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Spring temperature variability relative to the North Atlantic Oscillation and sunspots — A correlation analysis with a Monte Carlo implementation

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Abstract

A reconstruction of past spring temperatures was analysed and compared to long-term records of the North Atlantic Oscillation (NAO) and sunspots. This palaeoclimate reconstruction, built previously using multiple proxy evidence of historical and natural sources from southwest Finland, explained approx. 70% of the instrumental temperature variance over a spring season (February–June) and covered the time period from 1750 to the present. Correlations between the NAO and sunspots appear markedly high and, based on Monte Carlo tests, statistically significant ($p<0.01$) since around 1925. Correlation between sunspots and temperatures appeared notably high over the past 50years, but this association could not be confirmed by the significance test. Correlations between the NAO and temperatures were high and statistically significant. However, the pre-1860s NAO–temperature correlations were lower than the correlations after that date. Previous studies have emphasized the possibility of enhanced solar forcing on NAO variability over the past 30–40years broadly operative on decadal scales (with so far unresolved explanatory mechanisms). Our results correlate with this view to a statistically significant extent ($p<0.01$) in the context of the past two centuries of regional climate variability. The NAO–temperature correlations were clearly stronger than the correlations between sunspots and temperatures. Moreover, the correlations were stronger between decadally filtered records. Consequently, the potential solar forcing on regional temperatures may have operated on decadal scales and been augmented by the NAO–temperature association.

Highlights

► We evaluate the role of external and internal forcings in temperature variability. ► We examine scales appropriate for solar and atmospheric oscillations. ► North Atlantic Oscillation drives the spring temperature variability. ► Solar forcing modulates the North Atlantic Oscillation in spring. ► Solar forcing on temperatures may have been augmented by the atmospheric pathway.

Introduction

Direct temperature observations show that Earth's average surface temperature has increased by three-quarters of a degree Celsius in the course of the last 100years (IPCC, 2007), but on smaller scales the view likely becomes more complex. Whereas a significant proportion of global warming is due to anthropogenic emissions of greenhouse gases, regional temperature variations exhibit a variety of linkages to internal modes of climate variability (Wanner, 2005). In Finland, the mean temperature has increased noticeably since the beginning of systematic meteorological observations150 years ago, but spring temperatures have warmed more than the temperatures of the other seasons (Tuomenvirta, 2004). These phenomena can tell us about the complexity of the climate system on restricted geographical scales, especially since temperature and precipitation variations in Finland are known to be forced to a certain degree by internal climate dynamics due particularly to the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) (Hurrell, 1995, Tuomenvirta et al., 2000, Uvo and Berndtsson, 2002, Helama et al., 2008). Both the NAO and the AO (also referred to as Northern Annular Mode) are major internal modes of climate variability in the North Atlantic (Hurrell, 1995, Thompson and Wallace, 1998, Thompson and Wallace, 2000, Hurrell et al., 2001). The NAO and the AO are frequently used to describe variations in the atmosphere over the study area and northwestern Europe (Hurrell, 1995, Thompson and Wallace, 1998, Thompson and Wallace, 2000, Hurrell et al., 2001, Marshall et al., 2001). These variations are characterized by the oscillation of atmospheric masses producing large-scale changes in the mean wind speed and direction over the North Atlantic. The AO is characterized by the alternation of atmospheric masses between the Arctic and the middle latitudes, and it accounts for a significantly larger fraction of the variance in Northern Hemisphere surface air temperatures than the NAO does (Thompson and Wallace, 1998, Thompson and Wallace, 2000).

The history of temperatures in Finland was recently complemented by Holopainen et al. (2009), who used multi-proxy evidence to reconstruct the temporal evolution of regional spring temperatures (February–June). Their reconstruction spanned over the past 250years (since 1750) and focused on spring temperature variability. The reconstruction showed positive correlations between the NAO and temperatures but also, although to a lesser extent, between variations in solar activity and temperatures (Holopainen et al., 2009). In that study, the positive correlation coefficients between the NAO (1824–1979) and temperatures and between the sunspots and temperatures (1865–1979) were 0.32 and 0.12, respectively. Similar results are becoming of primary interest, as a series of recent studies have implied the possibility that at least the recent variations in the NAO and the AO might have been driven by solar activity variation occurring on a decadal scale (Bucha and Bucha, 1998, Shindell et al., 2001, Kodera, 2002, Kodera, 2003, Thejll et al., 2003, Lukianova and Alekseev, 2004, Palamara and Bryant, 2004, Kuroda et al., 2008). Accordingly to the model of Shindell et al. (2001), regional temperature changes occur with the index state of the NAO/AO when the solar irradiance changes, this linkage leading to corresponding temperature changes over the Northern Hemisphere continent. These connections are commonly ascribed to winter conditions but it has also been shown that the winter NAO can widely influence the spring and even the summer atmosphere, the positive wintertime NAO bringing warmer summertime surface air temperatures over circumpolar regions in northern Eurasia and subarctic North America (Ogi et al., 2003a, Ogi et al., 2003b). Topically, given that the described association between solar and atmospheric changes is strong enough to produce noticeable changes in the surface climate of selected spatial domains, one could assume that this type of a linkage exists in areas such as Finland, due to the aforementioned correlation between the NAO and regional temperatures.

Consequently, the recently compiled and annually-resolved reconstruction of spring temperatures (Holopainen et al., 2009) would offer an excellent opportunity to analyse regional climate variability on multi-year to multi-decade timescales over the past two and half centuries. The source region of the reconstruction makes it central to other long temperature datasets from adjacent locations in southern

Scandinavia and northwestern Russia (Moberg and Bergström, 1996, Jones and Lister, 2002, Leijohufvud et al., 2008) and to their evaluation. Moreover, the study region provides a relatively rich source of documentary archives with information on historical agriculture, human ecology and reproduction (Holopainen and Helama, 2009, Rickard et al., 2010). Providing this information with a wider palaeoclimatic context makes for a fruitful target for interdisciplinary research. Previous studies examining the associations between solar activity, the NAO/AO and the climate of northern Europe and Nordic areas have concentrated on winter phenomena, whereas spring conditions have received considerably less attention with only few studies (Yoo and D'odorico, 2002, Ogi et al., 2003a, Ogi et al., 2003b). In these regards, the temperature record (Holopainen et al., 2009) was compared to the series of the NAO index (since 1821) and the observations of sunspots (since 1750). Our objectives included to (I) compute the correlations between the sunspots and the NAO indices to detect potential linkage between the potential external climatic forcing and internal climate variability, (II) calculate the correlations between the NAO indices and the temperatures to determine the strength of the coupling, and (III) correlate the sunspots and temperatures to find out whether the external climatic forcing can be directly detected from reginonal temperatures. Our fundamental aim was to increase and enhance information regarding regional climate variability in the context of internal and external forcings, topically such as the NAO and the activity of the Sun, and to advance critical understanding of the evolution of regional spring temperature perturbations.

Section snippets

Palaeoclimate reconstruction

Spring temperatures (February–June) were reconstructed in a previous study using a network of multi-proxy evidence from south-western Finland since 1750 (Holopainen, 2006, Holopainen et al., 2009). The proxy records used in this study were the ice break-up record of the Aura River (Johansson, 1932), the Baltic Sea ice extent (Seinä and Palosuo, 1993, Seinä and Palosuo, 1996, Seinä et al., 2001), the plant phenological index (Holopainen et al., 2006) and the annual varve thickness in Lake…

Results

The sunspot record was dominated by the classical solar variability but this variation was superimposed by a transient low number of sunspots during the early 19th century and by an increase in sunspots since the mid-1940s (Fig. 1, Fig. 2). Albeit the number of sunspots has undergone a change that appears as a slight decline since the early 1990s, their current number has nevertheless remained higher than during any other interval before the aforementioned rise in 1940s (Solanki et al., 2004).…

Discussion

Temporal changes in the climatic components can be analysed reasonably in terms of forcing and response. External forcing, such as the changing intensity of solar radiation, can cause many different responses among the various internal components of the climate system, for example the NAO and the AO. Changes in some of these components can then further perturb the climate through the action of feedbacks. If climate forcing occurs in cycles, differing cyclic responses in the climate system can…

Conclusions

Statistical analyses were performed for the reconstruction of spring temperature (February–June) variations in Finland, sunspot records and the NAO index. These data were studied in terms of forcing and response in the climate system over an extensive period of time, ultimately since 1750. Our results agreed with previous studies in showing that solar activity and the NAO can be linked statistically, at least over the latter part of the 20th century (objective I in the introduction). We found…

Acknowledgements

The algorithms of Macias Fauria et al. (2010) and Macias-Fauria et al. (2012) can be downloaded via http://www.helsinki.fi/science/dendro/reconstats.html↗. The sunspot data was downloaded via ftp://ftp.ngdc.noaa.gov/STP↗ and the data of the North Atlantic Oscillation index via http://www.cru.uea.ac.uk/cru/data/↗. The authors acknowledge the contributors of these sources. This study was supported by Koneen Säätiö and the Academy of Finland (number 122033, 217724).…

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>
> …Since solar activity influences most oceanic modes of variability, it therefore likely contributes indirectly in a non-linear way to changes in African rainfall. A link to solar activity changes has been reported for NAO (Helama and Holopainen, 2012; Kodera, 2002; Thiéblemont et al., 2015), AMO (Knudsen et al., 2014; Malik et al., 2018; Muthers et al., 2016; Otterå et al., 2010; Wang et al., 2017a), IOD (Kodera et al., 2007; Nugroho, 2007), PDO (Maruyama et al., 2017; Yamakawa et al., 2016), and ENSO (Huo and Xiao, 2016; Kirov and Georgieva, 2002; Kodera, 2005; Wallace, 2019). Haywood et al. (2013) suggested that sporadic volcanic eruptions in the Northern Hemisphere strongly influenced the Atlantic SST gradient and caused Sahelian drought.…

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> …Other authors consider AMO variability to be mostly controlled by anthropogenic aerosol emissions and volcanic activity (e.g. Booth et al., 2012). The quasi-decadal NAO variability seems to be synchronized by the solar Schwabe cycle (Helama and Holopainen, 2012; Kodera, 2002; Thiéblemont et al., 2015). NAO+ (NAO-) typically lags the solar maximum (minimum) by a few years, possibly due to accumulation and memory effects in the Atlantic (Andrews et al., 2015; Gray et al., 2013, 2016; Ma et al., 2018; Roy et al., 2016; Scaife et al., 2013; Sfîcă et al., 2015; Sjolte et al., 2018; Thiéblemont et al., 2015; Zhou et al., 2014).…

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