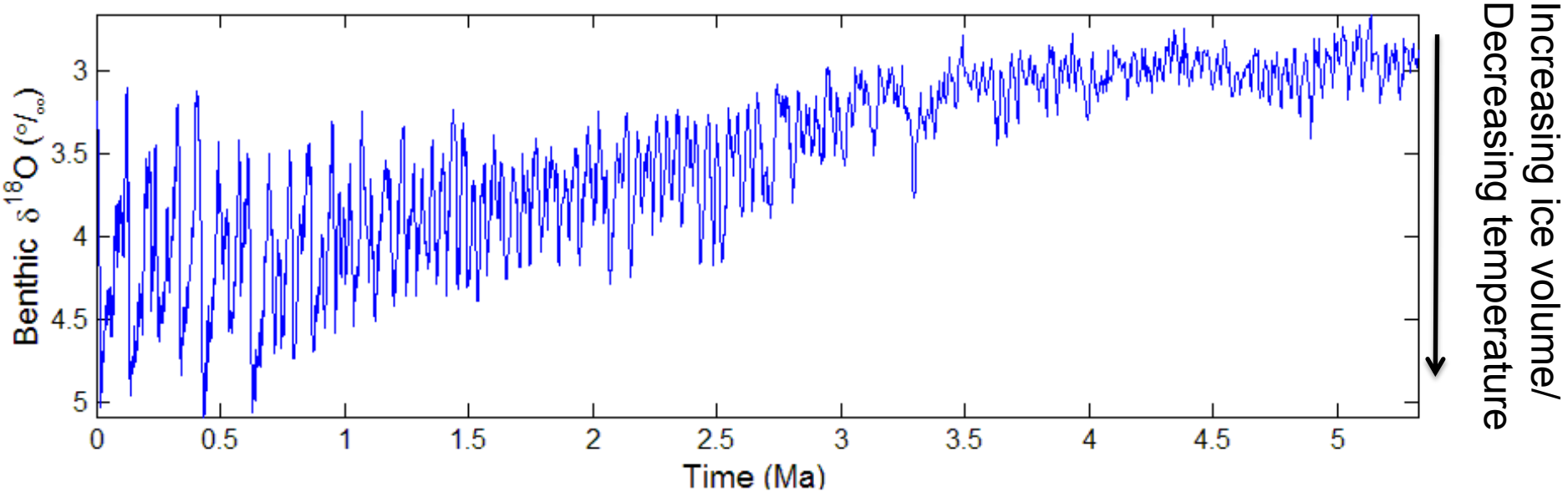
Paleoclimate, part 2: From 3 million years ago to the instrumental period

12.340 Global Warming Science

February 16, 2012

David McGee

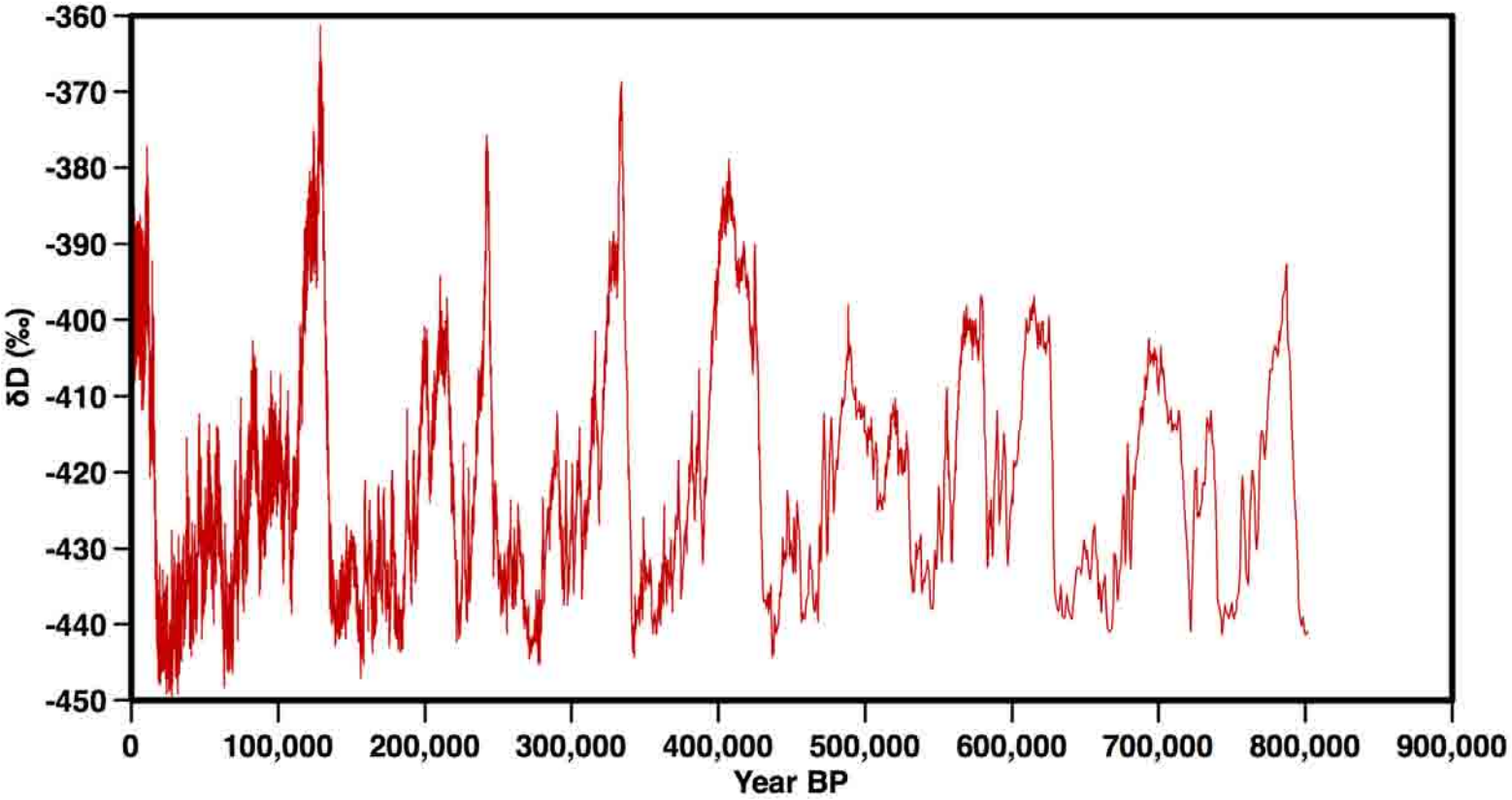
Climate change captured by seafloor foraminifera



Over the last 3 Myr:
Increasing ice volume
Decreasing temperature
Increasing variability
Cyclic changes (glacial-interglacial cycles)

Data from Lisiecki and Raymo, Paleoceanography 2005

Climate change over the last 1 Myr in Antarctic ice



Note: dD is just the hydrogen isotope equivalent of d18O – a larger amplitude, but scales linearly with d18O.

After Jouzel et al., 2007

Oxygen (and hydrogen) isotope fractionation

Water vapor is depleted in ^{18}O (and D) relative to liquid water due to the greater mass of $H_2{}^{18}O$ vs. $H_2{}^{16}O$

Air masses become more ^{18}O-depleted with increasing rain-out and decreasing temperatures

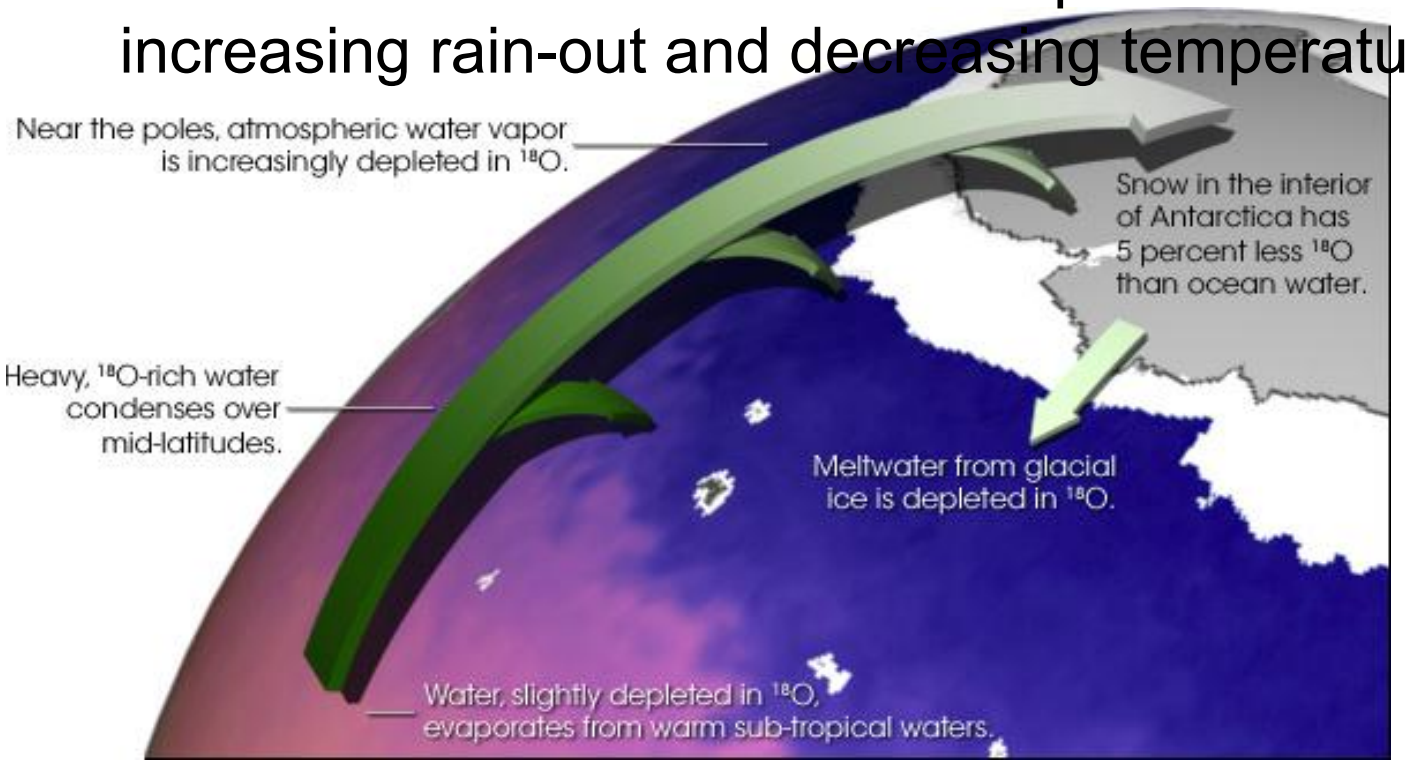
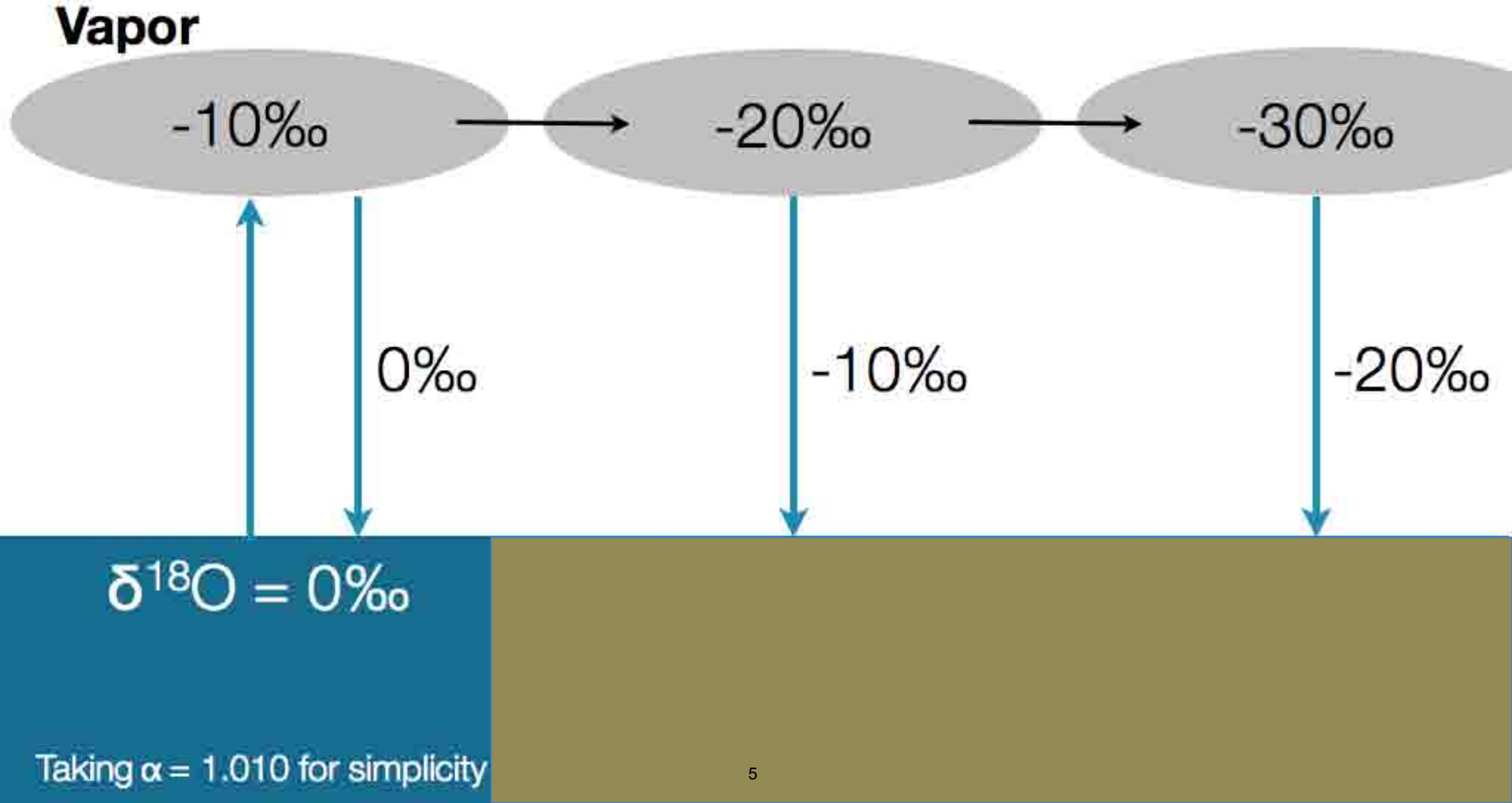


Image courtesy of NASA.

Fractionation in the hydrological cycle



Rayleigh distillation

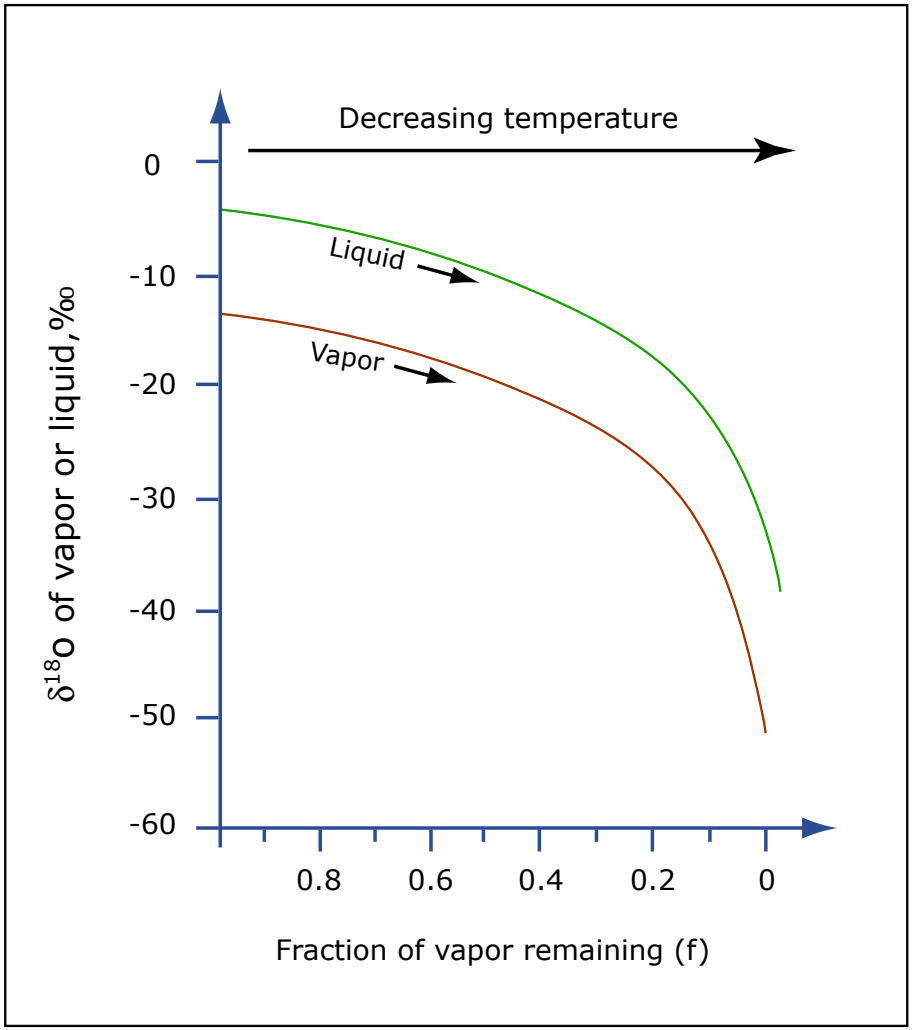


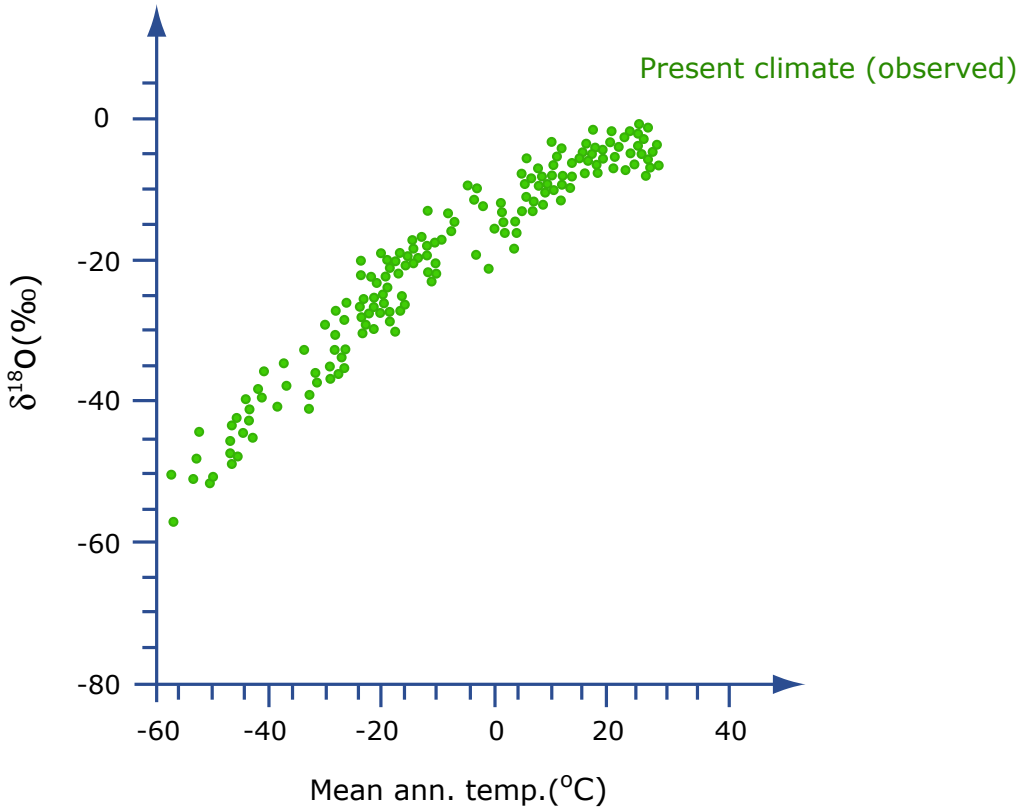
Image by MIT OpenCourseWare.

Describes the evolution of rainfall $\delta^{18}O$ as the amount of water vapor in a cloud becomes depleted.

$$R_v = R_v^0 f^{\alpha-1}$$

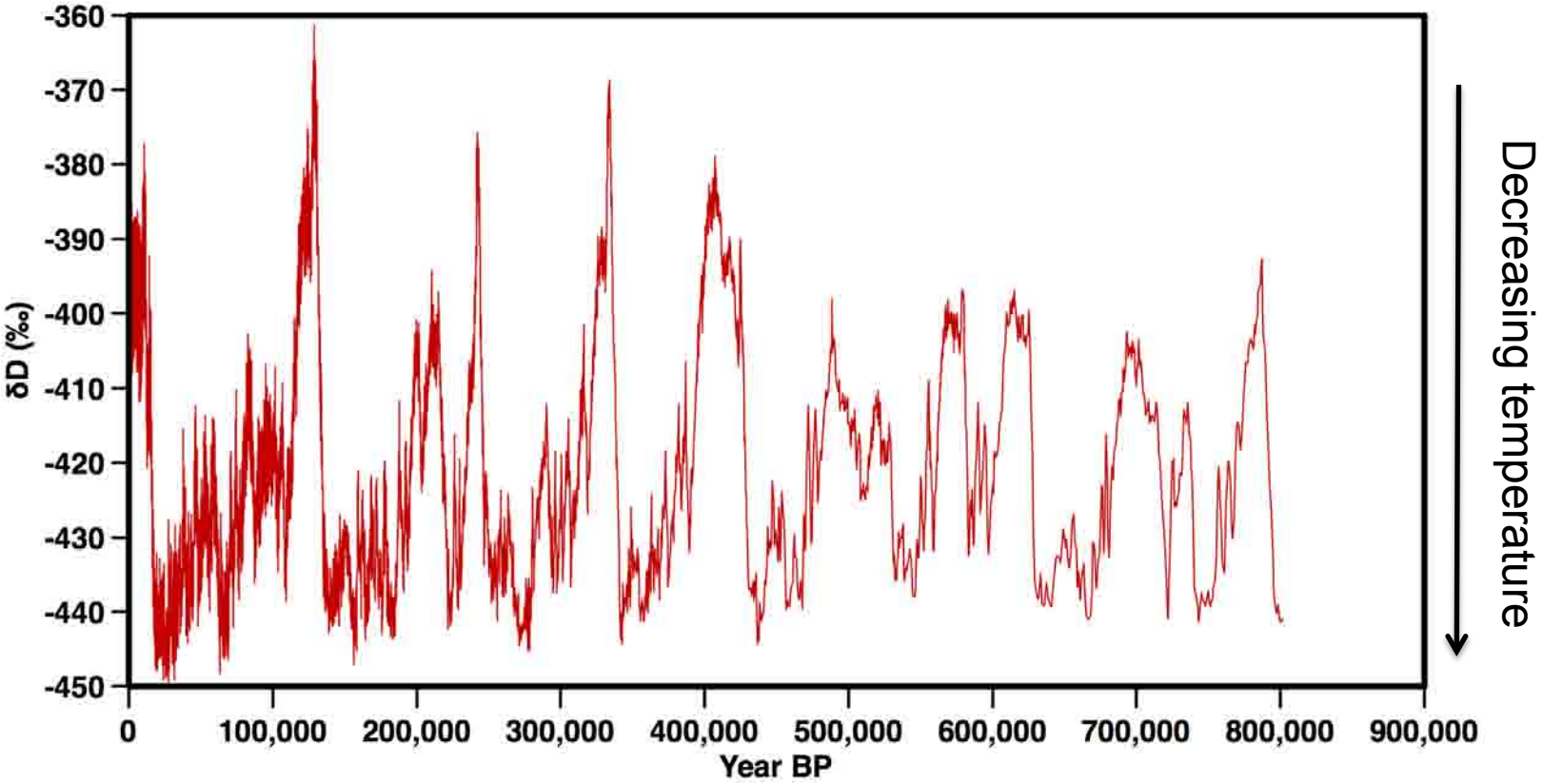
Where
R_v = $^{18}O/^{16}O$ ratio
R_v^0 = initial $^{18}O/^{16}O$ ratio
f = fraction of vapor remaining
α = fractionation factor (~1.01)

Spatial relationship in the modern world



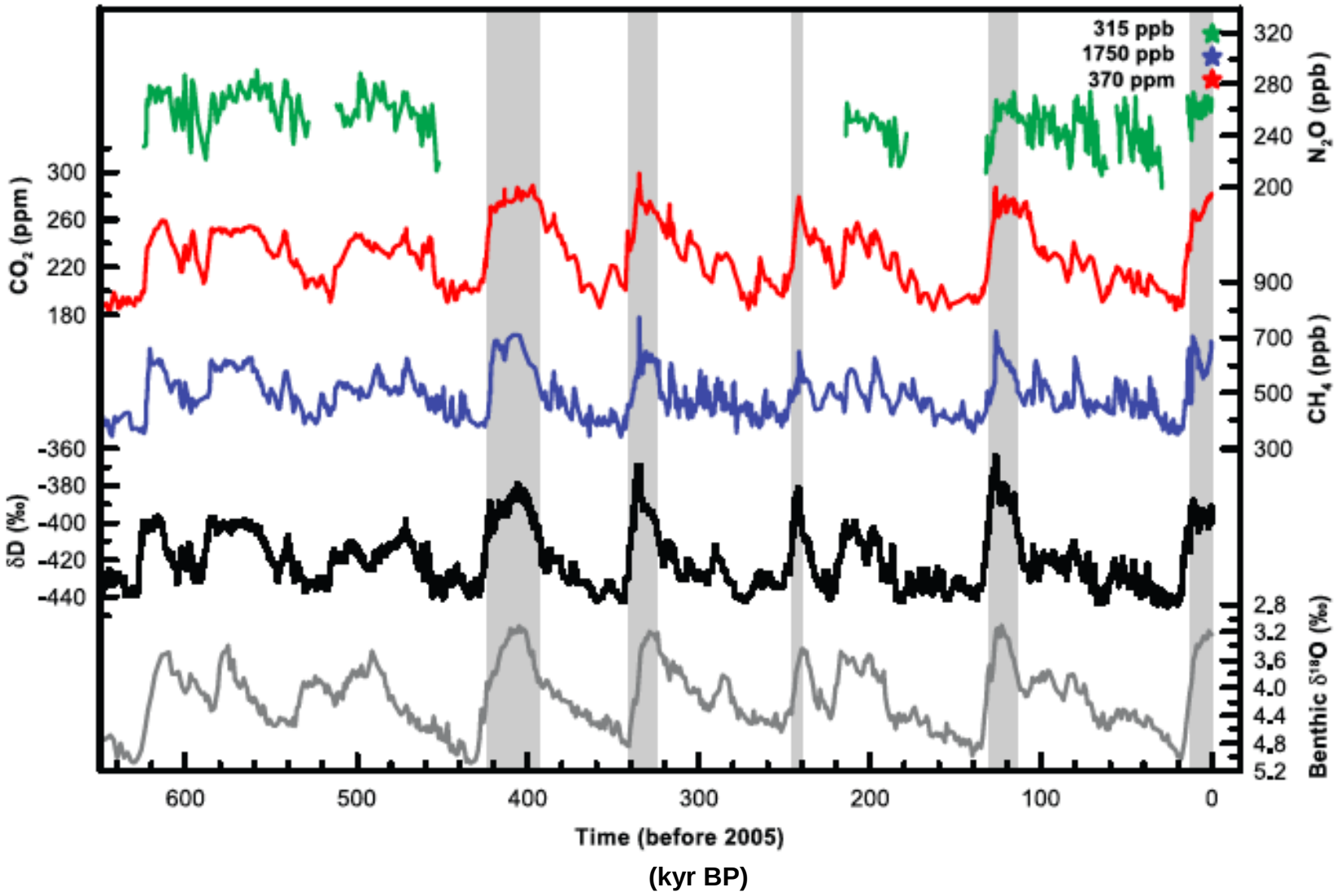
Annual $\delta^{18}O$ in precipitation in relation to mean annual temperature at the same site, based on data from the International Atomic Authority (Jouzel et al., 1994).

Climate change over the last 1 Myr in Antarctic ice



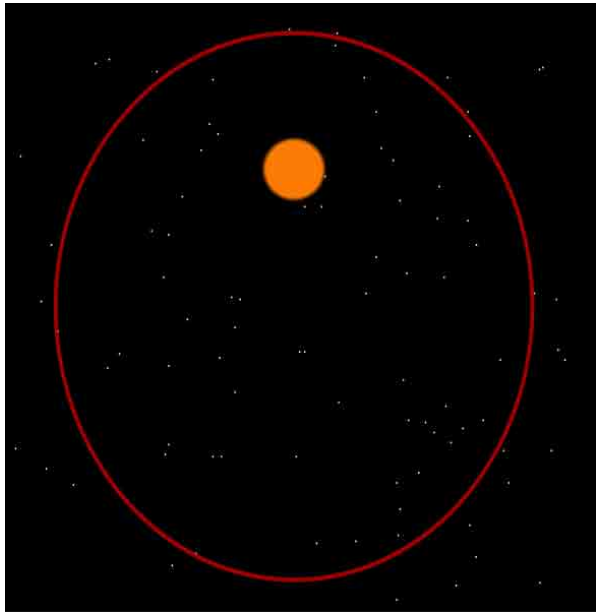
After Jouzel et al., 2007

Climate change and GHGs

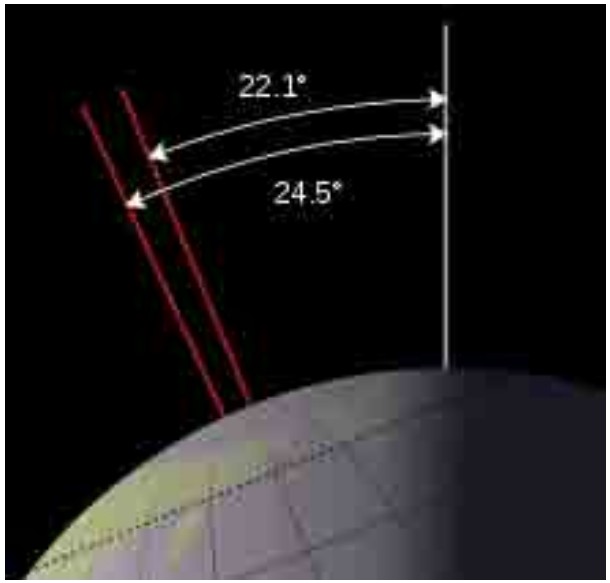


Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 6.3. Cambridge University Press. Used with permission.

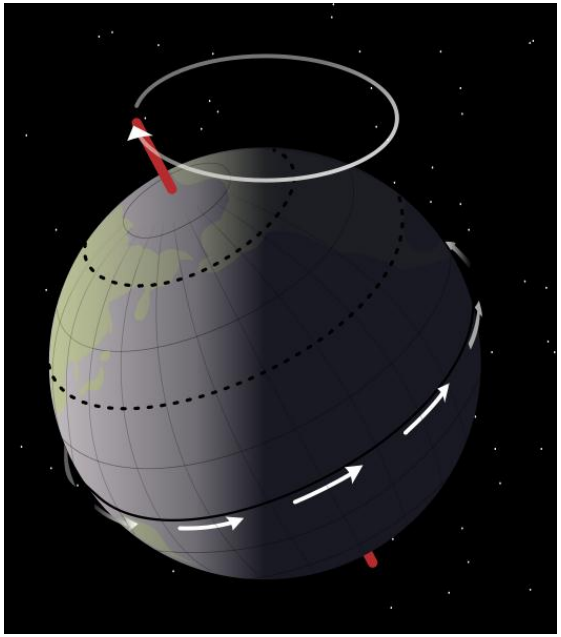
Orbital changes thought to drive climate change on timescales of 10s of thousands of years



Eccentricity
~100 kyr



Obliquity (tilt)
~41 kyr



Precession
~22 kyr

Image courtesy of NASA.

Precise links between orbital changes and glacial-interglacial changes still debated

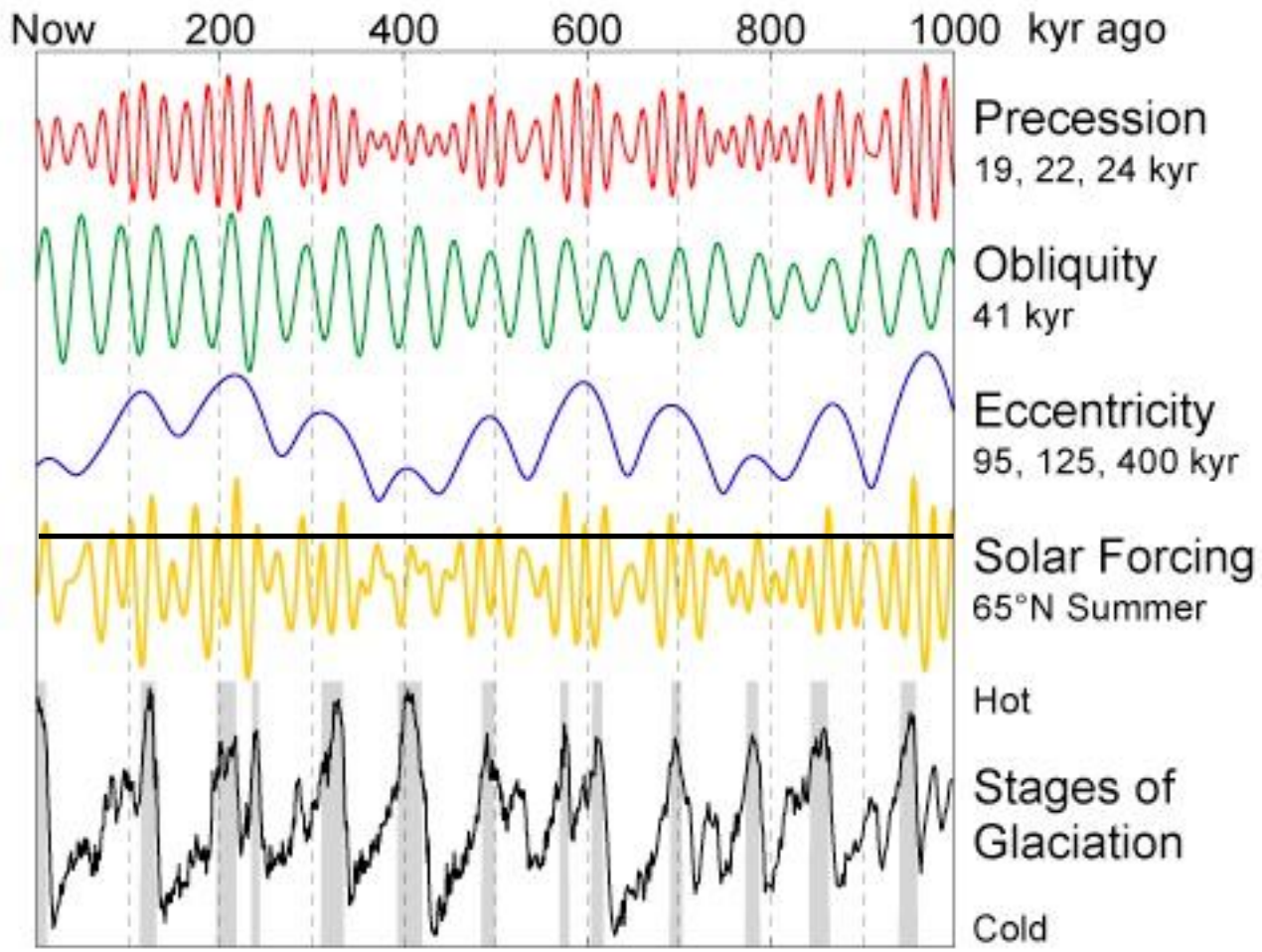


Image courtesy of Global Warming Art.

Orbital changes amplified by GHG changes

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Please see: Figure 1, Monnin et al., Science 2001.
on page,
http://www.sciencemag.org/content/291/5501/112.full

The end of the last glacial period recorded in Antarctic ice. The warming starts before CO_2 (and methane) rise, but CO_2 rise is an important amplifier during the deglaciation.
It is generally agreed that this CO_2 is coming out of the deep ocean, but the mechanisms for this transfer are not agreed upon.

Climate change over the last 100,000 yrs in Greenland ice

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Please see
Grootes, P. M. and M. Stuiver (1997), Oxygen 18/16 variability in Greenland snow and ice with 10−3- to 105-year time resolution. *J. Geophys. Res*., 102(C12), 26,455–26,470, doi:10.1029/97JC00880.

Relationship between temperature changes at the poles

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Please see Figure 2 on page
http://www.ncdc.noaa.gov/paleo/pubs/jouzel2007/jouzel2007.html
The image was published in Science, Vol. 317, No. 5839, pp.793-797, 10 August 2007. DOI: 10.1126/science.1141038.

Greenland and Antarctica vary together from glacial to interglacial, but are out of phase during the abrupt climate changes of the last glacial period.

Abrupt climate changes in Greenland are thought to accompany ocean circulation changes that redistribute heat to the southern hemisphere.

The last interglacial:
High-latitude temperatures 3-5˚C warmer than today

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Please see Figure 2 on page
http://www.ncdc.noaa.gov/paleo/pubs/jouzel2007/jouzel2007.html
The image was published in Science, Vol. 317, No. 5839, pp.793-797, 10 August 2007. DOI: 10.1126/science.1141038.

May have some relevance for future climate, though the warm high latitude temperatures appear to have been caused by high obliquity and eccentricity, not GHGs.

The last interglacial:
High-latitude temperatures 3-5˚C warmer than today

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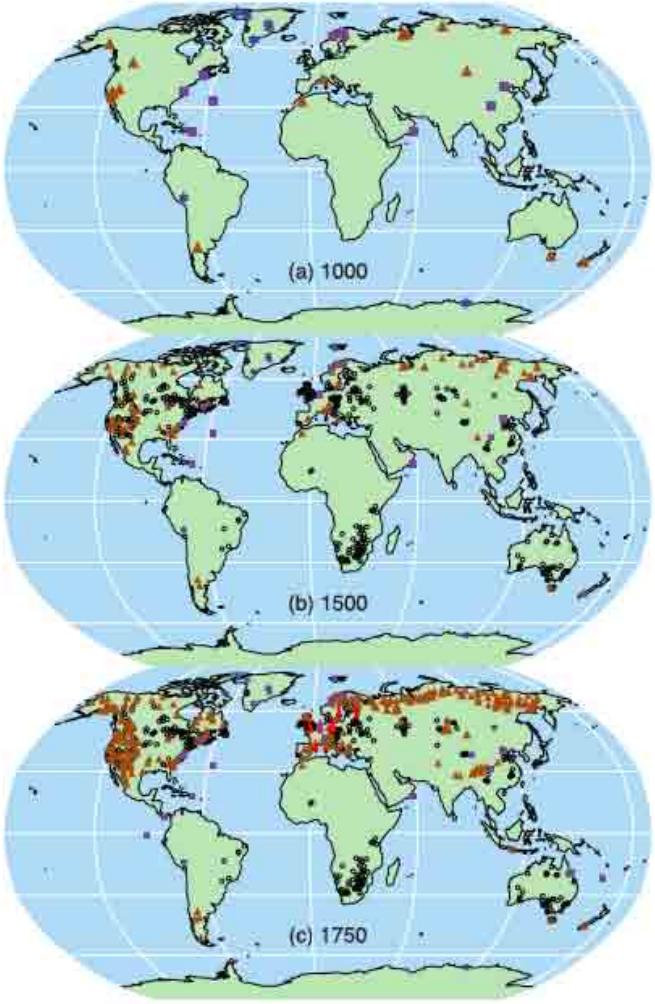
Global sea levels likely at least 6.6 m higher than present (95% confidence), and less than 9.0 m higher (33% confidence) (Kopp et al., 2009)

6 m of sea level rise implies substantial melting of both the Greenland and West Antarctic ice sheets.

The last 2000 years: temperature



Data primarily comes from:
-tree rings
-boreholes
-lake sediments

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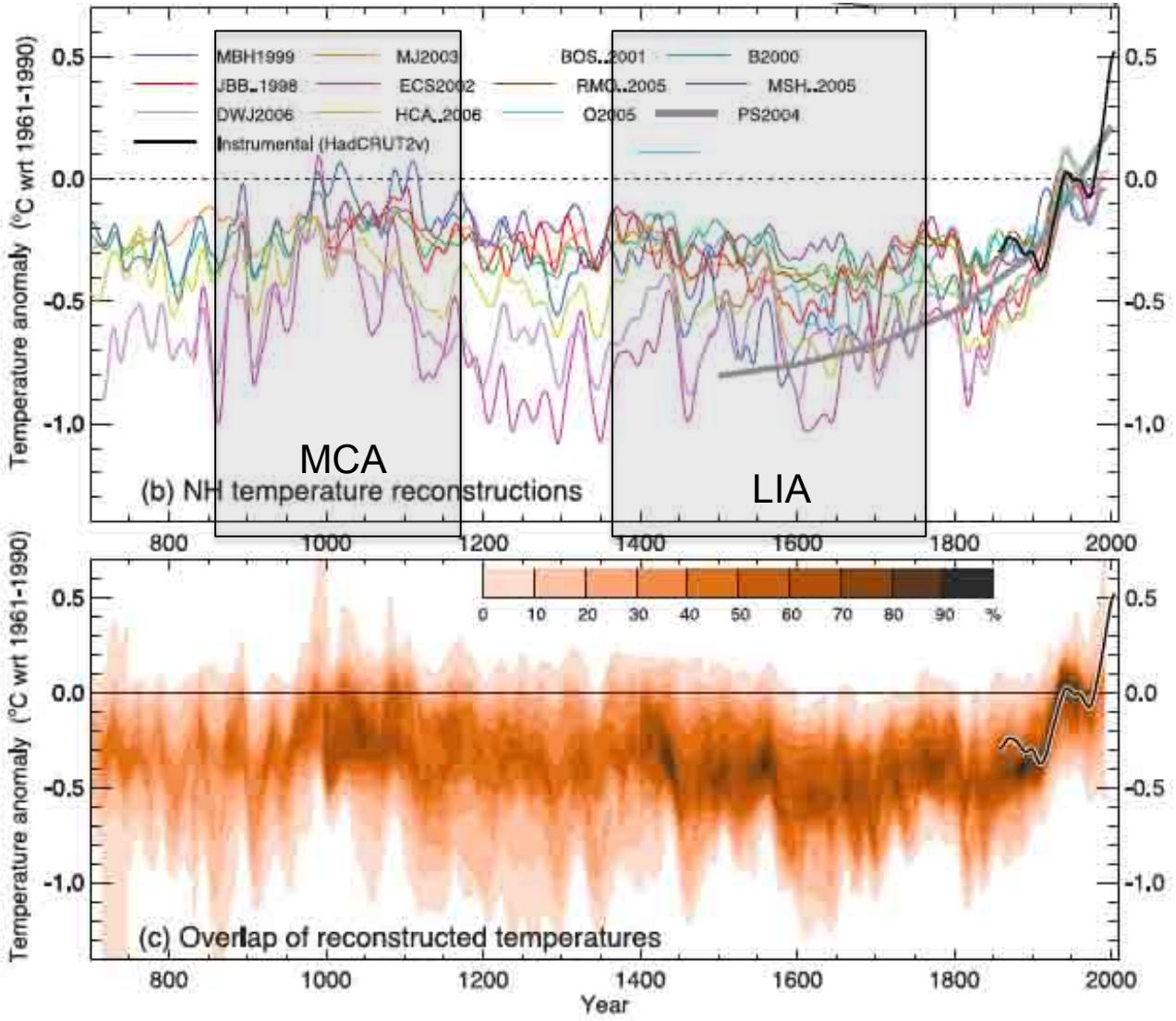
The last 2000 years: temperature



MCA =
Medieval Climatic Anomaly
(aka Medieval Warm Period)

LIA=
Little Ice Age

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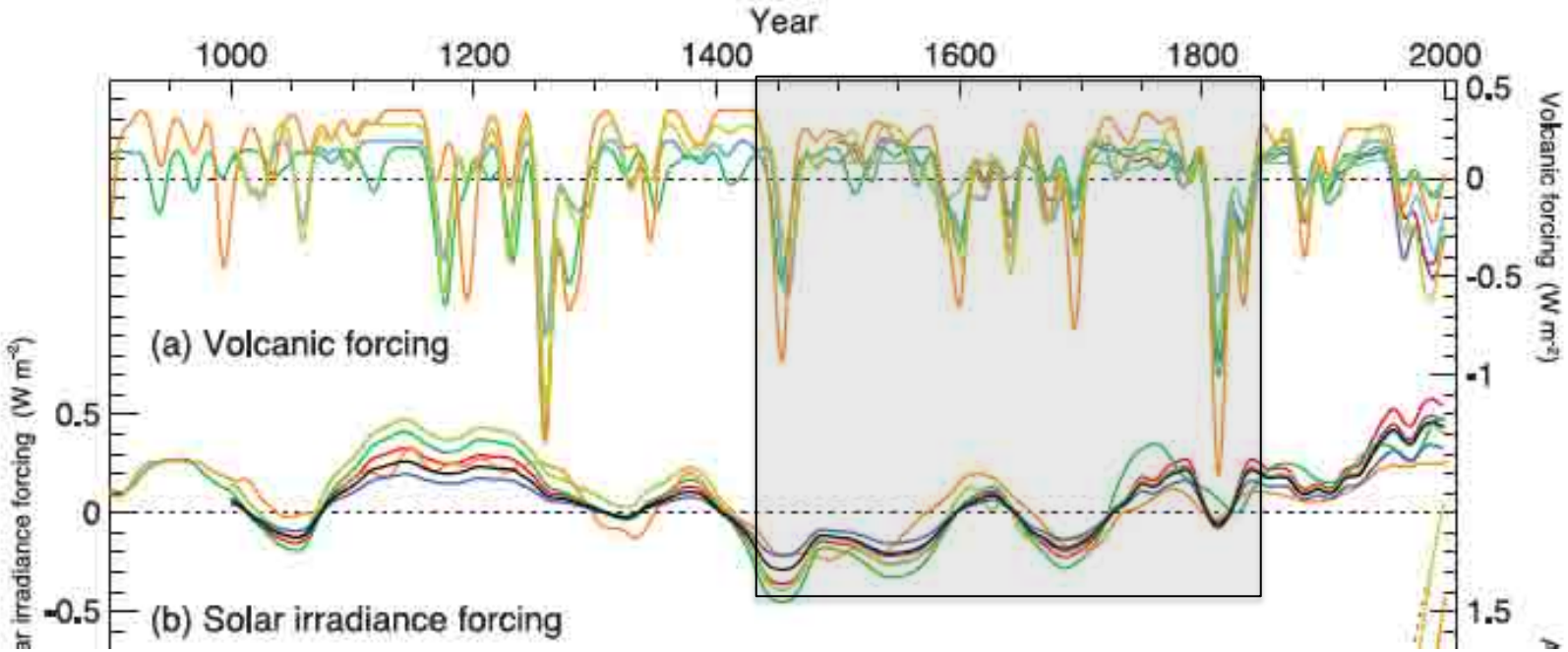
What caused the Little Ice Age?



Coincides with increased volcanic activity and decreased solar irradiance

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The last 2000 years: hydrologic variability

- North American Drought Atlas

Data point to important regional-scale hydrologic changes, e.g. drier conditions in the western U.S. during the MCA

The last 2000 years: sea level rise

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Please see Figure 2, Kemp et al., PNAS 2011
on page
http://www.pnas.org/content/early/2011/06/13/1015619108.full.pdf

Kemp et al., PNAS 2011

A few questions for paleo-records

- Are modern conditions and rates of change exceptional?
- What are the links between GHGs and climate?
- What nonlinear responses exist within the climate system?
- What climatic conditions characterized past warm climates and warmings?

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