













1411.8

1411.9



Ice cores give wonderful climate records:

- Age from counting annual layers (check many ways!);
- Snow accumulation from layer thicknesses;
- Temperature at site in several ways;
- Wind-blown dust, sea-salt, etc. from elsewhere;
- Old-air bubbles with swamp-gas methane, etc.;
- All on common time scale.

Many other sources of climate information

- Tree rings;
- Ocean sediments;
- Cave formations;
- Packrat middens;
- Glacial deposits;
- Etc.

A little more on ice dating:

- It isn't easy; there were days...
- But we got it pretty close:
 - Count more than once (I redid 1/2 mile...)
 - In more than one way (ECM, dust, vis., ...)
 - By more than one person
 - Check many ways (volcanoes, etc.)

Snow accumulation:

- We did by correcting annual-layer thickness for ice-flow thinning;
- “Normal” gas-isotopic fractionation check:
 - Snow turning to ice, =firn, ~ 70 m thick;
 - Thickness depends on temp. & snowfall;
 - Gases separated by gravity (heavier deeper)
 - N₂ nearly constant in atmosphere; measure in ice-core bubbles.

Temperature:

- Isotopic ratios--about 1 molecule in 500 in ocean has 1-2 extra protons in an atom;
- Heavy "likes" water, not vapor phase;
- As air mass moves over ice sheet, heavy preferentially condenses and precipitates;
- Colder-->more water removed-->more heavy removed-->less heavy left-->"lighter" snow.

Temperature:

- Borehole temperature: ice ~1 mile down colder than surface and colder than bed; not done warming from ice age;
- (Think of how long it takes to cook a turkey vs. cooking a hot-dog--twice as big takes four times as long);
- How cold the ice is "remembers" how cold the ice-age was;

Temperature:

- If warming abrupt, about 100 years to warm ice at 70-m bubble-trapping depth;
- Takes about 5 years for gas to diffuse through spaces to bubble-trapping depth;
- No wind mixing in firn, heavy gases to cold end;
- Gives anomaly in trapped gases in addition to gravity effect;
- Anomaly size tells how much warming.

Temperature:

- Count years between ice-phase and gas-phase record of abrupt warming;
- Depends on snowfall and temperature just before warming (averaged over time to bury the ice to the bubble-trapping depth);
- Check on absolute temperature and accumulation rate.

Other things:

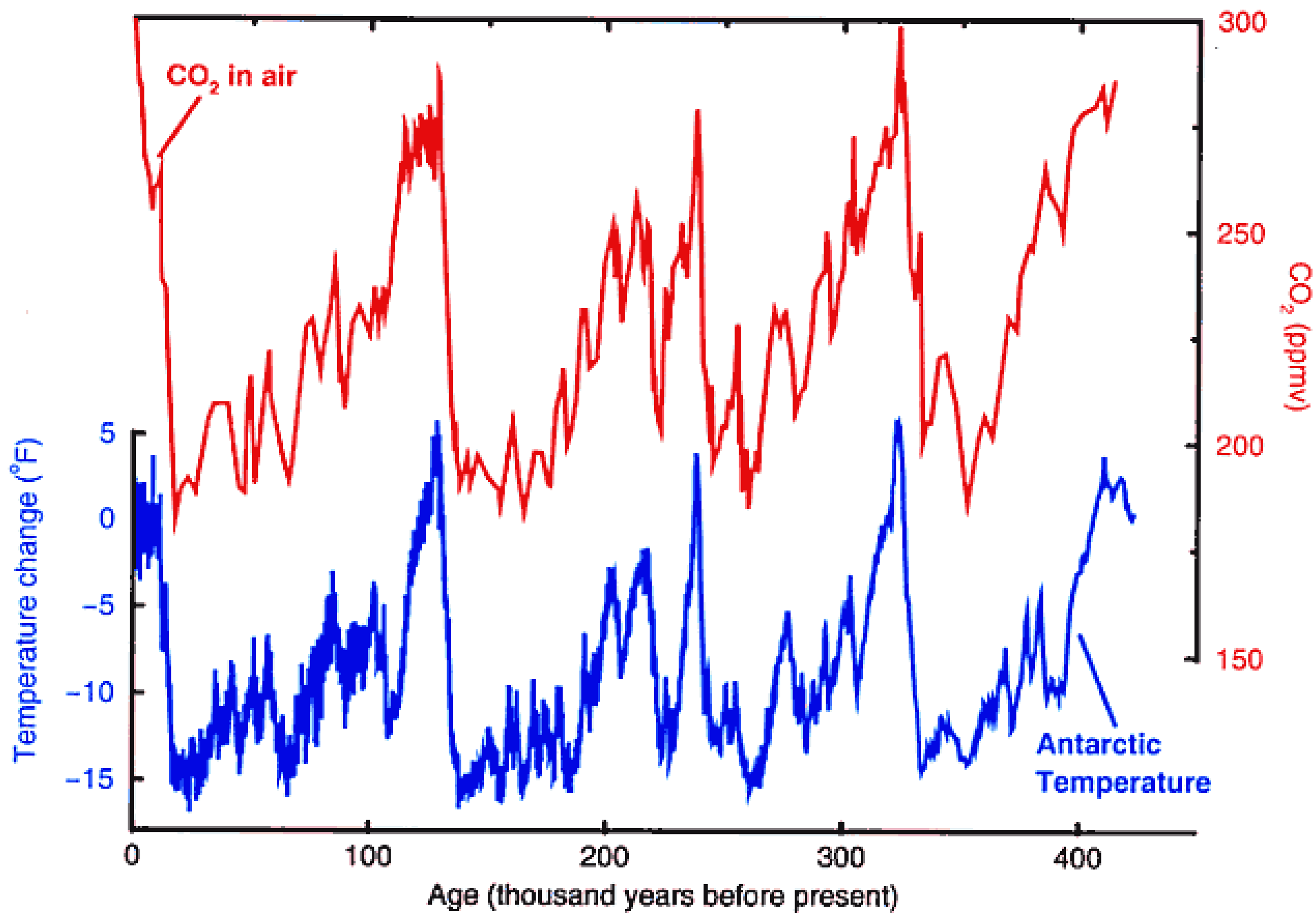
- In central Greenland, two groups (U.S., European) drilled ~30 km apart;
- Checked each other;
- Upper 110,000 years, same record (now duplicated again N-central Greenland);
- Older, ice-flow processes mixed ice of different ages; evident from mismatches (and from looking at core...).

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Hard to get time, money and patience to "do it right":

- Very clear that it is easier to "do it wrong";
- My prejudice is that we are a little too wedded to speed, fame and fortune;
- And we should spend a little more effort "doing it right".

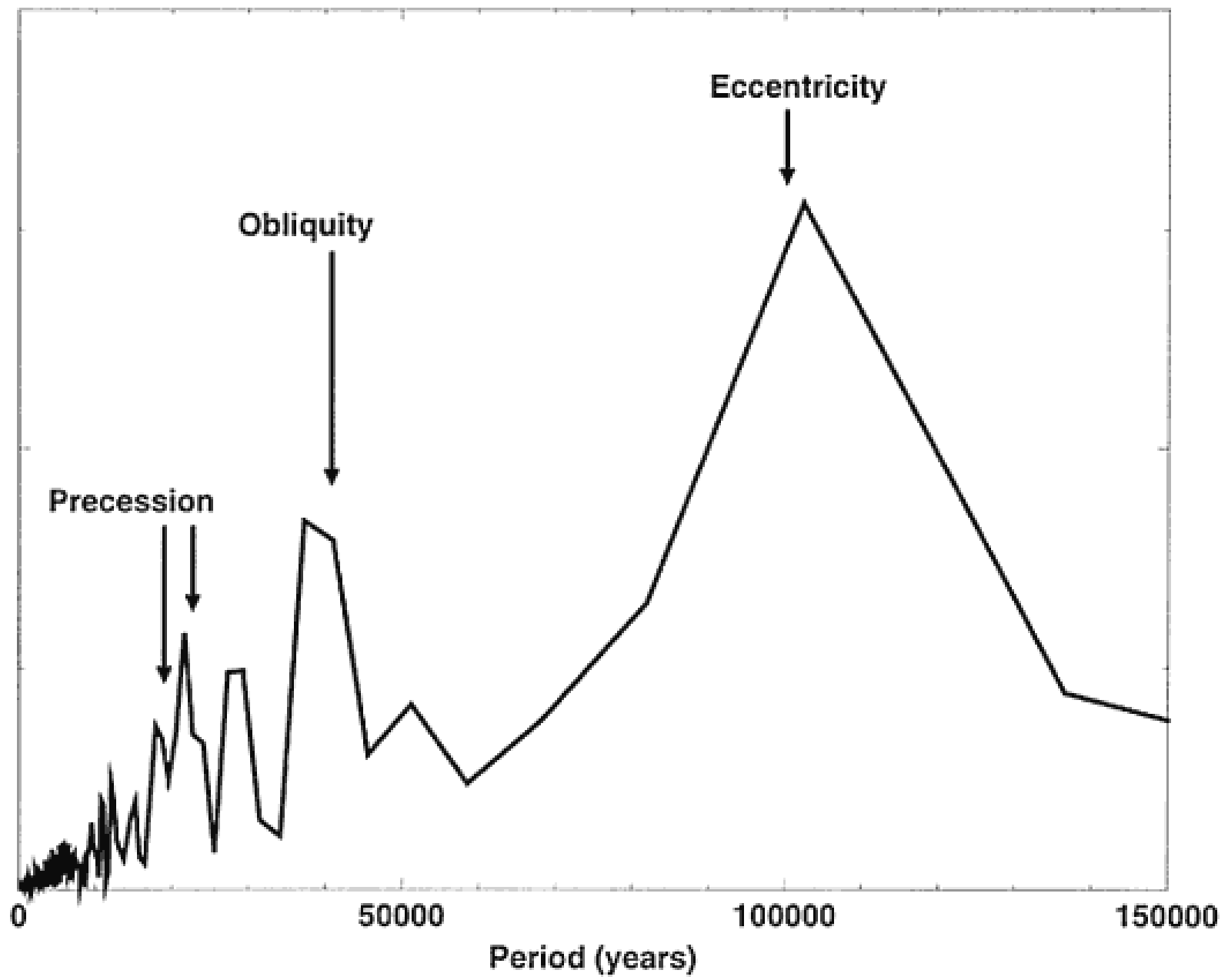


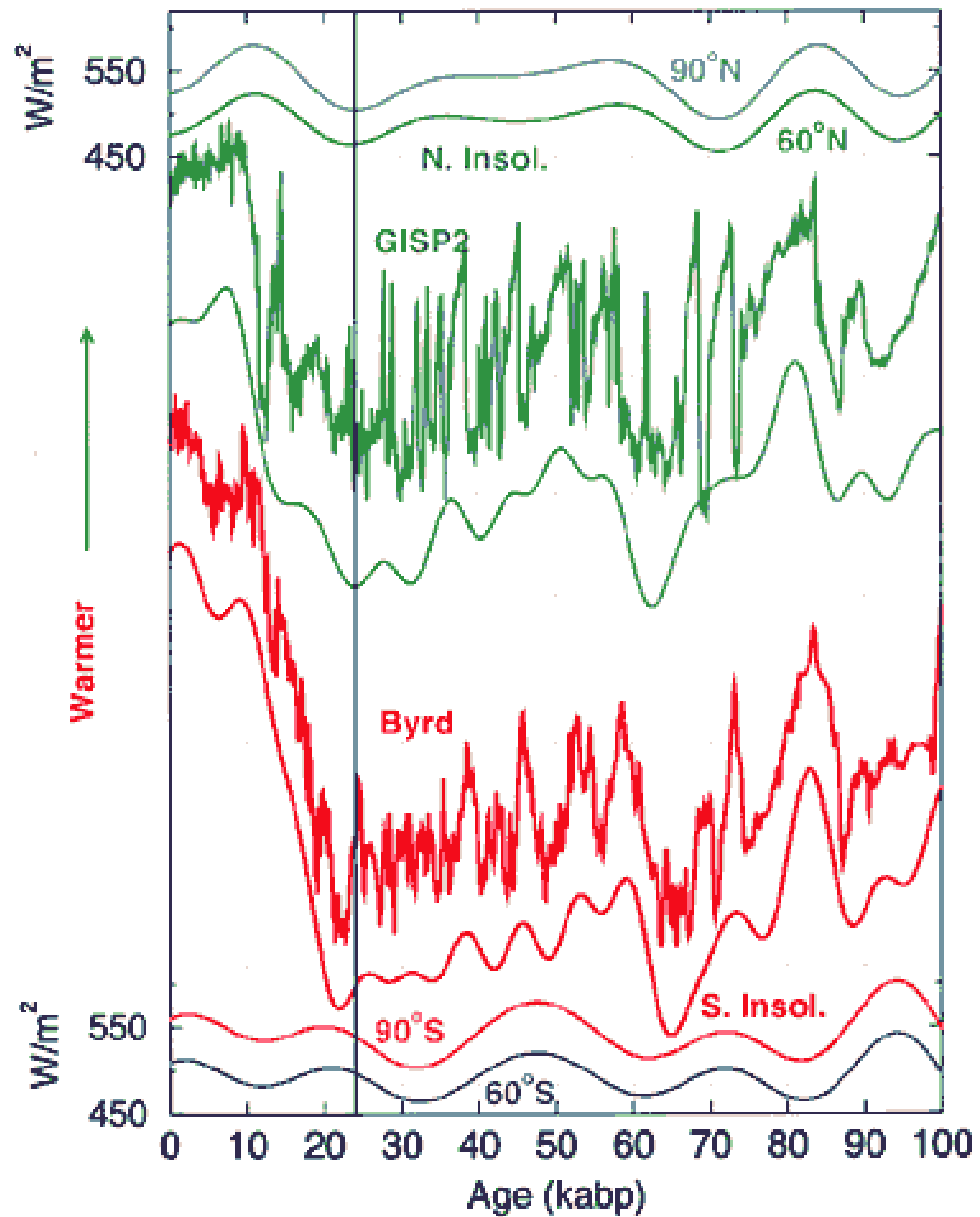
Ice-Age Cycles

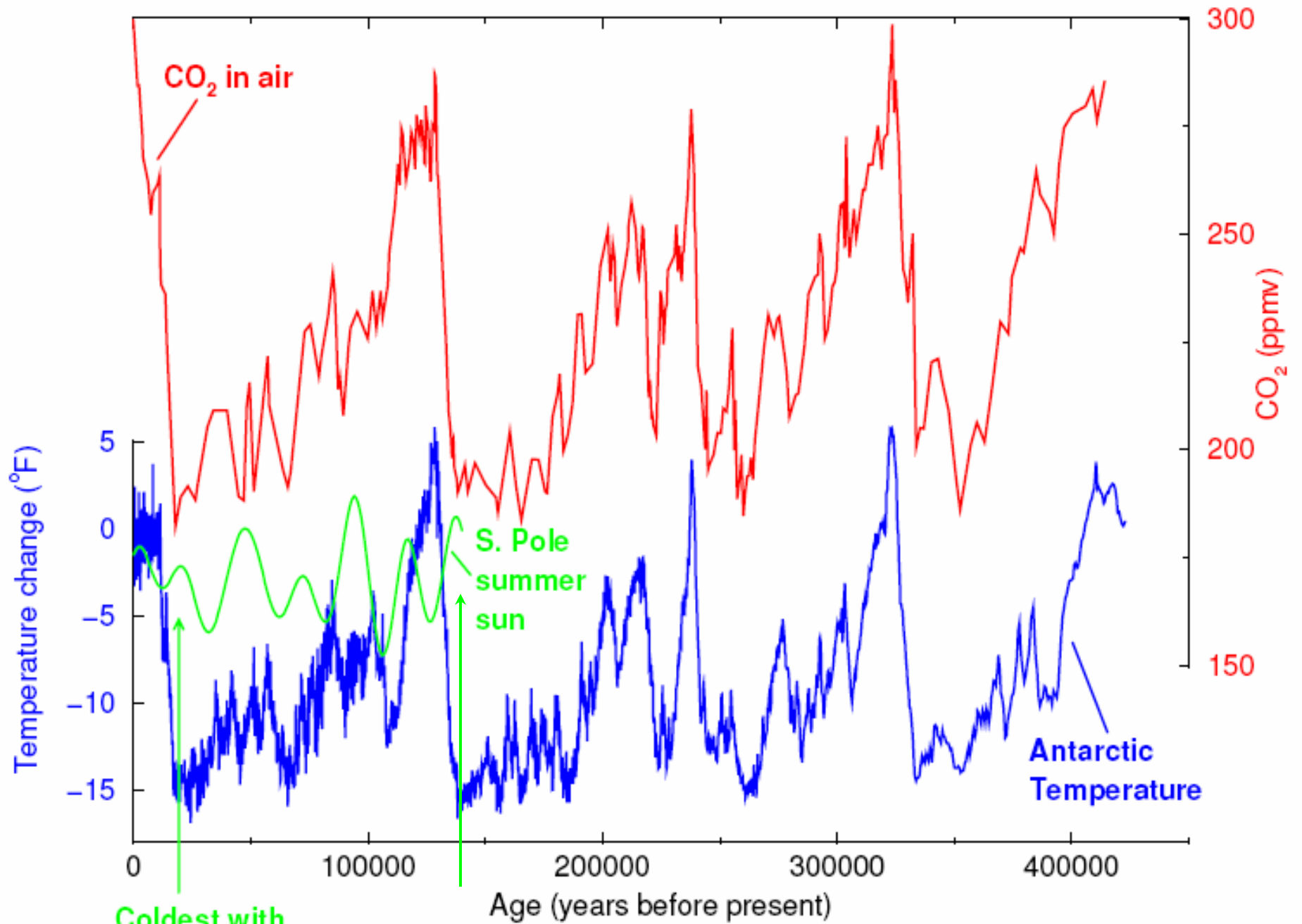
- Timing matches orbital features that rearranged sunshine (N/S, summer/winter) but with little effect on total sunshine;
- World followed N sun, not local sun;
- Thus far, CO_2 (which followed N. sun) is only plausible globalizer;
- Models with CO_2 skillful but tend to underestimate changes that occurred.

FFT of Vostok $\delta^{18}O$ data

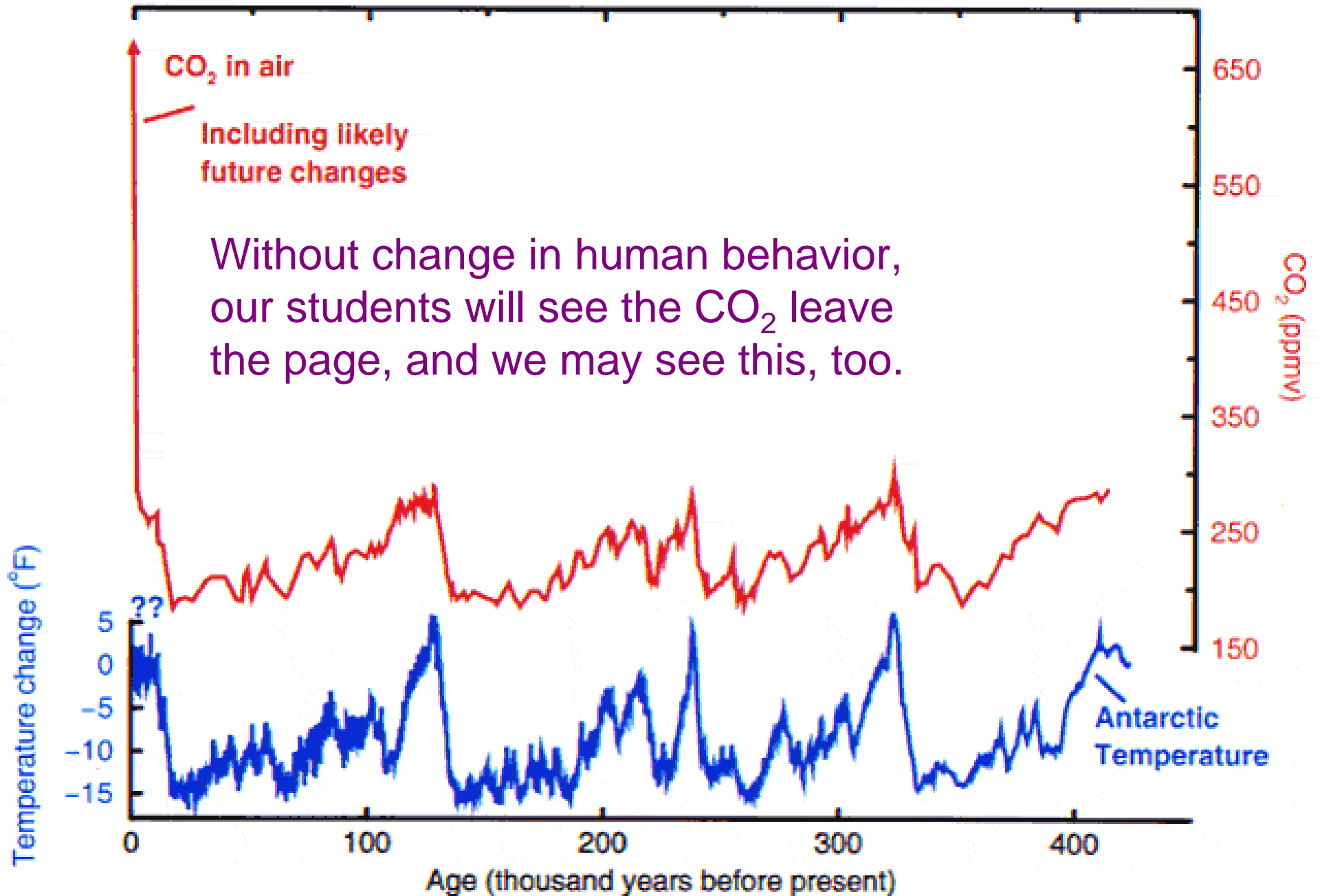
Petit et al., 1999



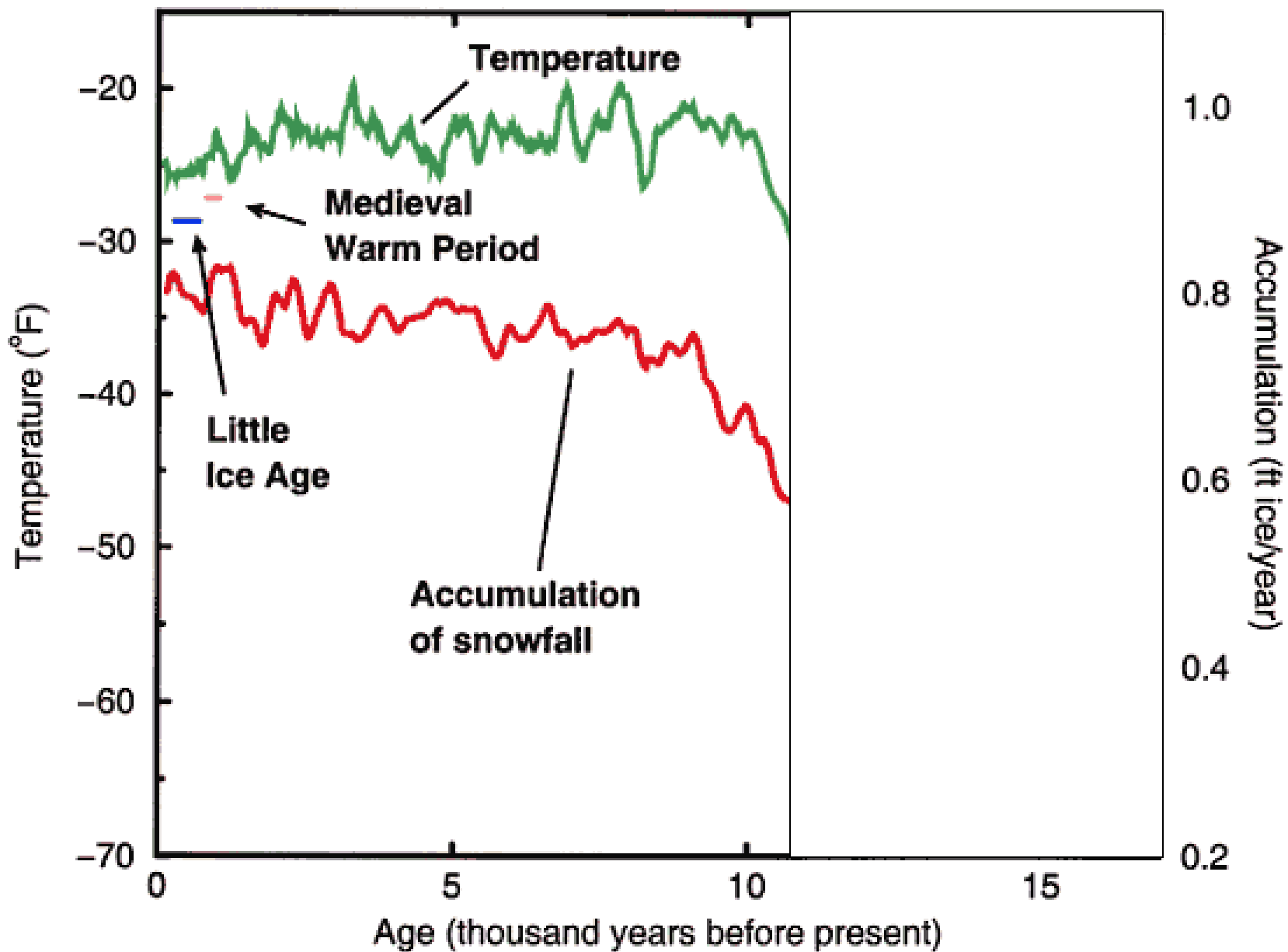




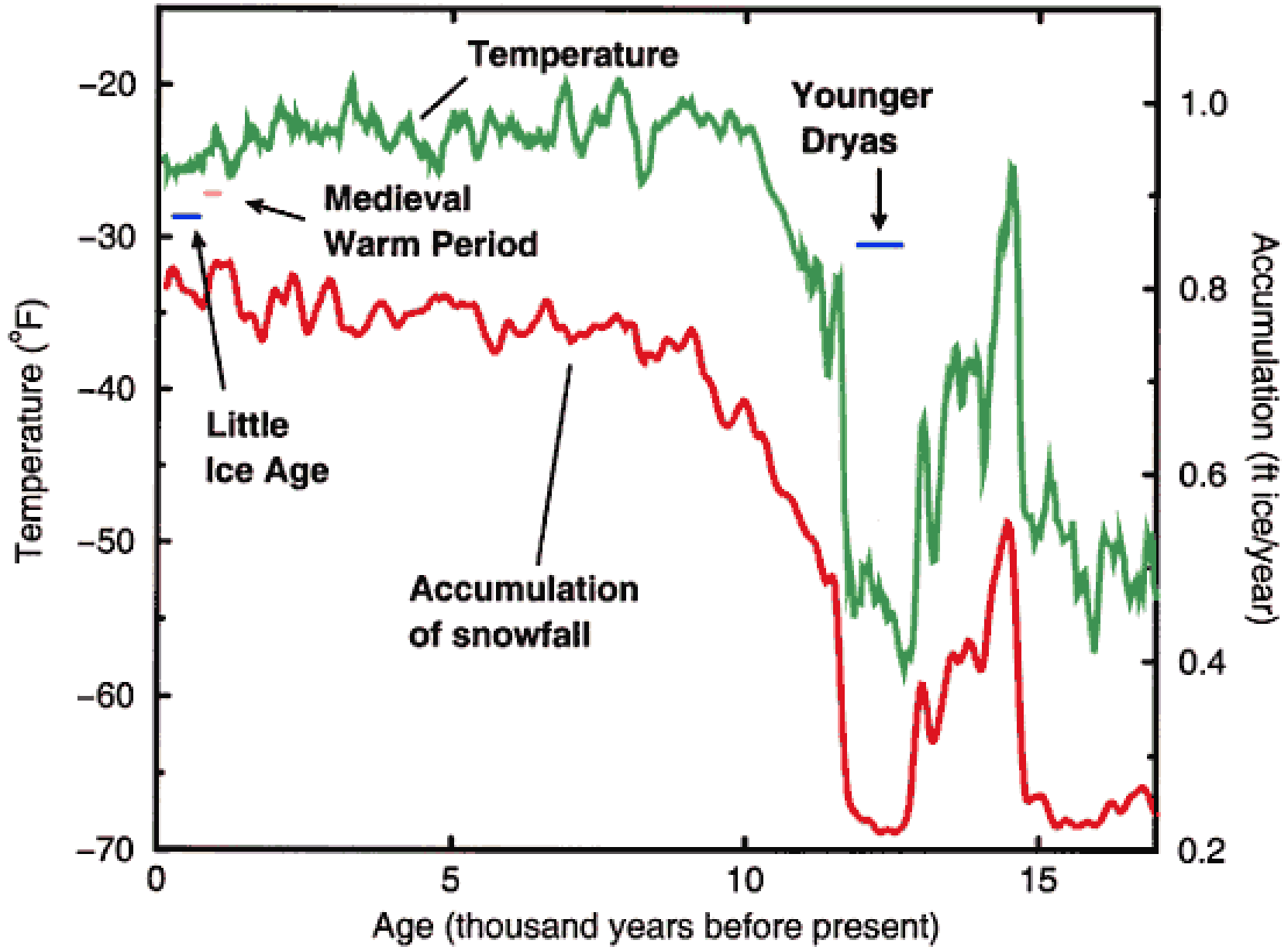
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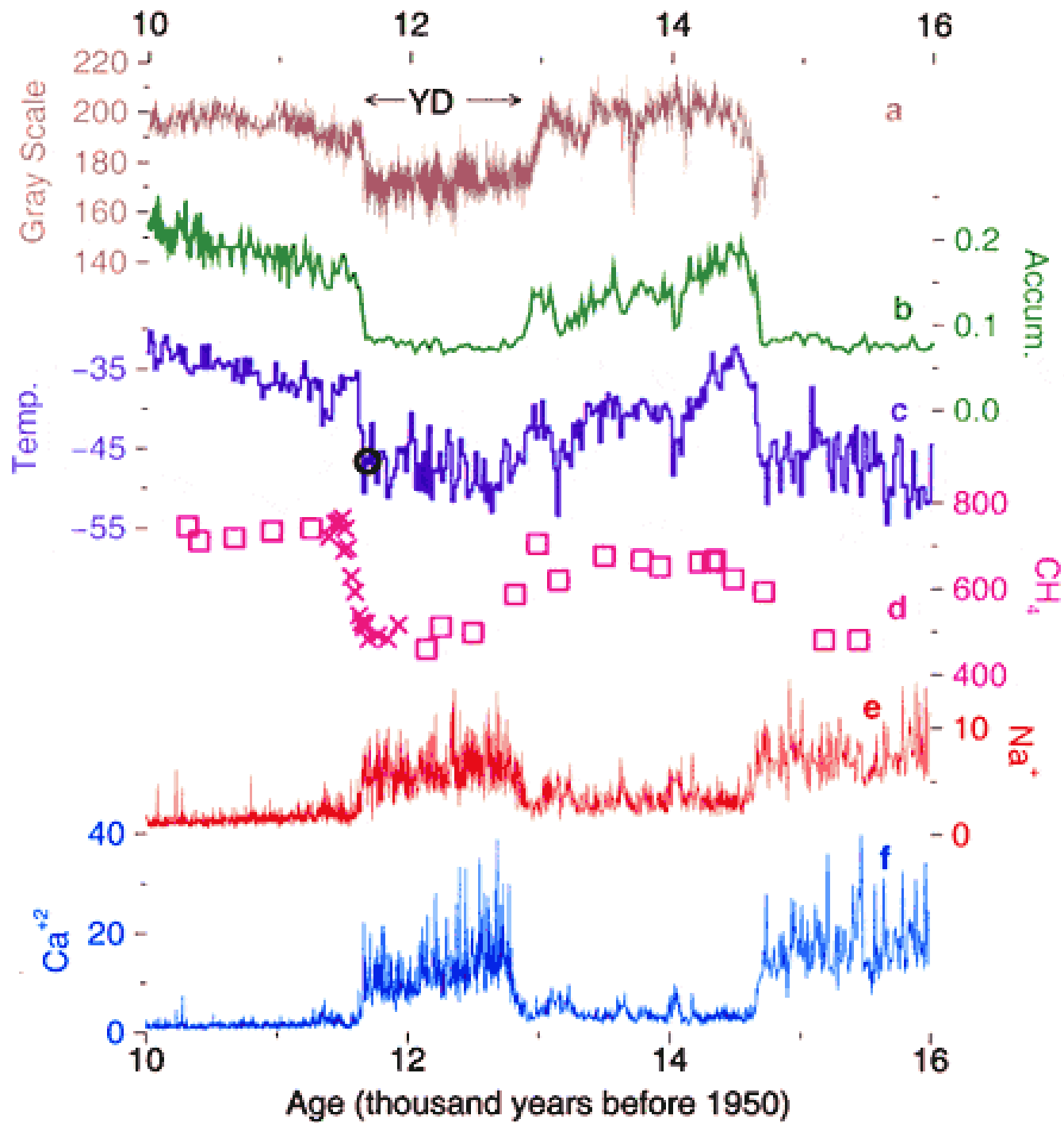


Central Greenland Climate



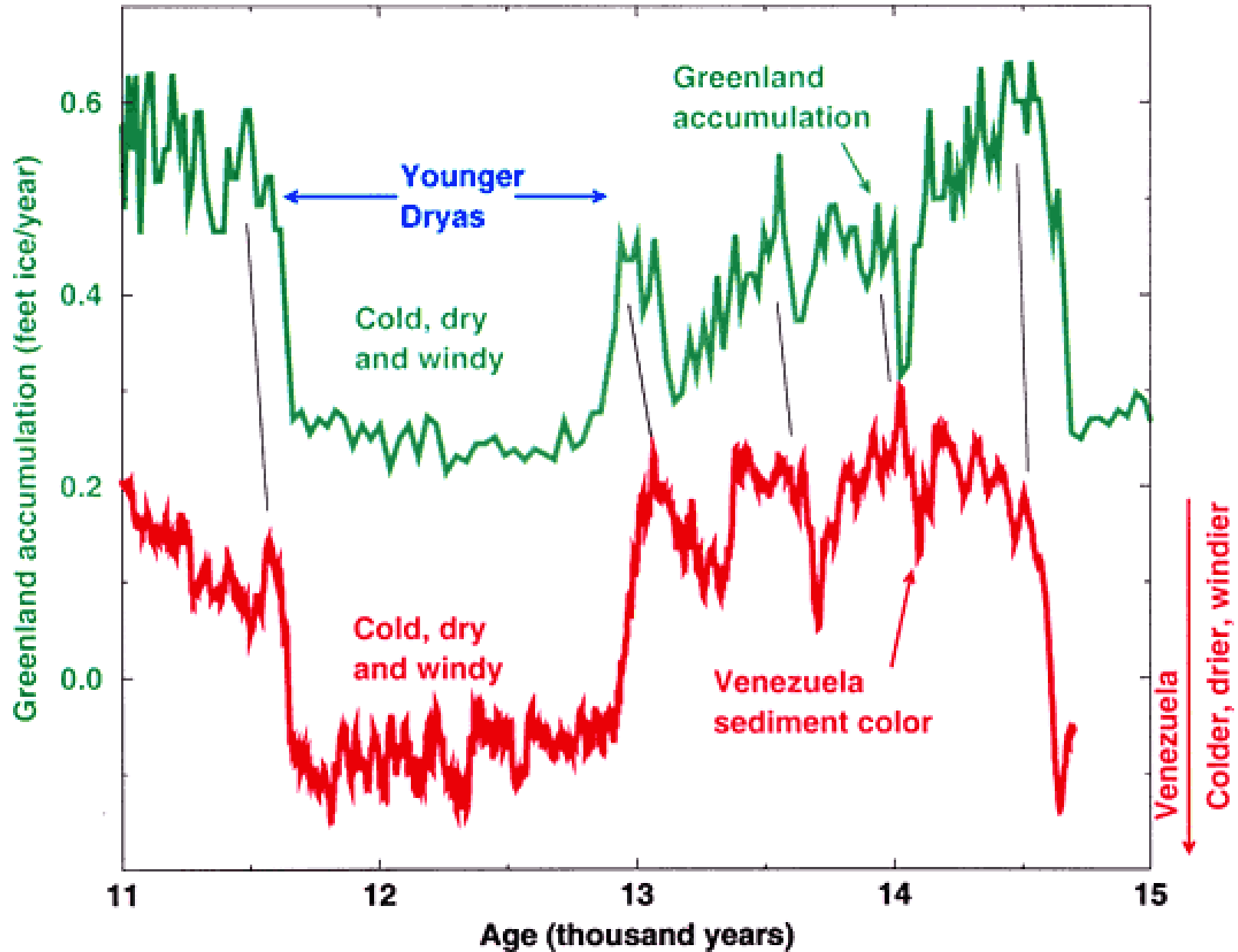
Central Greenland Climate



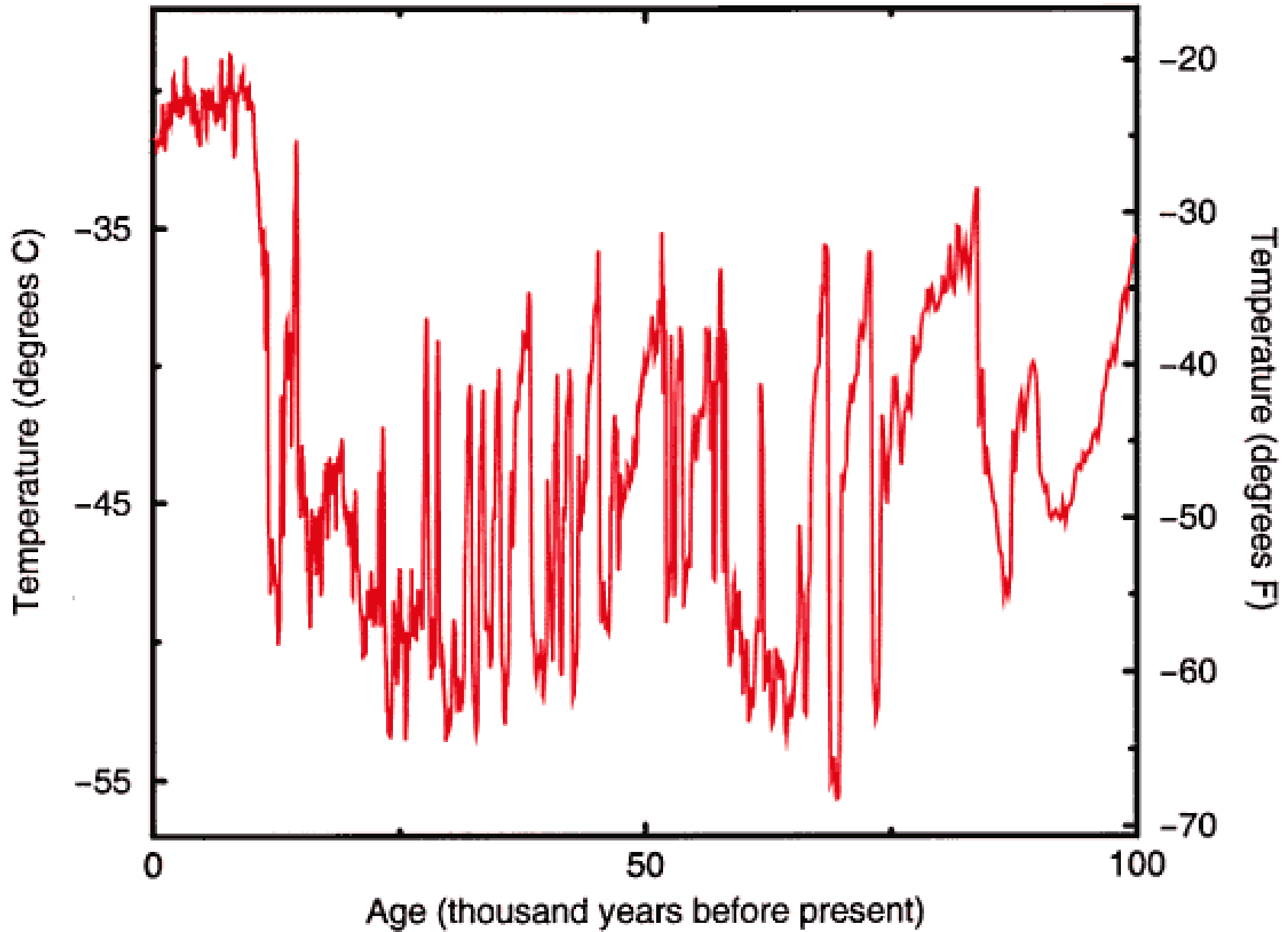


Venezuela and Greenland

Hughen et al., Hughen, pers. comm., Alley et al.

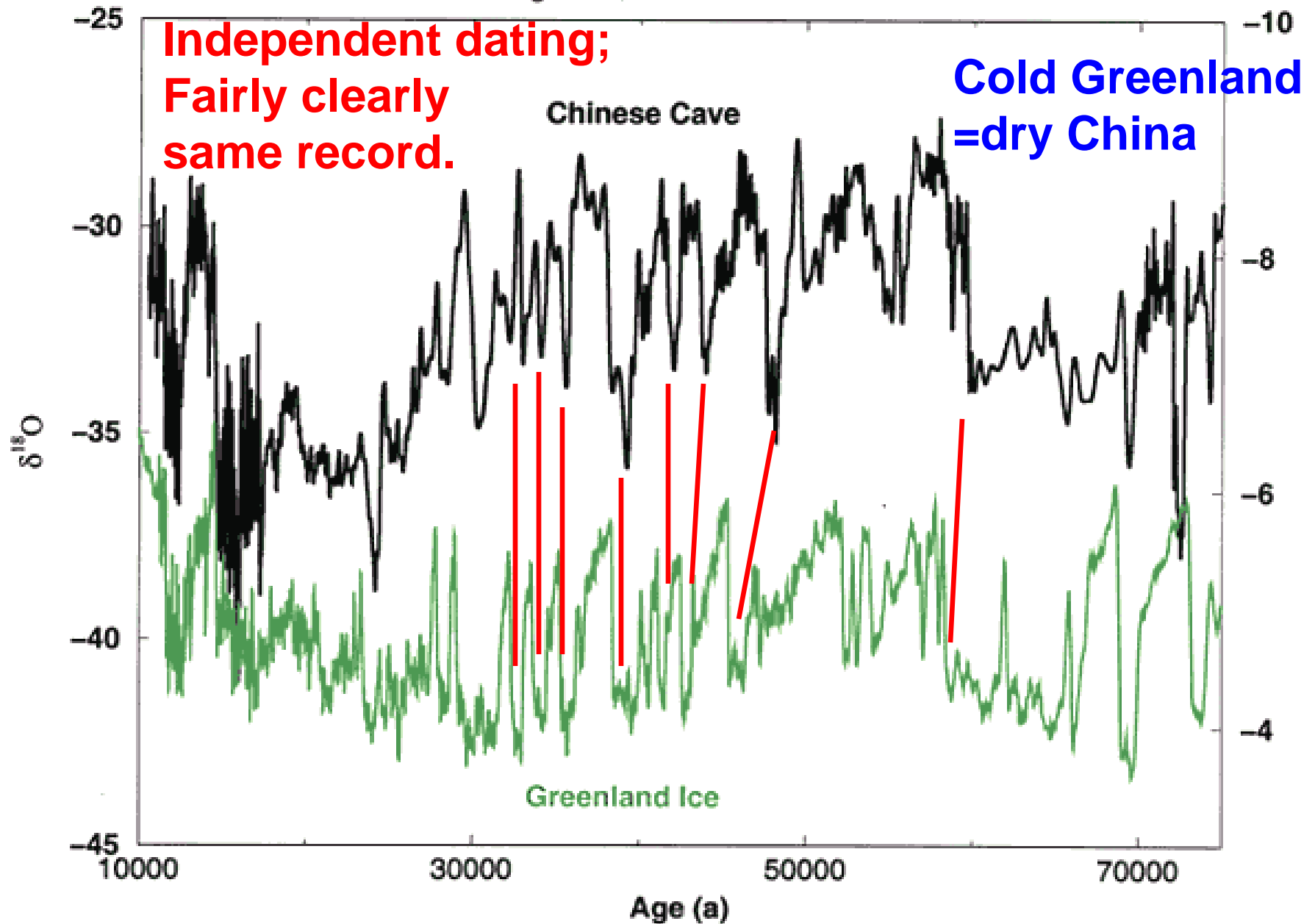


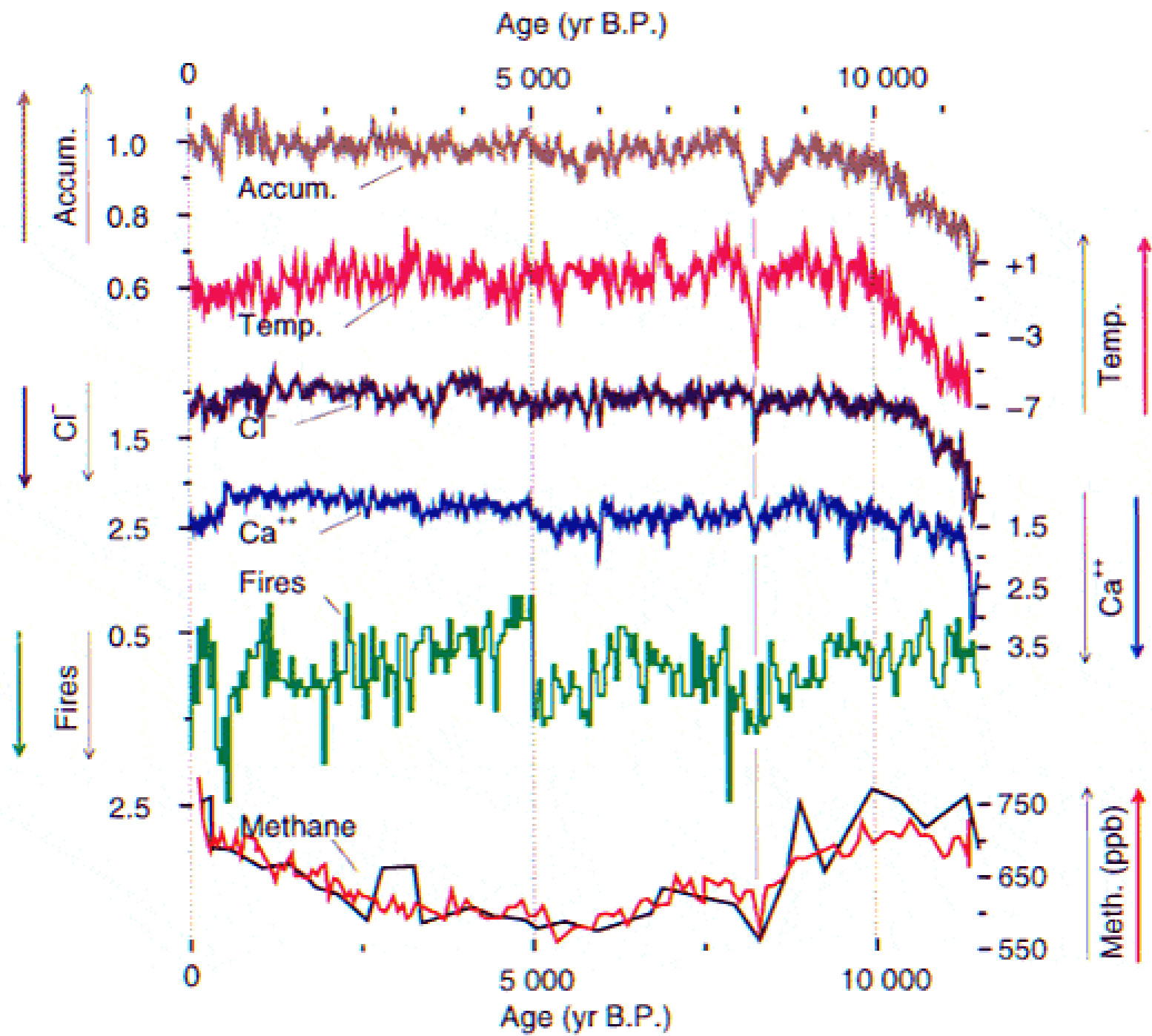
Temperature in central Greenland



Hulu Cave, China and GISP2, Greenland

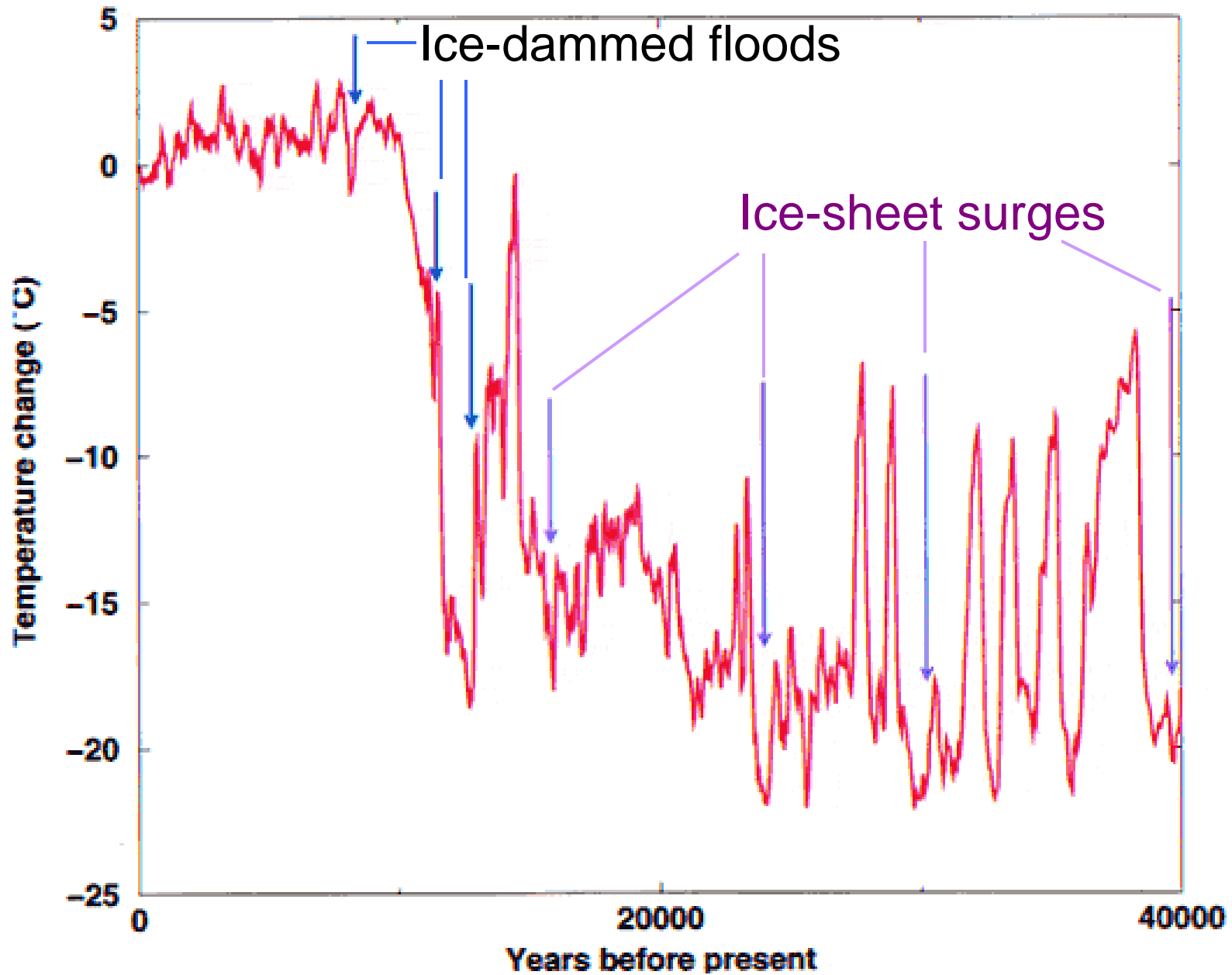
Wang et al., Grootes and Stuiver

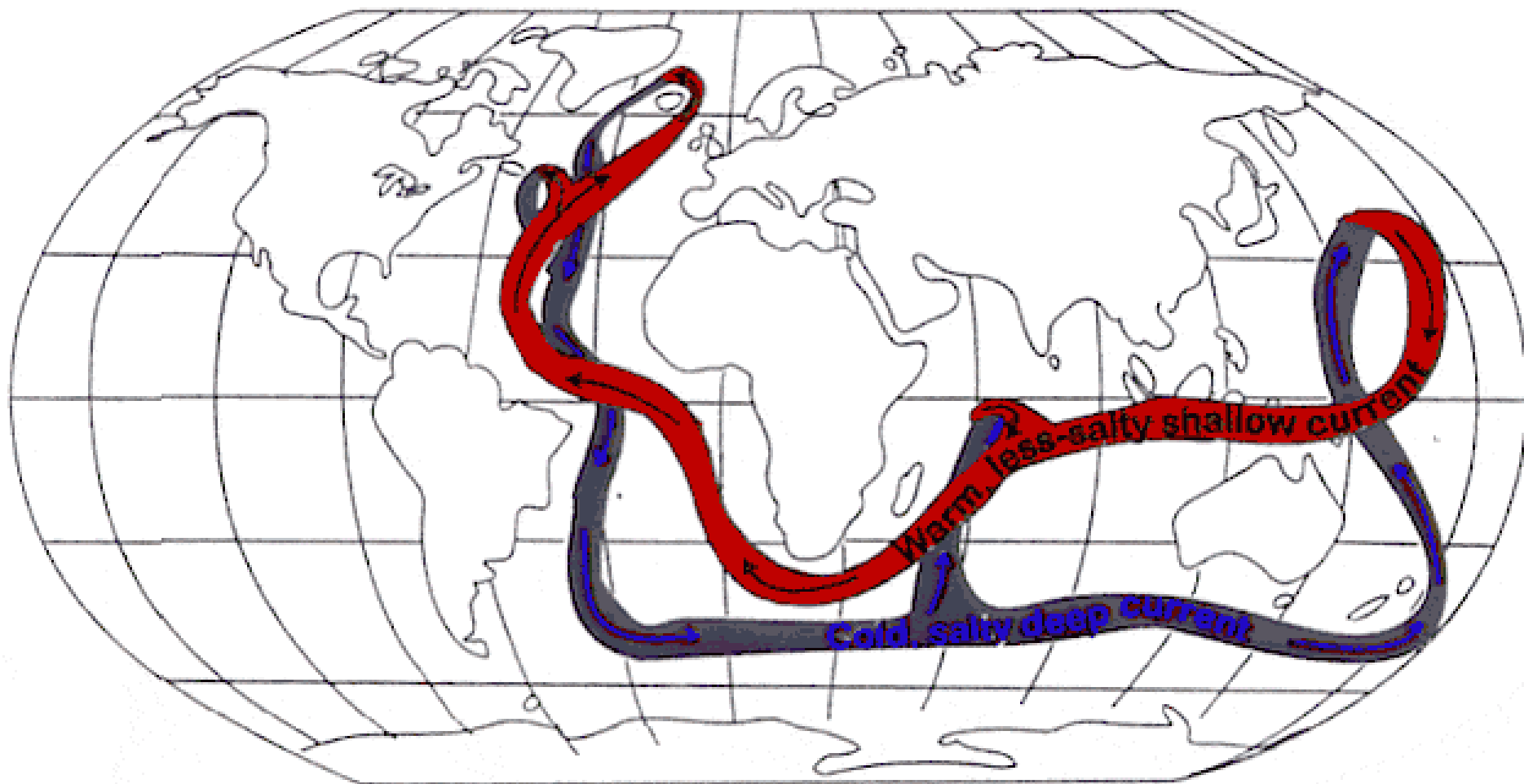




Temperature history in central Greenland

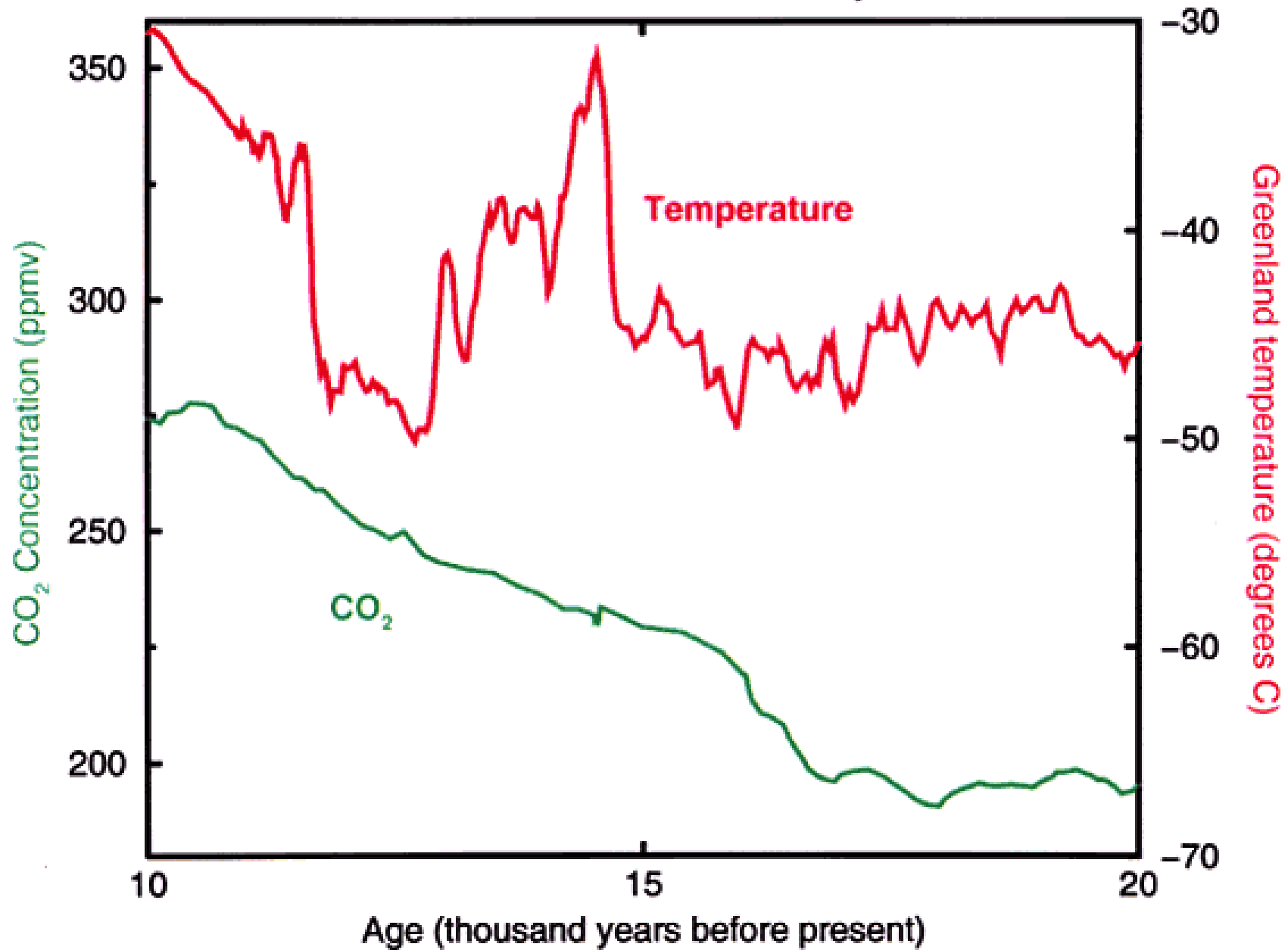
Cuffey and Clow, 1997



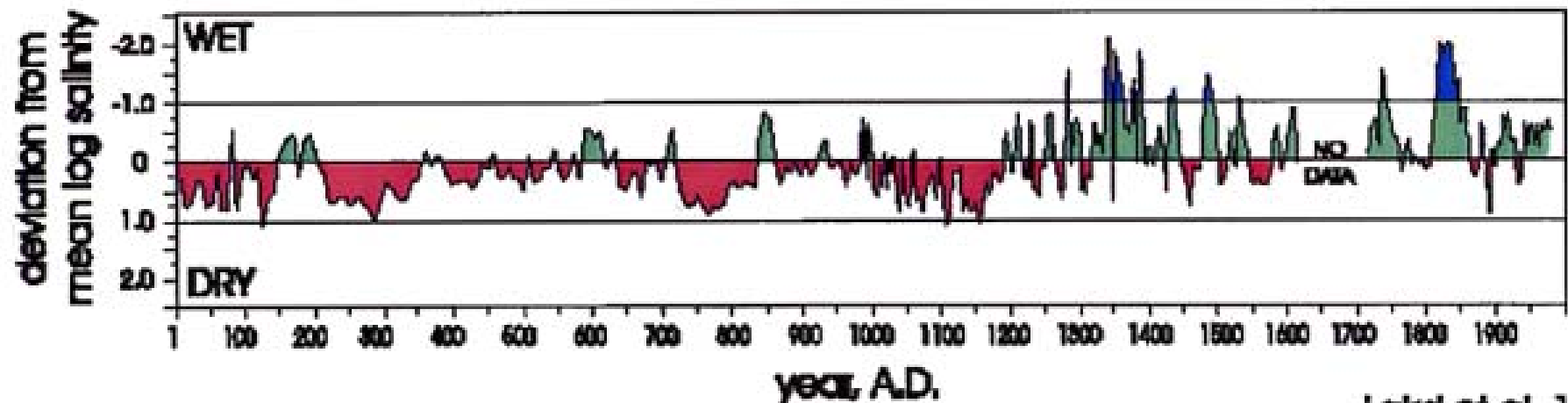


Greenland Climate and CO₂

Neftel et al, Sowers and Bender, Cuffey et al data



SALINITY as a MEASURE of DROUGHT, MOON LAKE



Laird et al. 1996

Abrupt Climate Change

- In north Atlantic, freshening led to freezing in wintertime, with huge changes;
- Future freshening from Greenland melt, etc. might possibly do something similar, but not too likely;
- Probably should worry more about droughts that get locked in...