Temperature reconstructions using argon and nitrogen isotopes in occluded air in ice cores

Stable Isotopes 2014

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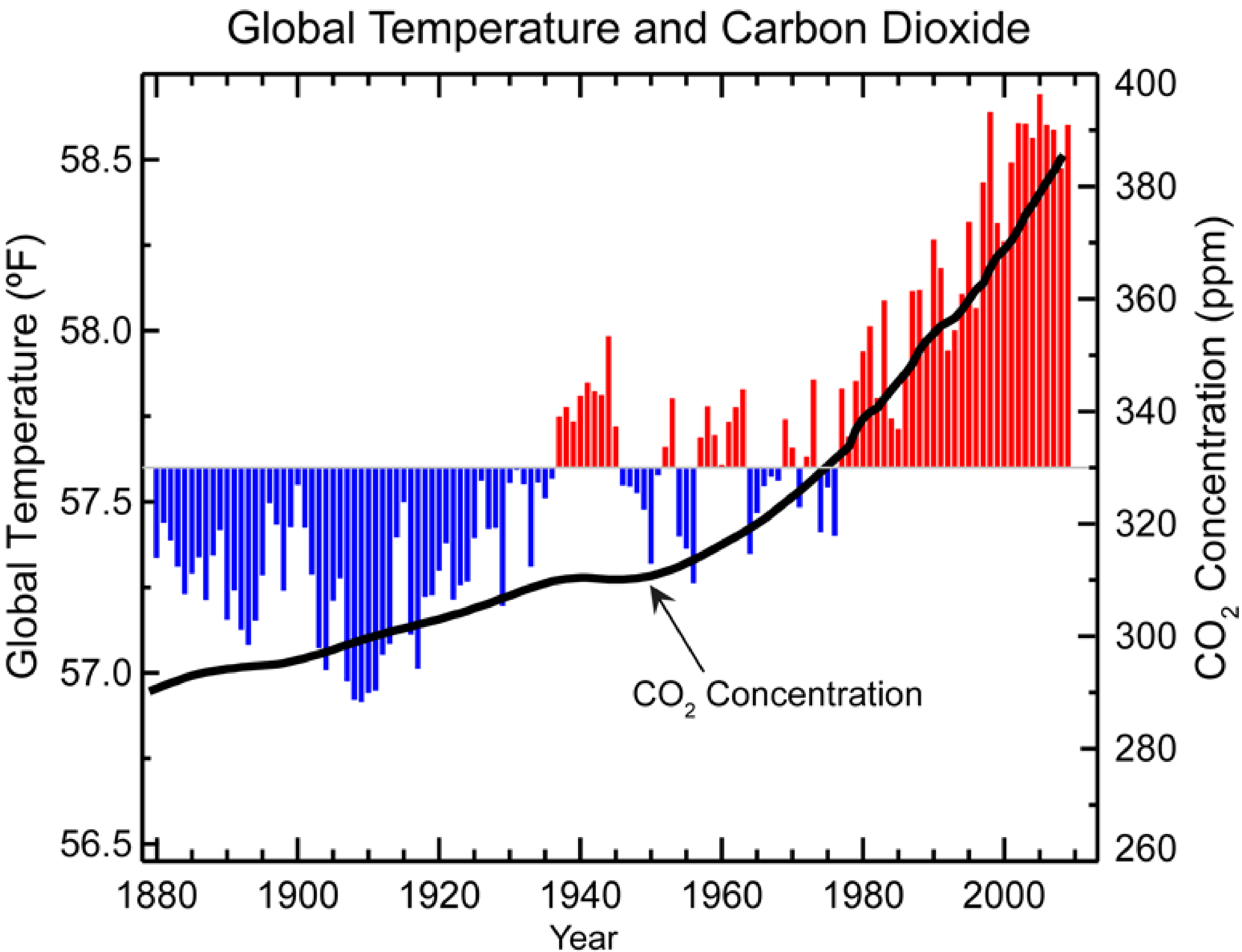
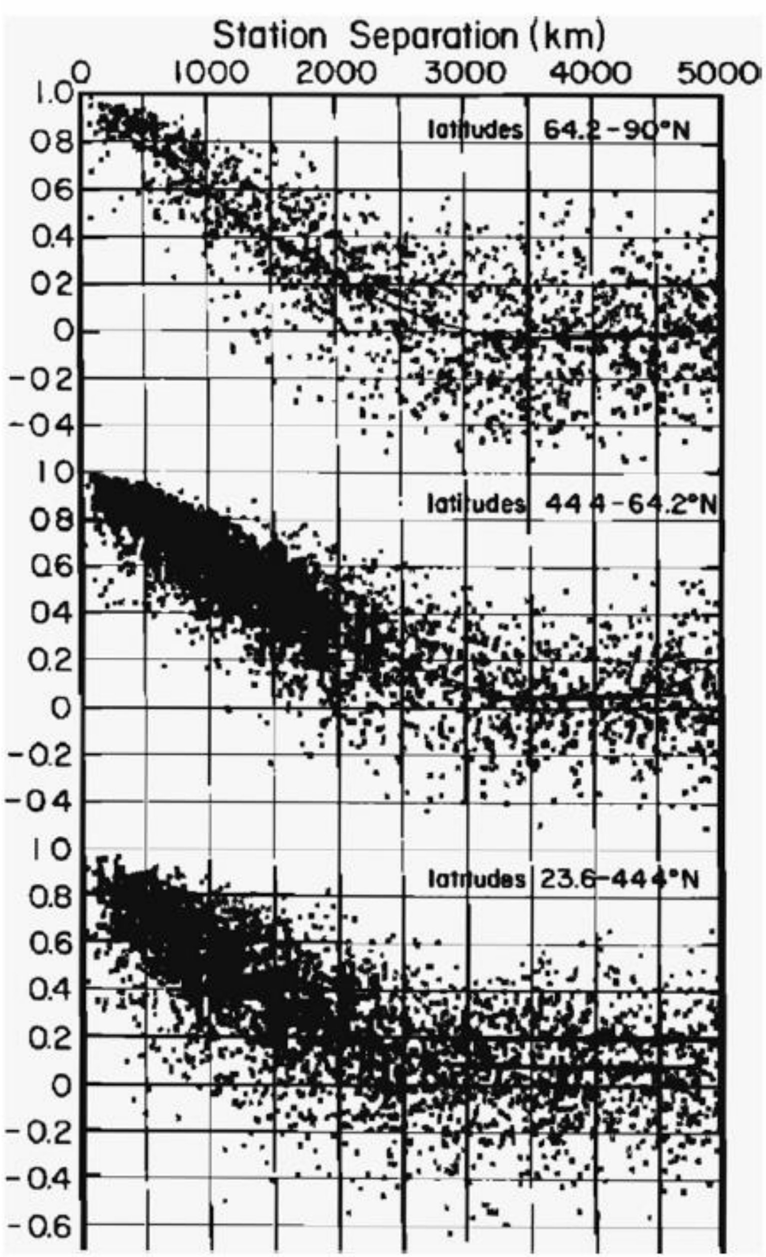


NOAA : http://www1.ncdc.noaa.gov/pub/data/cmb/images/indicators/global-temp-and-co2-1880-2009.gif



Spatial correlations of annual temperature time series over globe

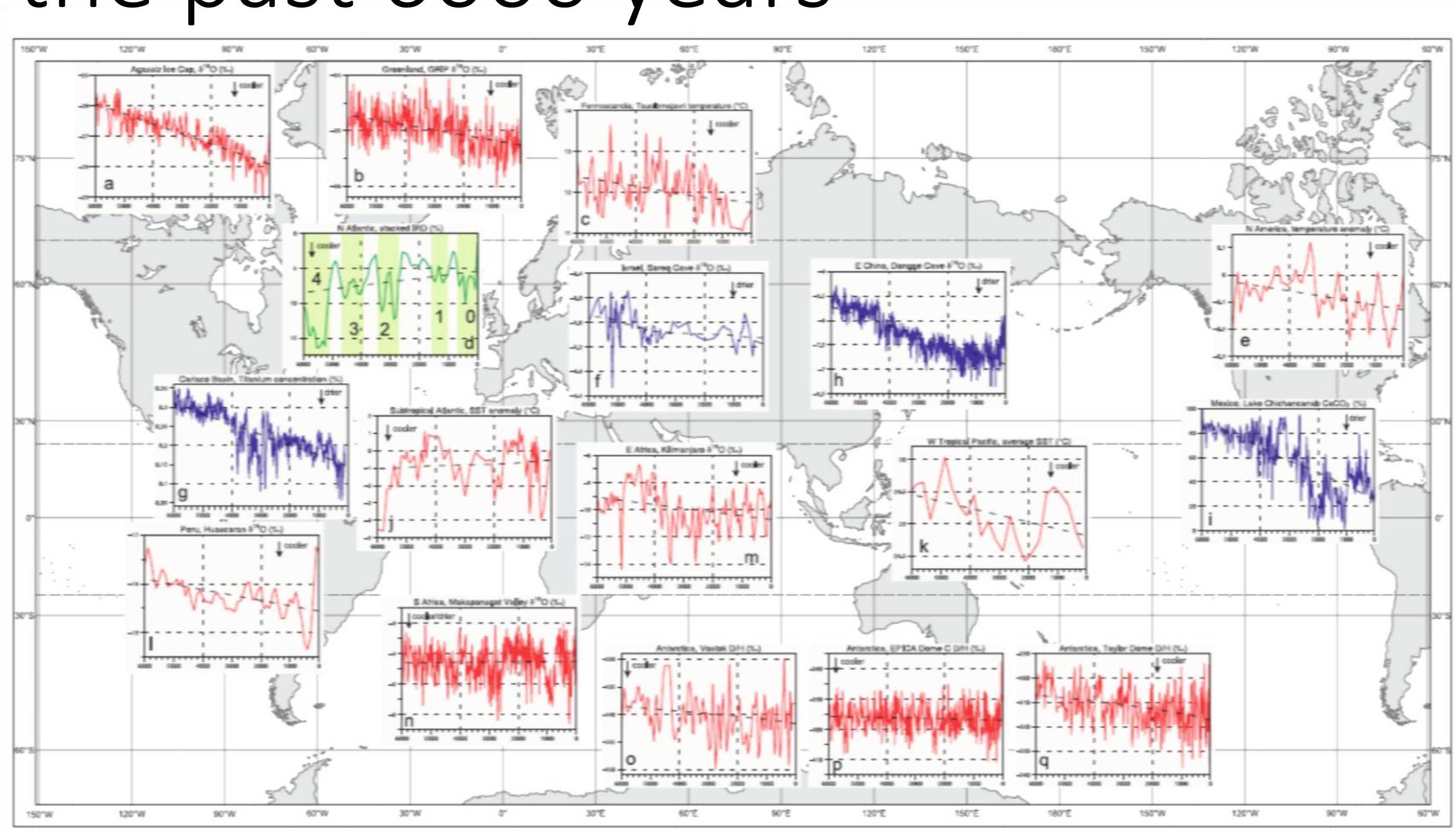
North et al. (2011)

Various methods of temperature reconstructions for the past millennia

- Glacial advance and retreat – integrated long-term climate record
- Tree ring width – low age uncertainty
- Pollen distribution from sediment cores – widely available
- Oxygen isotopes in carbonates (shells) – widely available
- Foraminifera distribution in ocean sediments – available from ocean sediment cores
- Oxygen isotopes of ice – age uncertainty

Many proxies are controlled not only by temperature but also humidity, etc.
Organically controlled proxies often reflect spring to summer temperatures.

Paleo-climate reconstruction over the past 6000 years



Wanner et al. (2008)

- Temperature reconstructions using various methods over the past 6000 years.

NH average temperature for the past millennium

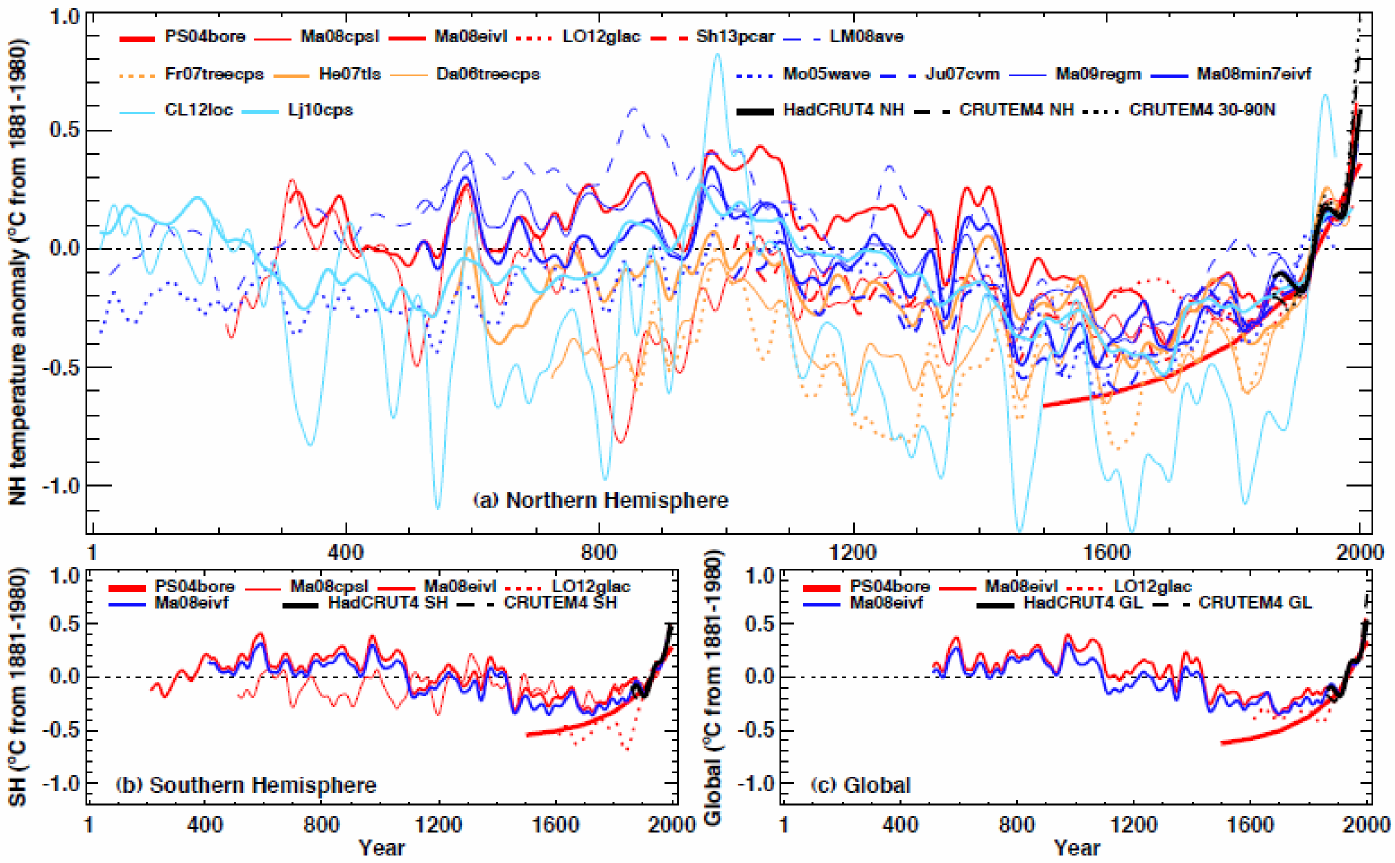


Figure 5.7 | Reconstructed (a) Northern Hemisphere and (b) Southern Hemisphere, and (c) global annual temperatures during the last 2000 years. Individual reconstructions (see Appendix 5.A.1 for further information about each one) are shown as indicated in the legends, grouped by colour according to their spatial representation (red: land-only all latitudes; orange: land-only extratropical latitudes; light blue: land and sea extra-tropical latitudes; dark blue: land and sea all latitudes) and instrumental temperatures shown in black (Hadley Centre/ Climatic Research Unit (CRU) gridded surface temperature-4 data set (HadCRUT4) land and sea, and CRU Gridded Dataset of Global Historical Near-Surface Air TEMperature Anomalies Over Land version 4 (CRUTEM4) land-only; Morice et al., 2012). All series represent anomalies (°C) from the 1881–1980 mean (horizontal dashed line) and have been smoothed with a filter that reduces variations on time scales less than about 50 years.

IPCC (2013)

Is it possible to develop a method, which only depends on physical process of temperature variation, like “thermometer” with precise age control?

Temperature reconstruction

from argon and nitrogen isotopes in trapped air in ice cores

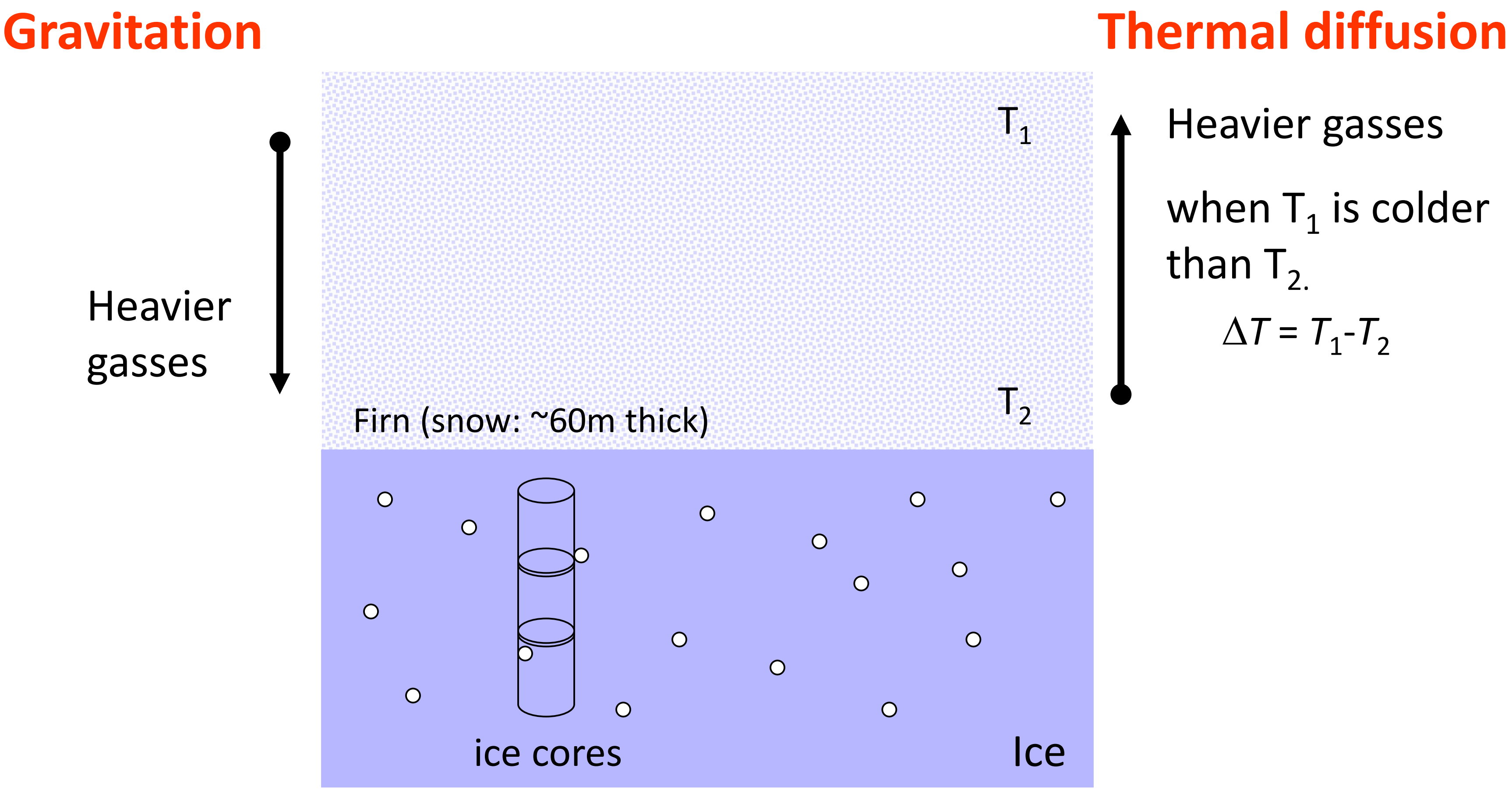
Argon and nitrogen isotopes of air

$$\delta^{40}\mathrm{Ar} = ((^{40}\mathrm{Ar}/^{36}\mathrm{Ar}_{\mathrm{sample}})/(^{40}\mathrm{Ar}/^{36}\mathrm{Ar}_{\mathrm{standard}}) - 1) * 10^3 ‰$$

$$\delta^{15}\mathrm{N} = ((^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{sample}})/(^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}) - 1) * 10^3 ‰$$

- Sample values are reported with a standard gas as the atmosphere.
- These isotopes are constant in the atmosphere for tens of thousands of years.

Gas fractionation in firn layer (snow)



Isotopic fractionation of nitrogen (15/14) and argon (40/36)

- $\delta^{15}N_{obs} = \delta^{15}N_{grav} + \delta^{15}N_{therm}$
- $\delta^{40}Ar_{obs} = \delta^{40}Ar_{grav} + \delta^{40}Ar_{therm}$
- $\delta^{15}N_{grav} = \delta^{40}Ar_{grav}/4 = \left[\exp\left(\frac{\Delta m \cdot g \cdot z}{R_g \cdot T}\right) - 1\right] \cdot 1000‰$
- $\delta^{15}N_{therm} = {}^{15}\Omega \times \Delta T$; $\delta^{40}Ar_{therm} = {}^{40}\Omega \times \Delta T$

Therefore,

- Temperature sensitivity of $\delta^{15}N$ is higher than that of $\delta^{40}Ar/4$ by 46%. Therefore, $\delta^{15}N$ more reflect temperature change, and $\delta^{40}Ar$ reflect more firn thickness.
- ΔT (° C) = $(\delta^{15}N_{obs} - \delta^{40}Ar_{obs}/4)/0.00466$ at -31 °C. (Grachev and Severinghaus, 2003 a,b)
- Surface temperatures can be calculated by integrating ΔT using a firn densification /heat diffusion model and constrained by borehole temperature (Kobashi et al., 2010).

Firn layer and gas diffusion

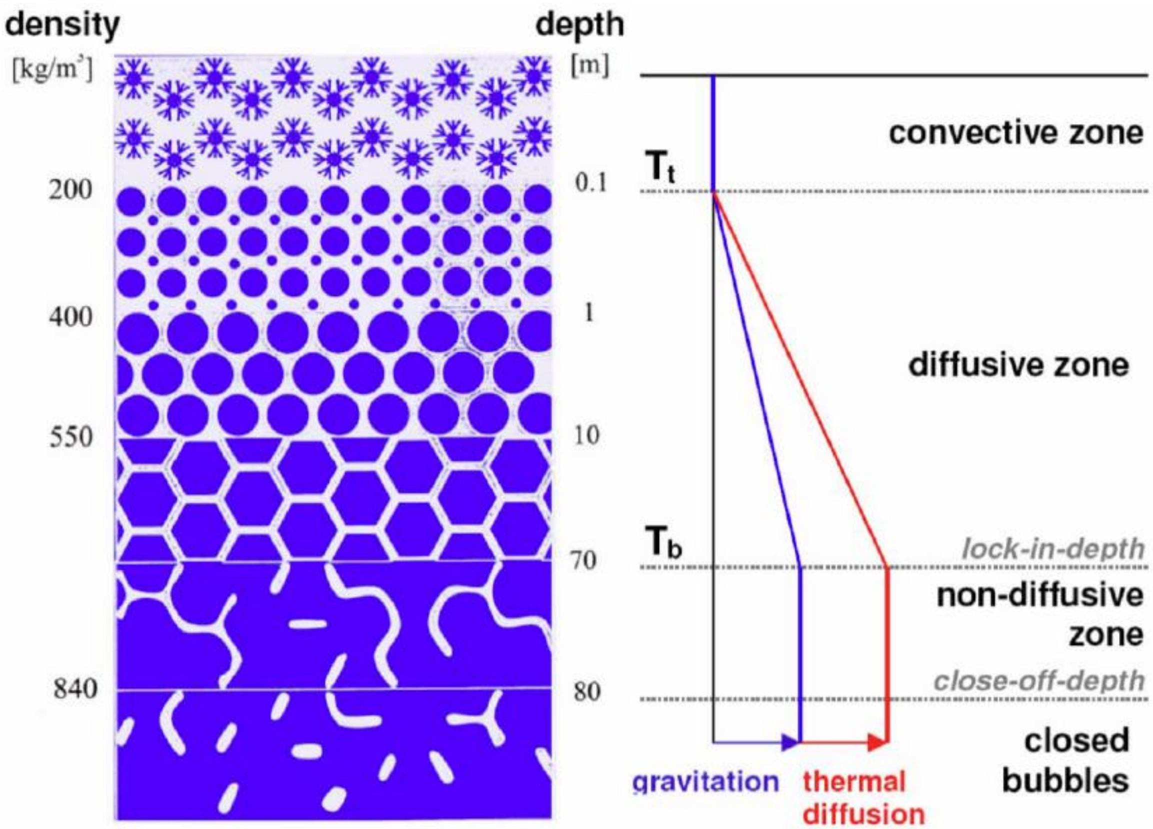
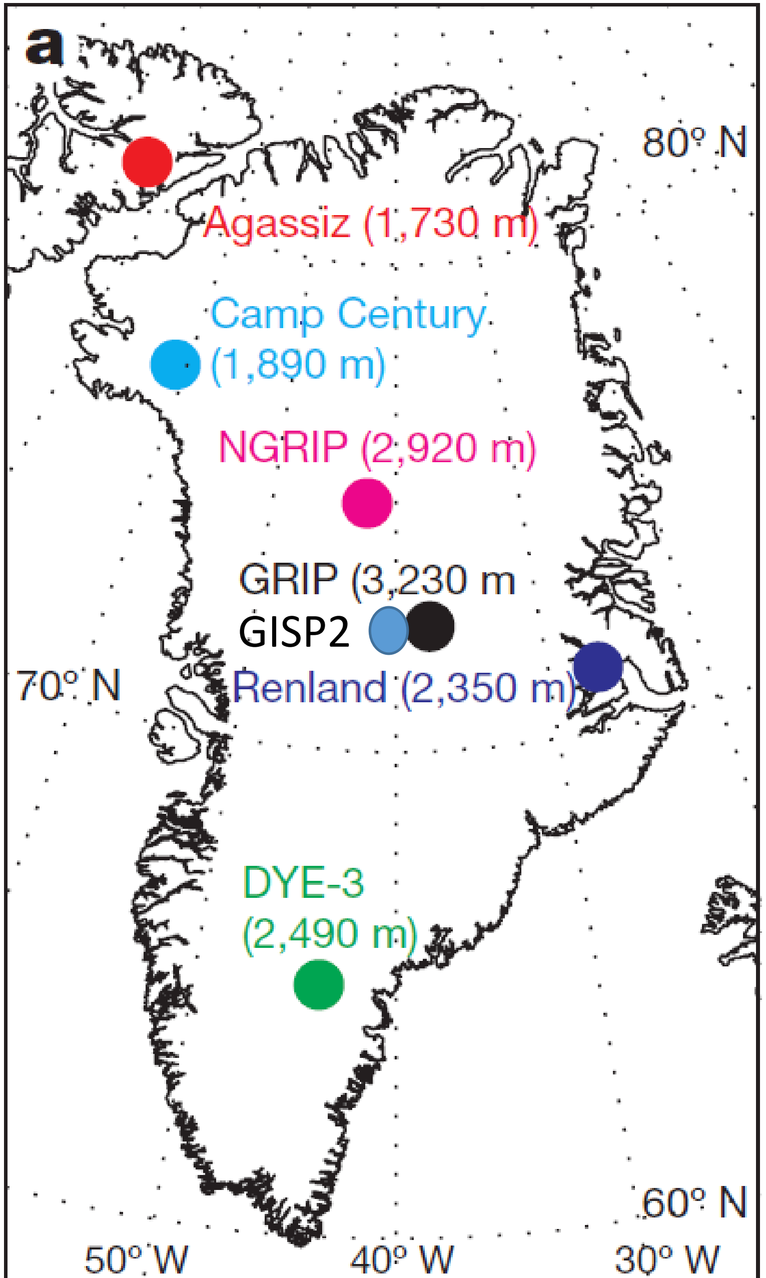


Figure 9.1: The firn structure. Snow is accumulated at the surface and gradually transformed to ice by a sintering process. During this process, atmospheric air is trapped in bubbles in the ice. The isotopic composition of the air is altered in the diffusive column of the firn by gravitational settling and thermal diffusion.



NGRIP and GISP2

- NGRIP and GISP2 are ~300km apart.

Ice Cores	Elevation (m a.s.l.)	Latitude (° N)	Longitude (° W)	Mean air temperature (°C)	Accumulation (m ice per year)
Agassiz 84/87	1730	80.7	73.1	–21.9	0.10
NGRIP	2920	75.1	42.3	–32	0.19
GISP2	3200	72.6	38.5	–30	0.21
GRIP	3230	72.6	37.6	–32	0.23
Renland	2350	71.3	26.7	–18	0.50
Dye-3	2490	65.2	43.8	–20	0.56

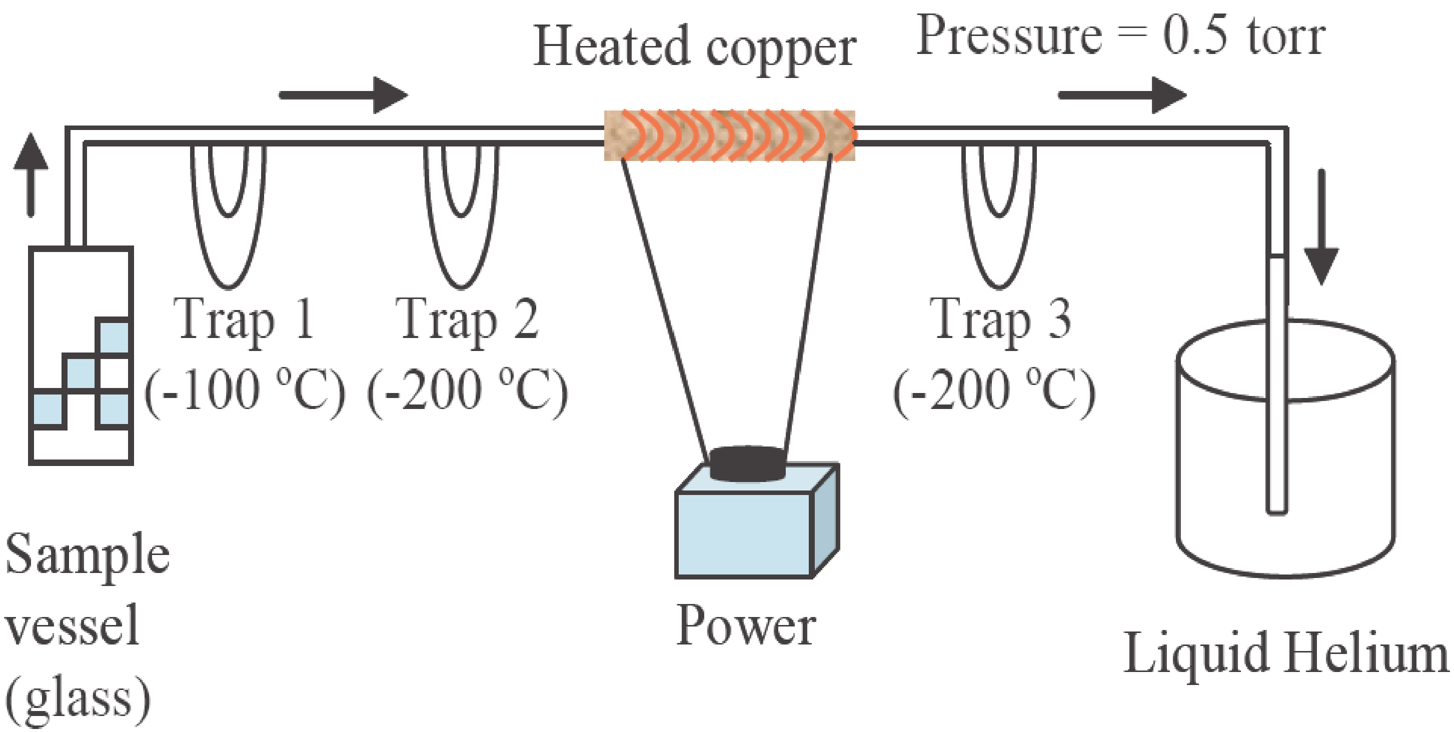
- NGRIP and GISP2 are generally quite similar environment except smaller accumulation rate in NGRIP.

Vinther et al. (2009)

Ice cores and experiments

GISP2 ice cores

Gas extraction process from ice core



- Simultaneous measurements of argon and nitrogen isotopes.

Kobashi et al., GCA, 2008.

Mass spectrometer

Finnigan MAT252 for GISP2 at Scripps

Thermo DELTA V for NGRIP at NIPR

Argon and nitrogen isotope records

Unpublished fig. Wait a bit!

Kobashi et al. (Submitted)

Resolution does matter

Unpublished fig. Wait a bit!

Kobashi et al. (Submitted)

Borehole temperatures

Unpublished fig. Wait a bit!

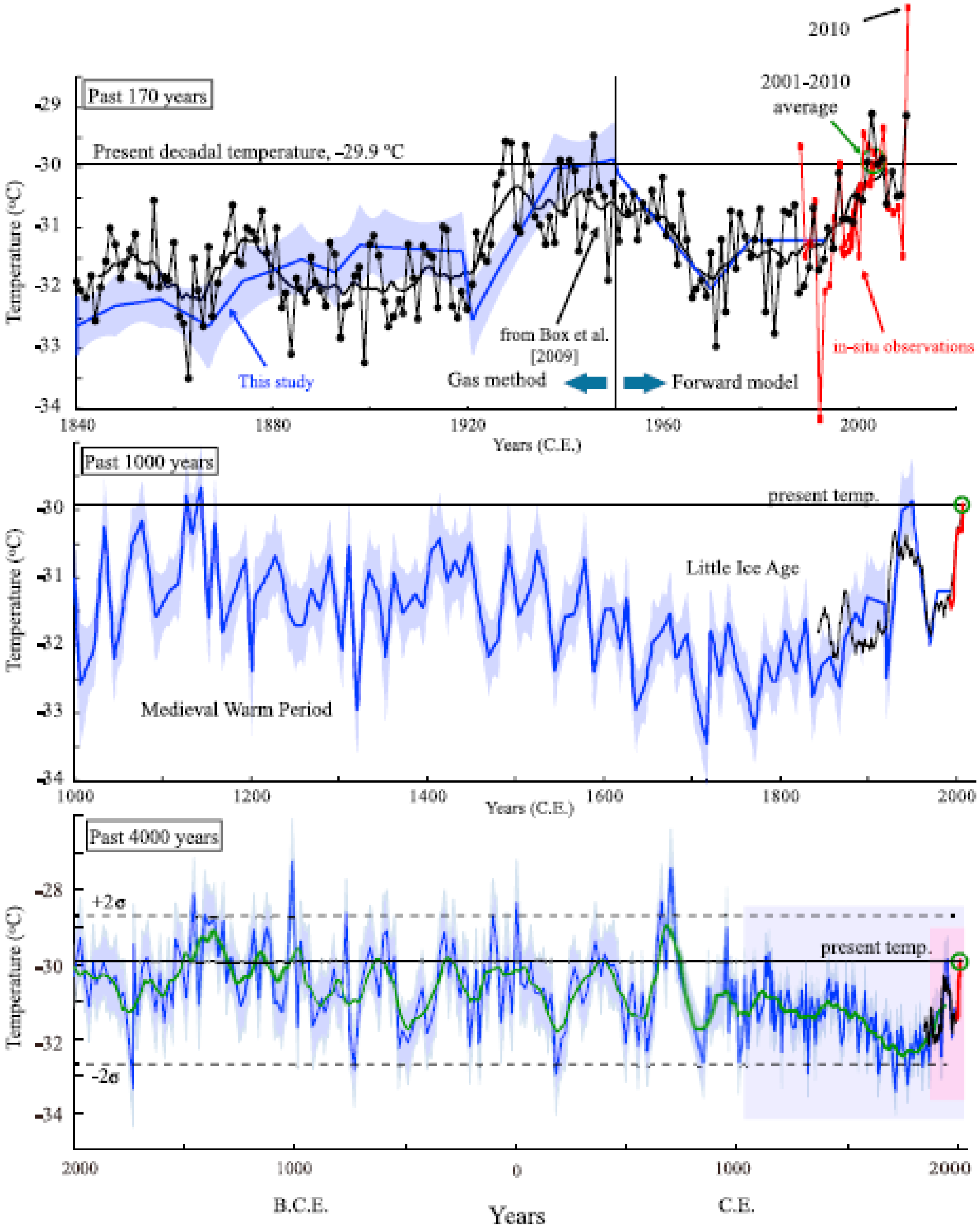
- Dots are observation.
- GISP2 is warmer by ~0.2 ^{o}C.
- GISP2 temperature shows larger decreases from 400m to 150m than NGRIP.
- Shaded areas are 95% intervals of model outputs for the surface temperature reconstructions.

Kobashi et al. (Submitted)

Data are from Schwander (2001), Dahl-Jensen et al. (2003) for NGRIP, Alley and Koci (1990), and Clow et al. (1996) for GISP2.

Temperature calculations

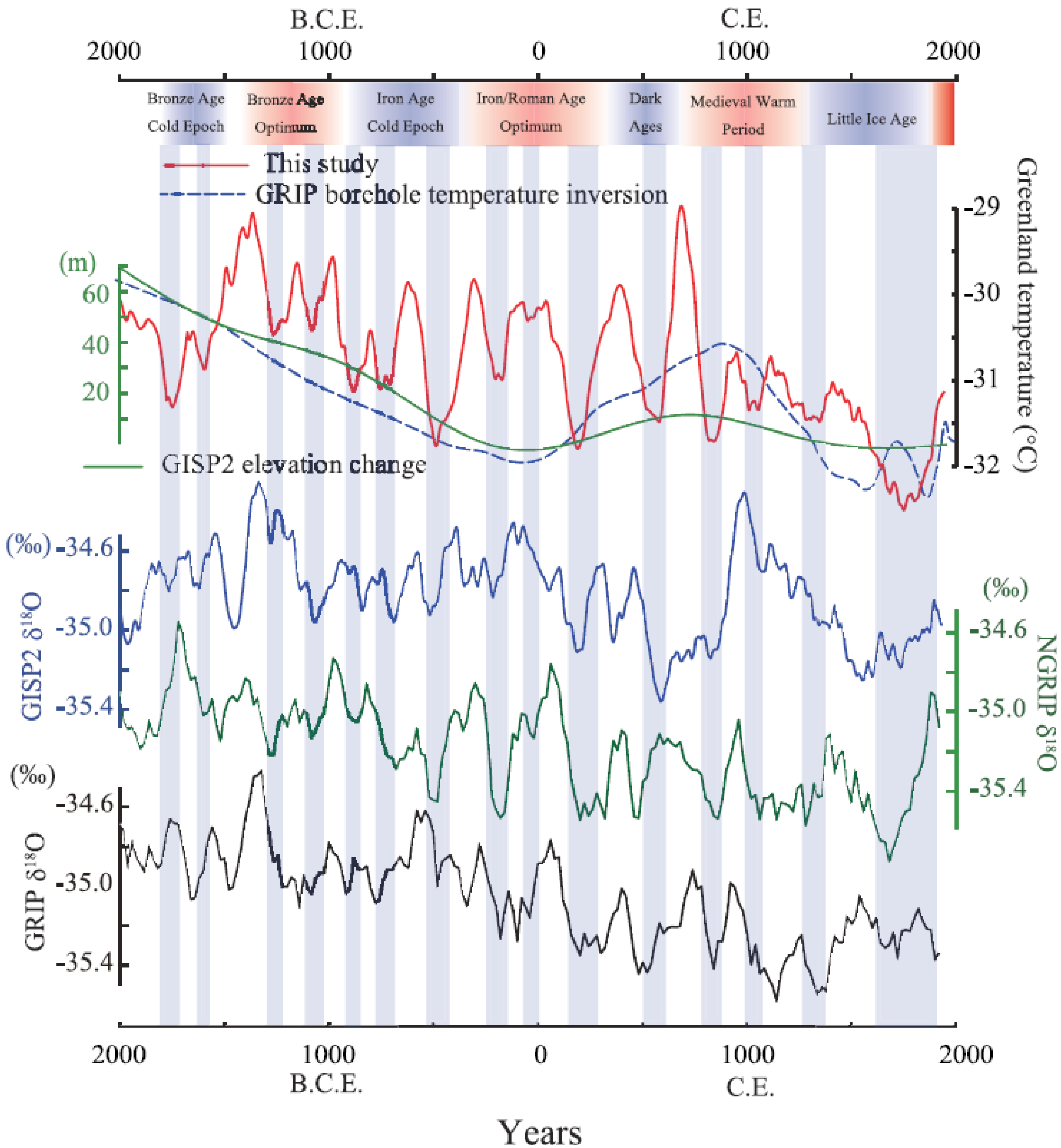
1. Time series of ΔTs in firn layer can be obtained from argon and nitrogen isotopes.
2. Use firn densification/heat diffusion model to integrate ΔT and calculate surface temperature.
3. Generate new ΔTs according to analytical uncertainty.
4. Calculate thousands of surface temperatures.
5. Use only surface temperature histories, which are consistent with borehole temperatures to obtain mean and errors of surface temperatures.



Greenland temperature (GISP2) over the past 4000 years

Why is the recent Greenland temperature trend not as high as NH temperature?

Kobashi et al. (2011)

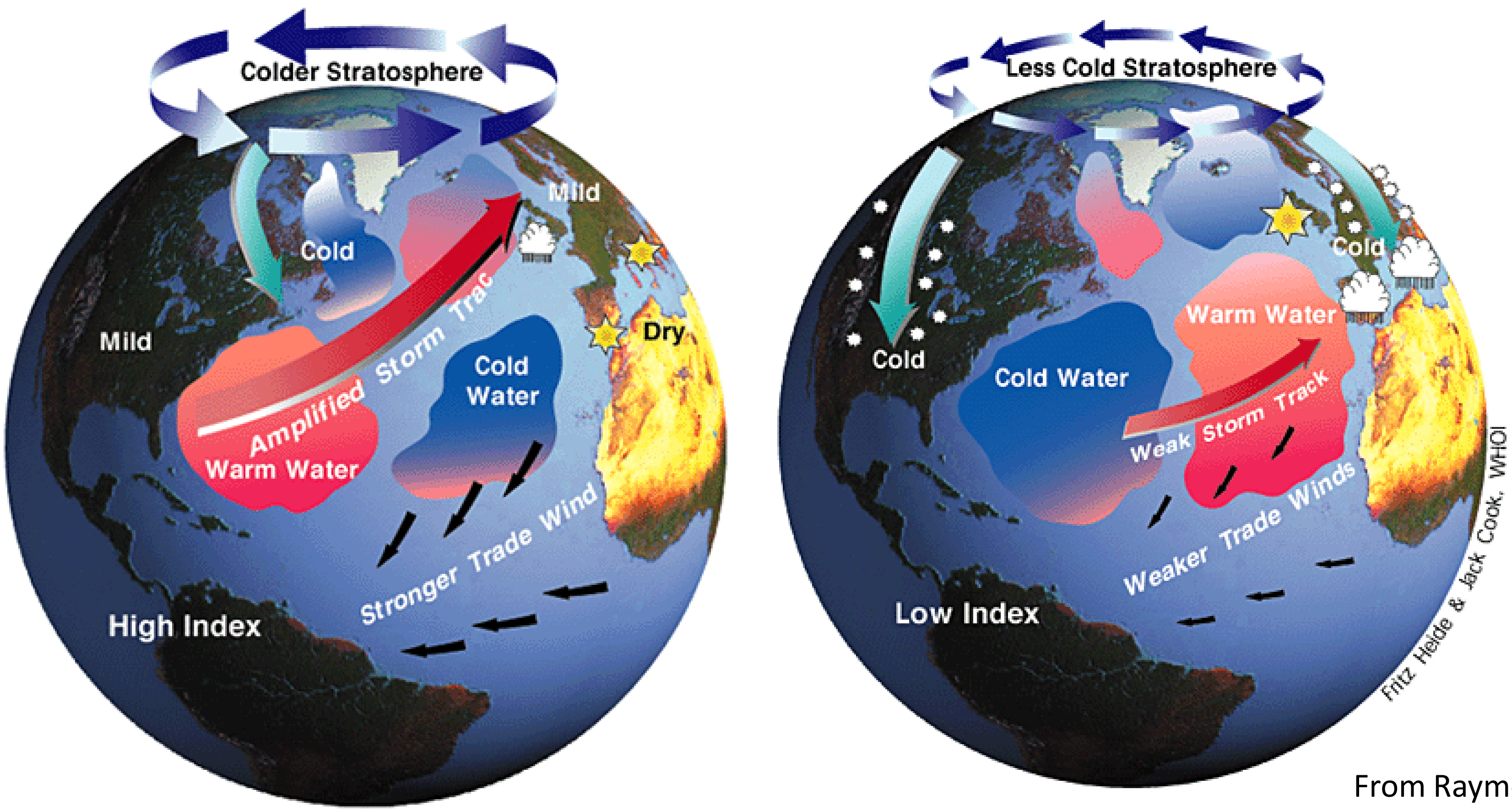


Greenland temperature oxygen isotopes

Kobashi et al. (2011)

Causes of Greenland temperature variation over the past 4000 years

North Atlantic Oscillation (NAO)



Positive NAO

Negative NAO

From Raymond W. Schmitt

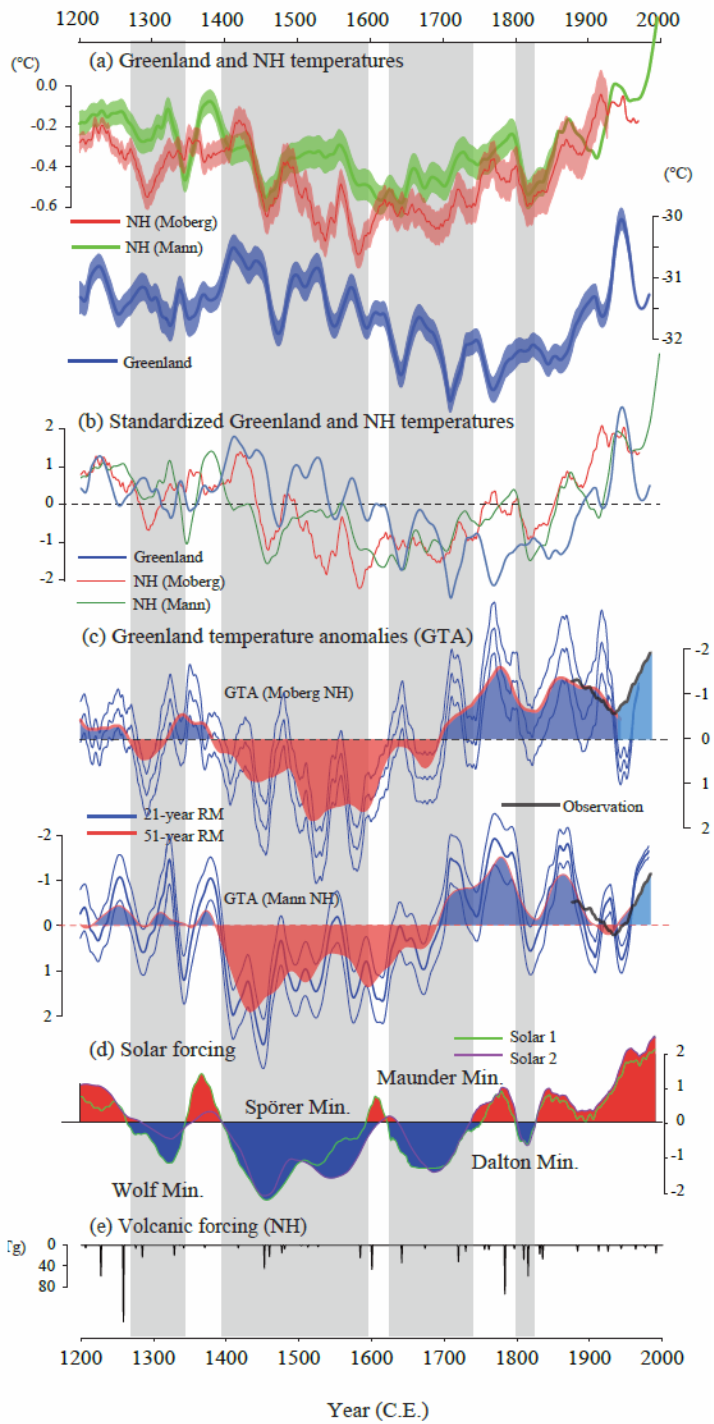
Solar variation induces NAO variability through stratospheric ozone feedbacks (Shindell et al., 2001). When solar activity is “stronger”, positive NAO is induced (“colder” Greenland).

Atlantic Meridional Overturning Circulation (AMOC)

Srokosz et al., 2012

Solar variation induces AMOC variability through voyancy forcing (Cubasch et al. 1997; Kobashi et al., 2013). When stronger solar activity, AMOC weakens (colder Greenland).

Solar induced Greenland temperature changes over the past 800 years



NH temperature

NH temperature

NH and Greenland

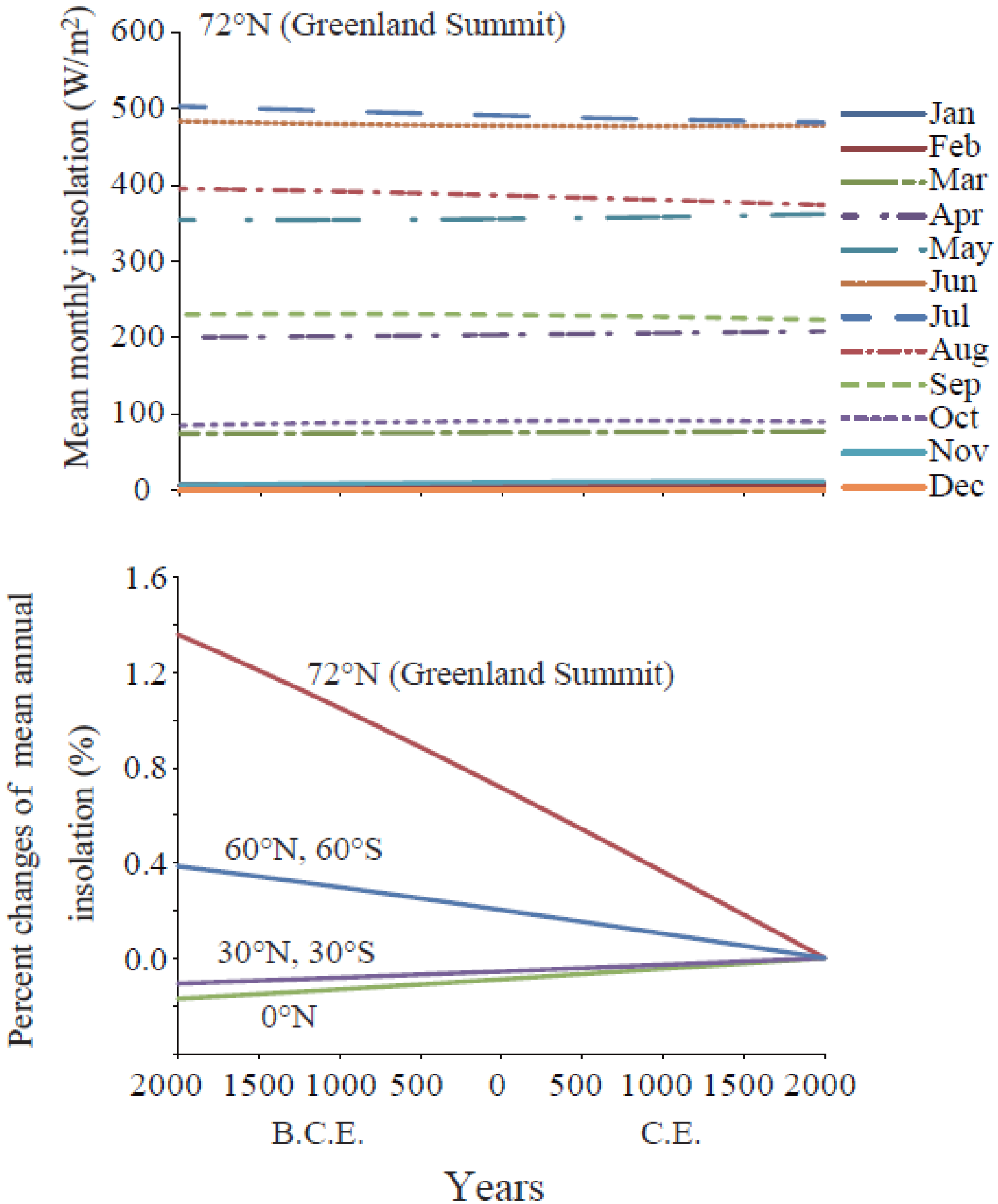
Greenland anomaly

Greenland anomaly

Solar activity

Volcanic activity

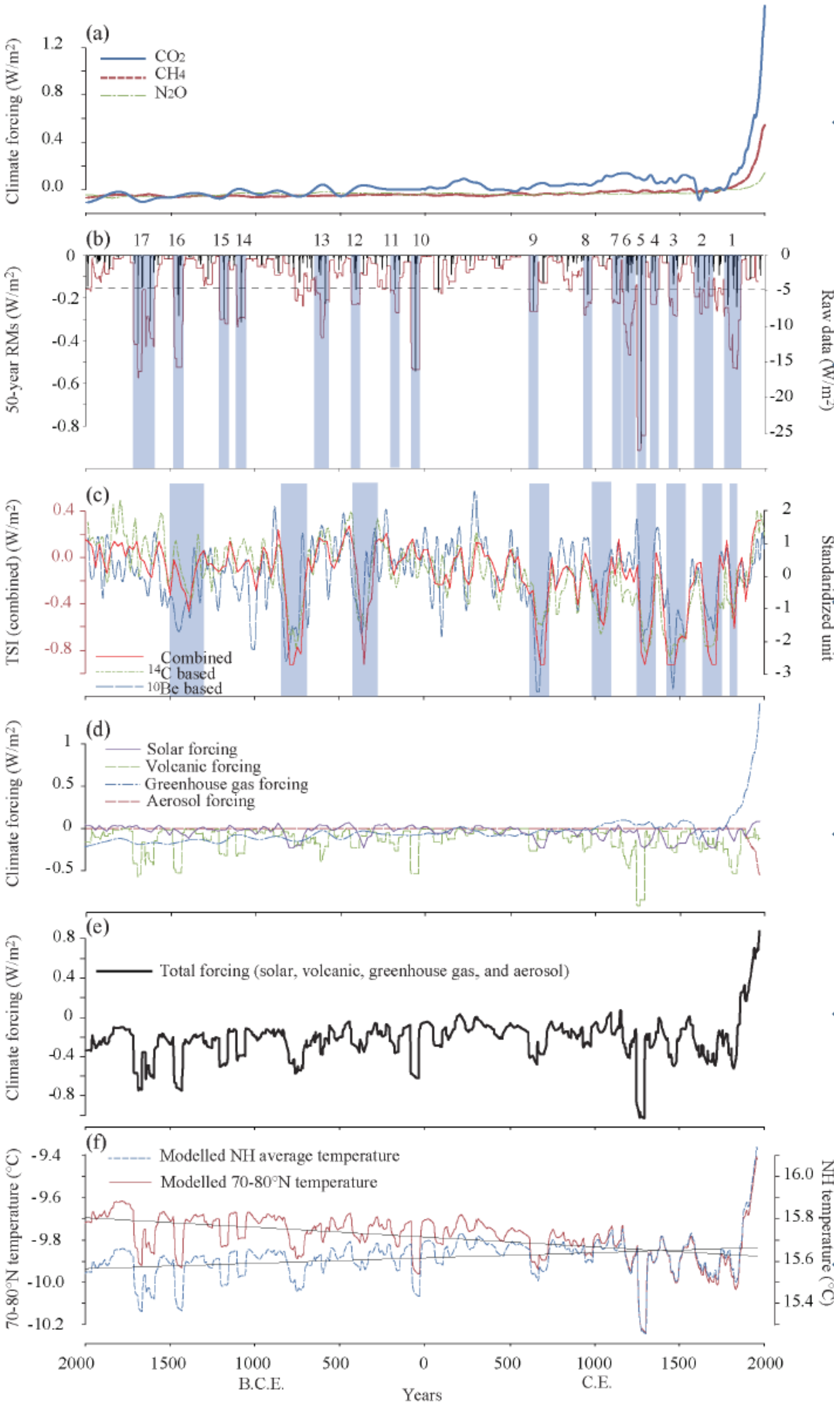
Kobashi et al. (2013a)



Earth orbital changes over the past 4000 years

Kobashi et al. (2013b)

Climate forcings over the past 4000 years



Greenhouse gasses

Volcanic forcing

Solar activity

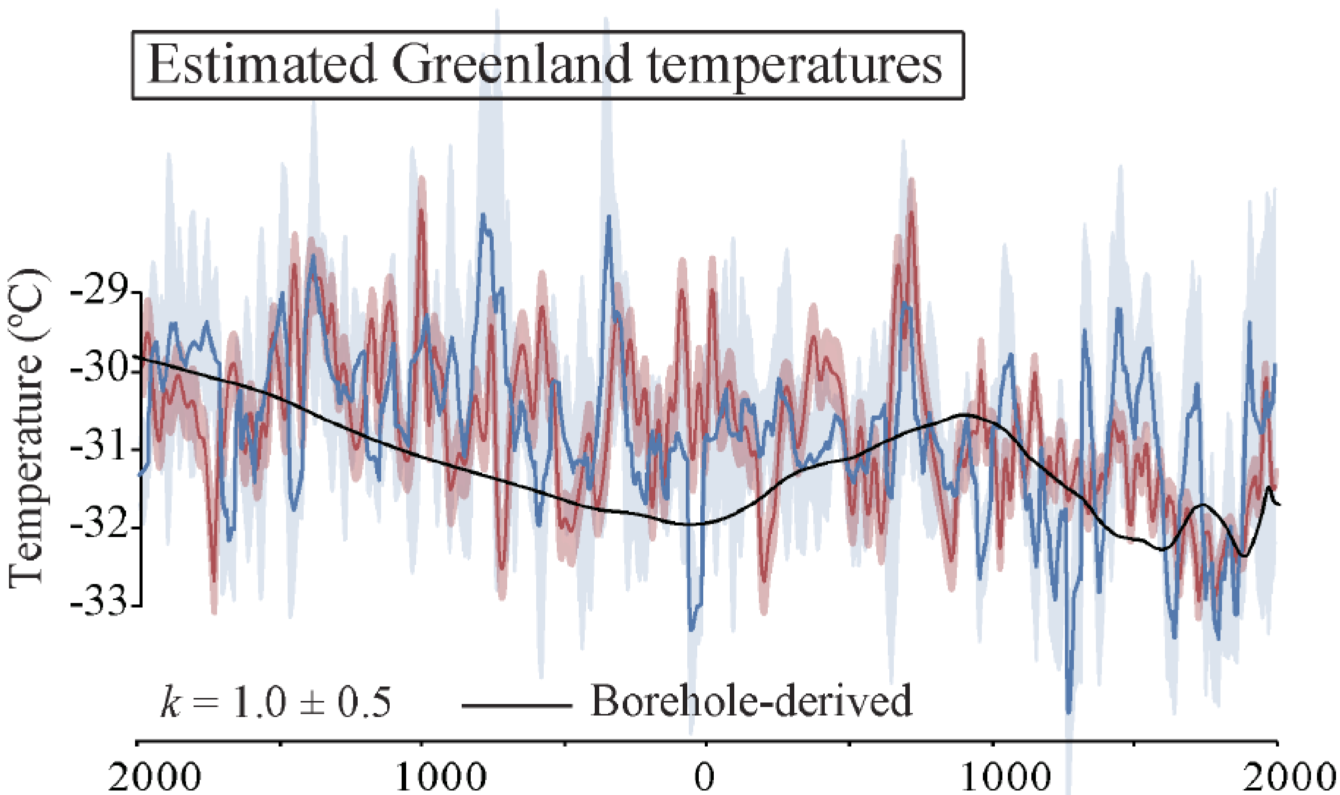
All forcing

Individual

Orbital forcing

Kobashi et al. 2013b

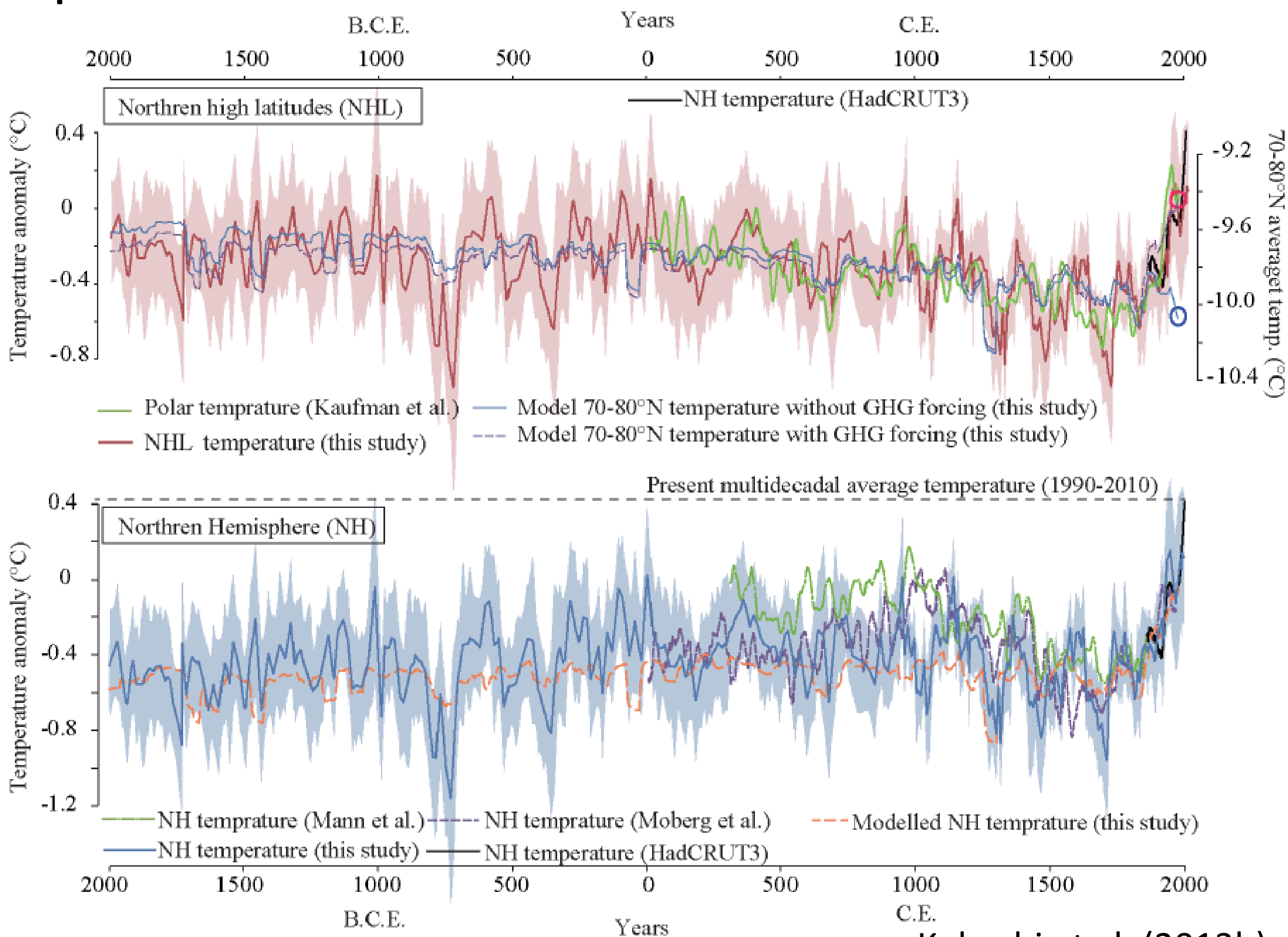
Model and reconstructed Greenland temperatures



$r = 0.34$, $p = 0.04$

Kobashi et al. (2013b)

Implications for Northern Hemispheric temperatures



Kobashi et al. (2013b)

Thank you for your attention!

Hope that you enjoy stable isotopes in your future career!