Volcanic eruptions: The forgotten source of abrupt climate change?

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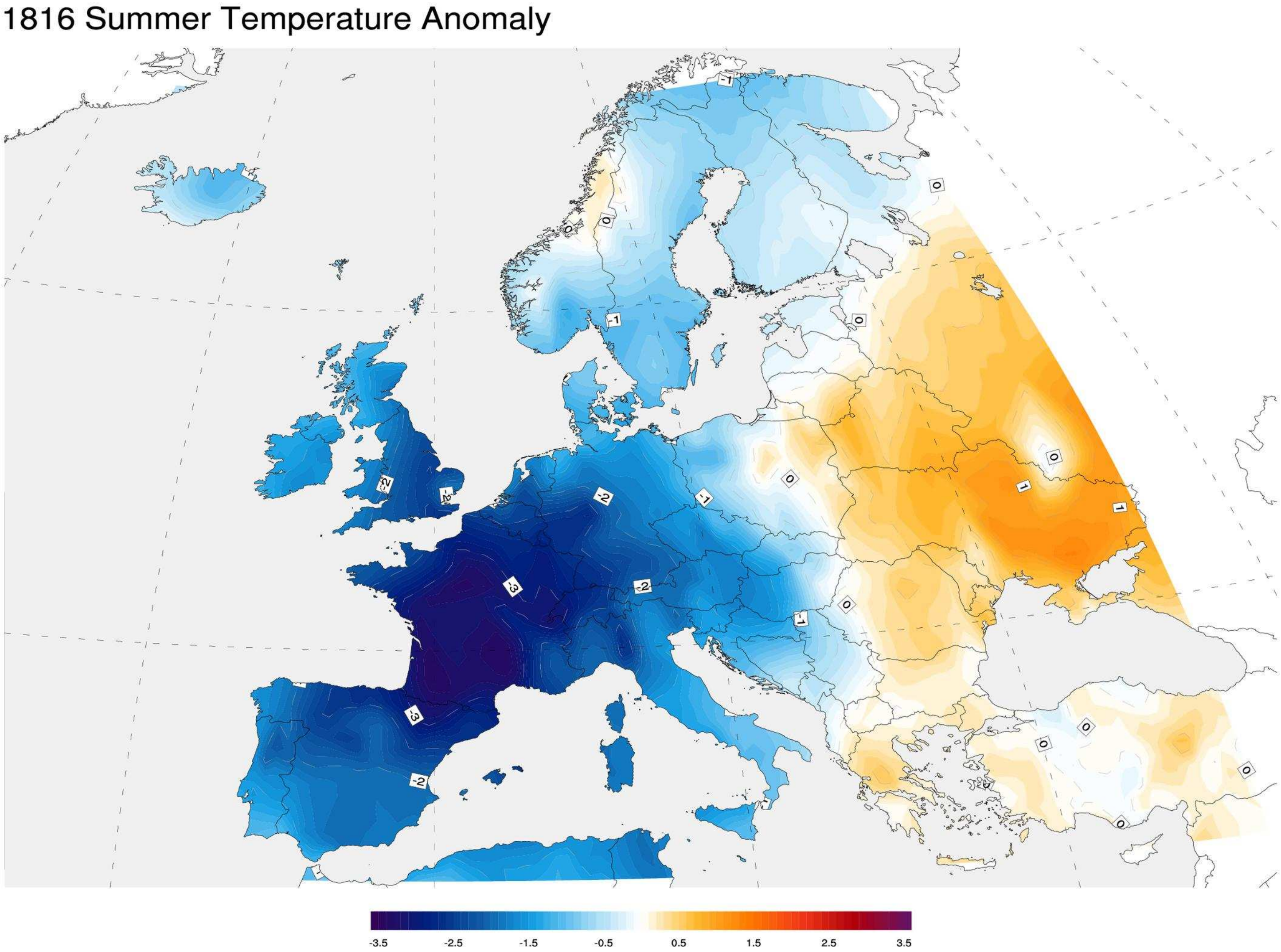
The "Year Without a Summer"



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.

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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

Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks

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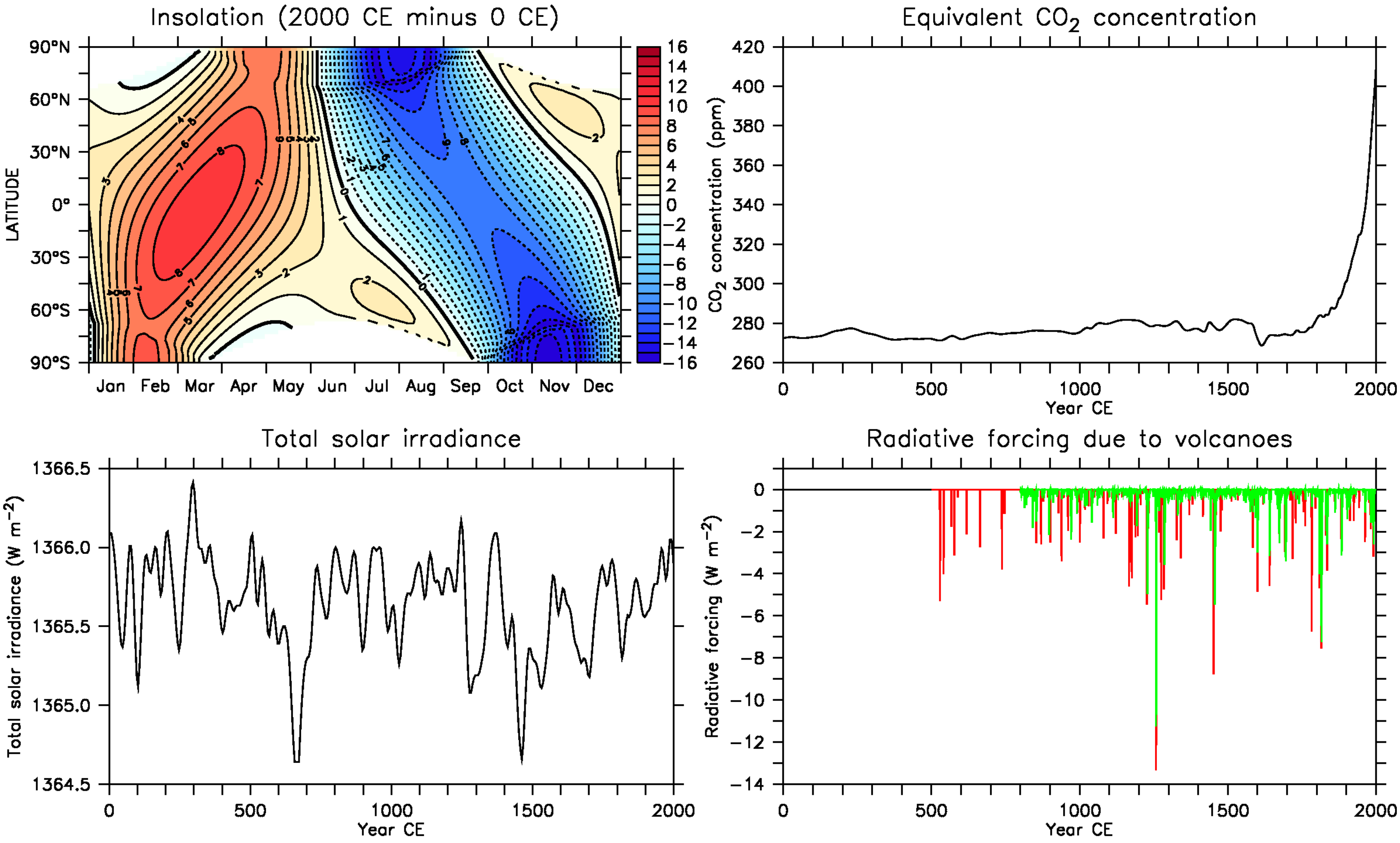
[1] Northern Hemisphere summer temperatures over the past 8000 years have been paced by the slow decrease in summer insolation resulting from the precession of the equinoxes. However, the causes of superposed century-scale cold summer anomalies, of which the Little Ice Age (LIA) is the most extreme, remain debated, largely because the natural forcings are either weak or, in the case of volcanism, short lived. Here we present precisely dated records of ice-cap growth from Arctic Canada and Iceland showing that LIA summer cold and ice growth began abruptly between 1275 and 1300 AD, followed by a substantial intensification 1430–1455 AD. Intervals of sudden ice growth coincide with two of the most volcanically perturbed half centuries of the past millennium. A transient climate model simulation shows that explosive volcanism produces abrupt summer cooling at these times, and that cold summers can be maintained by sea-ice/ocean feedbacks long after volcanic aerosols are removed. Our results suggest that the onset of the LIA can be linked to an unusual 50-year-long episode with four large sulfur-rich explosive eruptions, each with global sulfate loading >60 Tg. The persistence of cold summers is best explained by consequent sea-ice/ocean feedbacks during a hemispheric summer insolation minimum; large changes in solar irradiance are not required. **Citation:** Miller, G. H., et al. (2012), Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks, *Geophys. Res. Lett.*, *39*, L02708, doi:10.1029/2011GL050168.

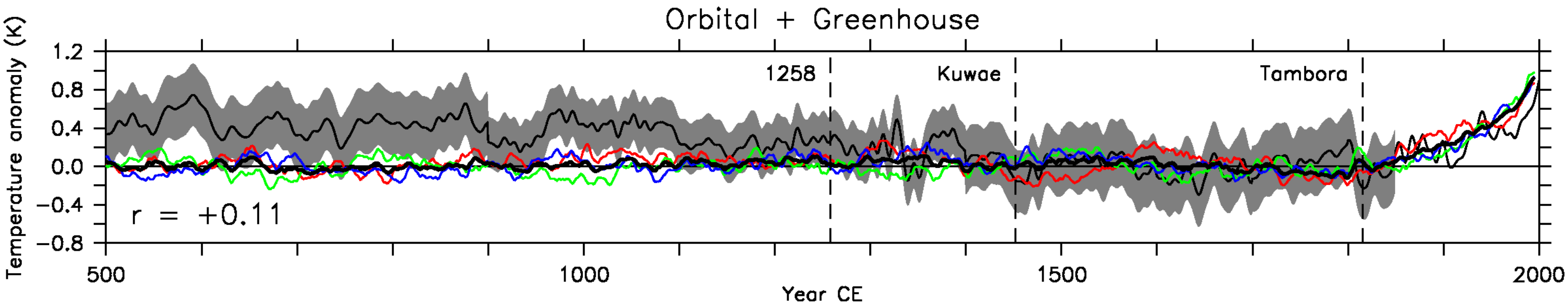
scale intervals of anomalously cold summers are recorded by the advance of glaciers throughout the Arctic and in mountainous regions at lower latitudes (Neoglaciation), with most glaciers and ice caps reaching their maximum dimensions of the past 8 ka during the Little Ice Age (LIA), prior to widespread recession during the 20th Century [*Miller et al.*, 2010]. Episodes of anomalously cold summers primarily are attributed to some combination of reductions in solar irradiance, especially the LIA Maunder sunspot minimum [*Eddy*, 1976], explosive volcanism, and changes in the internal modes of variability in the ocean–atmosphere system [*Crowley*, 2000; *Wanner et al.*, 2011]. However, the natural radiative forcings are either weak or, in the case of explosive volcanism, short-lived [*Robock*, 2000], thus requiring substantial internal feedback. The LIA is particularly enigmatic. Despite extensive historical documentation and a wide array of proxy records that define climate change during the past millennium [*Mann et al.*, 2008], there is no clear consensus on the timing, duration, or controlling mechanisms of the LIA.

[3] At high northern latitudes the most reliable summer temperature proxies are glaciers; 90% of the interannual variation in their mass balance is explained by summer temperature [*Koerner*, 2005]. Unlike biological proxies, glaciers have no strategies for survival nor are their dimensions particularly sensitive to brief, extreme years. Smaller ice bodies respond more rapidly than larger ones to summer temperature changes, and we therefore focused our investi-

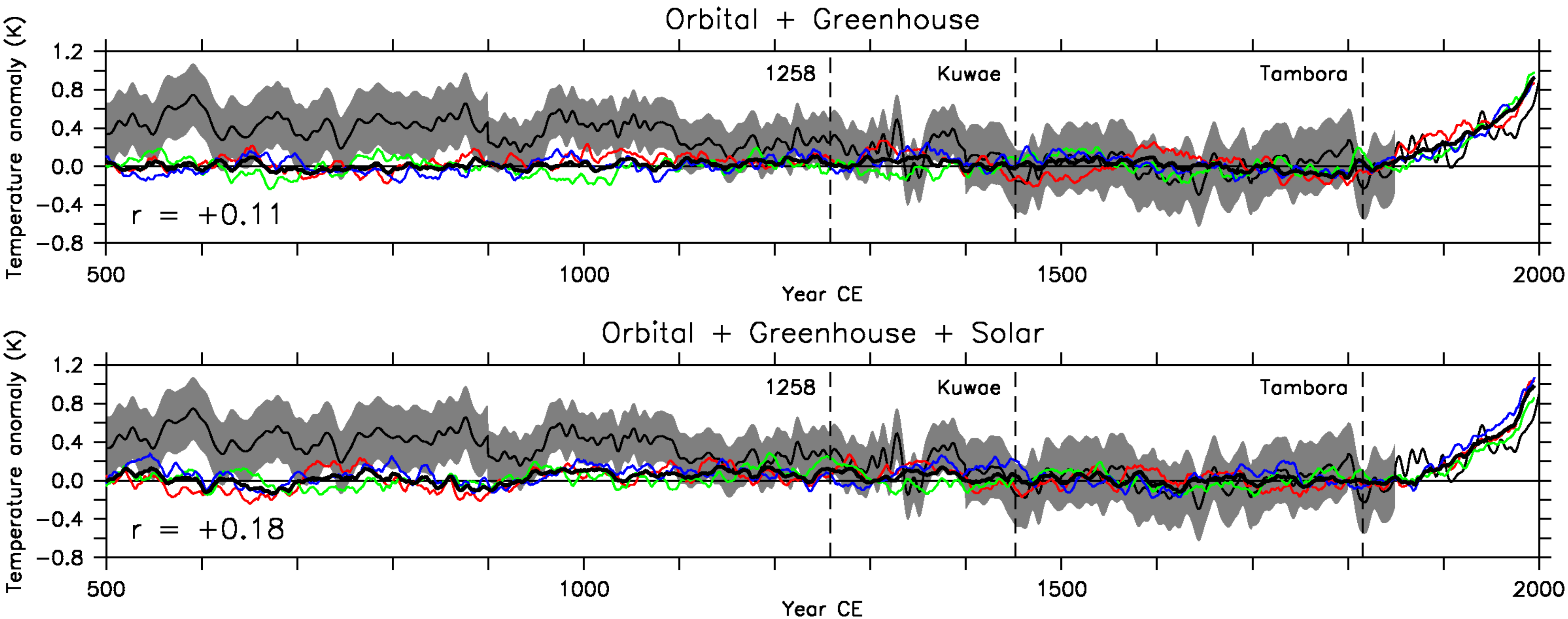
Boundary conditions over the past 2000 years



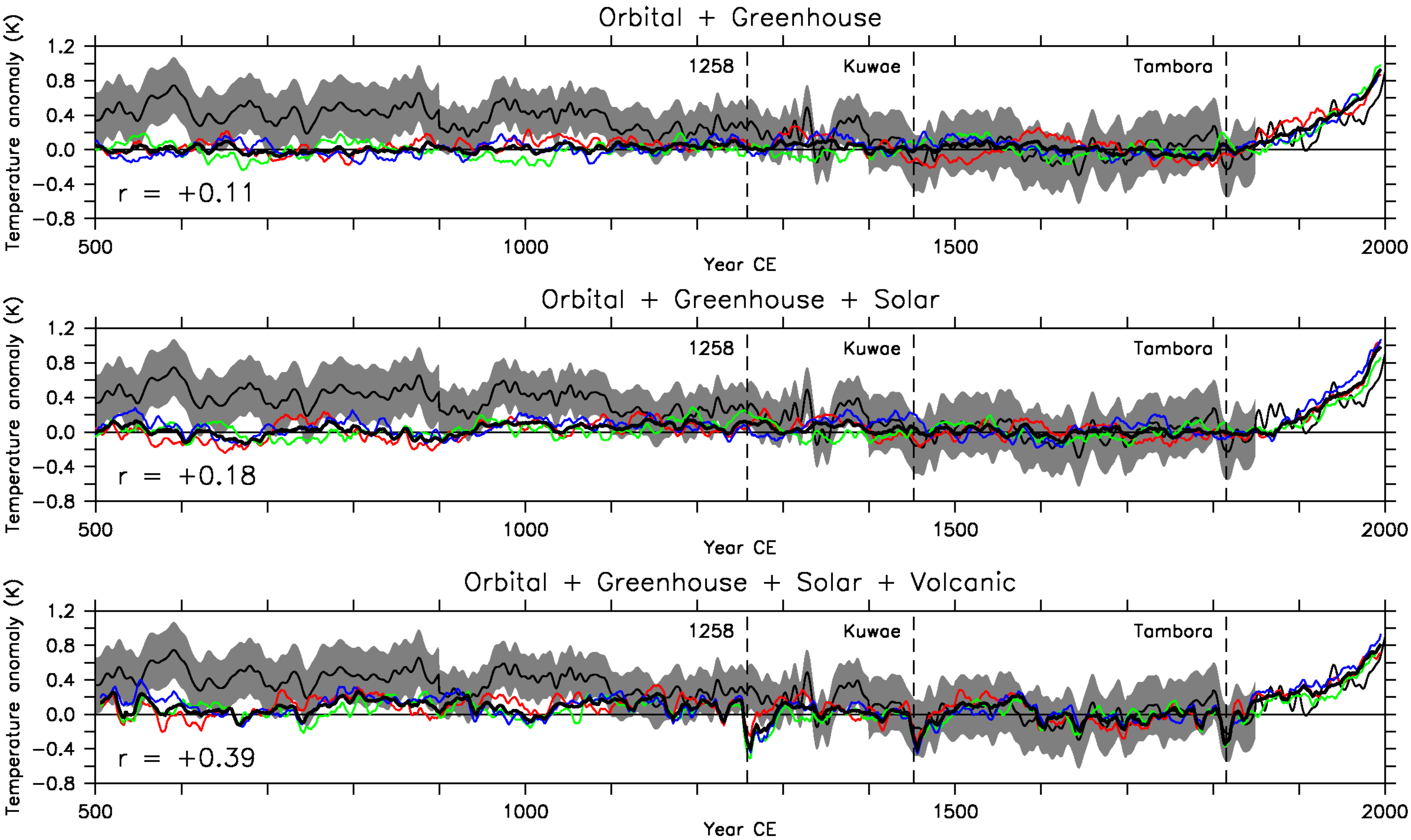
Annual-mean Northern Hemisphere temperature



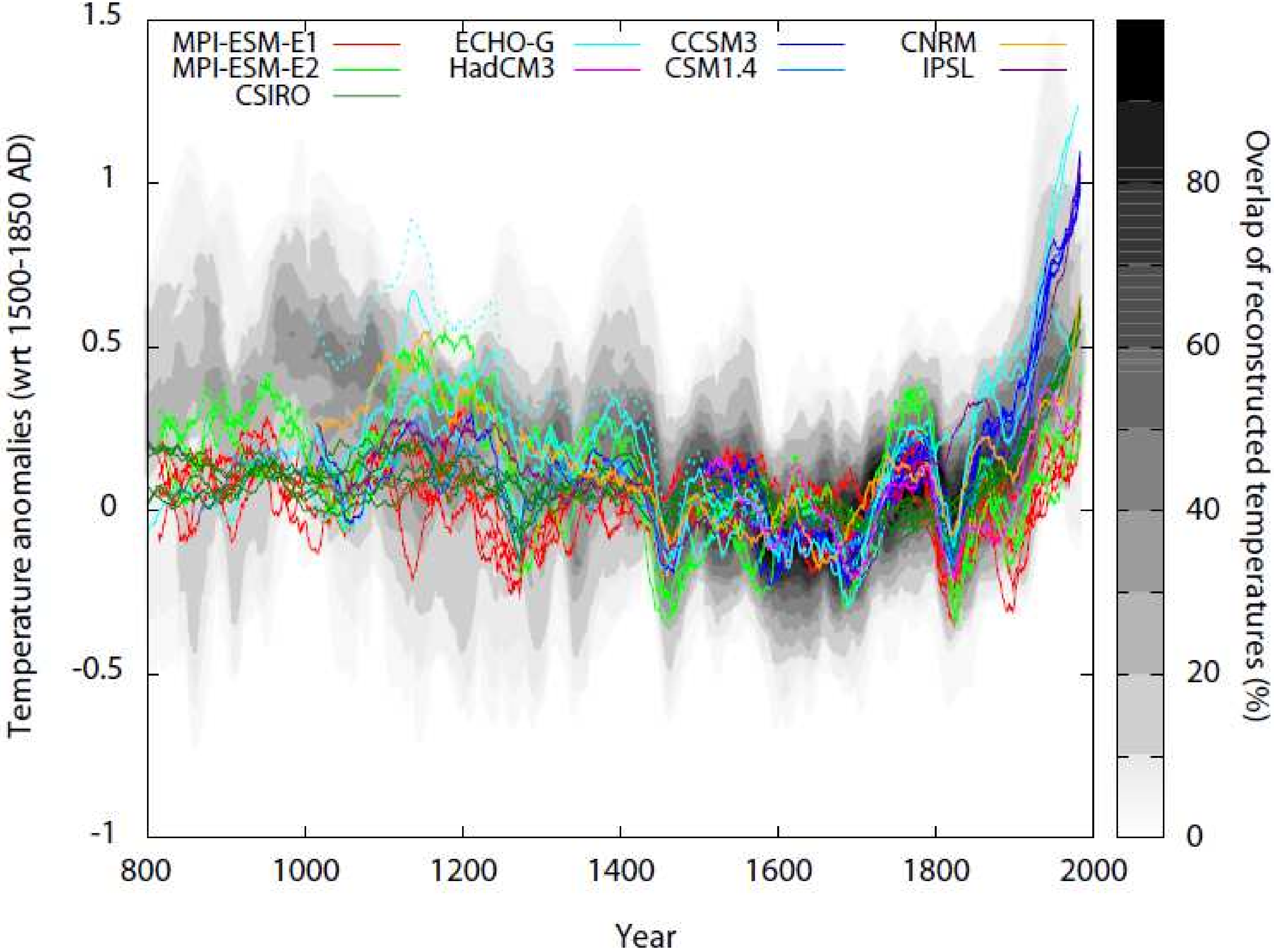
Annual-mean Northern Hemisphere temperature



Annual-mean Northern Hemisphere temperature

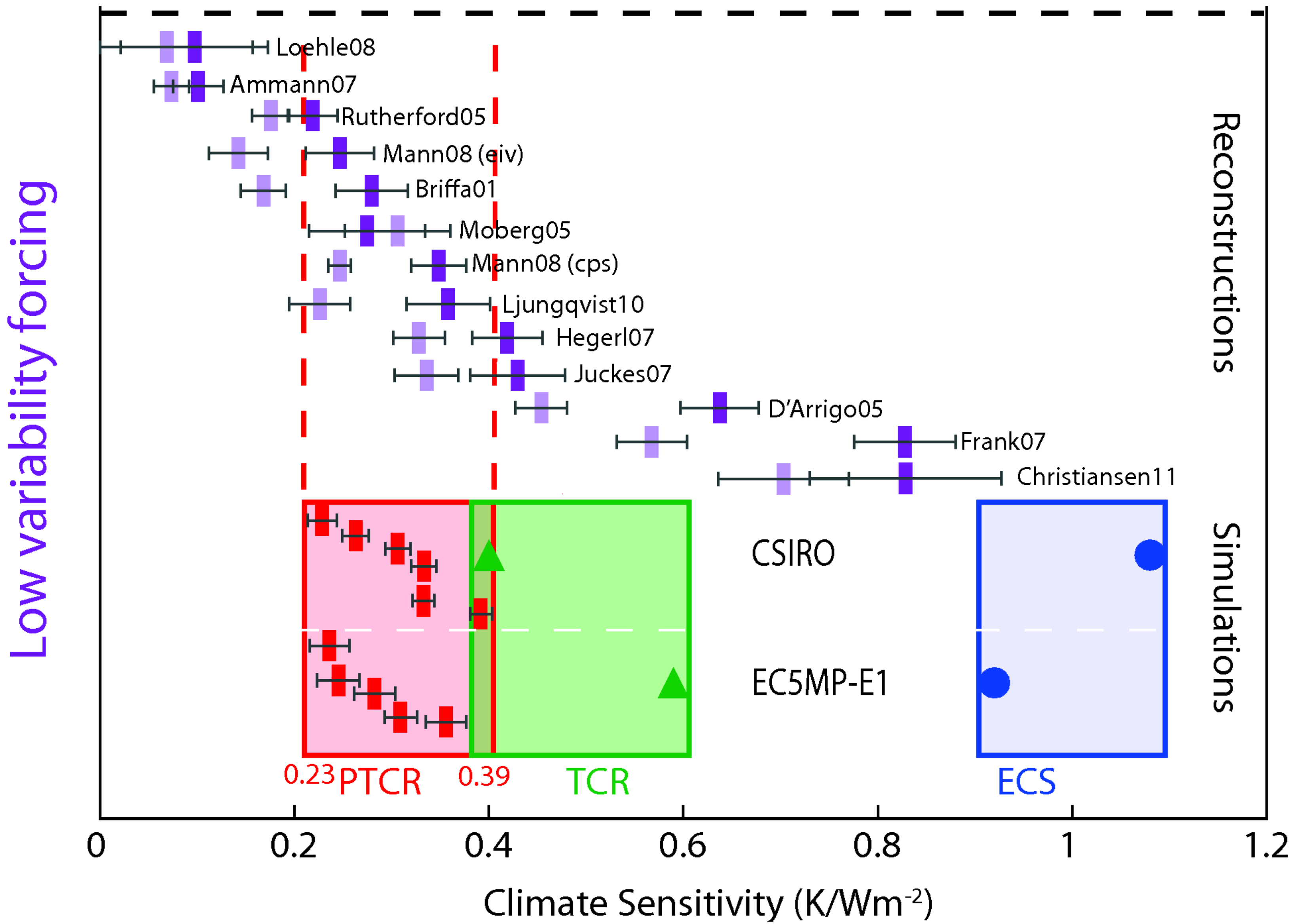


Annual-mean Northern Hemisphere temperature



Courtesy of Laura Fernández Donado, Universidad Complutense de Madrid

Palaeoclimate Transient Climate Response



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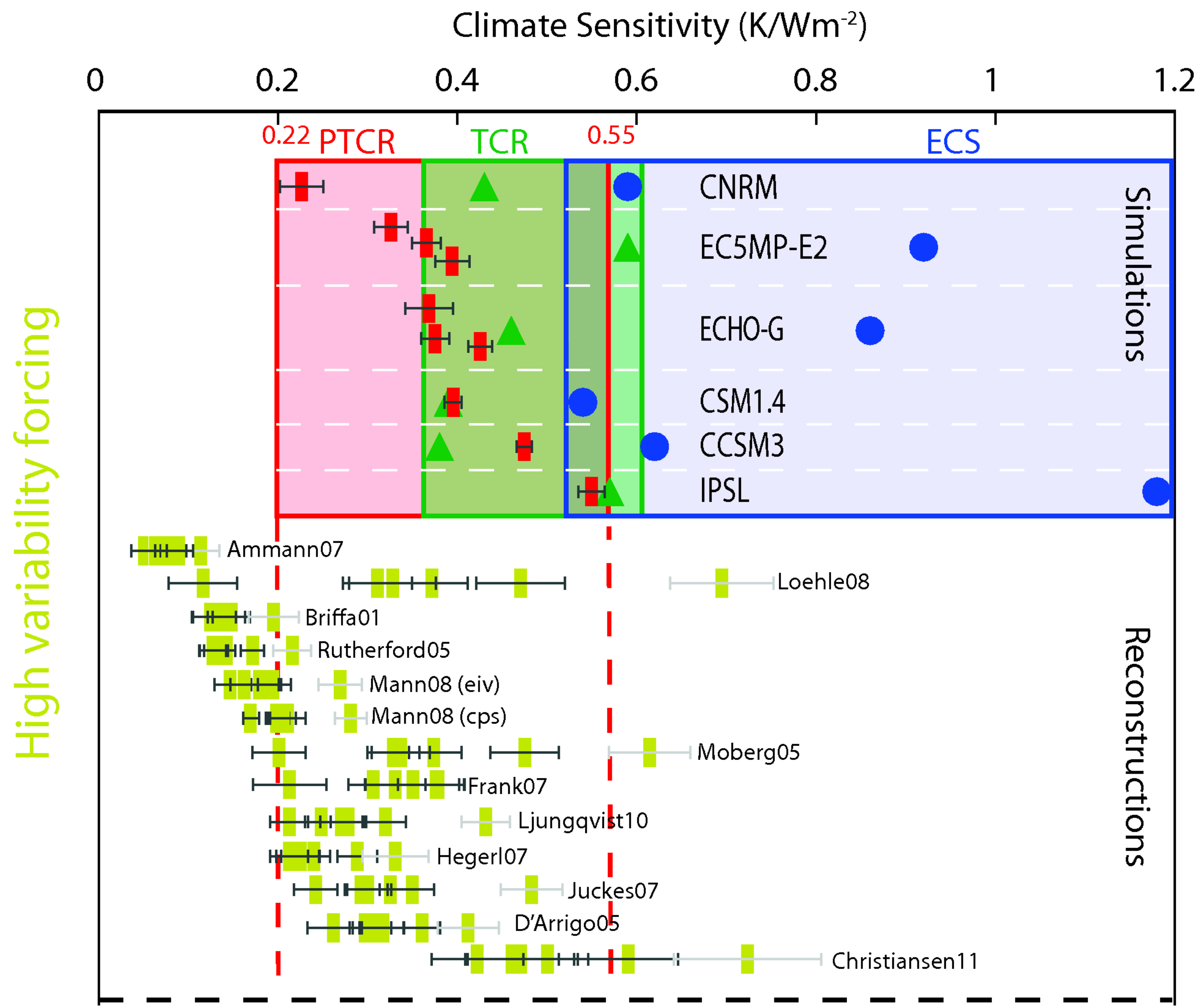
Palaeoclimate Transient Climate Response



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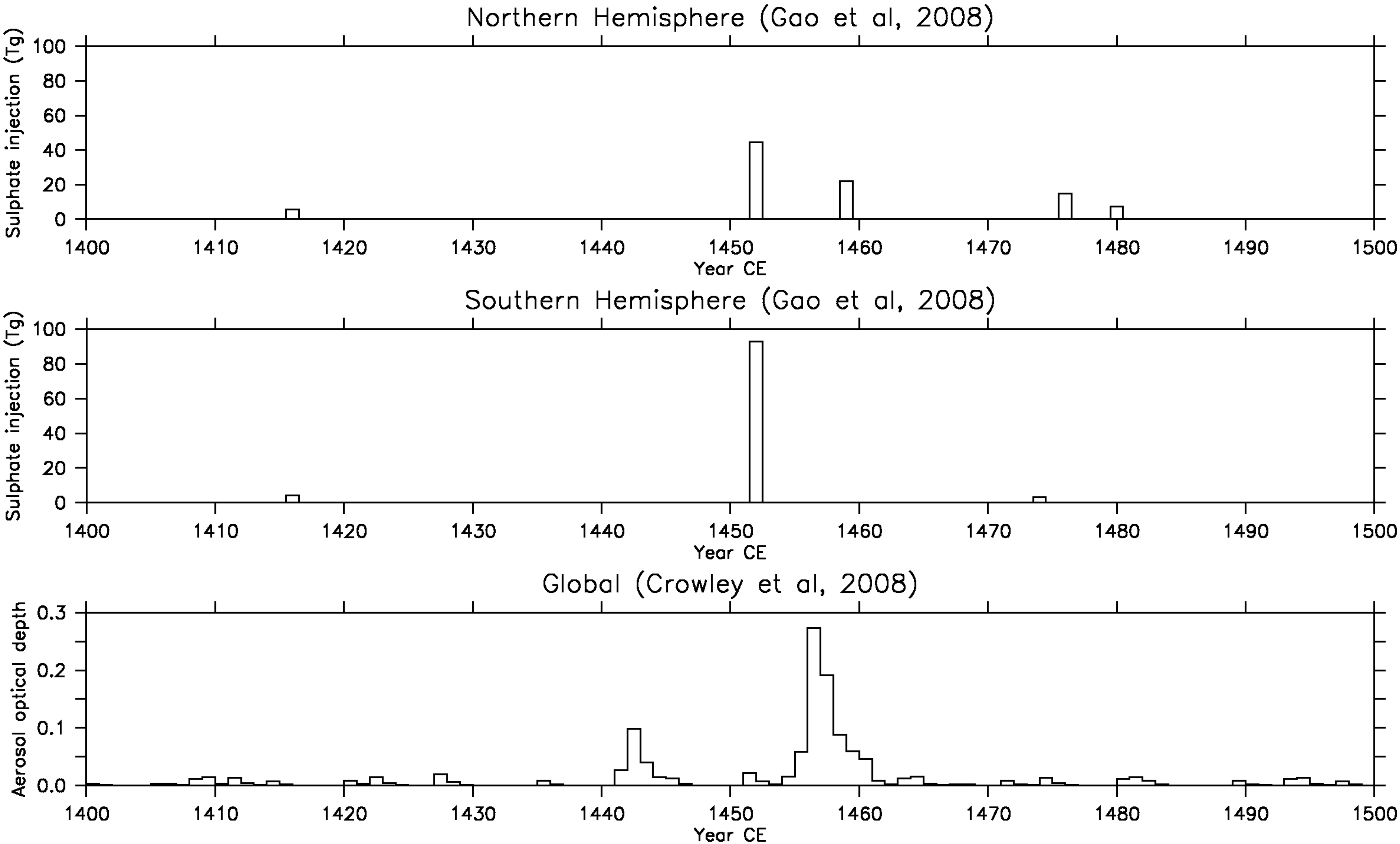
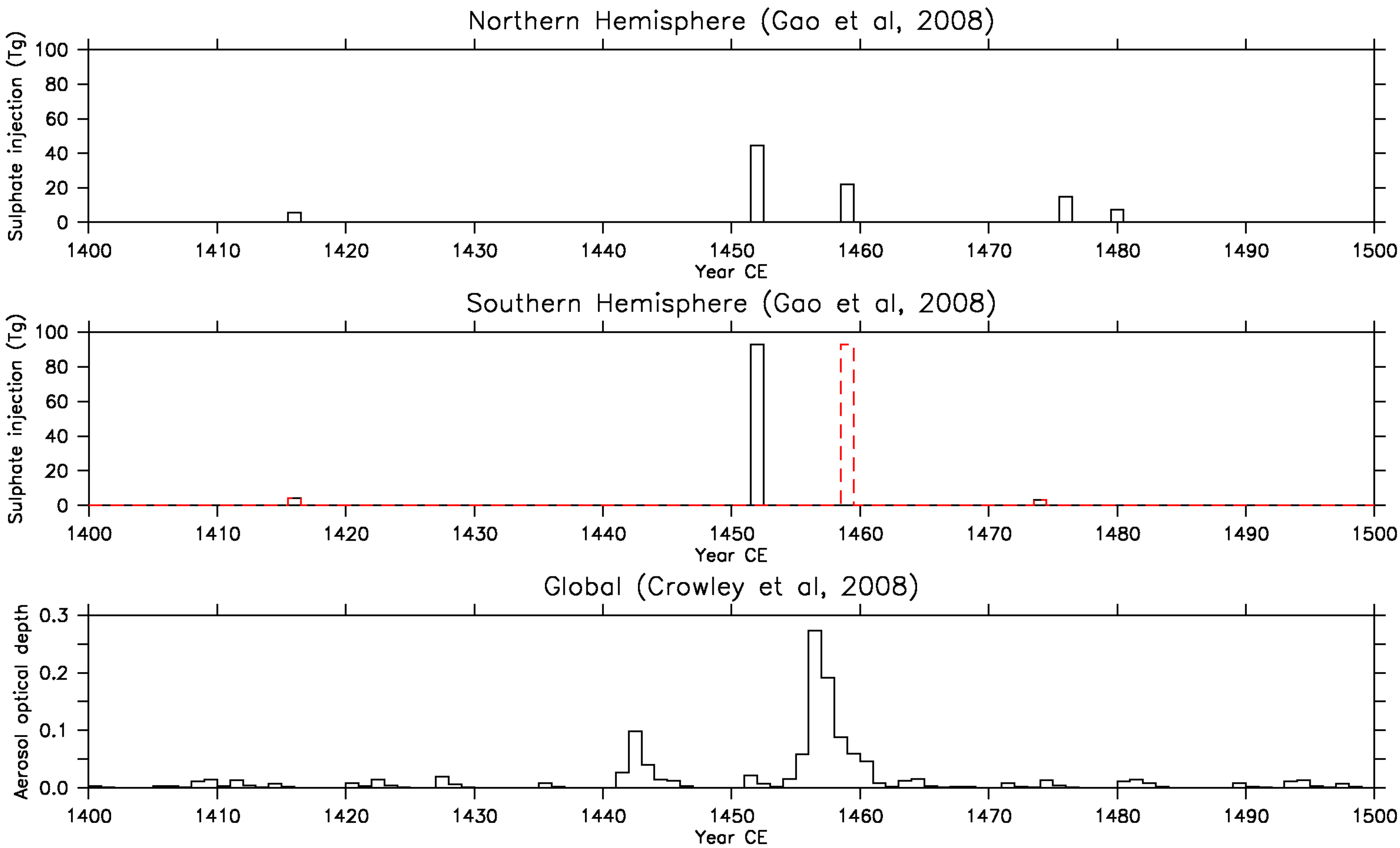
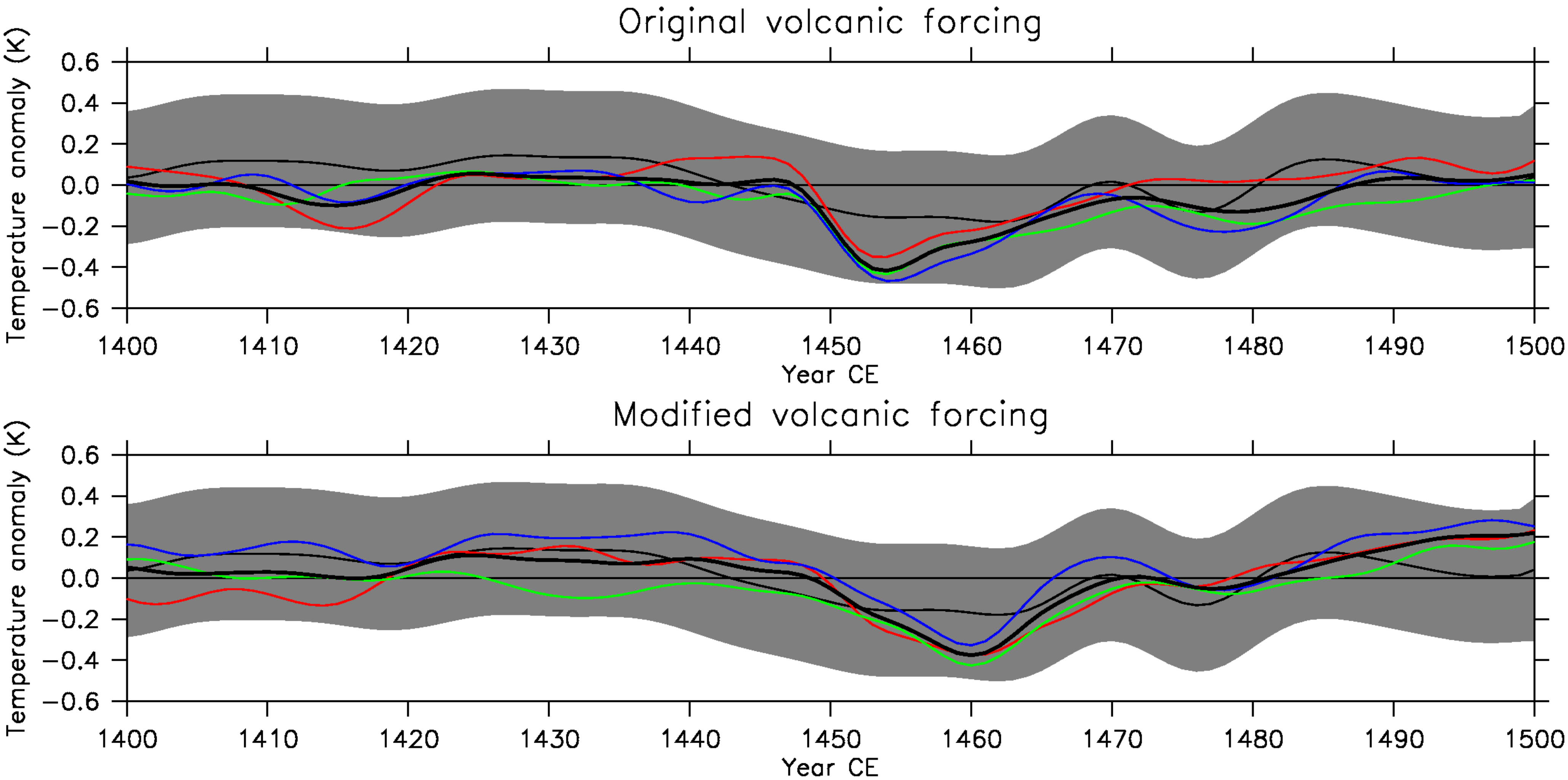
Volcanic forcing during the 15th century



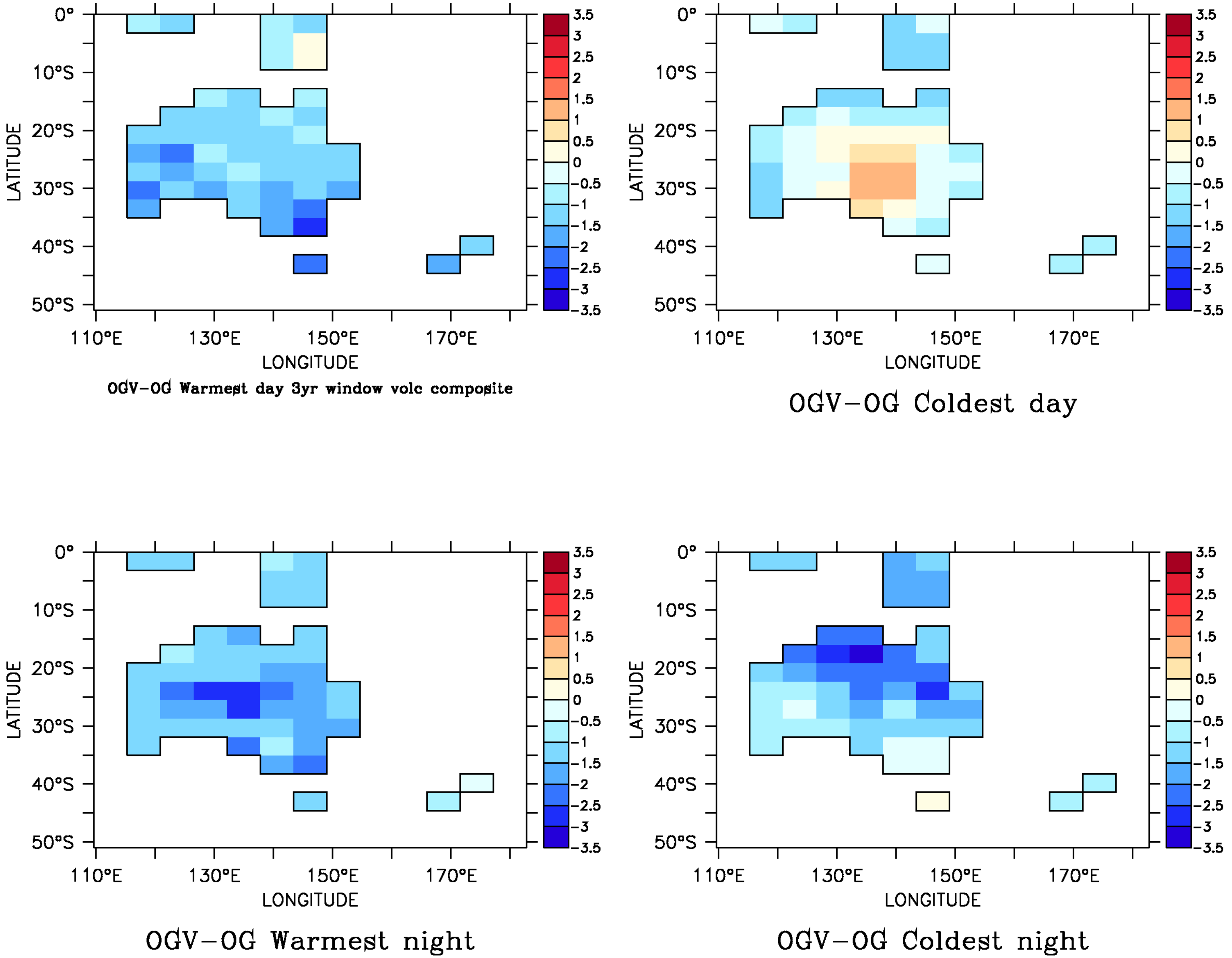
Volcanic forcing during the 15th century



NH temperature during the 15th century



Australalasian climate extremes



Courtesy of Tanya Lippmann, UNSW

Conclusions

- Volcanic eruptions can have catastrophic social and economic impacts. However, the industrial era has been a period of relatively low volcanic activity, so we don't know the impact that a major eruption would have today.
- There is evidence that volcanic eruptions can push the climate system past tipping points.
- Volcanoes appear to have been the dominant source of forced climate variability over the last millennium.
- Volcanic eruptions offer the potential to directly constrain the transient climate response. However, this requires much more accurate reconstructions of past eruptions and their impacts.