Winter amplification of the European Little Ice Age cooling by the subpolar gyre

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Take-home messages

1. During the Little Ice Age (LIA), Europe experienced much colder temperature anomalies in winter than in summer in the c. 16th–18th centuries, especially over Central and Northern regions, due to persistent, blocked atmospheric conditions.

2. The amplification of the winter cooling arouse from sea ice expansion and reduced air–sea heat flux in the Nordic and Barents seas driven by a multicentennial weakening in the northward oceanic heat transport through the Iceland–Scotland Ridge. These anomalous oceanic conditions were mostly decoupled from the European atmospheric variability in summer.

3. This reduction in the oceanic heat transport was driven by a weakening of the subpolar gyre, with no clear evidence of a leading role of the AMOC or NAO.

1. Experimental setup

Climate model simulations: MPI-ESM-P

- **Atmosphere GCM ECHAM-6:** T63 horizontal resolution; 47 vertical levels.
- **Ocean-sea ice GCM MPIOM:** 1.5º horizontal resolution (up to 15 km near Greenland, where the northern grid pole is situated); 40 vertical levels.

Simulations: Ensemble of three last millennium runs, following the CMIP5/PMIP3 protocol:

- *Past1000-R1, **-R2**, and -R3* [Jungclaus et al., 2014]
- *PiControl* (PiC): constant 1850 CE boundary conditions

European temperature reconstructions

- Summer: Luterbacher et al. [2016] (LUT16)
- *Winter:* Luterbacher et al. [2004] (LUT04)

2. Reconstructed and simulated European temperatures during the past millennium: Winter amplification of the LIA cooling

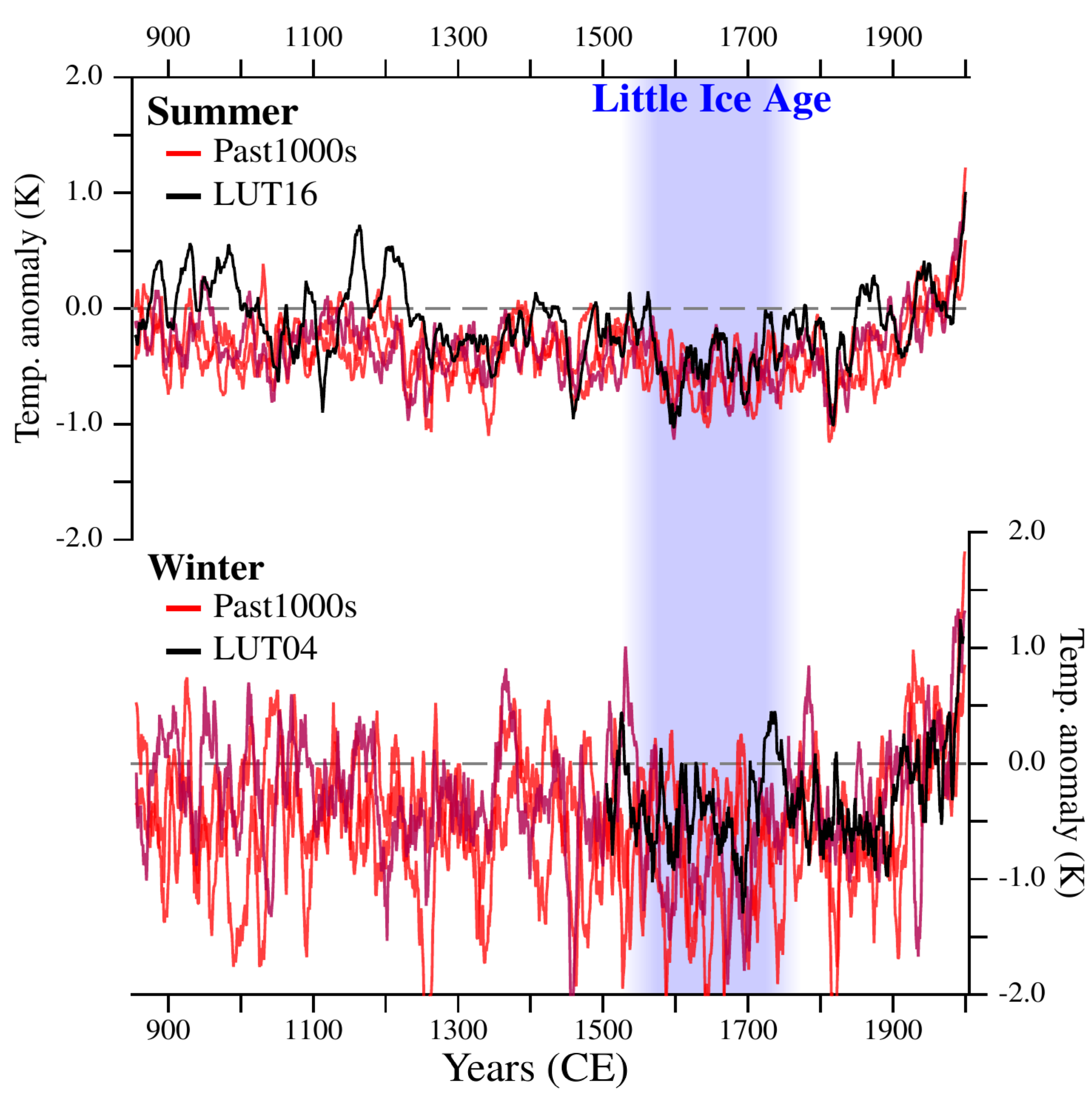


Fig. 1 (above) European temp. anomalies (wrt 1901–1990 CE) averaged over the land-only region shown in **Fig. 2**, with an 11-year running mean. Past1000-R2, which shows the highest correlation coefficient with both reconstructions, is shown in a darker color.

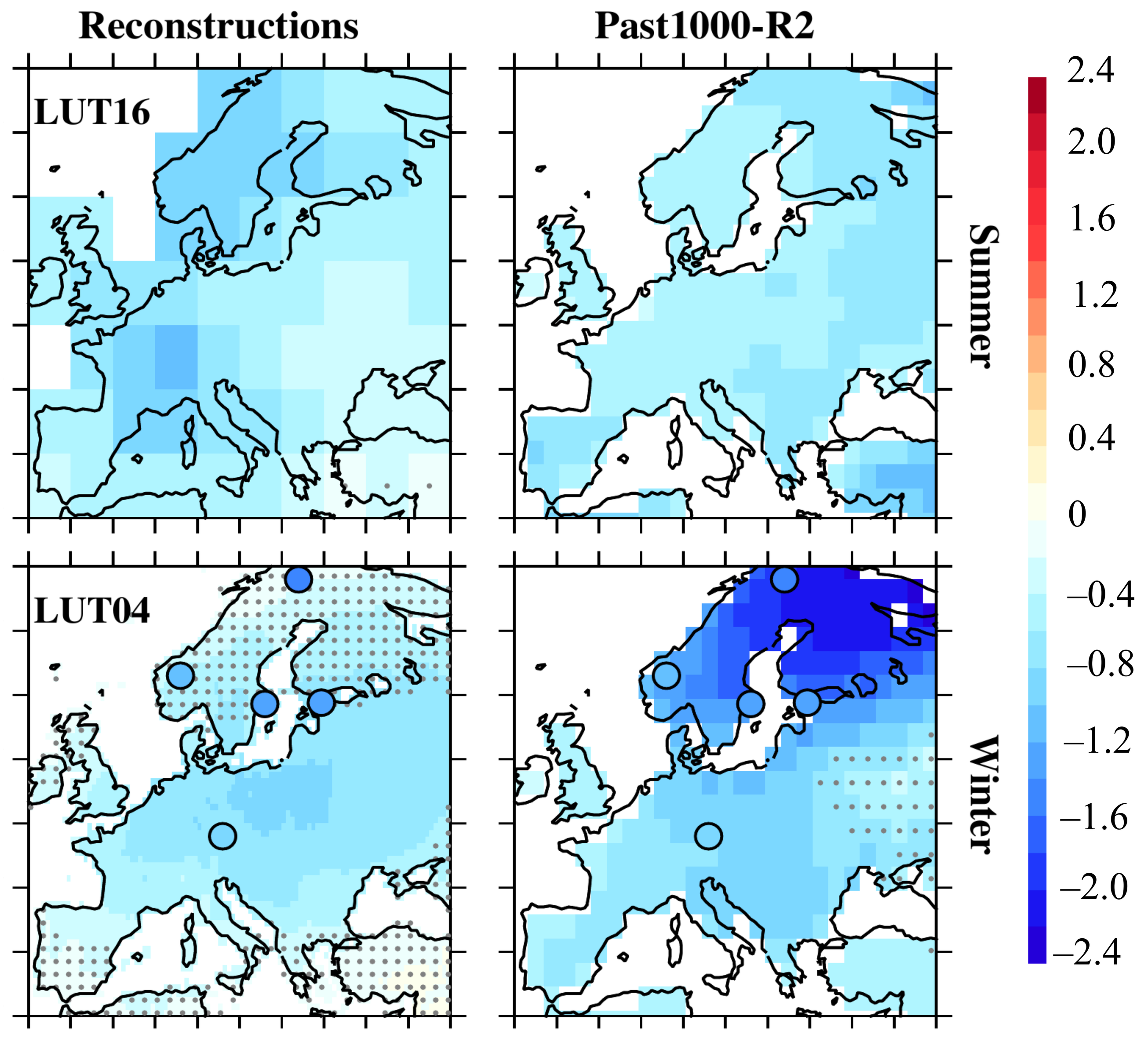


Fig 2. (above) Land temp. anomalies between the periods 1575–1724 CE (*shading* in **Fig. 1**) and 1901–1990 CE. *Stippling*: statistically non-significant anomalies at the 5% level. *Circles*: locations of independent winter temperature reconstructions; their color accounts for the corresponding temperature anomaly.

– Agreement between the simulations and the reconstructions largely within the intra-ensemble range in each season
– Stronger influence of specific regional dynamics on the evolution of the European climate in winter than in summer
– Regional impact particularly important over Northern and Central European regions: reconstructed and simulated winter cooling strongly amplified during the LIA's coldest period, in the c. 16th–18th centuries

3. Linking the European LIA winter cooling amplification to a subpolar gyre weakening

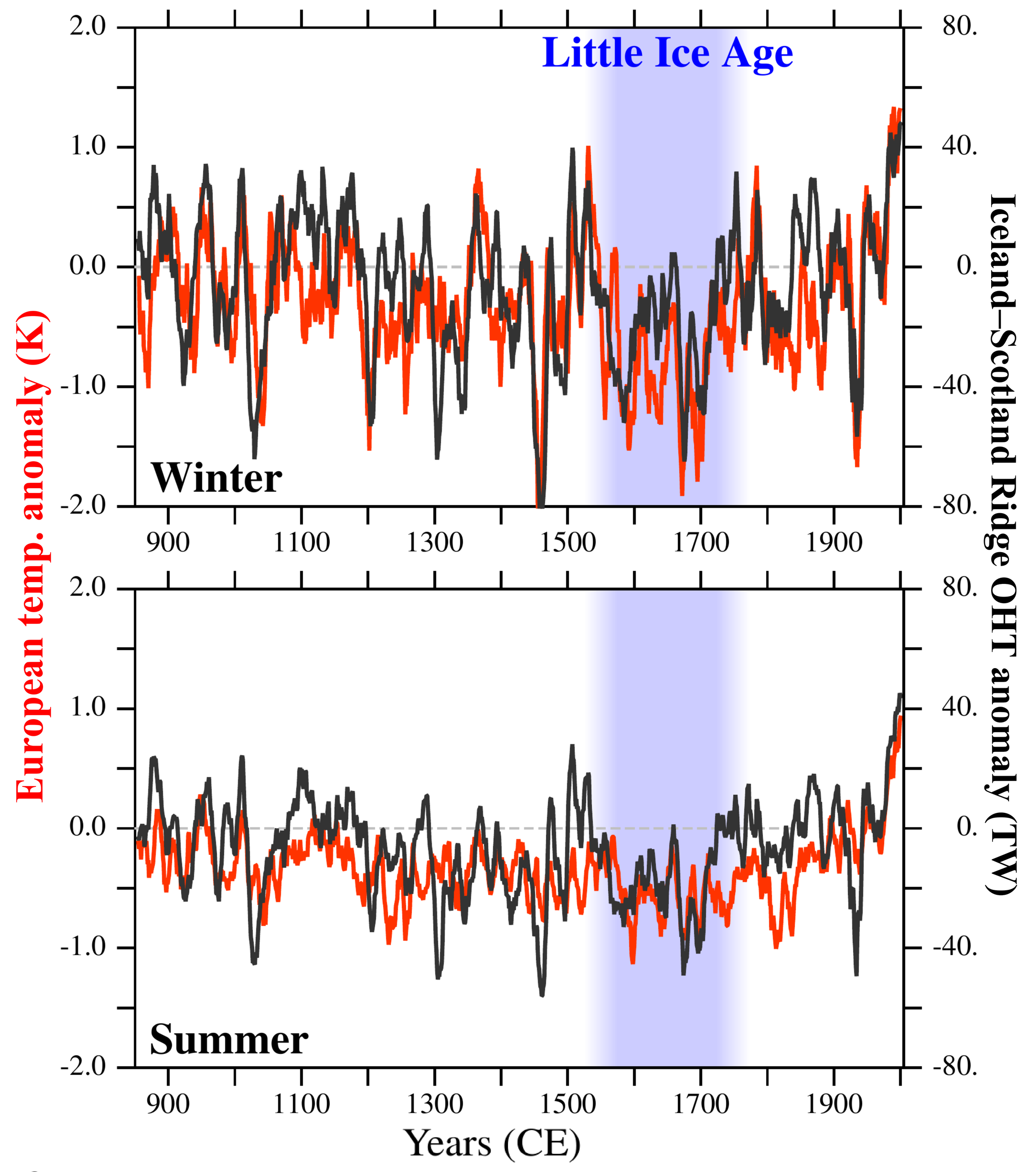


Fig. 3 (left) In Past1000-R2, European temp. (from **Fig. 1**) and Iceland–Scotland Ridge oceanic heat transport (ISR-OHT) anomalies (wrt 1901–1990 CE), with an 11-year running mean.

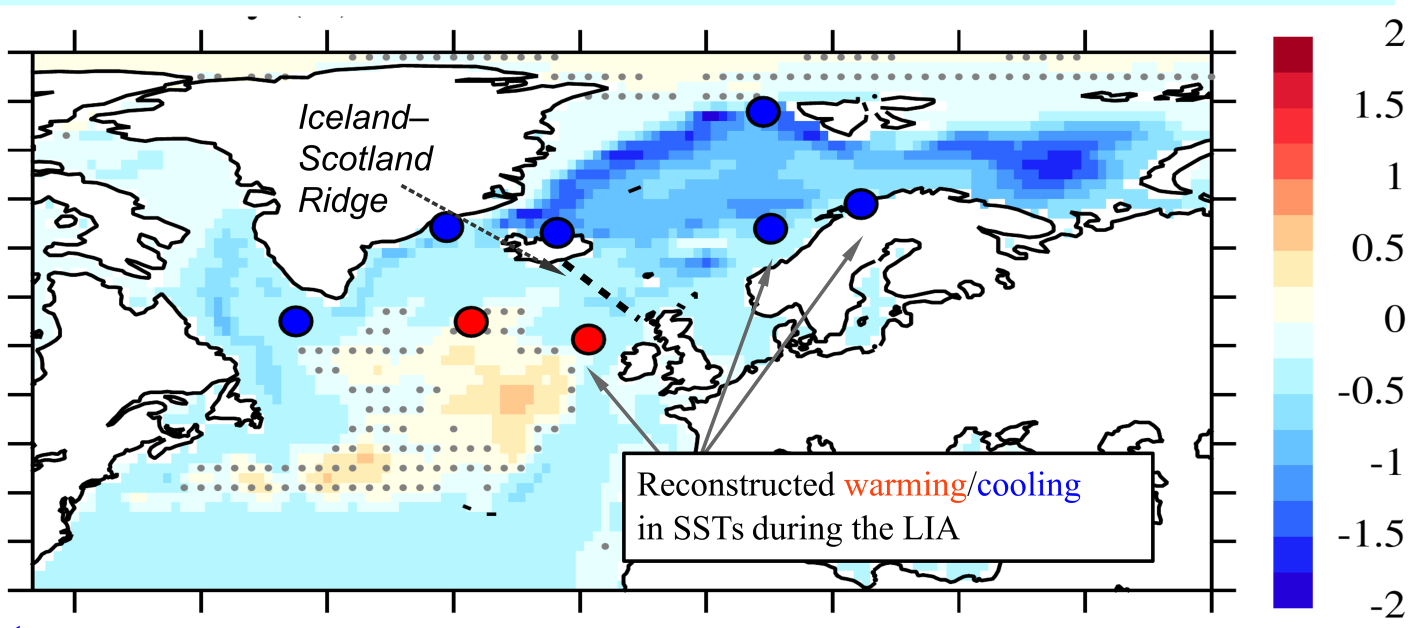


Fig. 4 (right) In Past1000-R2, SST anomalies between the period 1575–1724 CE and the PiC climatology. *Stippling*: statistically non-significant anomalies at the 5 % level.

European LIA cooling linked to a multicentennial reduction in the ISR-OHT and the associated ocean cooling in the Nordic and Barents seas, especially in winter

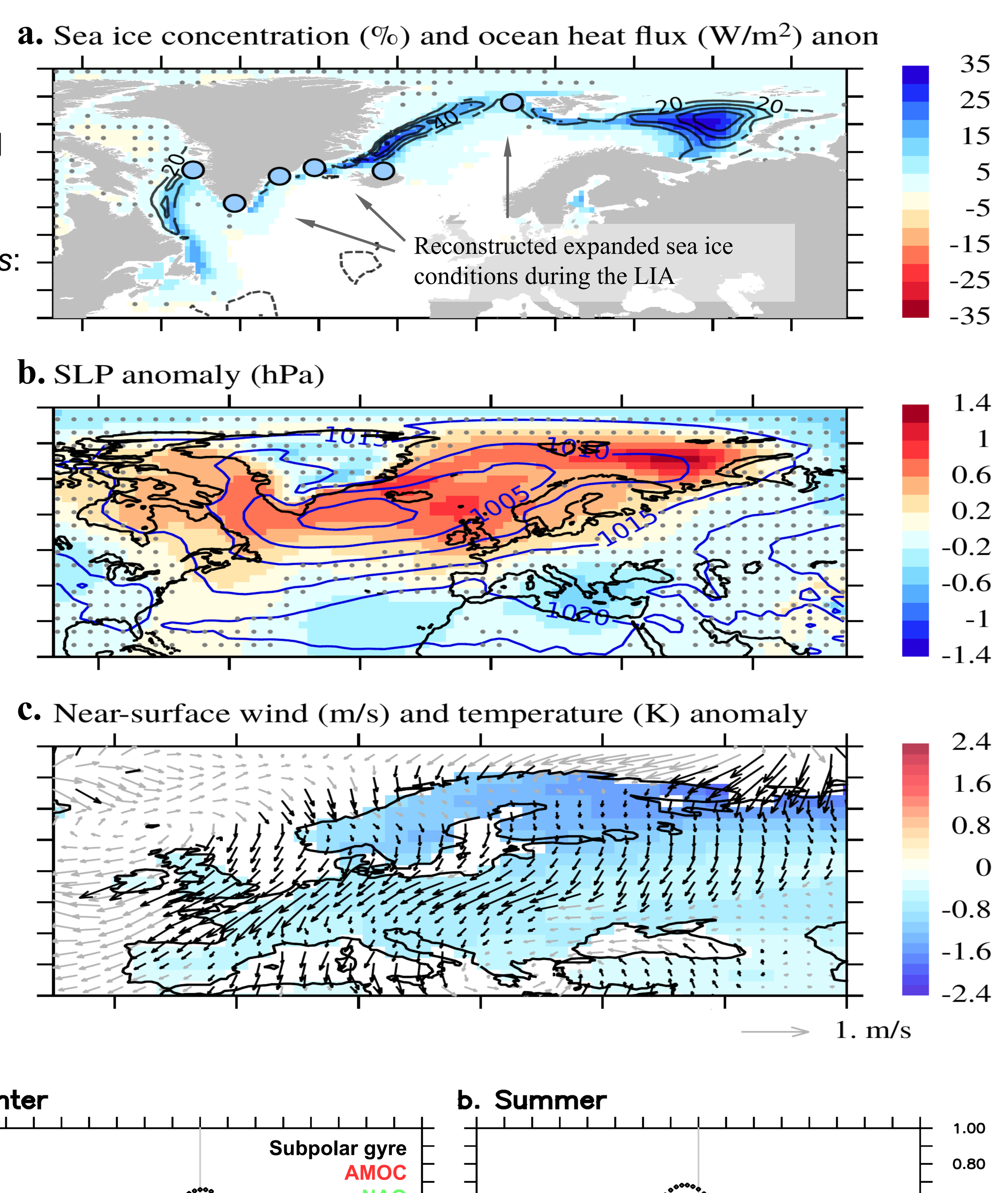


Fig. 5 (right) In Past1000-R2, anomalies between the period 1575–1724 CE and the PiC climatology in **(a)** sea ice concentration (*shading*) and ocean surface downward heat flux (*contours*), **(b)** SLP (*shading*; PiControl climatology in *contours*), and **(c)** near-surface winds (arrows) and temperature (*shading*). *Stippling/gray arrows*: statistically non-significant anomalies at the 5% level.

European winter cooling amplification during the LIA caused by persistent blocked atmospheric conditions and anomalous north–north-easterlies in response to oceanic cooling and sea ice growth. The amplifying mechanism inactive in summer.

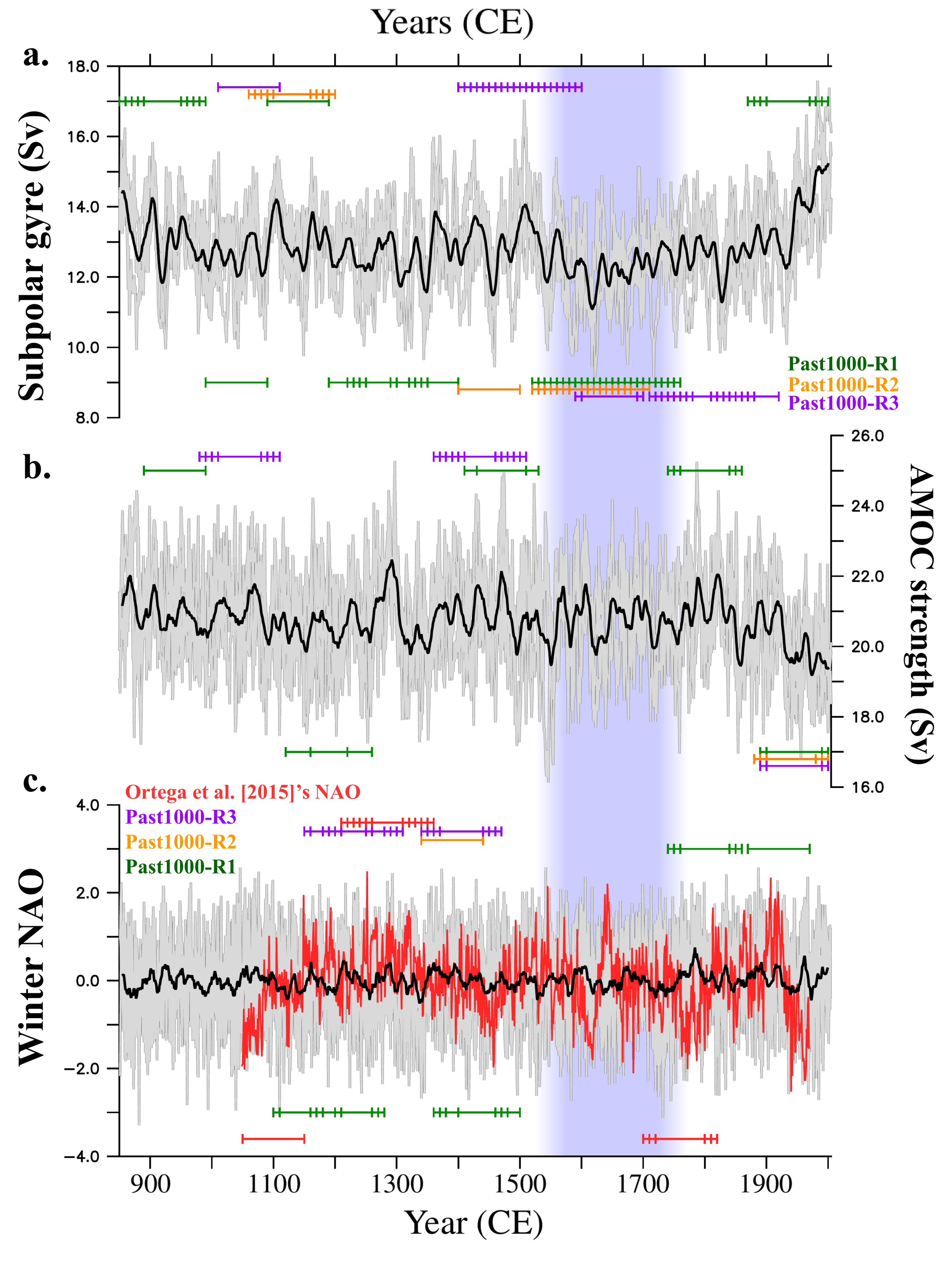
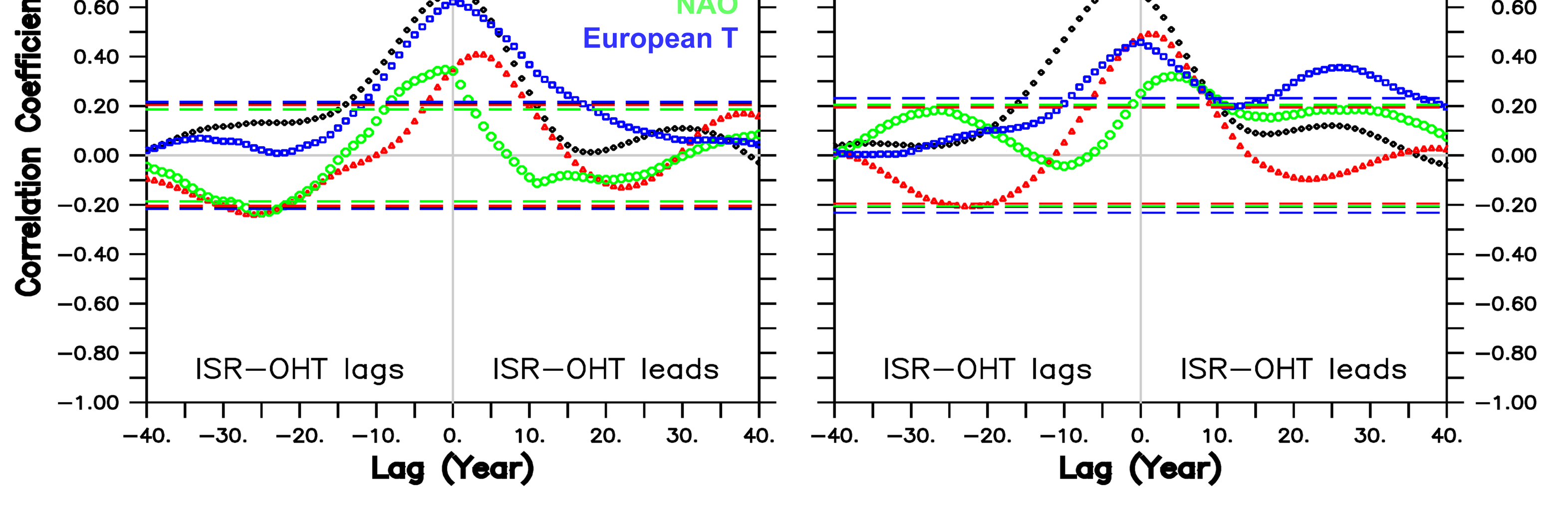


Fig. 6 (left) Subpolar gyre **(a)** and AMOC **(b)** strengths. **(c)** Winter NAO. *Gray and black lines*: yearly values in the three Past1000s and the 11-year running mean of the ensemble mean respectively. Also in **(c)**, NAO reconstruction by Ortega et al. [2015] in *red*. *Horizontal bars above (or below) the series*: centuries with positive (or negative) mean values significantly (p < 0.1) different from the PiControl climatological mean, or from zero for the reconstructed NAO.

Fig.7 (right, below) In Past1000-R2, cross-correlation profiles between the ISR-OHT and subpolar gyre and AMOC strength, the NAO, and the European temp, having first applied an 11-year running mean, and for the preindustrial period (850–1849 CE). *Horizontal dashed lines*: significances at the 5% level.



ISR-OHT reduction and the European winter cooling amplification linked to a subpolar gyre weakening during the LIA.

No clear evidence of a leading role of the AMOC or NAO in driving ISR-OHT variability; AMOC or NAO anomalous periods not persisting over the LIA

References
Jungclaus, et al., [2014] Climate of the Past, 10, 2201-2213.
Luterbacher, et al., [2004] Science 303.5663: 1499-1503.
Luterbacher, et al., [2016] Environmental Research Letters 11.2: 024001.
Ortega, et al., [2015] Nature 523.7558: 71-74.