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Possible effects of atmospheric teleconnections and solar variability on tropospheric and stratospheric temperatures in the Northern Hemisphere

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ABSTRACT

Possible relationships between tropospheric and stratospheric temperatures in the Northern Hemisphere and atmospheric oscillations, solar and geomagnetic activity are described, using correlation analysis. The dependence of correlations on season, solar activity level and phase of the Quasi Biennial Oscillation (QBO) is also investigated. An important finding is that the variability of the hemispheric tropospheric temperature is well connected to the Scandinavian Pattern, to the Pacific North American teleconnection and less with the North Atlantic Oscillation. There is also a possible link with the Southern Oscillation (SO) for winter. Solar UV and cosmic ray flux might influence tropospheric temperature during warm seasons, solar maximum or QBO West. Significant correlations between the Northern stratospheric temperature and the SO is observed especially during the Eastern phase of QBO and solar minimum. Signatures of geomagnetic variability are seen in the winter stratospheric temperature. The stratospheric temperature correlates with the cosmic ray flux and solar UV at annual level at solar maximum and QBO West. The UV effect at the stratospheric level is less clear than expected. The existence of some correlations between tropospheric/stratospheric temperatures and internal and external parameters under certain climatic circumstances and during different solar cycle phases might help in identifying processes that transfer energy from the Sun to different atmospheric layers and in assessing their role in climate variability.

1. Introduction

The effect of solar activity variations on climate is far from being correctly quantified, which leads to difficulties in distinguishing between various causes of climatic variations (Solomon et al., 2007; Gray et al., 2010). Solar effects on climate are usually investigated in terms of correlations between climatic parameters such as temperatures (global or regional averages), cloud cover, teleconnections or circulation patterns and solar proxies, such as cosmic ray (CR) flux, UV and total solar irradiance (TSI), geomagnetic indices or sunspot number. Existing relationships between solar variability and climate have been reviewed by Gray et al. (2010) and we will mention only some of these in the following. The variation in the TSI over the 11 year solar cycle is about 0.24 W/m^2 at the top of Earth's atmosphere, which is too small to have significant effects on the climate (Marsh and Svensmark, 2003). However, mechanisms exist, that might amplify the effects of solar irradiance on climate (e.g. Gray et al., 2010; Lockwood et al., 2010a). Correlations between 11-year running means of the solar activity and the global and Northern Hemisphere (NH) surface temperatures, respectively, were found by Mendoza (2005) for a period of 90 years ending in 1970. They claim that less than half of the observed temperature changes during the 20th century could be attributed to TSI variations. Other authors are more reserved towards the possible effect of solar irradiance variations on global temperatures, pointing out that solar activity forcing might be related to less than a third to half of the observed global heating (Lean et al., 1995; Cliver et al., 1998; Alley et al., 2007). A quantitative examination of the association between solar activity, described by the sunspot number, and terrestrial climate indicated by global temperatures revealed that a linear relation exists between the two parameters through the recent 135 years (Stauning, 2011). Some studies claim that the correlation of temperature anomaly with sunspot numbers is higher around the 22 year solar cycle band, which apparently has a higher impact over temperature than the 11 year cycle for both hemispheres (Souza Echer et al., 2009, 2011). Gray et al. (2010) show that proofs

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for solar impact on climate do exist but their quantification is still under debate.

Correlations between temperature anomalies and solar proxies have also been found at regional level. In a study of several temperature time series at various European locations, Le Mouël et al. (2009, 2010) found that correlation coefficients between local temperatures in Europe and solar variations exist. Their results have been criticized by Legras et al. (2010); however, correlations between temperature and solar proxies have been found in various other regions. Lockwood et al. (2010b) suggested that some colder winters might be associated with low solar activity and their effects on blocking events. Kilcik et al. (2008) present correlations between solar irradiance and surface temperatures for Turkey. Dobrica et al. (2009) have found positive correlation between mean air temperature in Romania and geomagnetic activity for the last century. Temperature disturbances in US from 1945 to 2008 are closely linked to solar variability (Courtillot et al., 2010). Marsh and Svensmark (2003) and Crowley (2000) suggested that the warming trend during the 20-th century may be attributed to the extremely high solar activity during the last solar cycles and that solar activity has an important effect upon our climate before the industrial era. However, other studies suggest that starting with 1985 a different forcing mechanism, greenhouse gases′ growth, contributes to climate variability (Stauning, 2011; Lockwood and Froehlich, 2007; Foukal et al., 2006; Scafetta and West, 2005).

The relationship between Sun and climate might depend on the phase of Quasi Biennial Oscillation (QBO) and on the level of solar activity (van Loon and Labitzke, 1994; Labitzke, 2003). Many sun-climate mechanisms rely on the role played by QBO (Moore et al., 2006). When QBO is in the West phase (QBO-W), the correlation between the solar activity and polar stratospheric temperature above the North Pole is strongly positive, whereas during the East phase of QBO (QBO-E), the correlation is weakly negative (van Loon and Labitzke, 1994). A strong correlation between the 10.7 cm solar radio flux (F10.7) and the stratospheric zonal mean temperatures in the Northern Hemisphere exists in July for QBO-E whereas the correlation is low for the QBO-W (Labitzke, 2003). Solar UV radiation is absorbed by the stratospheric ozone, which warms the stratosphere and the stratopause. Stratospheric and ocean responses during solar maximum might have an important effect on tropospheric weather (Meehl et al., 2009). A possible sun-climate mechanism could be the downward propagation of circulation perturbations due to UV heating of the stratosphere (Hameed and Lee, 2005). Changes in jet-streams in the upper troposphere following stratospheric heating caused by UV (Simpson et al., 2009). On the other hand Moore et al. (2006) suggest that tropospheric processes might affect the stratosphere more than the other way around. However, the effect of solar activity on climate is far from being known and internal climatic factors might have significant direct or indirect contribution to temperature variations via the so-called top-down or bottom-up mechanisms (Haigh, 2003; Lockwood et al., 2010a). The work of Gray et al. (2010) offers a comprehensive view on possible links between solar activity and terrestrial climate.

Teleconnections are links between atmospheric anomalies at planetary scale which often manifest as persistent relationships between pressure fields of various geopotential heights at far-apart locations (Glantz, 1990). They affect the weather at regional and global scale but their effect on temperature anomalies remains partly unknown. Possible effects of solar activity have been suggested e.g. for the Scandinavian Pattern or North Atlantic Oscillation (Barriopedro et al., 2008; Woollings et al., 2010; Dima et al., 2004), Pacific North American (Trouet and Taylor, 2010), Southern Oscillation (Kirov and Georgieva, 2002), and Arctic Oscillation (Huth et al., 2007).

In this paper we investigate the relationship between solar and internal climatic variabilities and temperature anomalies in the Northern Hemisphere at tropospheric and stratospheric levels. The study is based on correlation analysis of relationships between two climatic proxies, i.e. the tropospheric and stratospheric temperature anomalies for the Northern Hemisphere, on the one hand, and five teleconnection indices and three solar proxies, on the other hand. Using datasets spanning over 45 years (1959–2005) we will analyze whether correlations between temperature anomalies and internal and external parameters are seasonally dependent. By '*internal*' parameters we mean teleconnections, measured by their indices, while '*external*' refer to solar and geomagnetic activity. Effects of solar activity level and of QBO phase on correlations are also investigated.

2. Data

We have used global hemispheric averages of temperature anomaly data based on radiosonde measurements in the Northern Hemisphere at tropospheric level (850–300 hPa) and stratospheric level (100–50 hPa), which can be found at http://cdiac.ornl.gov/trends/temp/sterin/sterin.html (Sterin, 2007). Data from the Comprehensive Aerological Reference Data Set (CARDS) (Eskridge et al., 1995) were taken as primary input for obtaining the series. The radiosonde data are considered adequate for studying various signals present in troposphere, such as ENSO, volcanic or QBO (Siedel et al., 2004). This is valid especially for the Northern Hemisphere (Oort, 1978). The primary CARDS data, from which Sterin set is developed, have some discontinuities, but these are relatively small and thus datasets which were used here remain relevant for climate studies (Lanzante et al., 2003). The present study covers the time interval between January 1959 and December 2004. In the following, 'temperature' refers to temperature anomaly, i.e. the difference between the value of each annual or seasonal mean temperature and the corresponding average for the 1960–1975 period. Besides global hemispheric temperatures, extra-tropical Northern Hemisphere temperatures were also considered (30–90°N). Possible internal climatic parameters that might be related to temperatures are described by teleconnection indices. Teleconnections were considered, which have hemispheric extent, as the Arctic Oscillation, or regional extent, as the Northern Atlantic Oscillation, the Scandinavian Pattern, the Pacific North American Oscillation. We have also included the Southern Oscillation Index, taking into account its global impact. Data sources for all teleconnection indices are taken from the NOAA site (http://www.cpc.ncep.noaa.gov).

The Northern Atlantic Oscillation (NAO) refers to changes in the difference between sea level pressures in the Arctic and the subtropical Atlantic and is one of the most prominent climatic oscillations, with important effects at a global scale (Hurrel, 1995). The associated index is defined as the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland and is calculated since 1864. Positive values of the index, i.e. higher pressure over Southern Atlantic ocean, are typically associated with stronger-than-average westerlies over middle latitudes, more intense weather systems over the North Atlantic and wetter/milder weather over western Europe (Hurrel, 1995). In CPC data, the NAO index is obtained from rotated PCA at 500 hPA height.

The Arctic Oscillation (AO) is represented by the leading mode (the first empirical orthogonal function) of low-frequency variability of wintertime geopotential between 1000 and 10 hPa, AO anomalies typically appearing first in the stratosphere and propagate downward (Baldwin and Dunkerton, 1999). The principal mode of climate variability in the Northern Hemisphere is the