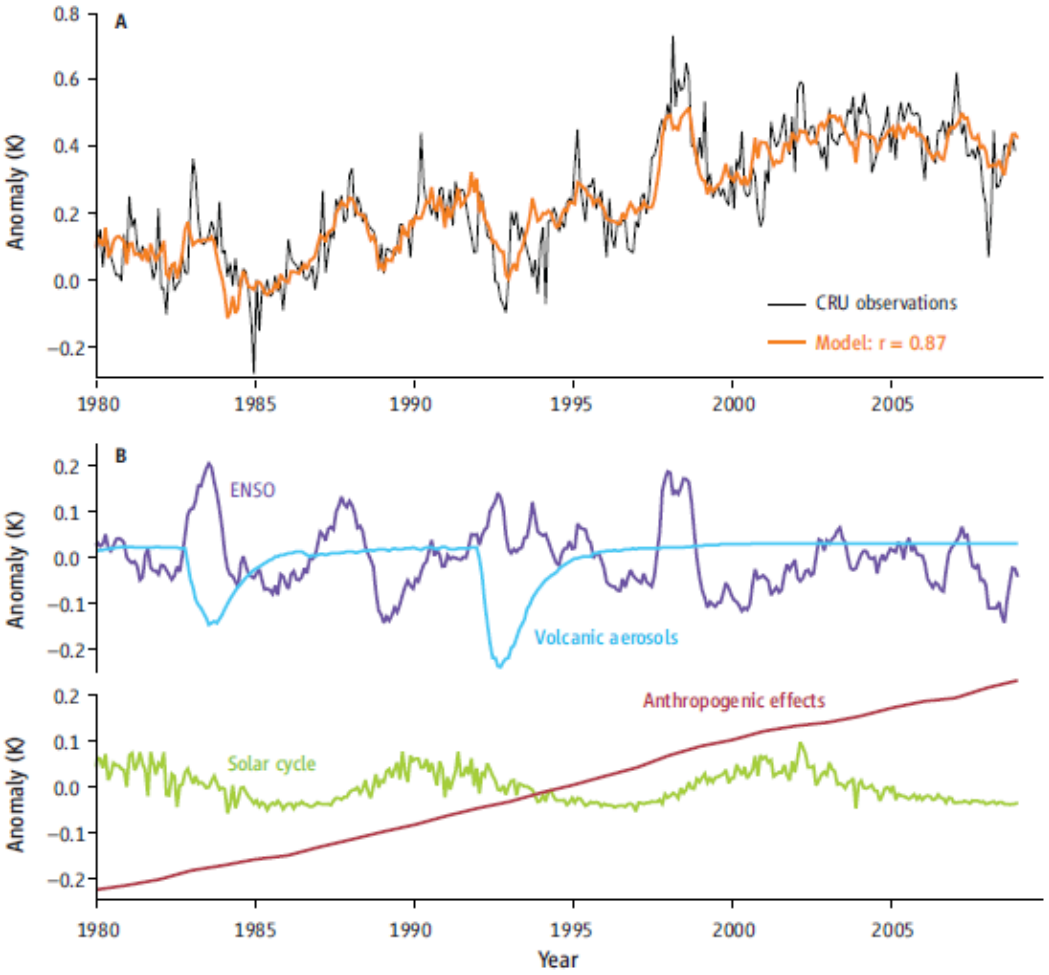


Fig. 7. Reconstructing Earth's recent climate. (**A**) Observed monthly mean global temperatures (black) and an empirical model (orange) that combines four different influences. (**B**) Individual contributions of these influences, namely El Niño–Southern Oscillation (purple), volcanic aerosols (blue), solar irradiance (green), and anthropogenic effects (red). Together the four influences explain 76% (r^2) of the variance in the global temperature observations.

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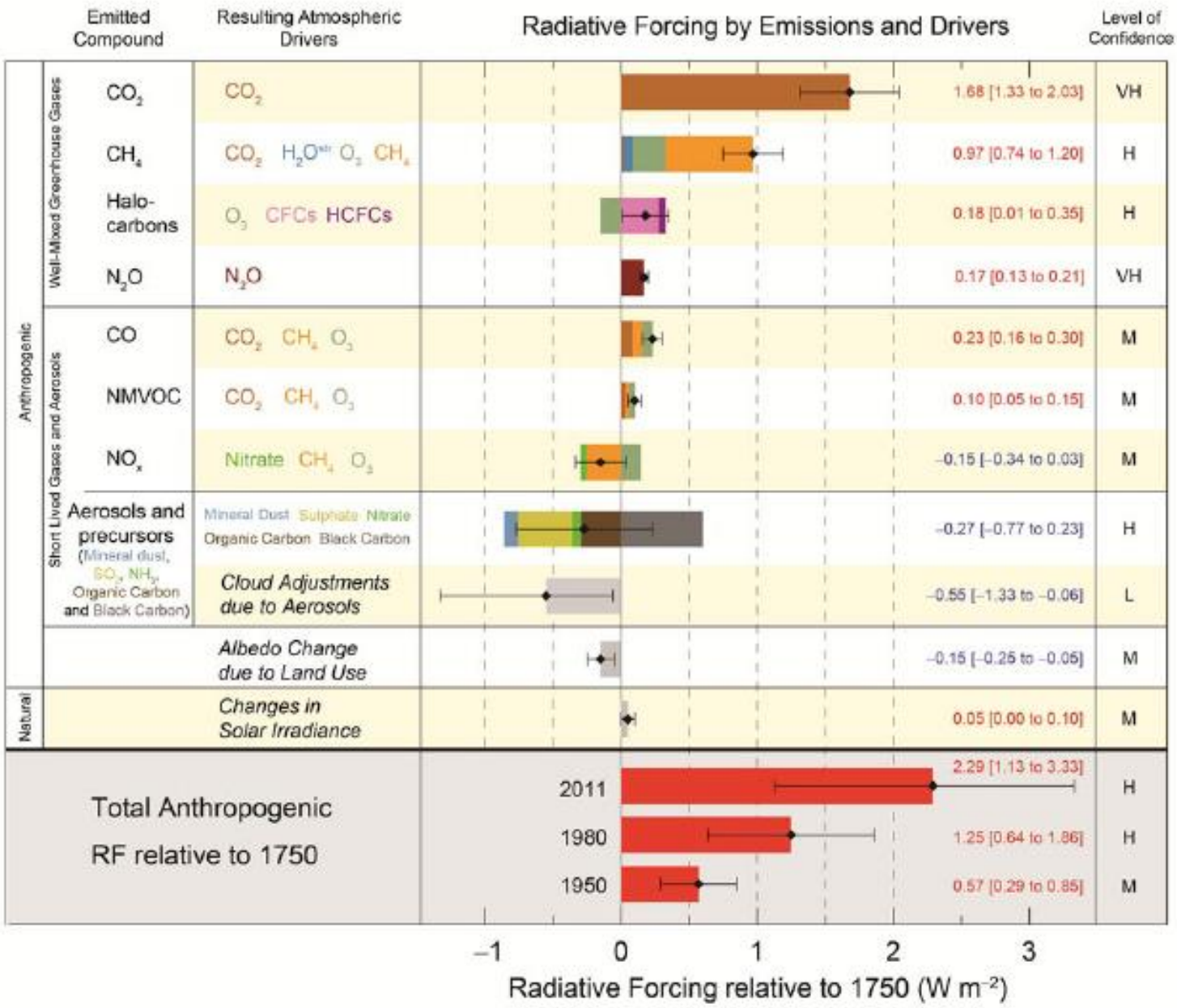
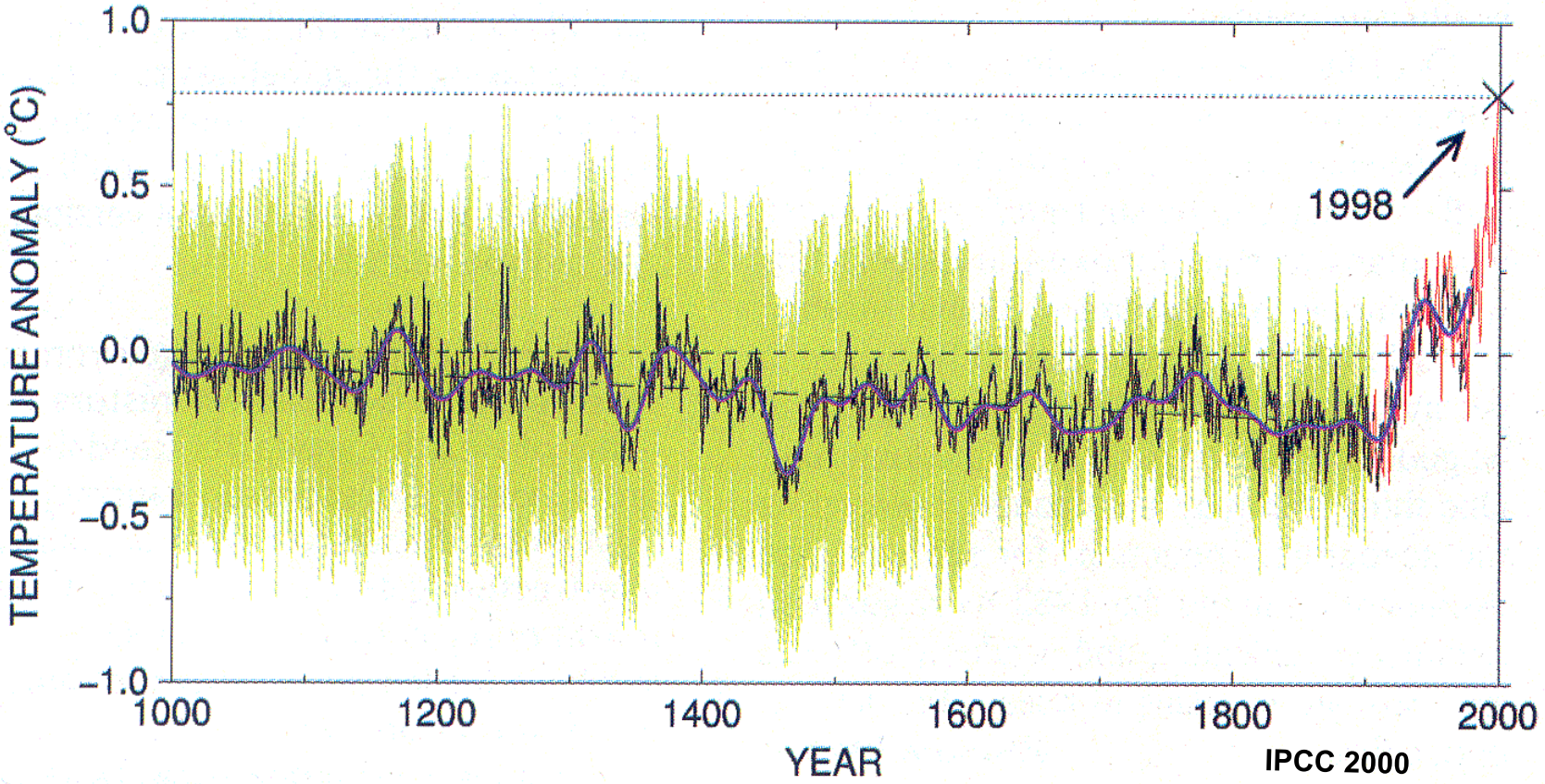
Is this Warming Due to Human Activities?



Human Induced Warming?

Mean global temperature has risen 0.6 deg C over past 130 years and is highest in 1000 years.



The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C 3, over the period 1880–2012.

IPCC WGI AR5. 2013

Human-Induced Global Warming?

GLOBAL CHANGE

It's Official: First Glimmer of Greenhouse Warming Seen

A war of words among scientists and politicians warmed the air in Madrid last week, but the final words from an international panel of scientists assessing the state of climate science were cool and measured. Many newly perceived fingerprint of human-induced climate change.

The first solid evidence that aerosols could be altering the signal of greenhouse warming came earlier this year when Gerald Meehl of the National Center for Atmospheric Research: "It's really encouraging that when we add aerosols [to model simulations] we do start to see better agreement with the [climate] patterns we've already observed."

Other runs of the same computer models, done without increases in greenhouse gases or aerosols, suggest that this greenhouse fingerprint is not likely to be a chance fluctuation of the climate system. As predicted by the models, the natural variability of an undisturbed climate system looks different, sta-

Intergovernmental Panel on Climate Change -

"…the balance of evidence suggests that there is a discernible human influence on global climate." December 1995.

Human-Induced Global Warming?

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Intergovernmental Panel on Climate Change -

"…the balance of evidence suggests that there is a discernible human influence on global climate." December 1995.

This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

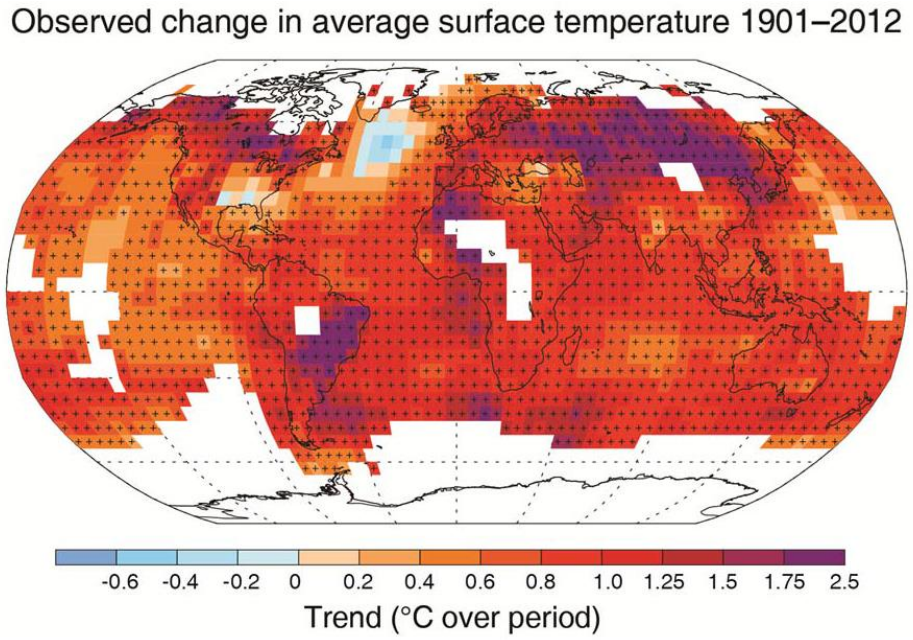
IPCC WGI AR5. 2013

Does Flattening in Temperature Increase Since 2000 Counter this Conclusion?

IPCC WGI AR5. 2013

"Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to +0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade)5."

Spatial Variability in Rates of Climate Change



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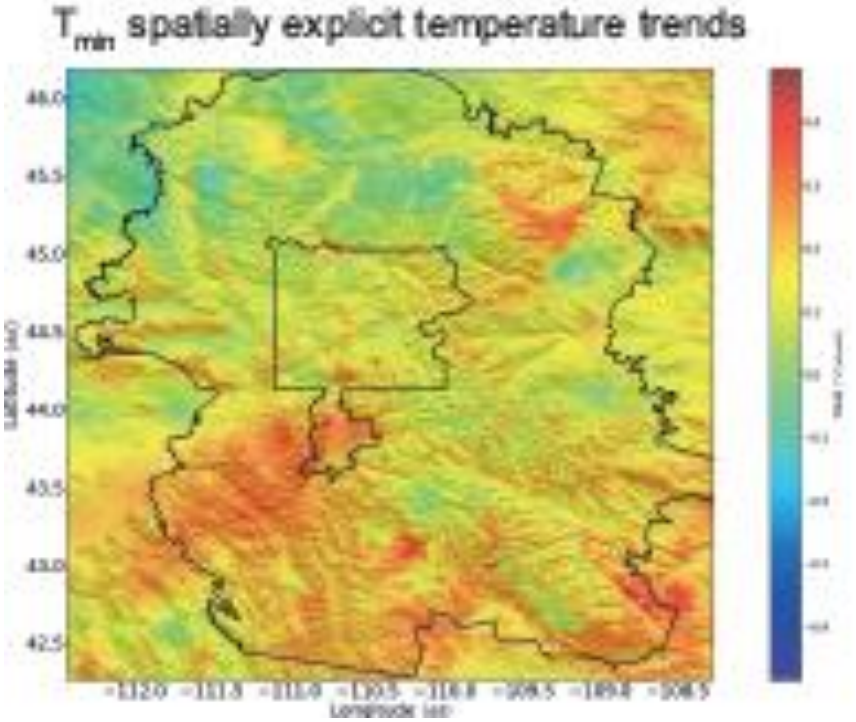
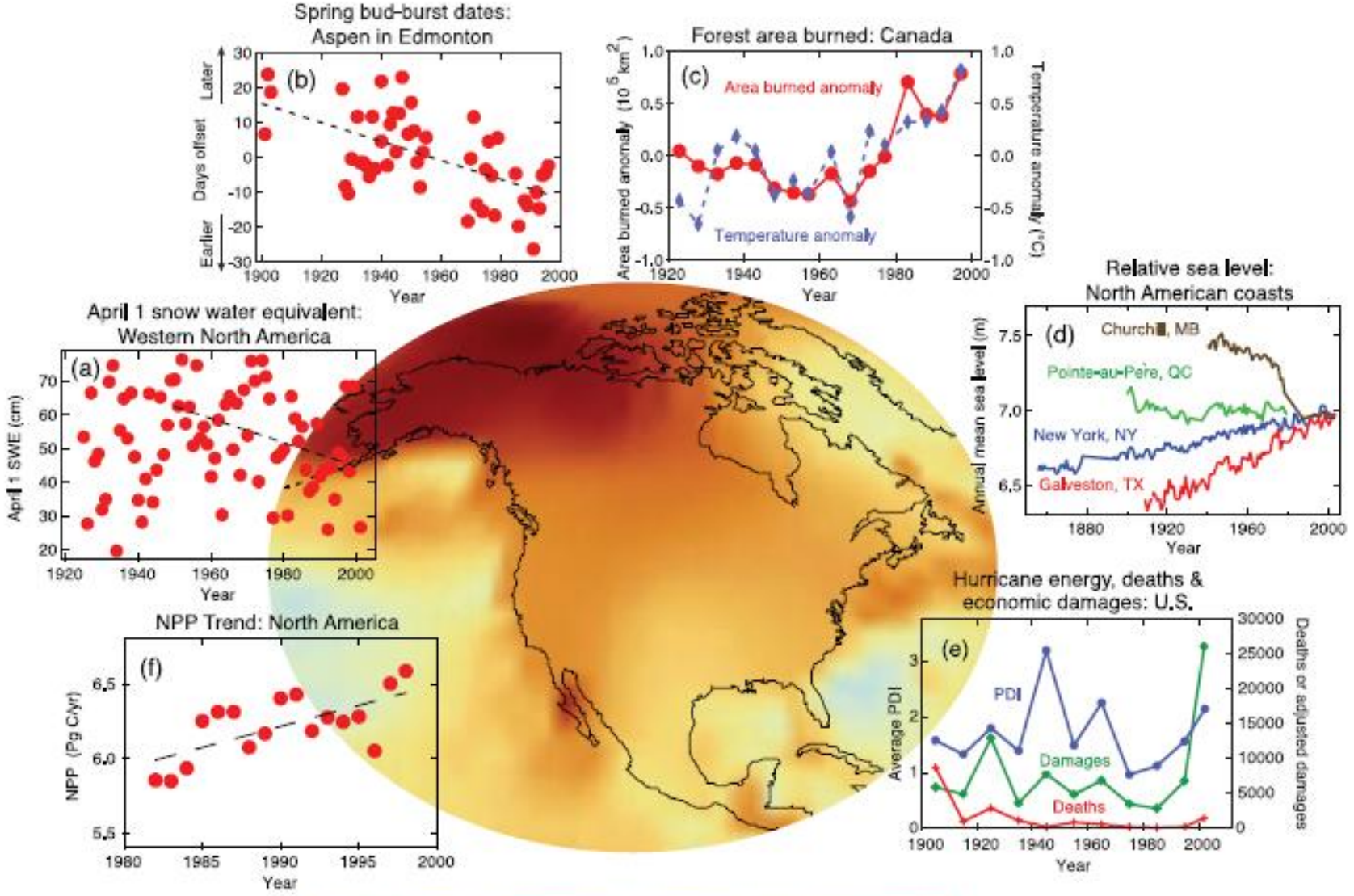


Chang. 2013

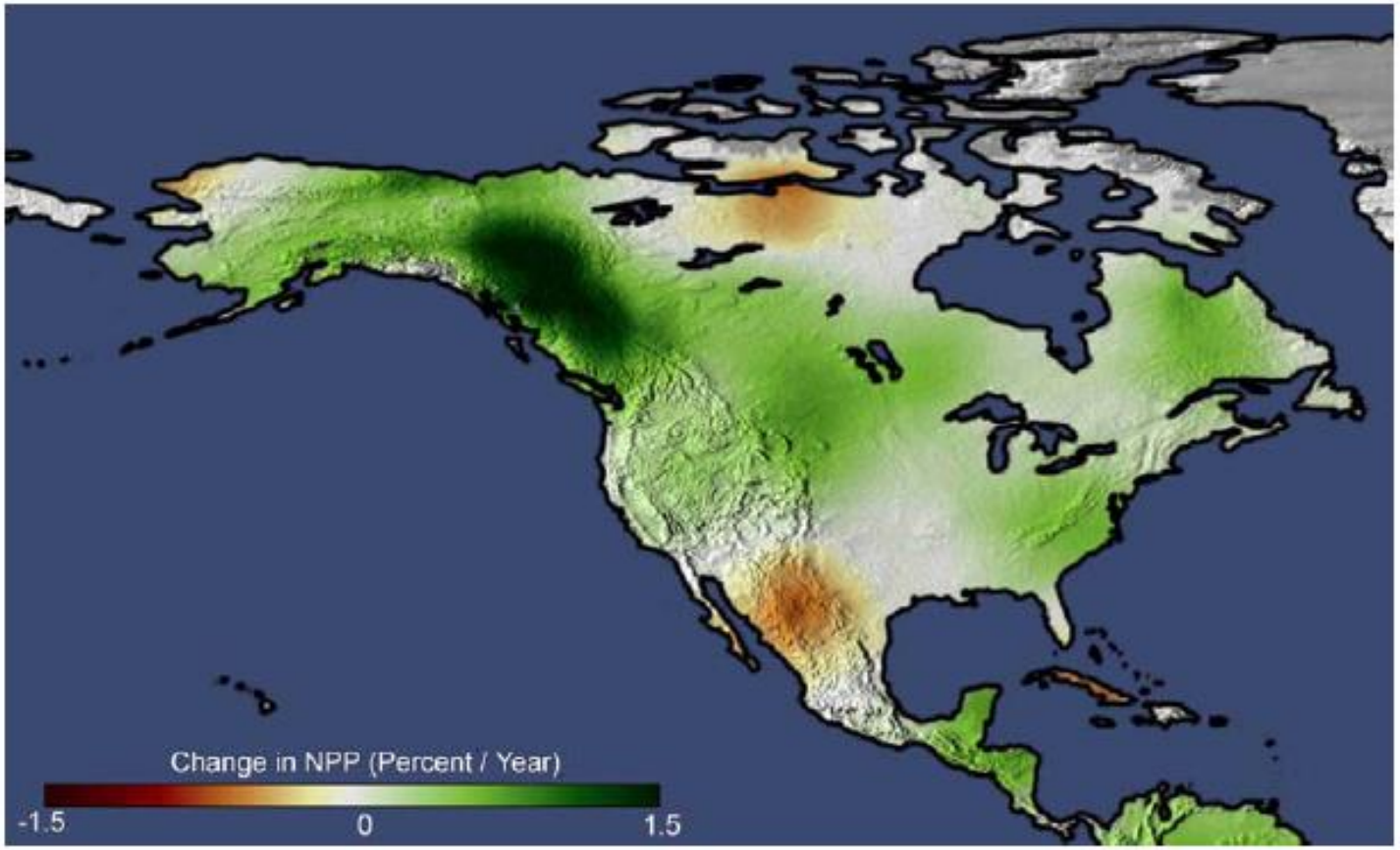
Ecological Consequences of Past Change



Global Change Impacts 2009.

Ecological Consequences of Past Change

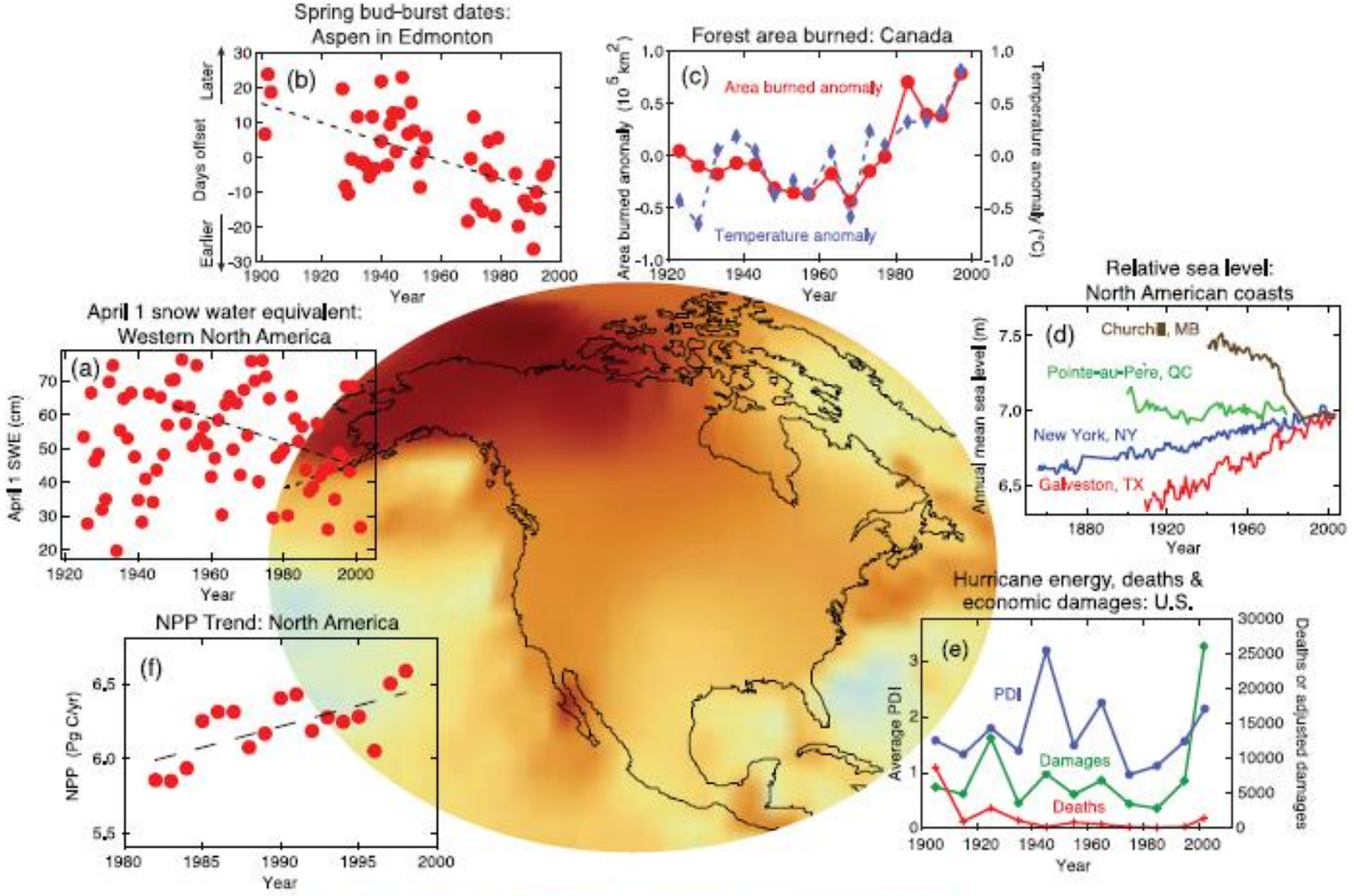
Figure 7. Changes from 1982 to 1999 in Terrestrial NPP



Source: Nemani et al. 2003.

Limiting factors
- **Temperature**
- **Water**
- **Light**

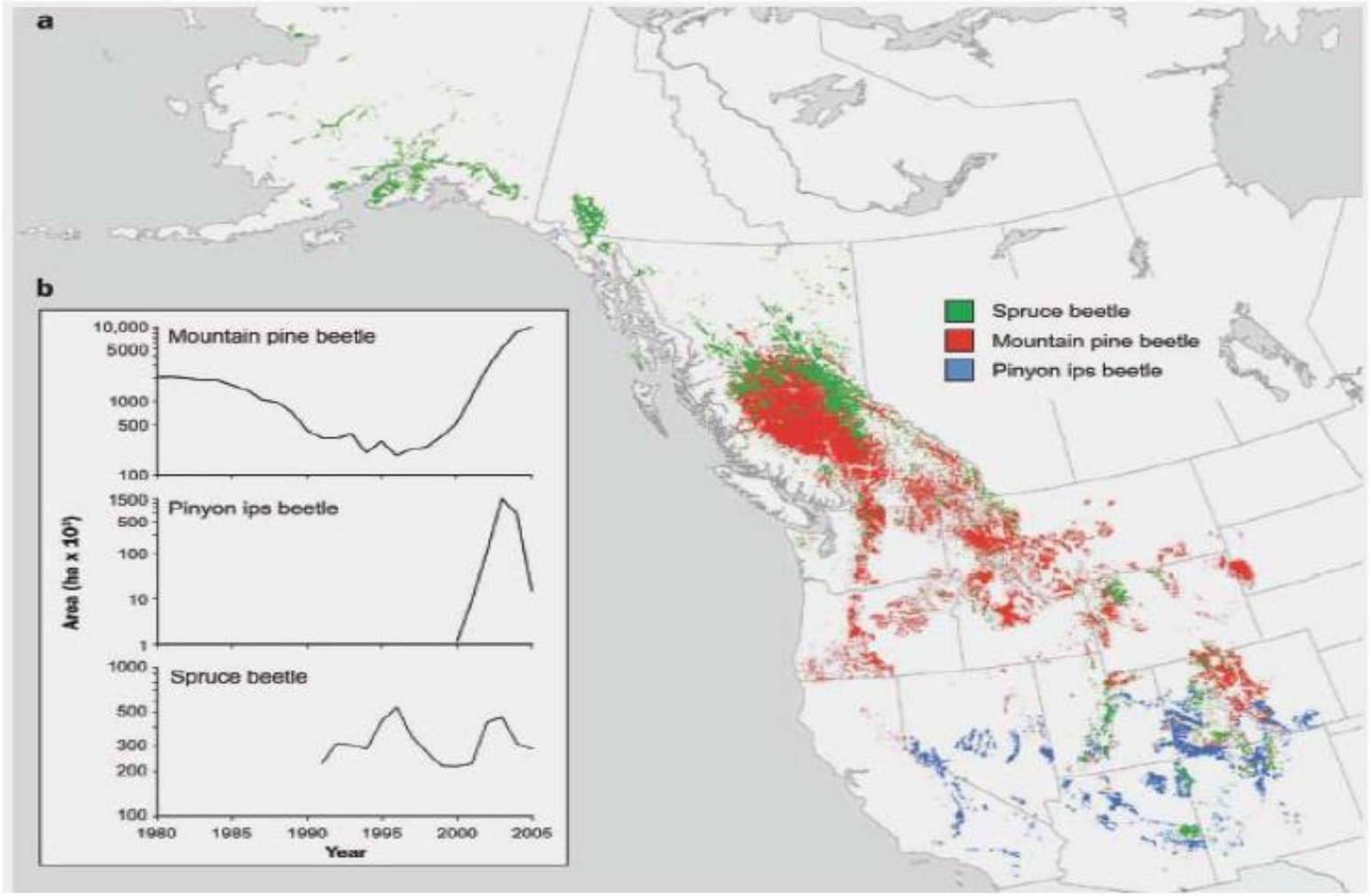
Ecological Consequences of Past Change



Global Change Impacts 2009.

Ecological Consequences of Past Change

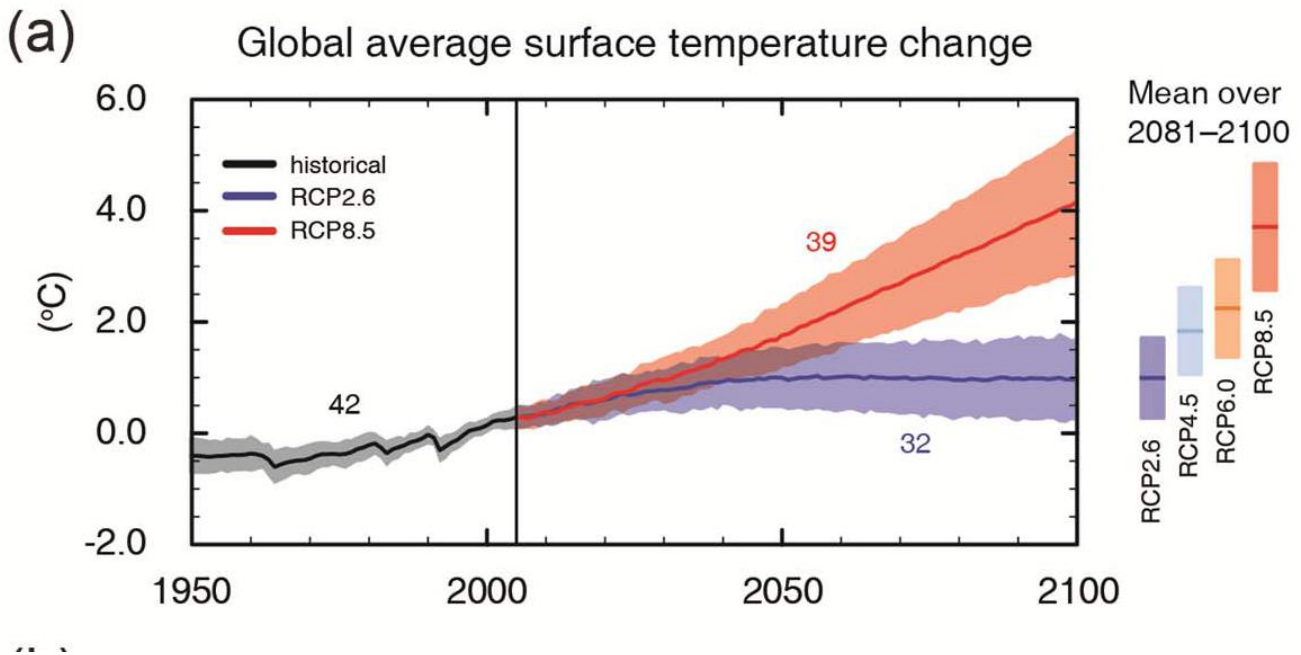
Figure 9. Timing and Affected Area of Major Forest Insect Epidemics in the Western United States from 1998 to 2002

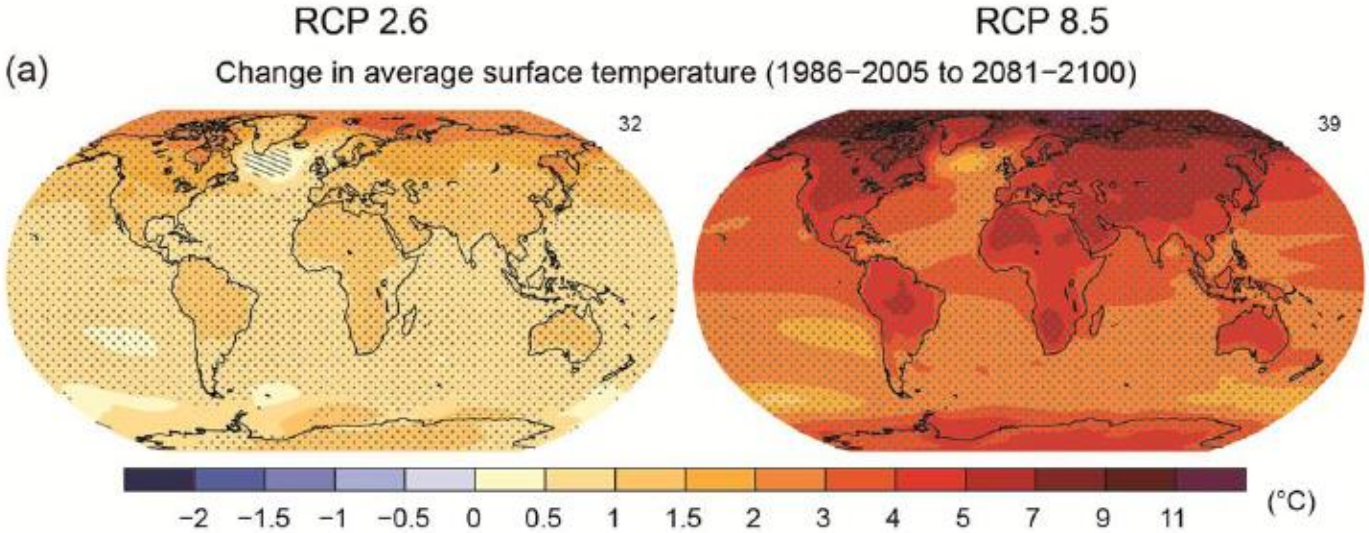


Source: Raffa et al. 2008.

Projected Future Climate

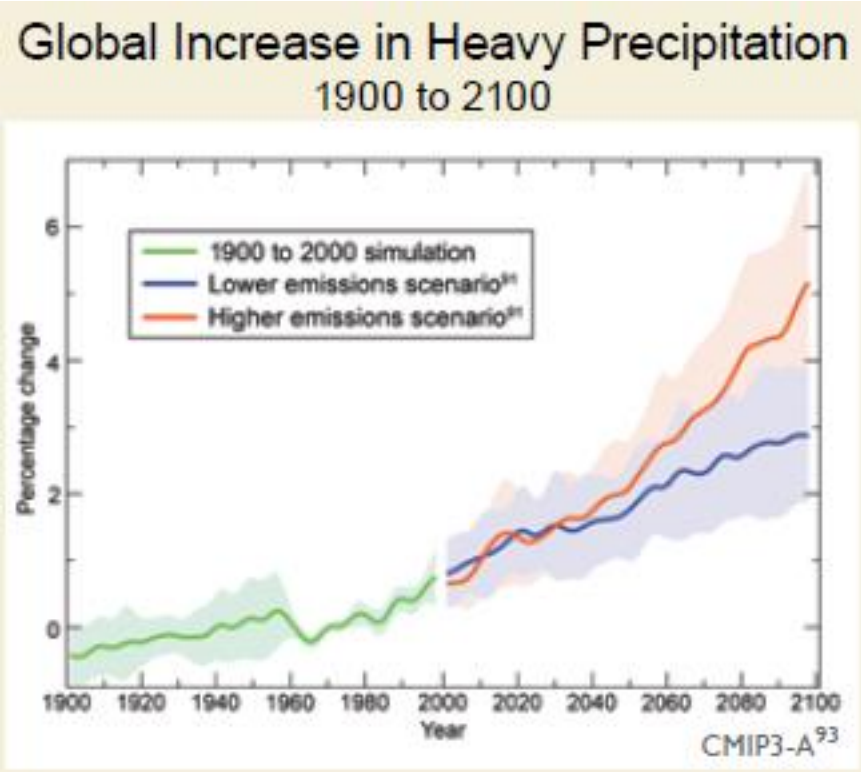
IPCC WGI AR5. 2013





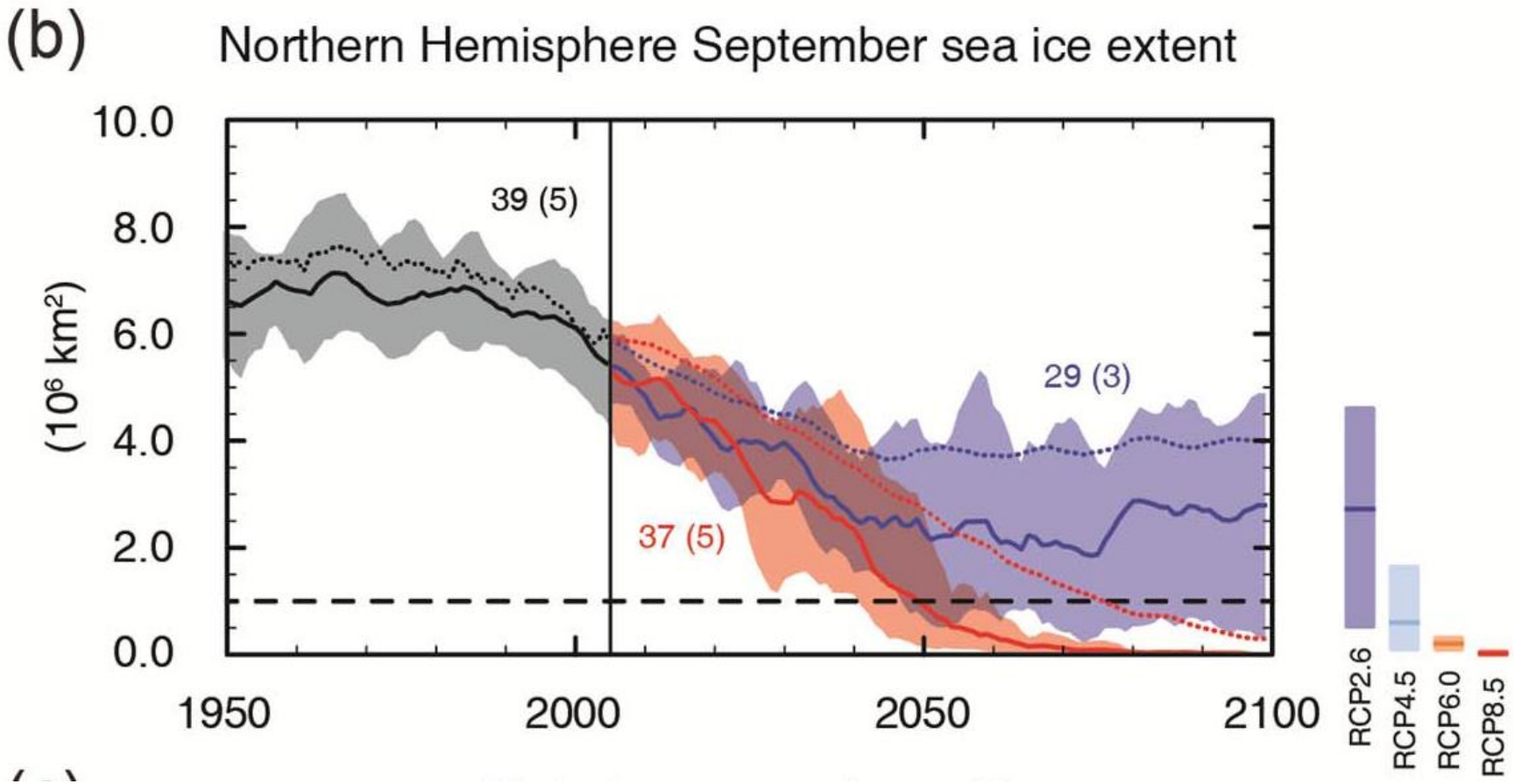
Projected Future Precipitation

- Increase in global average
- More ppt in high latitudes
- Less in 30 deg lat dry belts
- Drier in SW US and Mediterranean
- Increase in heavy downpours



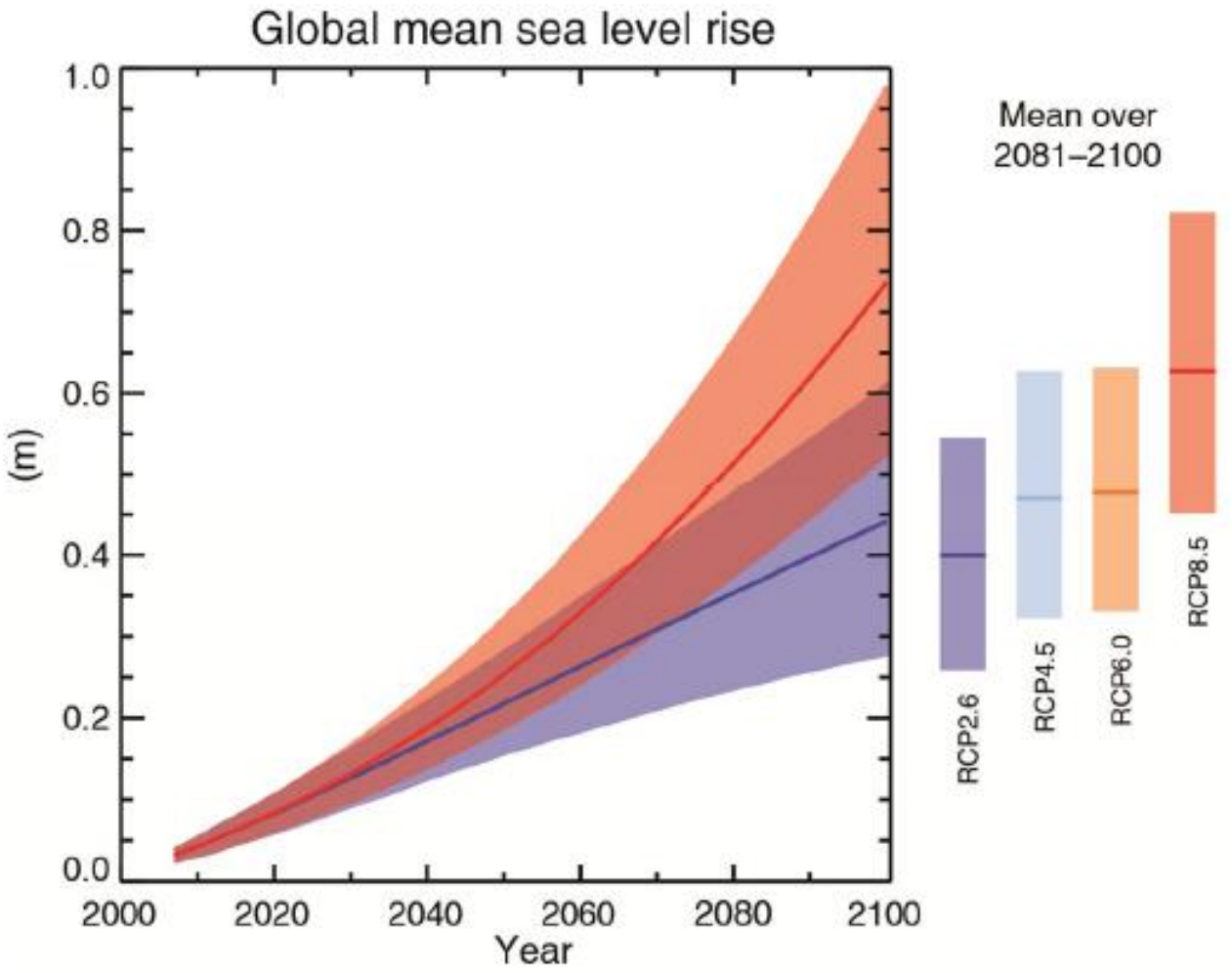
Global Change Impacts 2009.

Projected Future Climate



IPCC WGI AR5. 2013

Projected Future Climate



IPCC WGI AR5. 2013

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IPCC WGI AR5. 2013. Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis. Summary for Policymakers. IPCC.

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