The sun, volcanoes, computers and the foundations of palaeoclimate

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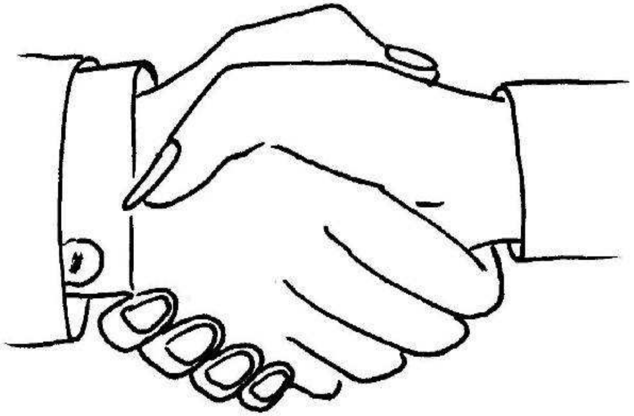
Overview

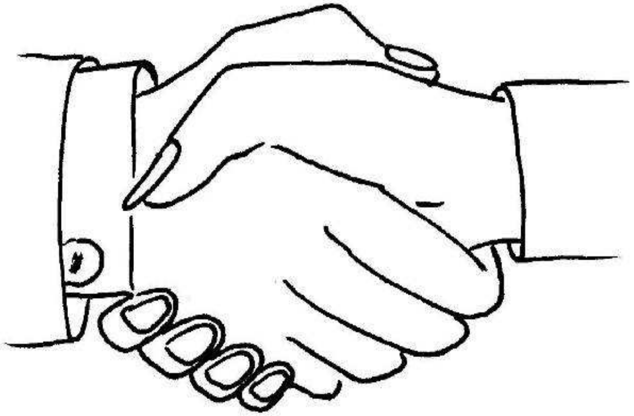
1. Basic concepts
2. The climate of the past 1500 years
3. Uncertainties
4. Assumption of stationarity
5. Conclusions and the way forward

1. Basic concepts

The “handshake” question

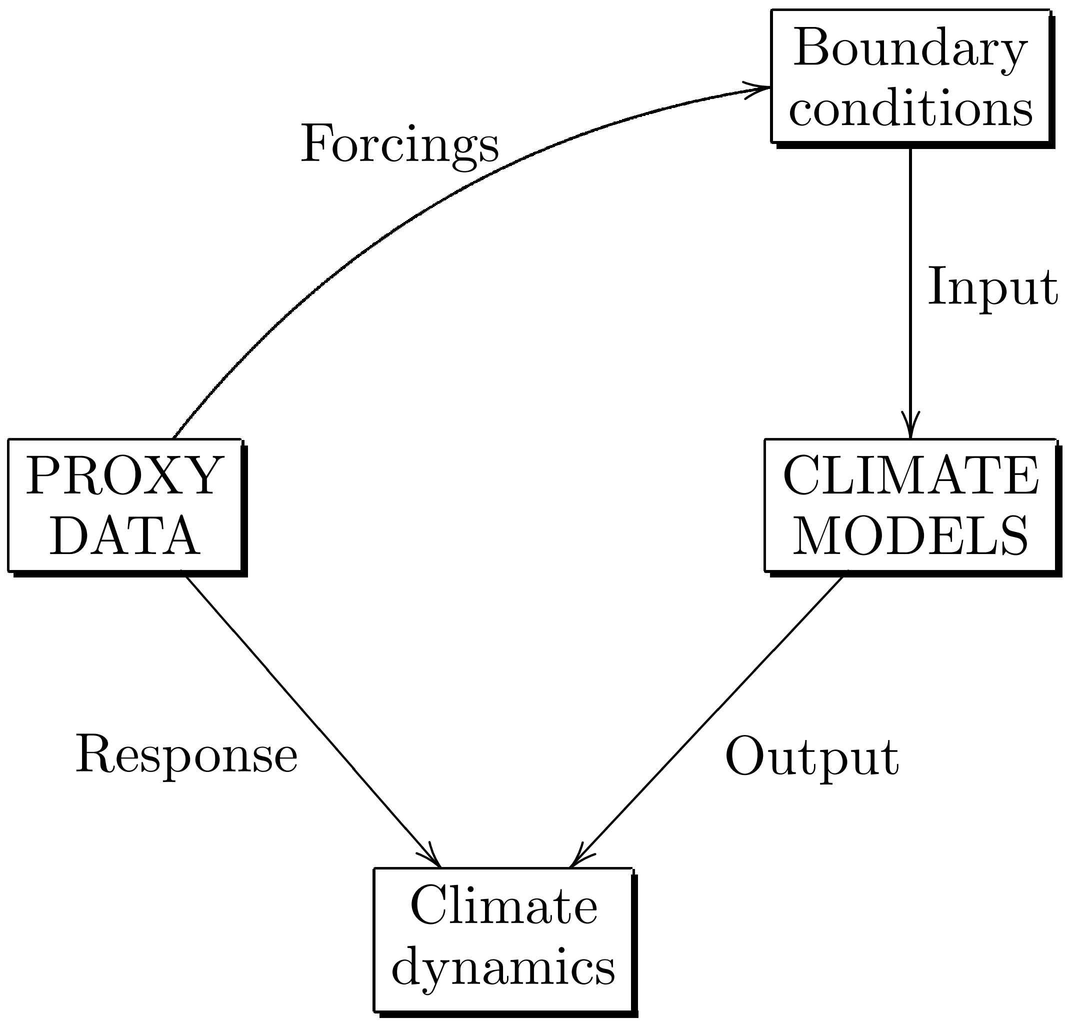




The “handshake” question



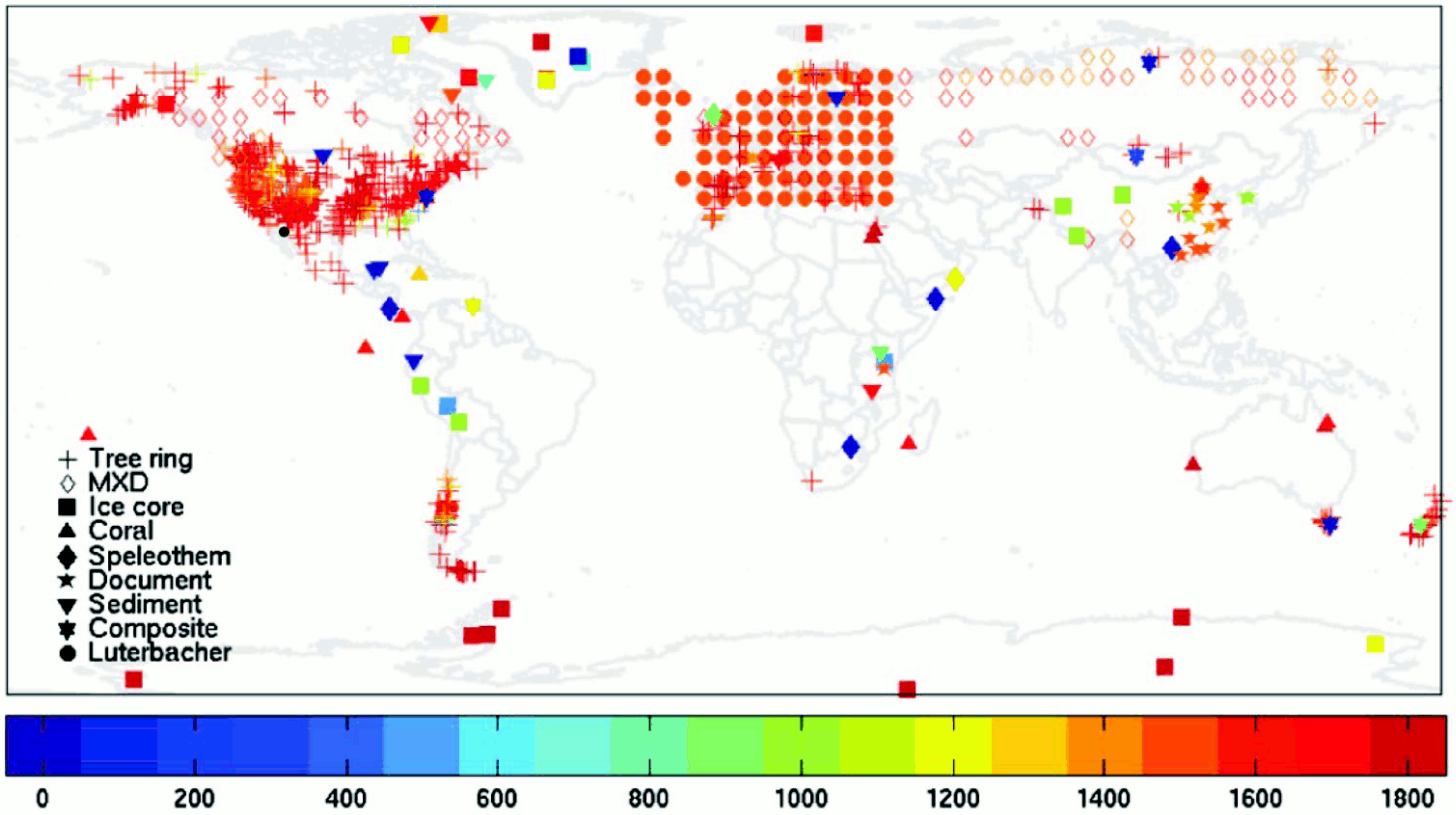
How do we integrate proxy data and climate models in a way that extracts the maximum possible information about the dynamics of the climate system?

Unlocking the secrets of the past...



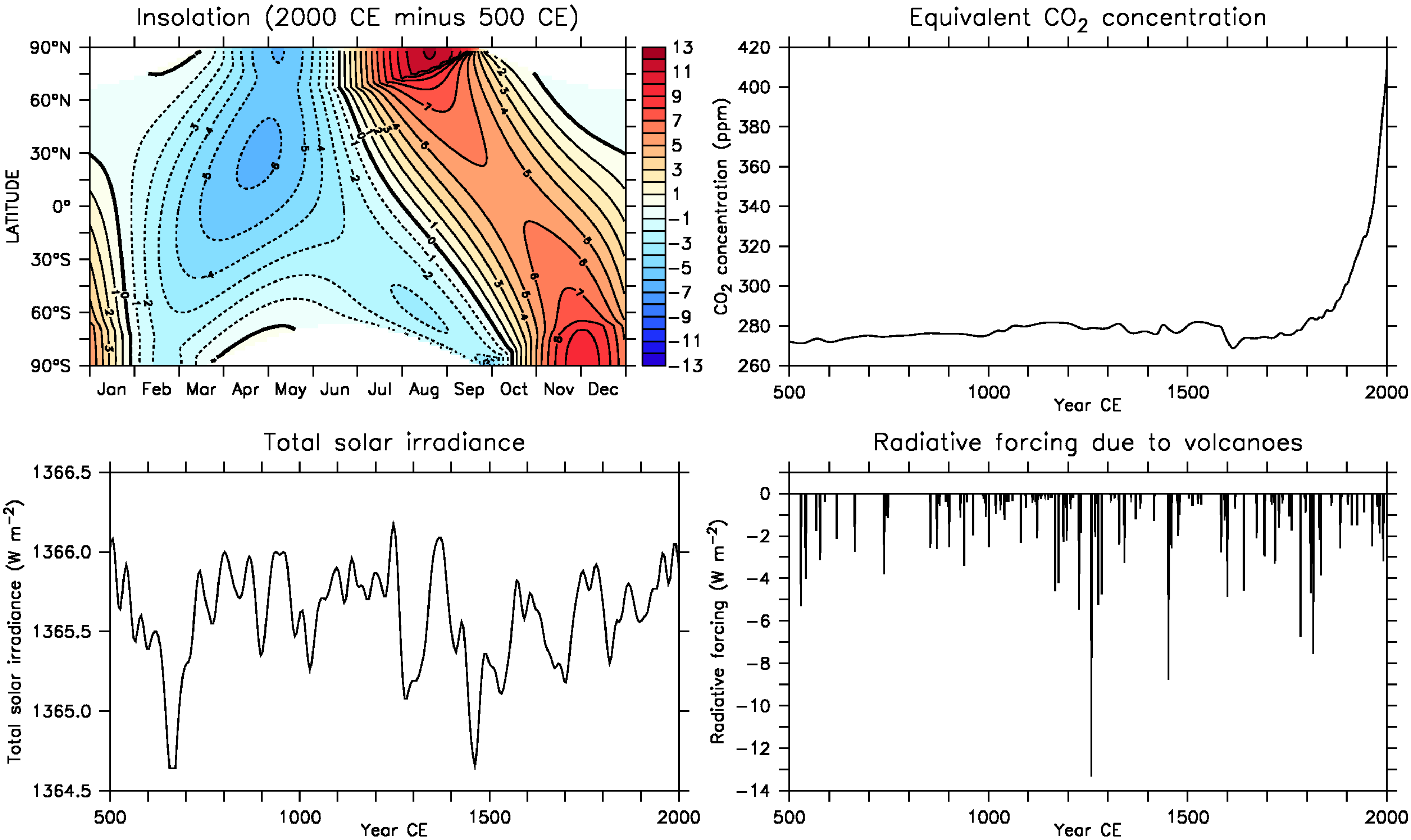
2. The climate of the past 1500 years

Proxy data covers wide area and has high resolution

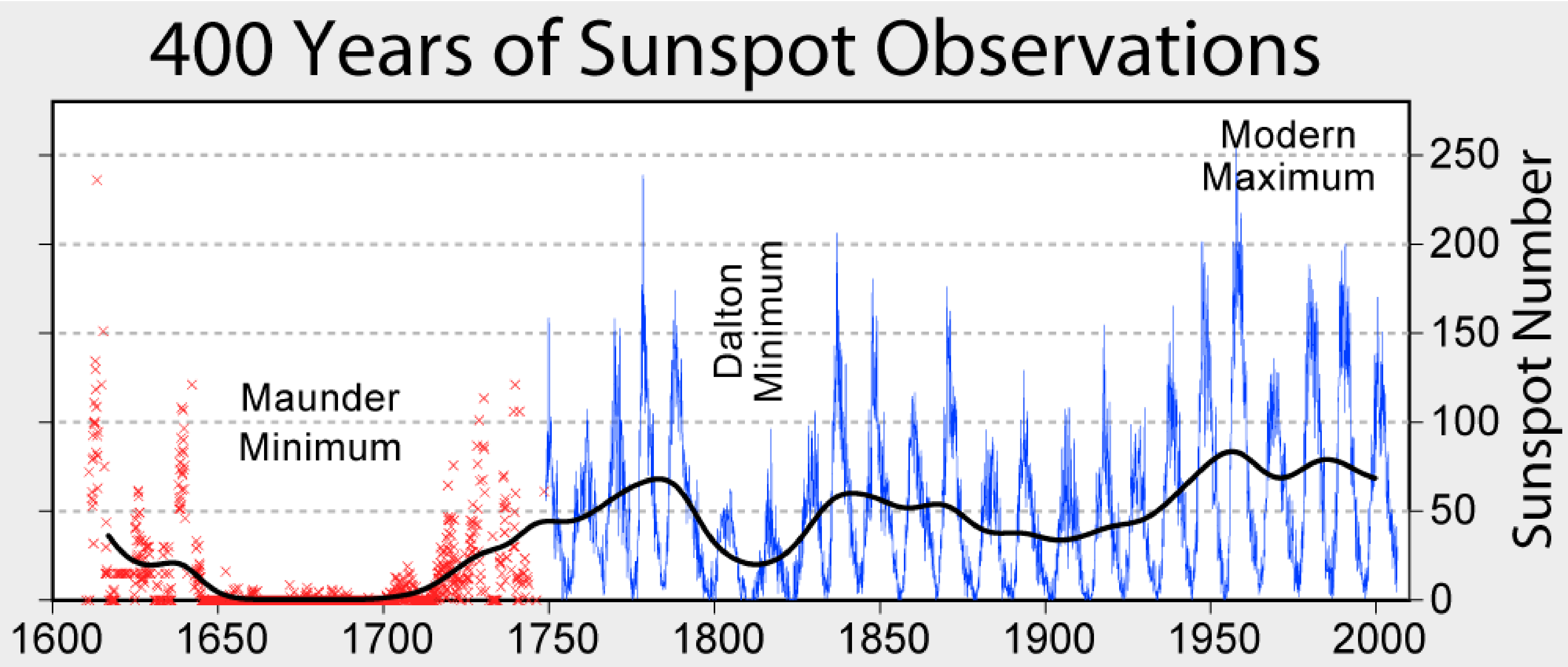


Mann et al. (2008), *PNAS*

Boundary conditions over the past 1500 years

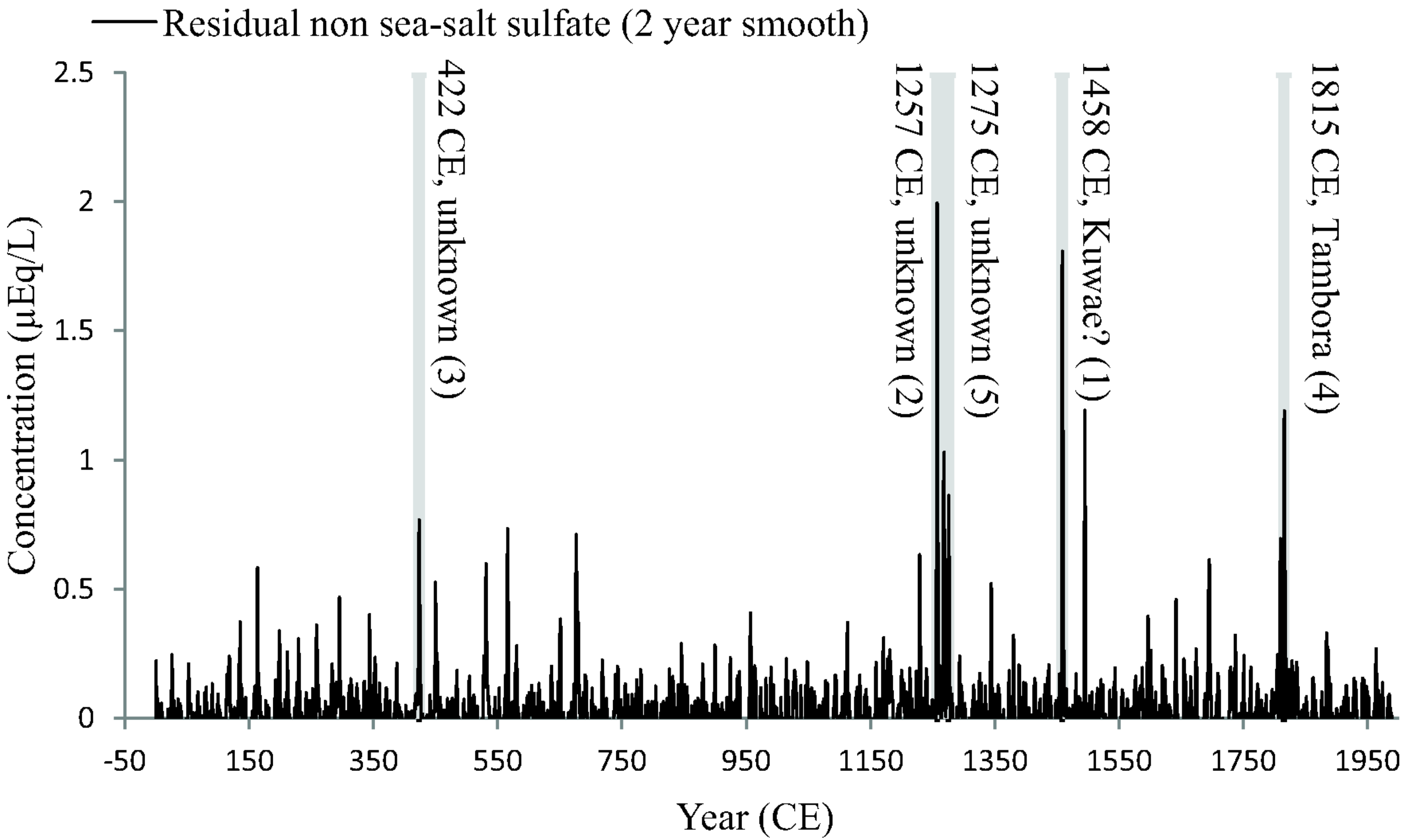


The solar cycle and grand minima



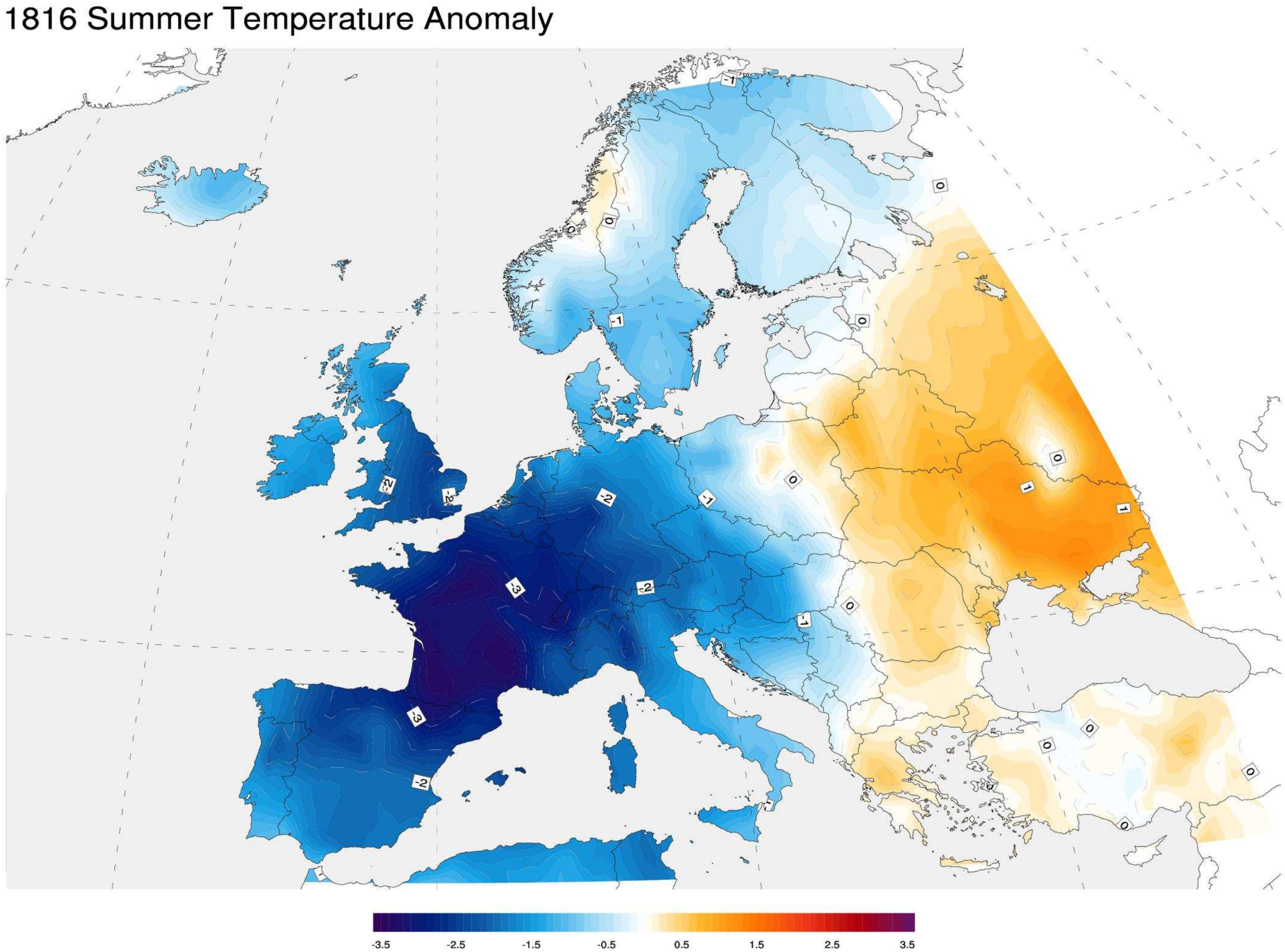
Robert A. Rohde, Global Warming Art Project

The Law Dome sulphate record



Plummer at al (2012), *Climate of the Past Discussions*

The "Year Without a Summer"



Luterbacher et al. (2004), *Science*, **303**, 1499–1503

CLIMATIC AND DEMOGRAPHIC CONSEQUENCES OF THE MASSIVE VOLCANIC ERUPTION OF 1258

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Abstract. Somewhere in the tropics, a volcano exploded violently during the year 1258, producing a massive stratospheric aerosol veil that eventually blanketed the globe. Arctic and Antarctic ice cores suggest that this was the world's largest volcanic eruption of the past millennium. According to contemporary chronicles, the stratospheric dry fog possibly manifested itself in Europe as a persistently cloudy aspect of the sky and also through an apparently total darkening of the eclipsed Moon. Based on a sudden temperature drop for several months in England, the eruption's initiation date can be inferred to have been probably January 1258. The frequent cold and rain that year led to severe crop damage and famine throughout much of Europe. Pestilence repeatedly broke out in 1258 and 1259; it occurred also in the Middle East, reportedly there as plague. Another very cold winter followed in 1260–1261. The troubled period's wars, famines, pestilences, and earthquakes appear to have contributed in part to the rise of the European flagellant movement of 1260, one of the most bizarre social phenomena of the Middle Ages. Analogies can be drawn with the climatic aftereffects and European social unrest following another great tropical eruption, Tambora in 1815. Some generalizations about the climatic impacts of tropical eruptions are made from these and other data.

Climatic Change, **45**, 361–374, 2000

Makīn, 1260; Bar-Hebraeus, 1286). Because the Middle East has been historically prone to epidemics of bubonic plague, possibly that is what it was.

6. The Flagellants

Flagellation, or scourging, had long been practiced as an occasional form of discipline or penance within Christian monastic communities. In the spring of 1260, however, a popular penitential movement of self-flagellation arose in Perugia, central Italy, and spread south, in the autumn, to Rome and north toward central Europe. Wholly orthodox at first, it attracted not only members of the clergy but all ranks and ages of pious lay people. Early in the following year, though, it degenerated into a heterodox movement of peasants and malcontents, which was put down finally by the ecclesiastical and civil authorities. In its typical manifestation, bands of unshirted male flagellants marched through the streets in double file, uttering hymns and religious slogans and flogging their backs with whips until blood began to flow. Troops of flagellants traveled from town to town. It was one of the oddest mass social phenomena of the Middle Ages.

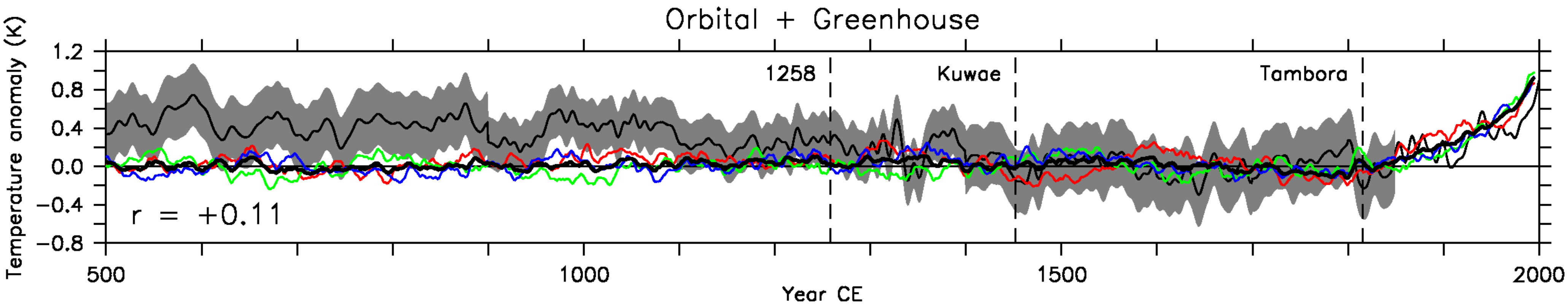
Extreme weather events of 535–536 CE

- *The sun was dark and its darkness lasted for eighteen months; each day it shone for about four hours; and still this light was only a feeble shadow; the fruits did not ripen and the wine tasted like sour grapes.* - Michael the Syrian
- *During this year [536 CE] a most dread portent took place. For the sun gave forth its light without brightness ... and it seemed exceedingly like the sun in eclipse, for the beams it shed were not clear.* - Procopius of Caesarea
- Crop failures and famine worldwide.
- Low temperatures, including summer snowfall, in China.
- A "dense, dry fog" in the Middle East, China and Europe.
- Drought in Central and Southern America; fall of the city of Teotihuacán.
- Scandinavian elites sacrificed large amounts of gold, possibly to appease the angry gods and get the sunlight back.
- Probably caused by a volcanic eruption in around 533 CE.

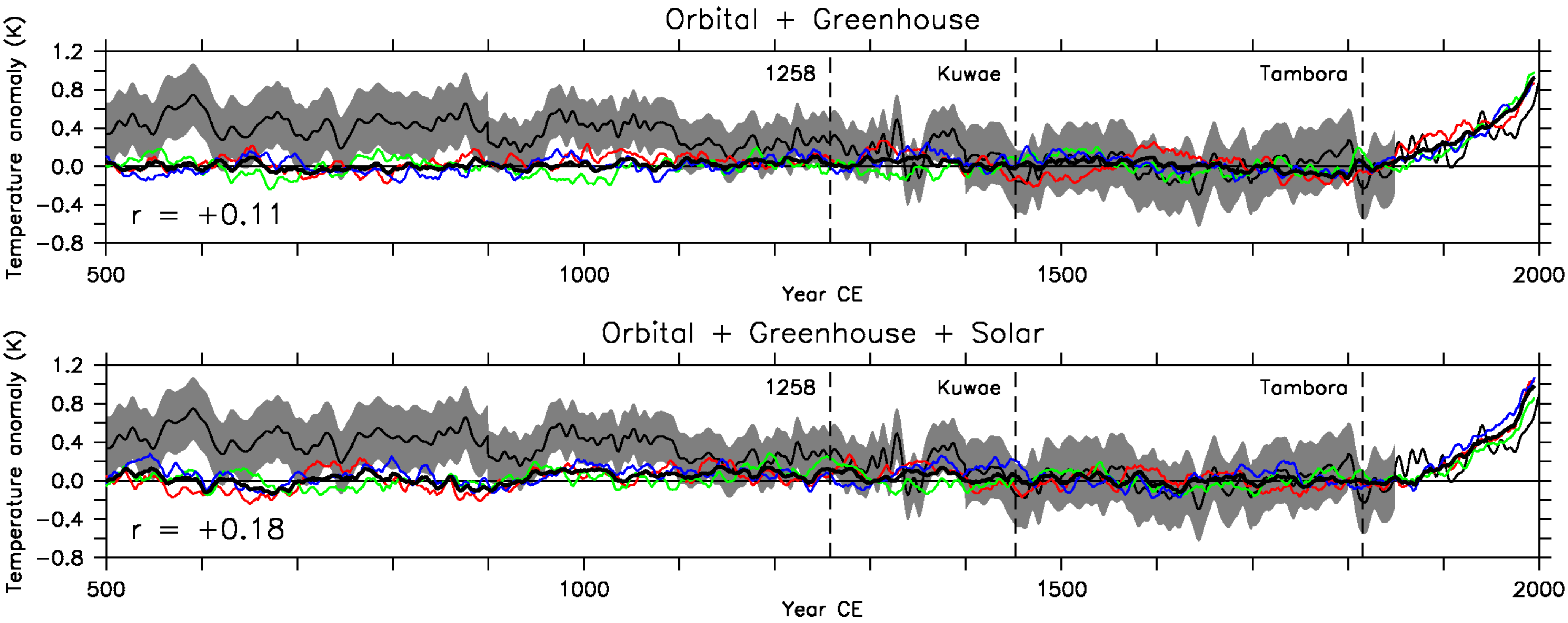
Climate modelling and proxy data

- The CSIRO Mk3L climate system model (Phipps et al., 2011, 2012)
  - Atmosphere-land-sea ice-ocean general circulation model.
  - Used to conduct transient simulations of the past 1500 years.
  - Different combinations of orbital, greenhouse gas, solar and volcanic forcing applied.
  - Three-member ensembles used to help distinguish between forced and unforced variability.
- Northern Hemisphere temperature reconstruction (Mann et al., 2009)
  - Network of 1209 annually- and decadally-resolved proxies.
  - Used to reconstruct annual-mean NH temperature for 500–2006 CE.

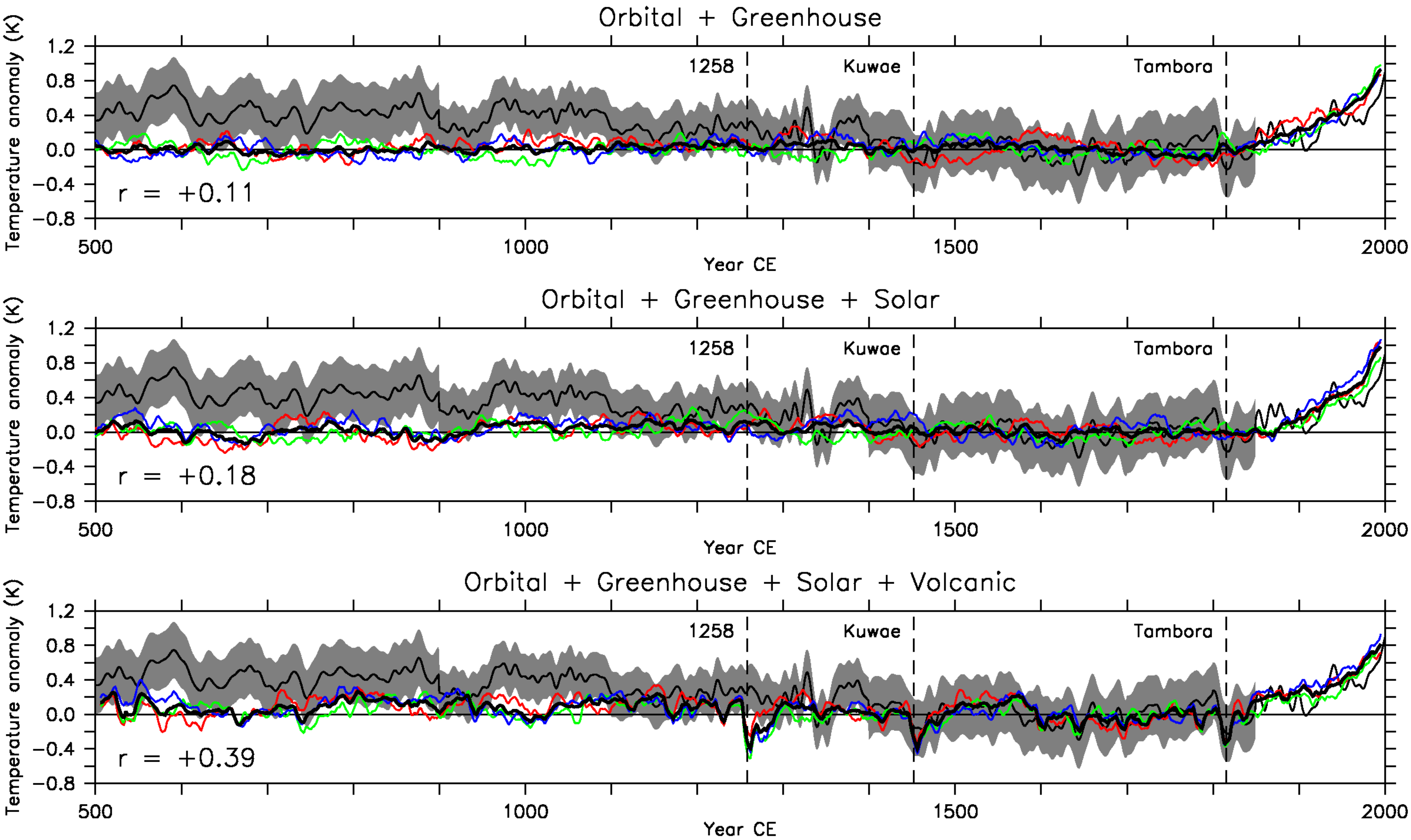
Annual-mean Northern Hemisphere temperature

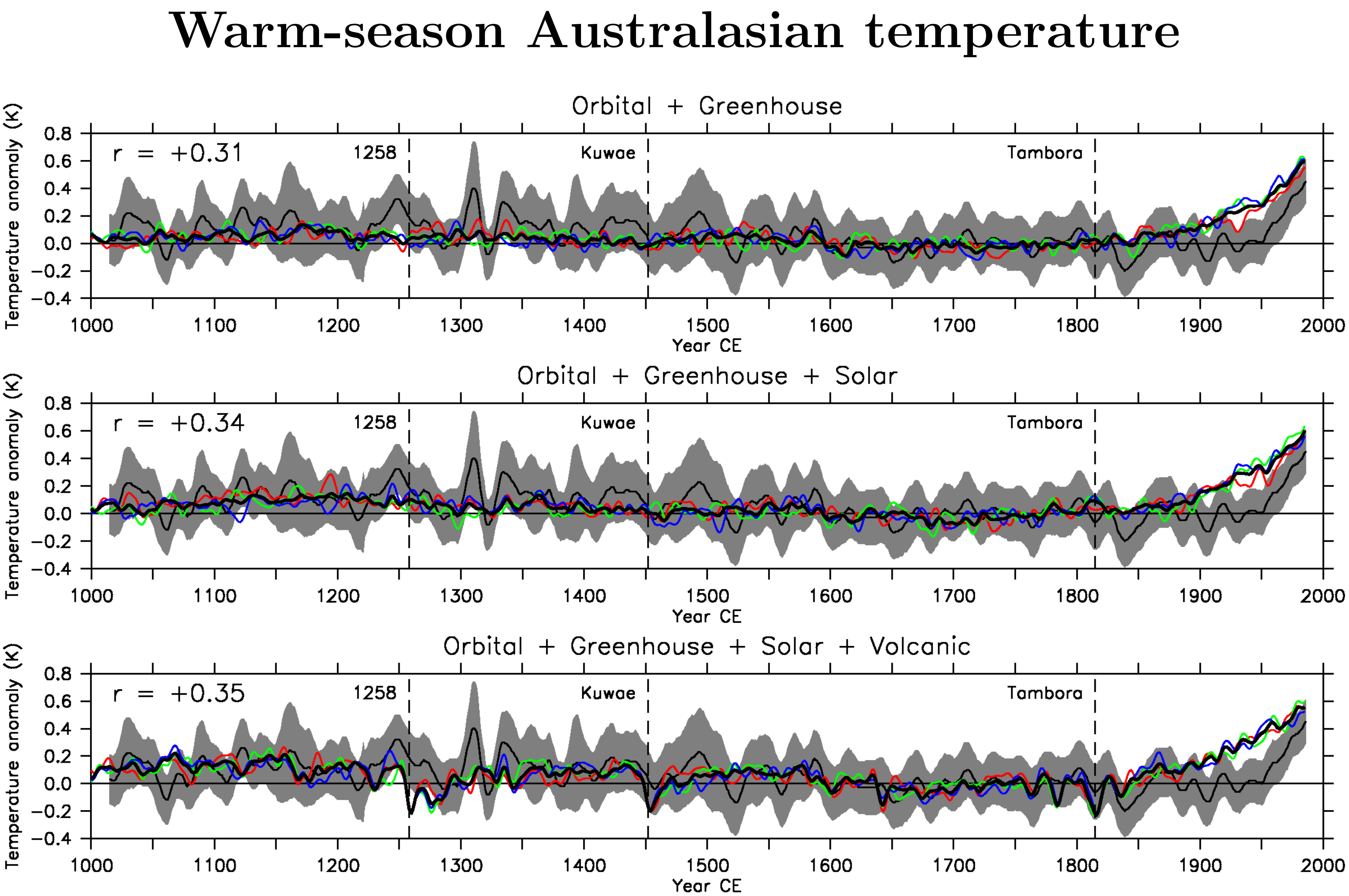


Annual-mean Northern Hemisphere temperature



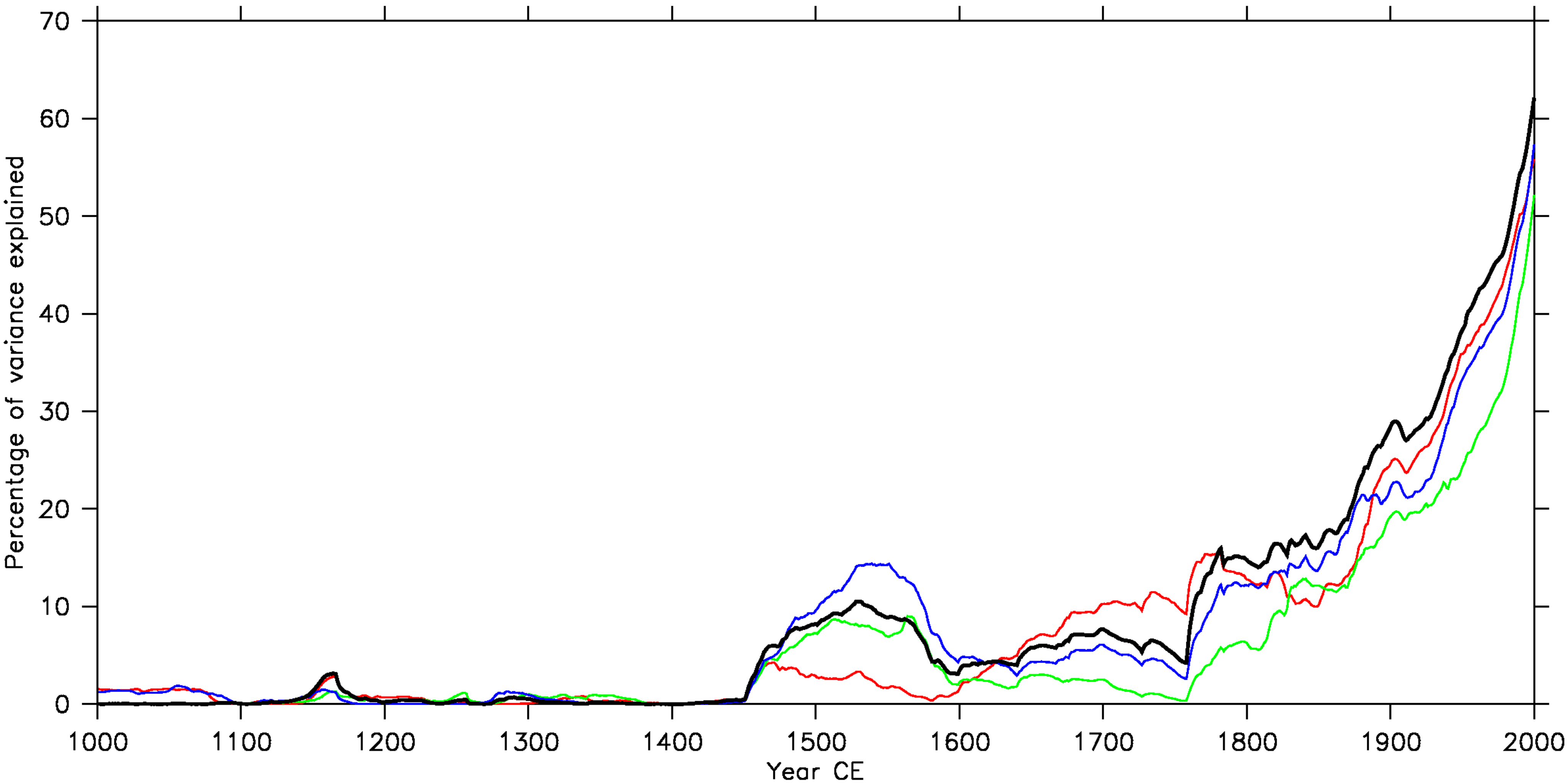
Annual-mean Northern Hemisphere temperature





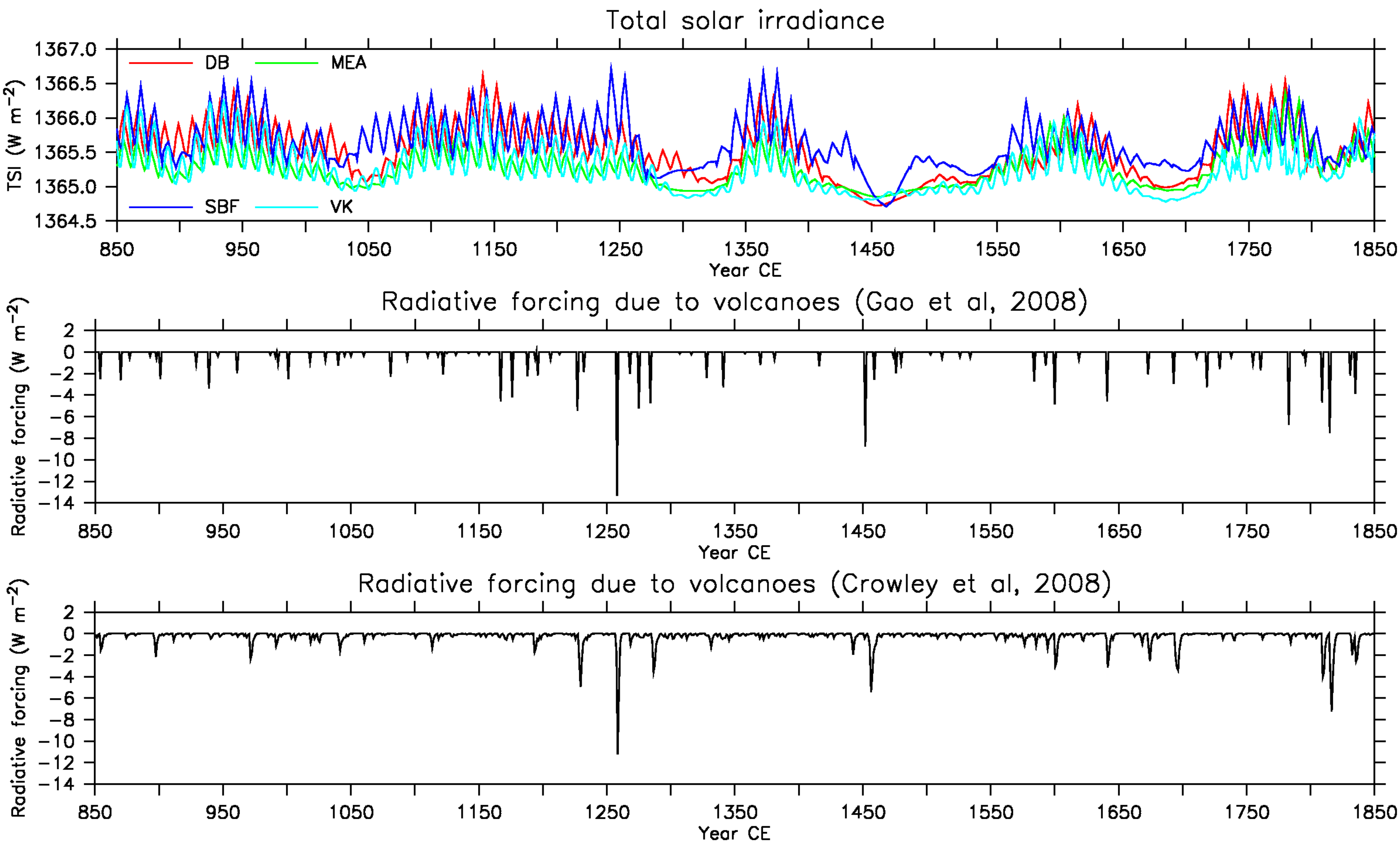
Warm-season Australasian temperature
Orbital + Greenhouse
r = +0.31
1258
Kuwae
Tambora
Orbital + Greenhouse + Solar
r = +0.34
1258
Kuwae
Tambora
Orbital + Greenhouse + Solar + Volcanic
r = +0.35
1258
Kuwae
Tambora
Temperature anomaly (K)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year CE

NH variability explained over previous 501 years

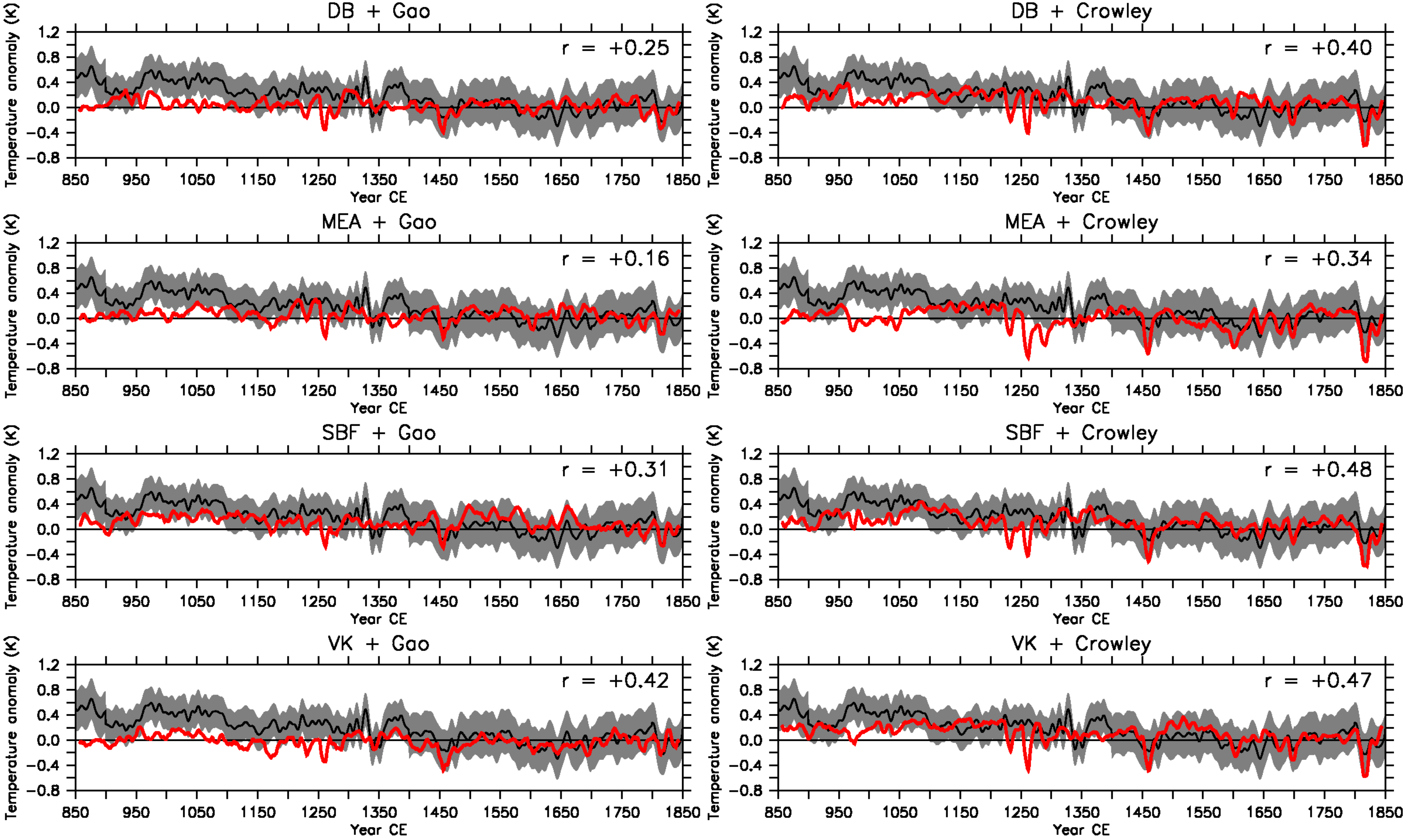


3. Uncertainties

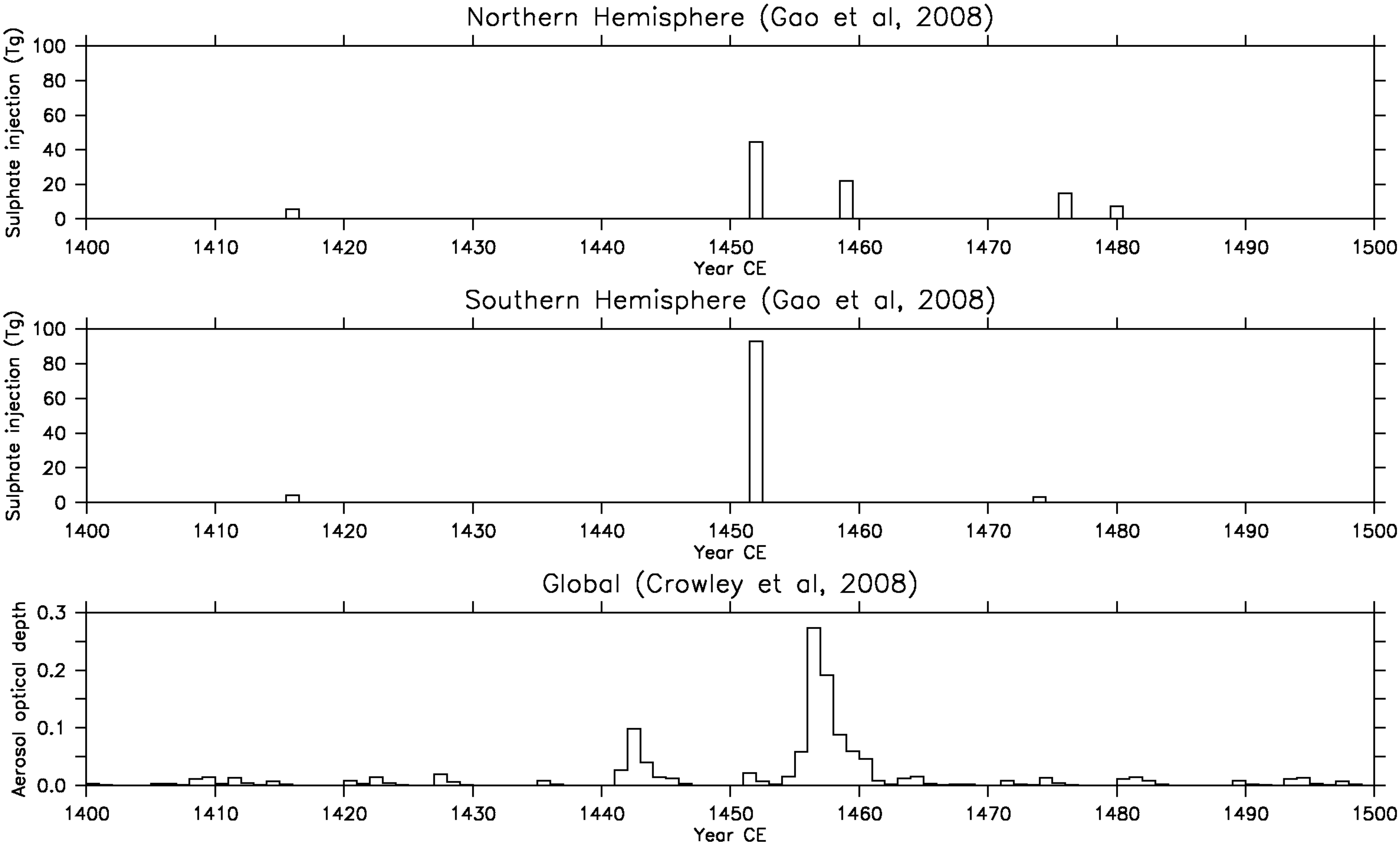
(a) Magnitude of solar and volcanic forcing



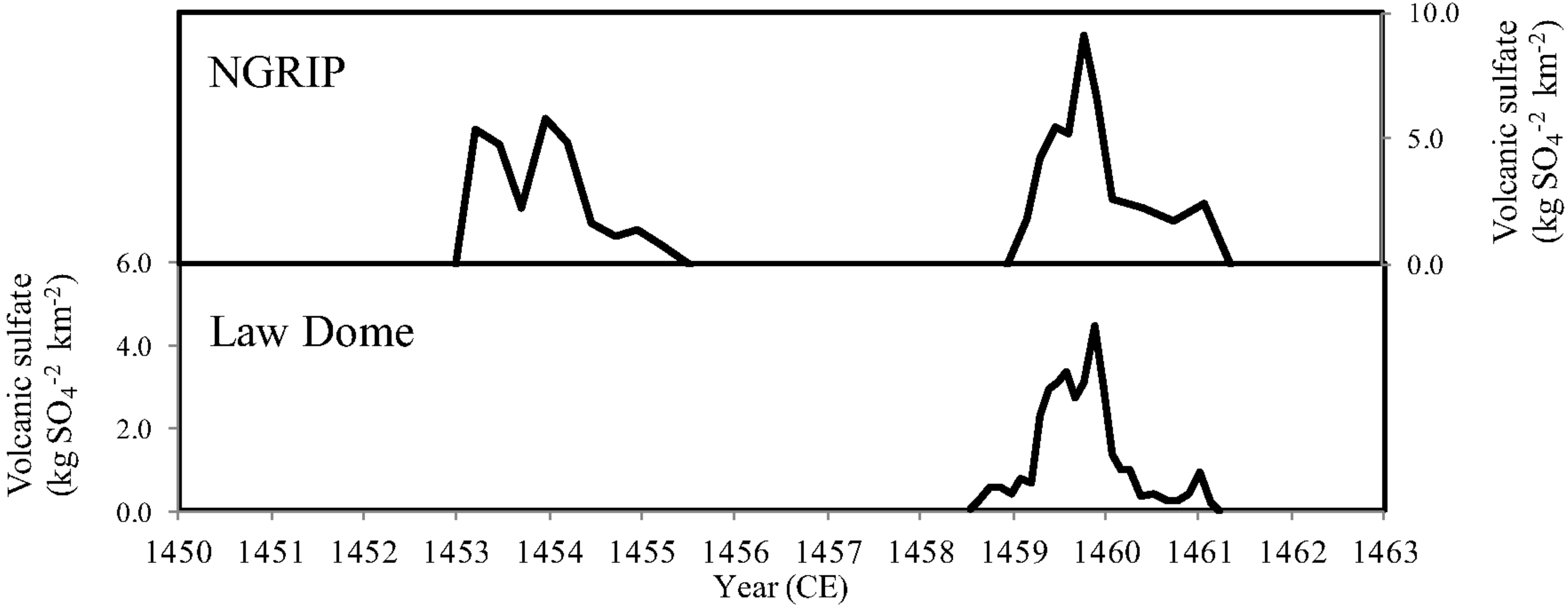
Annual-mean Northern Hemisphere temperature



(b) Dating of past volcanic eruptions

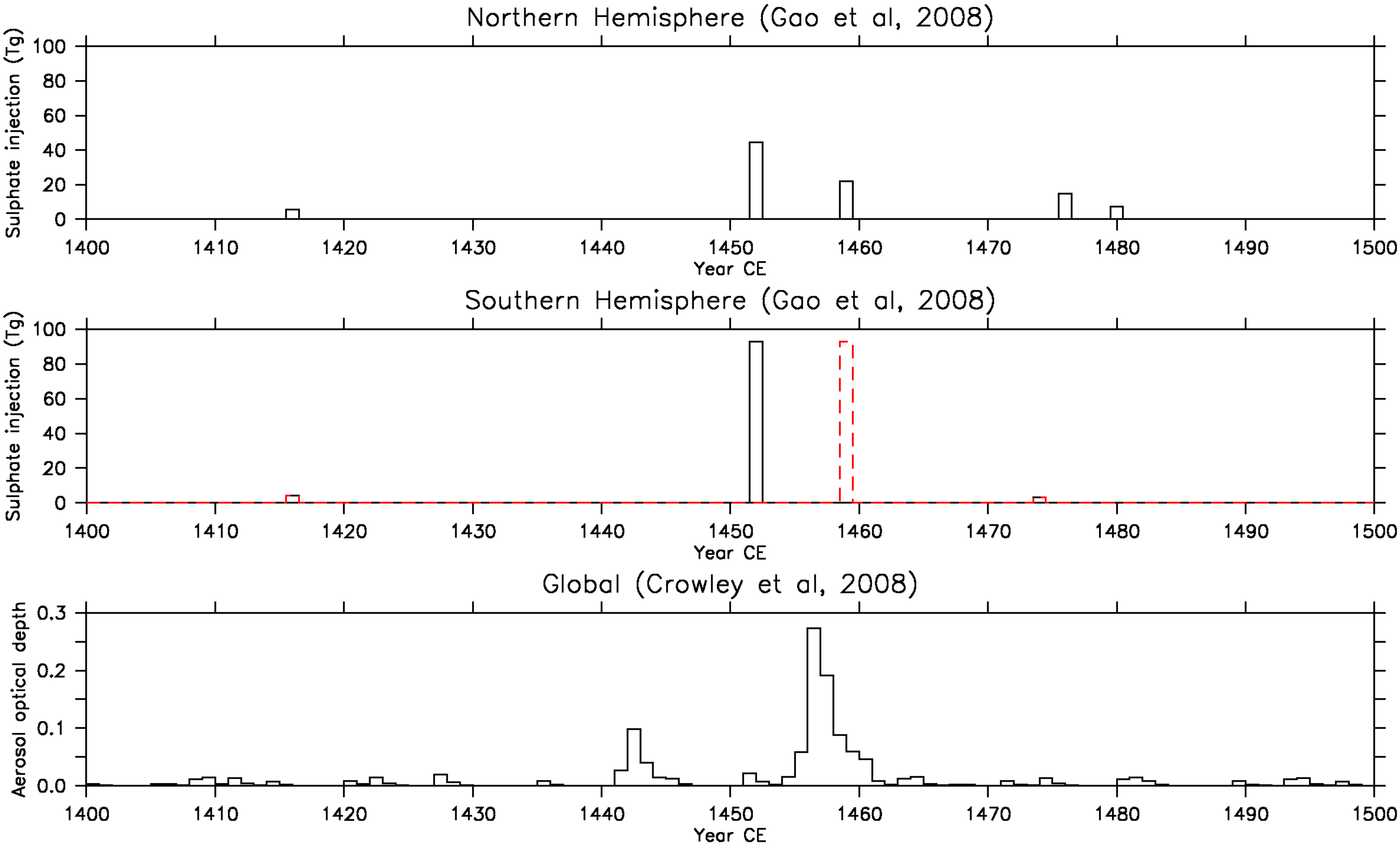


The dating of the 1450s Kuwae eruption

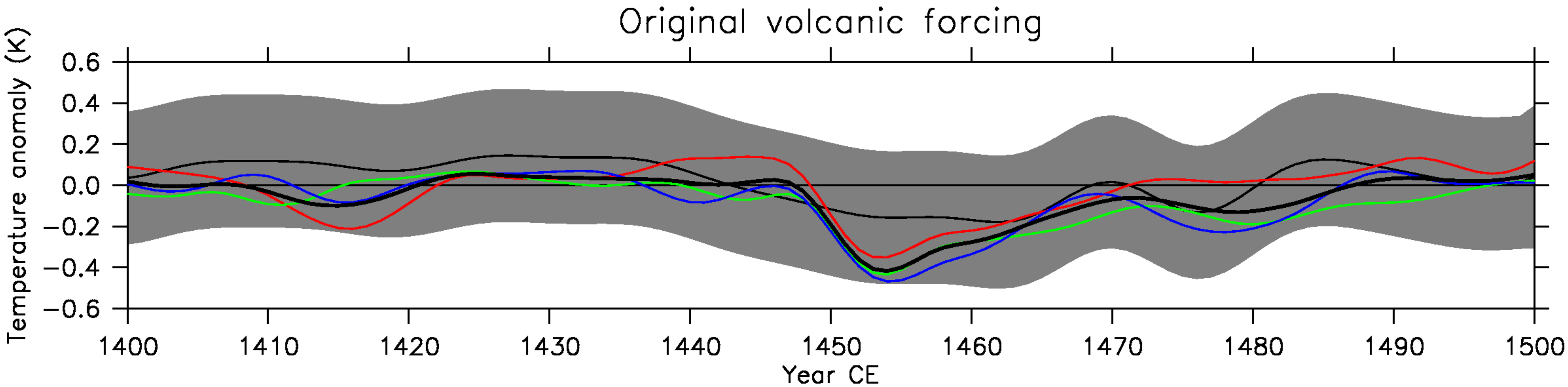


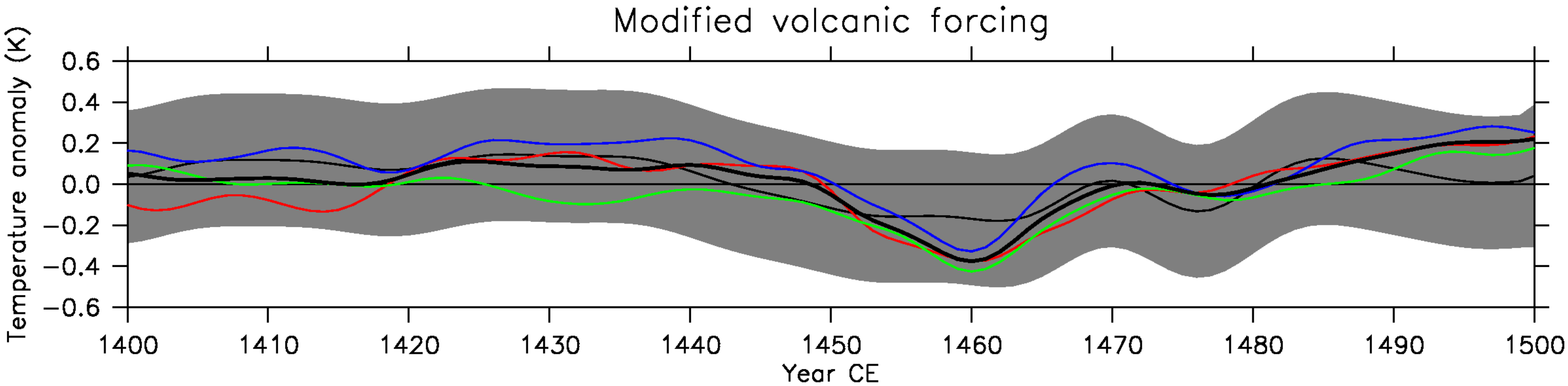
Plummer at al (2012), *Climate of the Past Discussions*

Revised dating of the Kuwae eruption



NH temperature during the 15th century

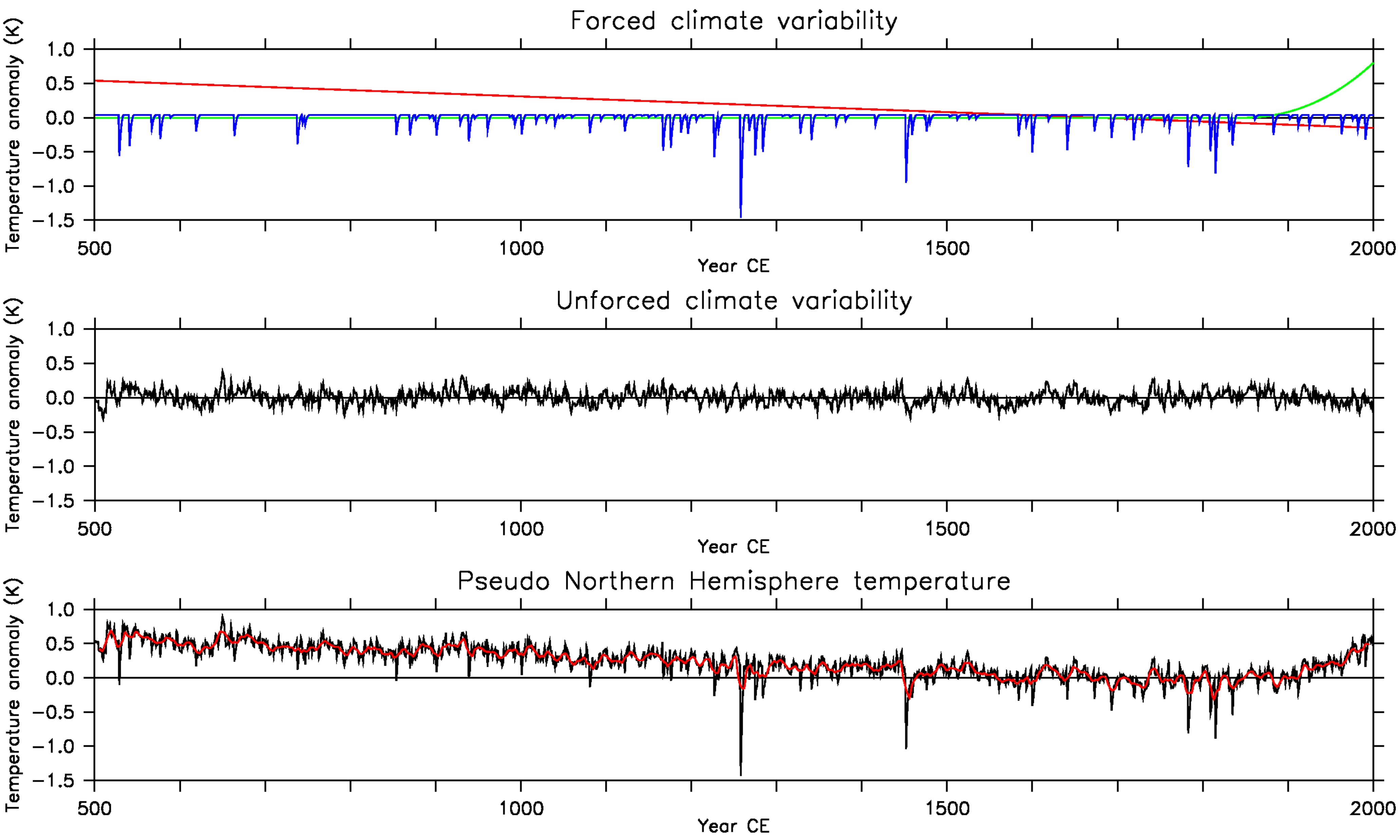




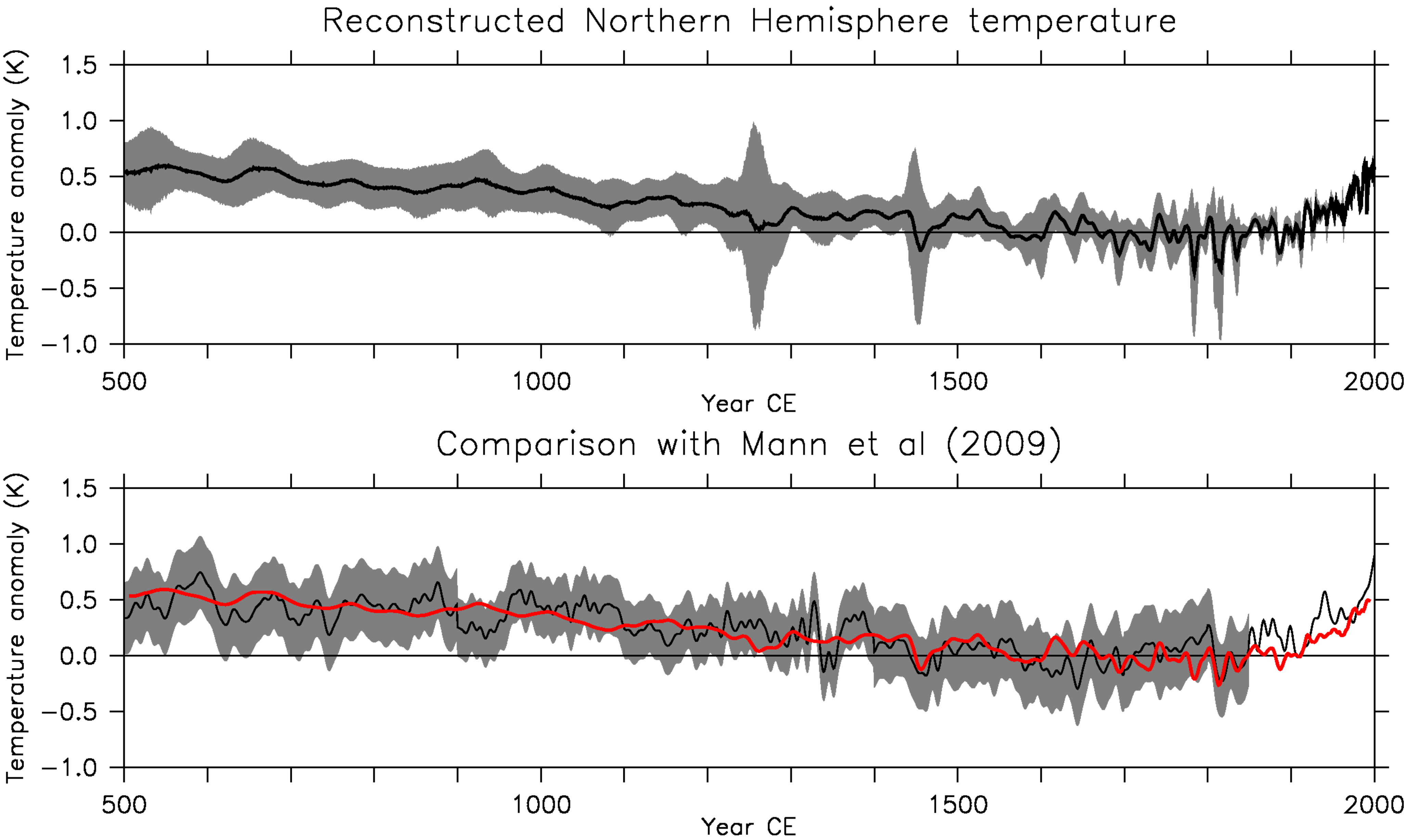
(c) Dating of past climatic changes

- To explore this, generate a "pseudo Northern Hemisphere" and then attempt to reconstruct it.
- Pseudo Northern Hemisphere:
  - Orbital response: Cooling trend of 0.46 K per 1000 years.
  - Anthropogenic response: Warming of 0.8 K after 1850 CE.
  - Volcanic response: Cooling of 1.5 K in response to 1258 CE eruption; scale other eruptions accordingly.
  - Stochastic variability: AR(1) red noise with amplitude of 0.1 K and autocorrelation coefficient of 0.7.
- Reconstruction:
  - Network of 1000 proxies.
  - Assume that each proxy is perfect, except for dating uncertainties that are normally distributed with a standard deviation of 1%.

Pseudo Northern Hemisphere temperature



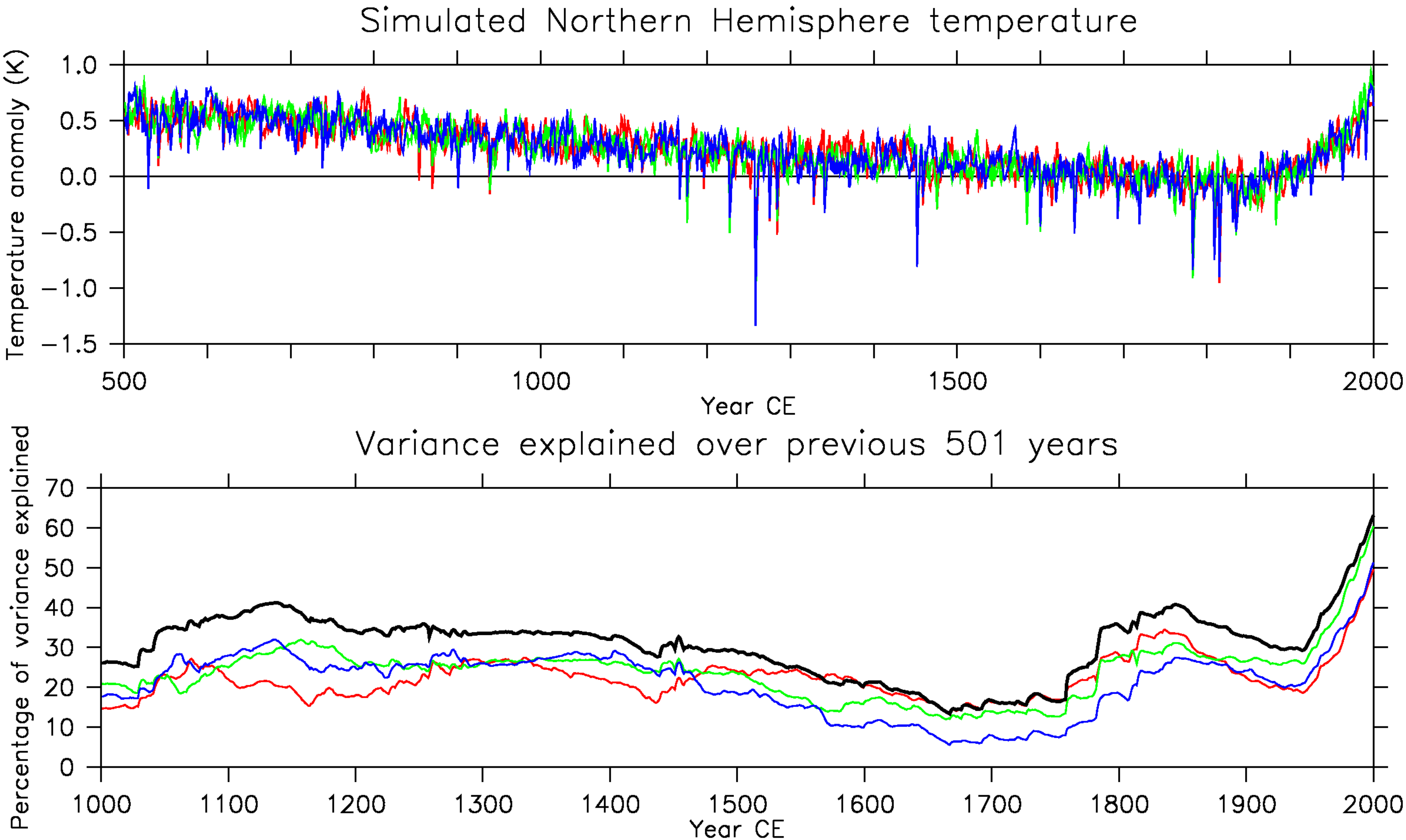
Reconstruction with dating uncertainty

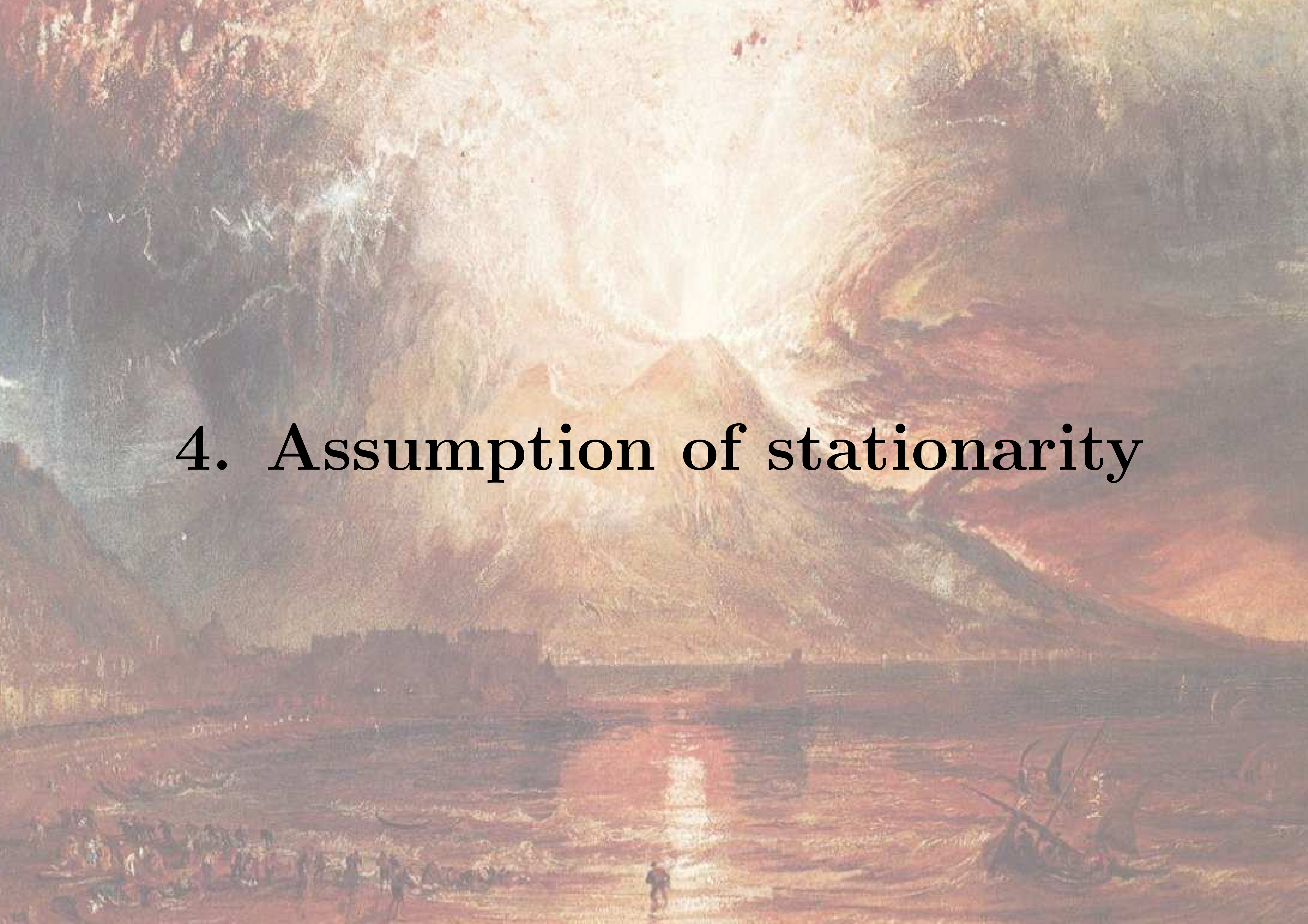


Pseudo climate model

- Now generate a "pseudo model" to compare with the reconstruction.
- Assume that the model has perfect representations of both forced and unforced climate variability.
- Assume that the boundary conditions on the model are perfect.
- The simulated response to orbital, anthropogenic and volcanic forcings will therefore agree exactly with reality.
- The simulated stochastic climate variability will have the same characteristics as the real world, but the timing, amplitude and duration of specific events will differ.

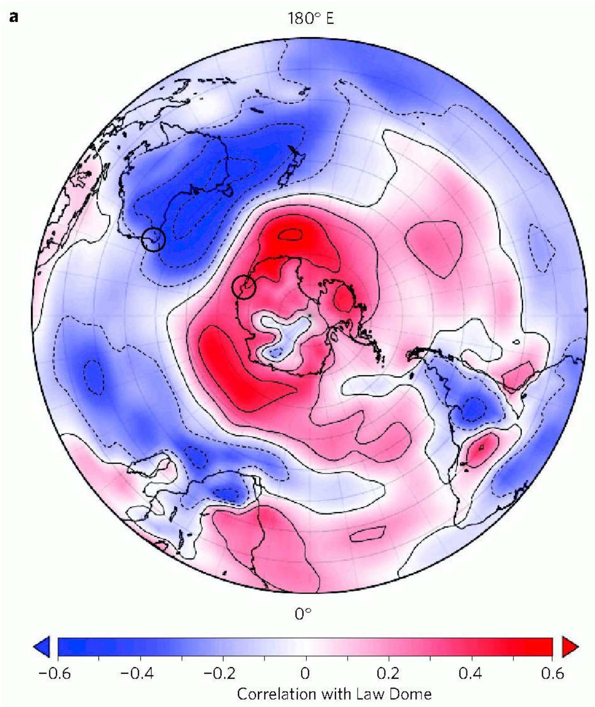
Comparison between "model" and "reconstruction"



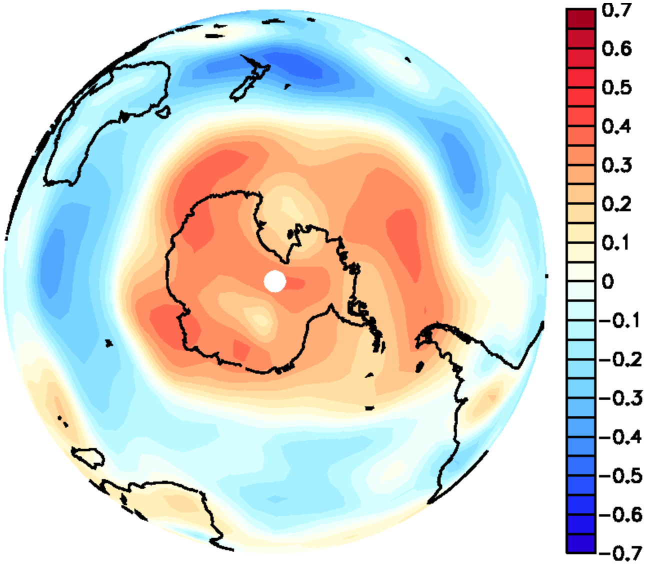


4. Assumption of stationarity

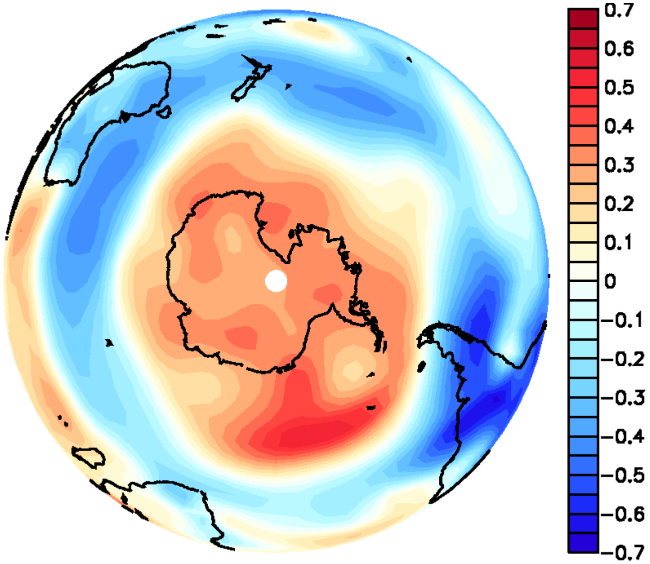
Correlation of MSLP with Law Dome precipitation (1979–2004)



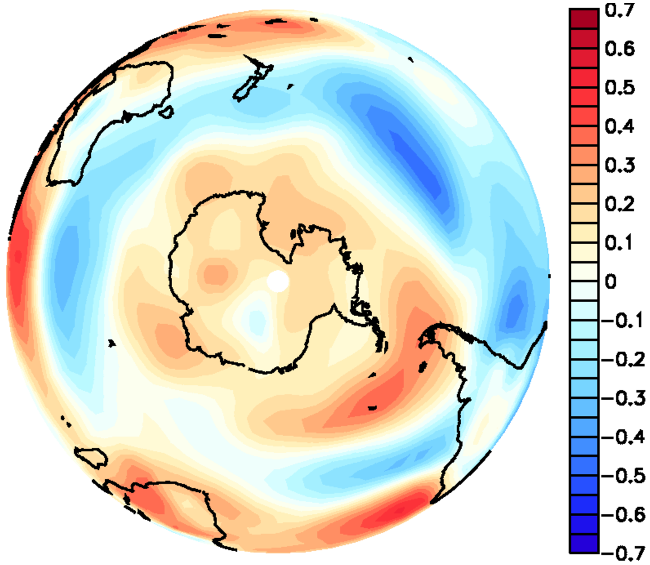
van Ommen and Morgan (2010), *Nature Geoscience*



Member 1 (1975–2000)

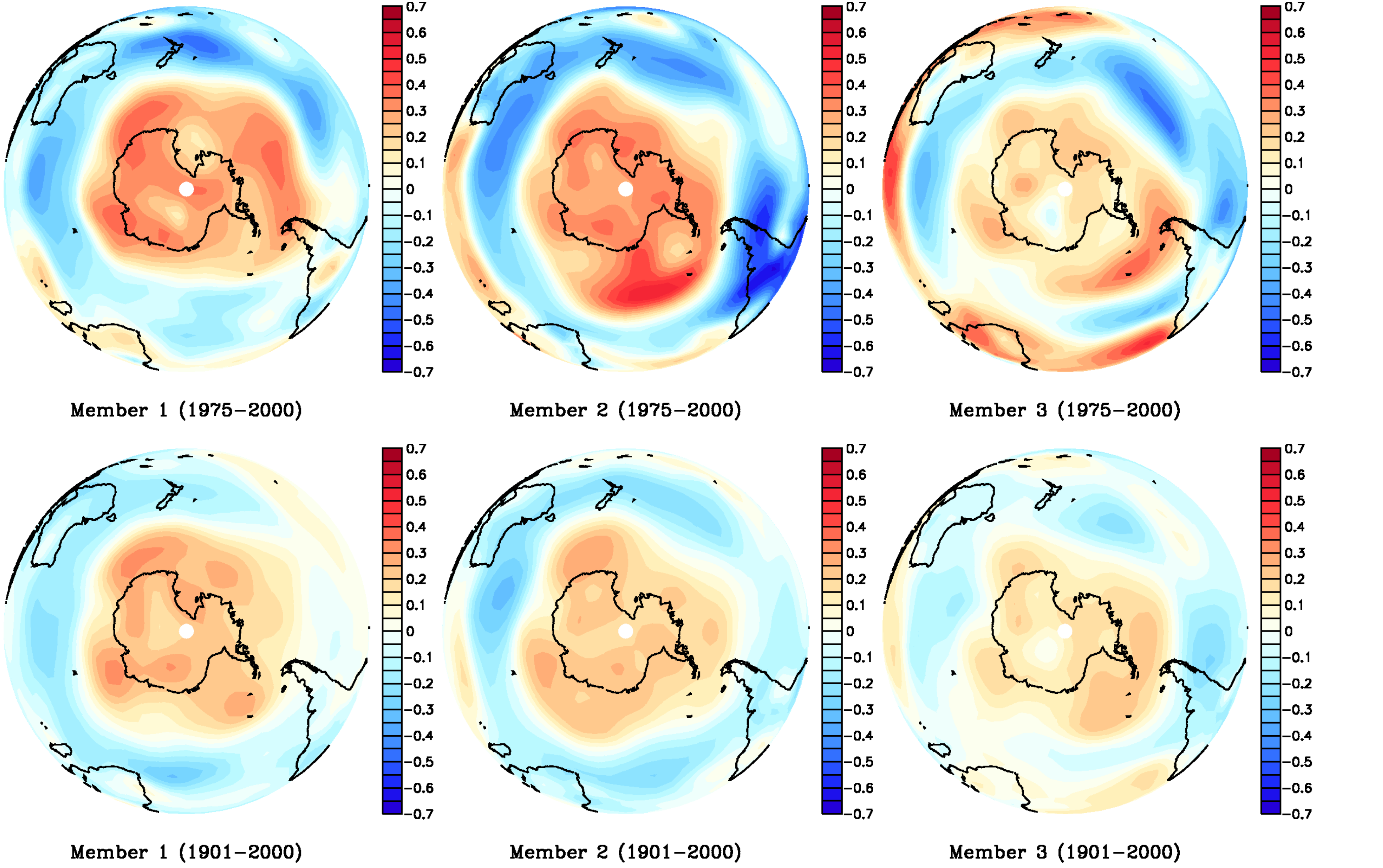


Member 2 (1975–2000)

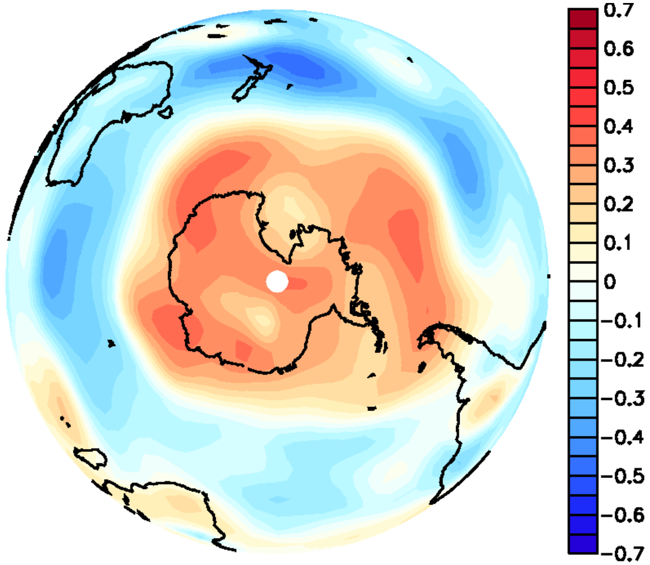


Member 3 (1975–2000)

Relationship is consistent over the 20th century ...



... and the full 1500 years ...



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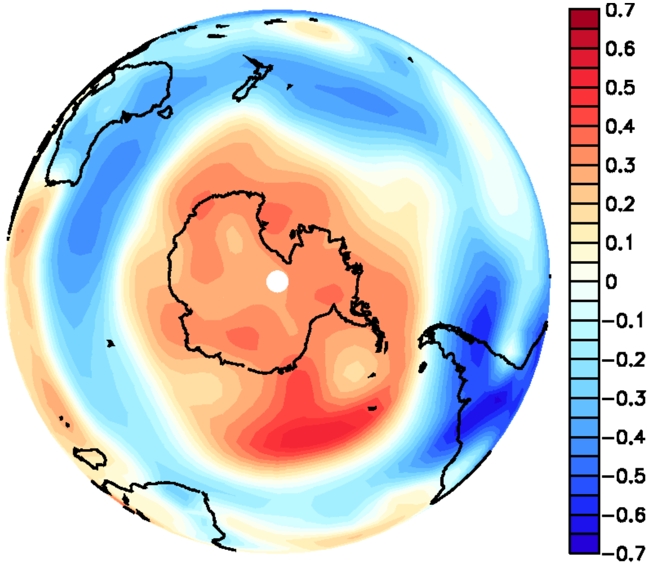

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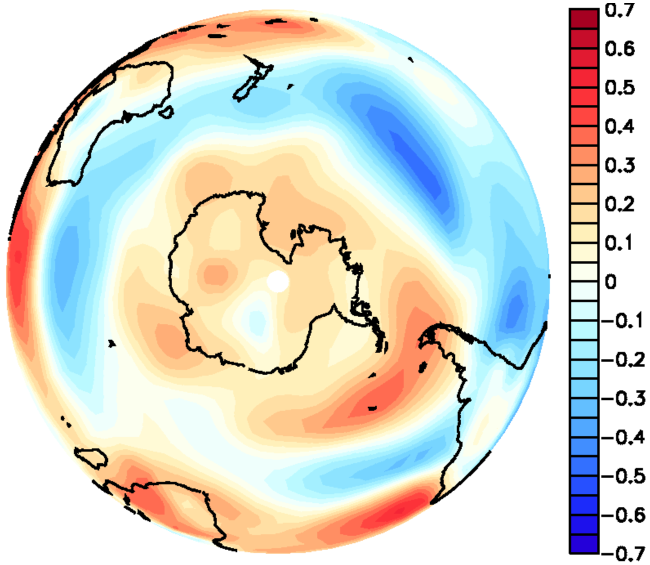

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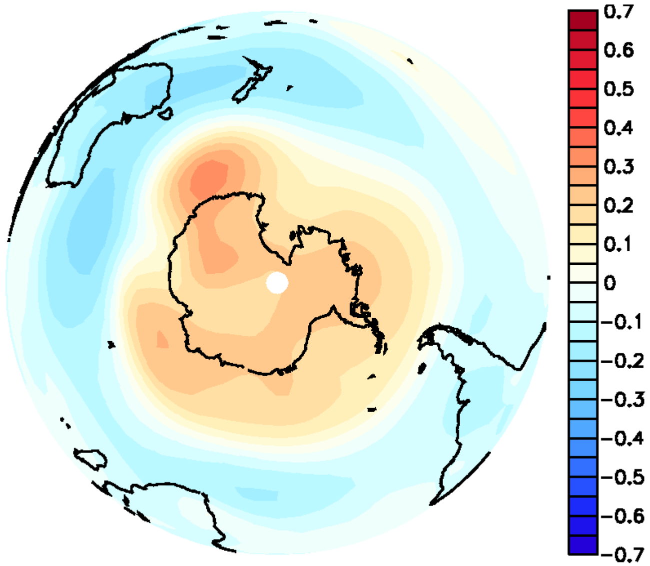
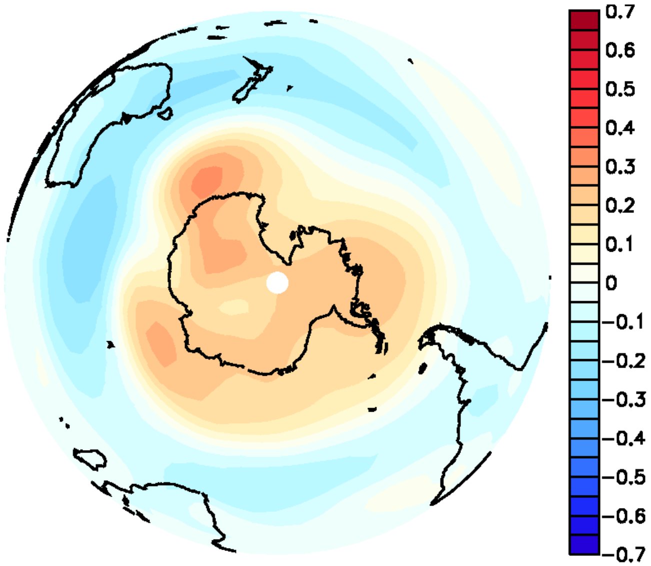
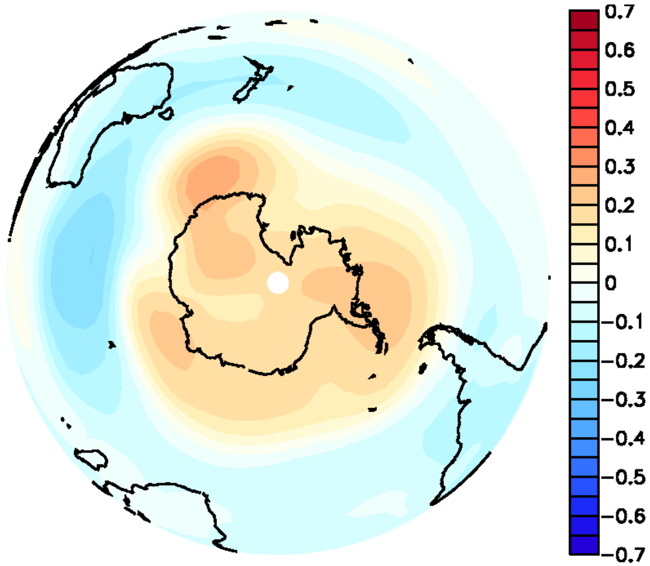


Member 1 (501–2000)

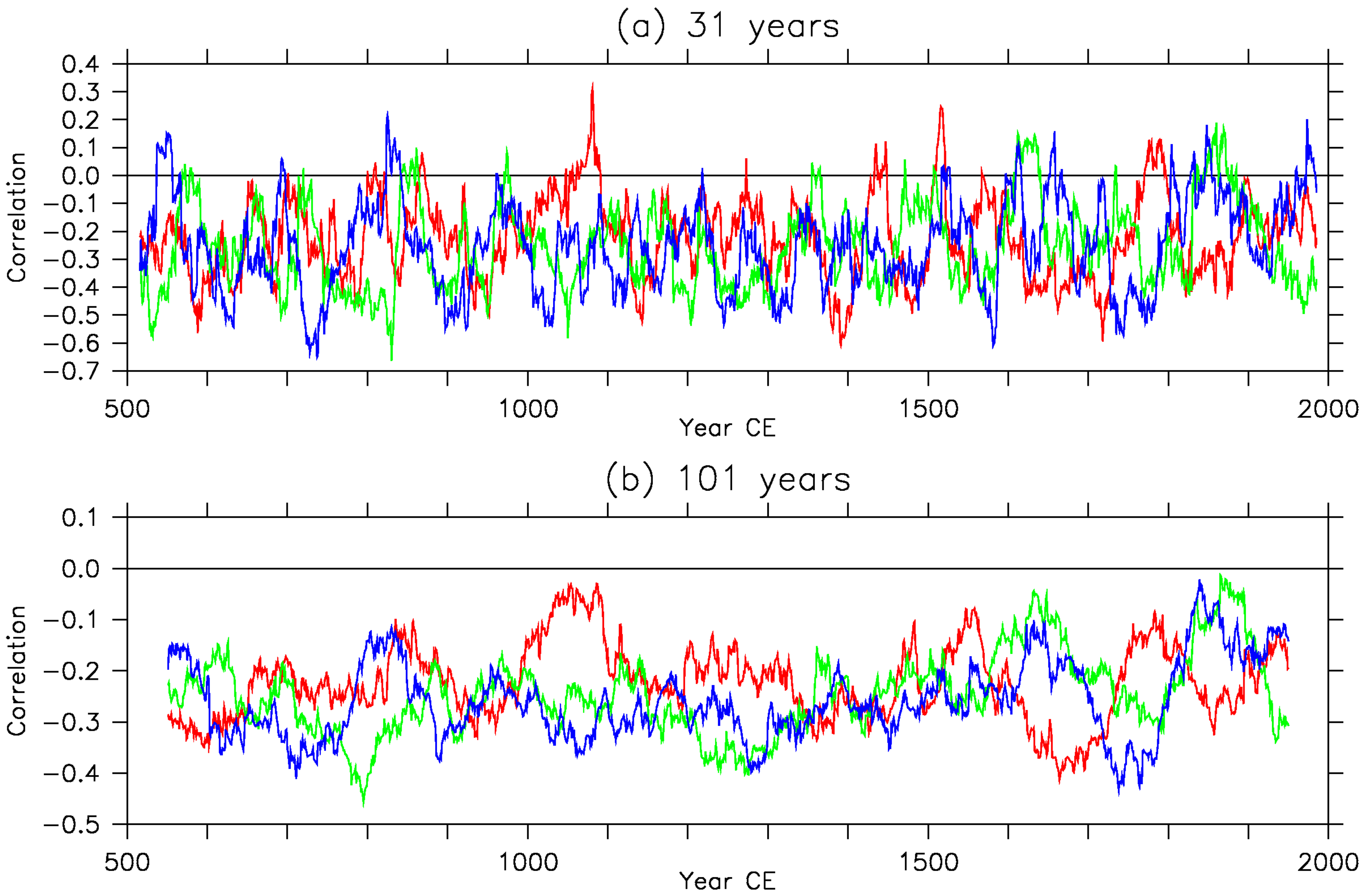


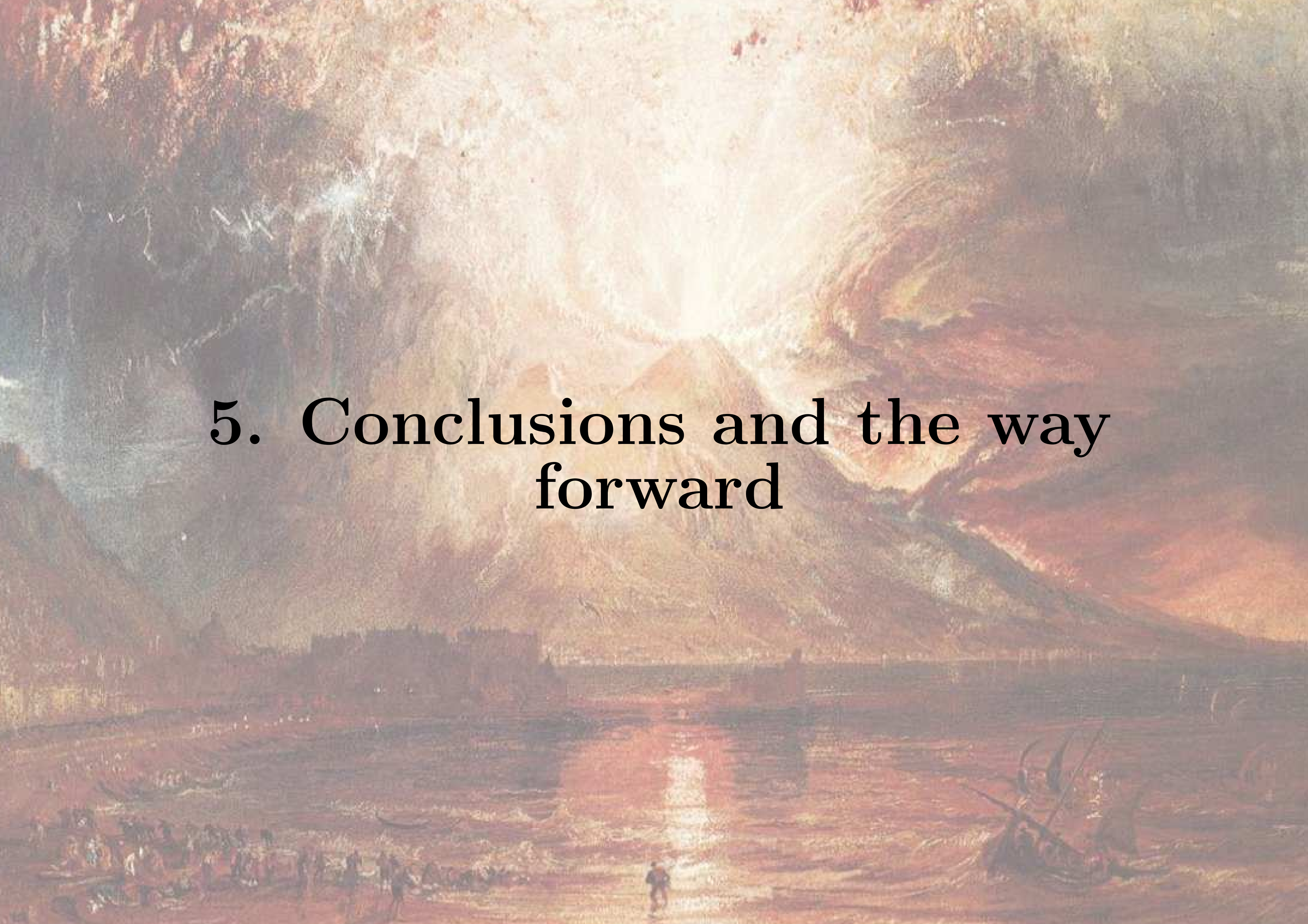
Member 2 (501–2000)



Member 3 (501–2000)

… but modulated by natural variability





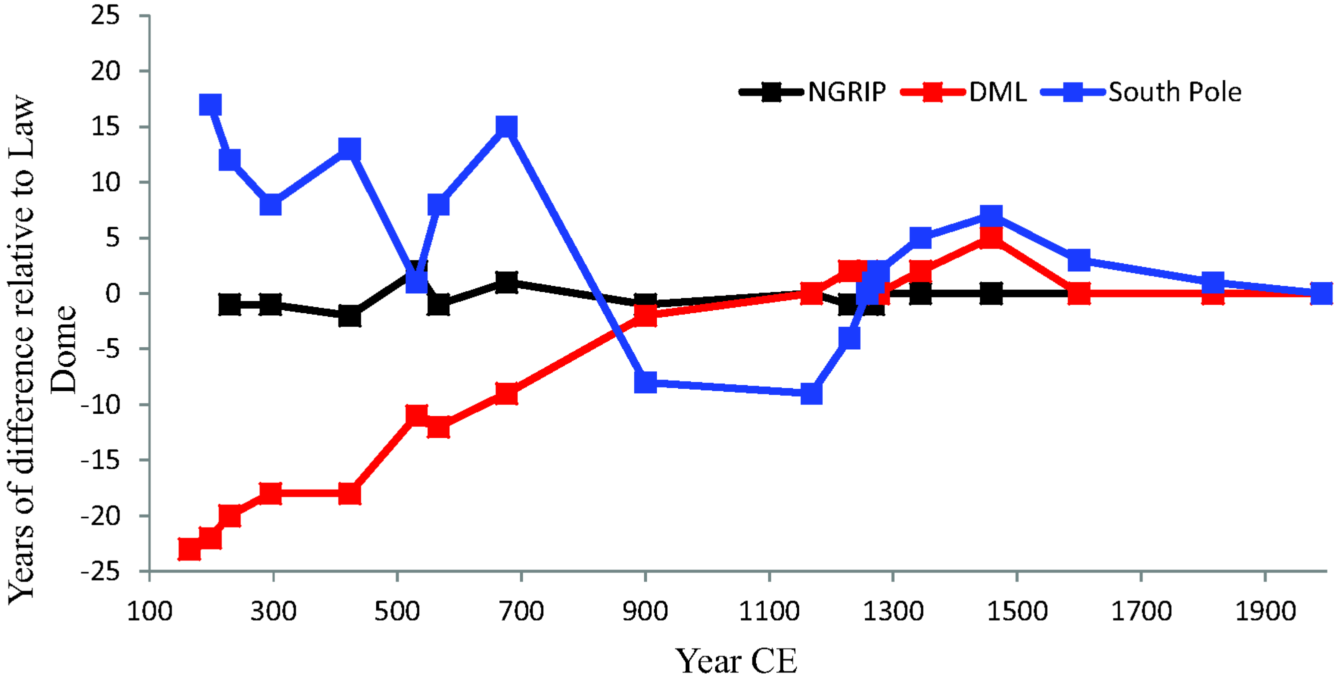
5. Conclusions and the way forward

Conclusions

- The combination of palaeoclimate proxy data with climate modelling can reveal insights into the dynamics of the climate system.
- Volcanoes appear to have been the dominant driver of forced climate variability over the past 1500 years in the Northern Hemisphere, but the pre-industrial climate of Australasia appears to have been essentially stochastic.
- Our ability to learn from the past is constrained by our understanding of climatic forcings — particularly volcanic eruptions — and uncertainties in dating of proxy records.
- The fundamental assumption of stationarity in relationships within the climate system may not be tenable, particularly on decadal timescales, and warrants further investigation.

The way forward

- Climate modelling has an essential role to play in the process of palaeoclimate reconstruction, with the models used to test the stability of relationships within the climate system.
- There is a critical need for better reconstructions of past climatic forcings and more accurate dating of proxy records.



Plummer at al (2012), *Climate of the Past Discussions*