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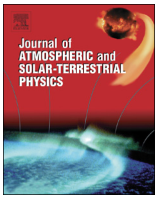

Correlations of global sea surface temperatures with the solar wind speed

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ABSTRACT

A significant correlation between the solar wind speed (SWS) and sea surface temperature (SST) in the region of the North Atlantic Ocean has been found for the Northern Hemisphere winter from 1963 to 2010, based on 3-month seasonal averages. The correlation is dependent on B_z (the interplanetary magnetic field component parallel to the Earth's magnetic dipole) as well as the SWS, and somewhat stronger in the stratospheric quasi-biennial oscillation (QBO) west phase than in the east phase. The correlations with the SWS are stronger than those with the F10.7 parameter representing solar UV inputs to the stratosphere. SST responds to changes in tropospheric dynamics via wind stress, and to changes in cloud cover affecting the radiative balance. Suggested mechanisms for the solar influence on SST include changes in atmospheric ionization and cloud microphysics affecting cloud cover, storm invigoration, and tropospheric dynamics. Such changes modify upward wave propagation to the stratosphere, affecting the dynamics of the polar vortex. Also, direct solar inputs, including energetic particles and solar UV, produce stratospheric dynamical changes. Downward propagation of stratospheric dynamical changes eventually further perturbs tropospheric dynamics and SST.

1. Introduction

1.1. Linkages and timescales

There is much evidence of significant tropospheric responses to space weather and space climate in the form of variations of galactic cosmic rays (GCR) (Tinsley and Deen, 1991; Svensmark and Friis-Christensen, 1997; Artamonova and Veretenenko, 2011), solar energetic particle events (SEP) (Veretenenko and Thejll, 2004; Mironova et al., 2012a; Mironova and Usoskin, 2013, 2014), interplanetary magnetic field (IMF) (Tinsley and Heelis, 1993). A mechanism has been proposed by which the global electric circuit is influenced immediately by the above inputs from the solar wind, with the downward current density (J_z) affecting meteorology via changes in cloud microphysics (Markson and Muir, 1980; Tinsley, 1996, 2008, 2012).

A relation between energetic electron precipitation (EEP) with the energy of few hundred keV and northern polar winter climate variations has been inferred from data analyses by Seppälä et al. (2009) and Andersson et al. (2014), and climate model simulations such as by Rozanov et al. (2005) and Baumgaertner et al. (2011) support an explanation in terms of stratospheric ozone chemistry affecting the atmospheric radiation balance (Rozanov et al., 2012, Seppälä and Clilverd, 2014). Analysis of observations by Maliniemi et al. (2013) has shown correlations of the North Atlantic Oscillation (NAO) index and surface temperature with EEP (30–100 keV and 100–300 keV) that are significantly stronger during the easterly quasi-biennial oscillation (QBO) phase than in the westerly phase.

Responses to changes in total solar irradiance and solar UV irradiance have been inferred by many authors, with more than a thousand reports over the past two centuries (Hoyt and Schatten, 1997), with recent examples including Haigh (1996), Matthes et al. (2006), Gray et al. (2010) and Ermolli et al. (2013). For the solar UV input, which is absorbed in the stratosphere, as well as the EEP input, the connection to tropospheric dynamics is by slow downward propagation on a timescale of weeks to a month or so, involving planetary wave propagation and synoptic-scale Rossby wave breaking. These analyses treat data in three-month and inter-annual and decadal averages, in which there is enough time for downward propagation from the stratosphere to affect the

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tropospheric dynamics (Baldwin and Dunkerton, 1999; Lu et al., 2013).

Responses on the day-to-day timescale have been extensively reviewed by Tinsley (2008) and Lam and Tinsley (2016). These responses are consistent with the global circuit-cloud microphysics mechanism and tend to occur when changes in ionospheric potential or atmospheric conductivity occur at locations where clouds or atmospheric instabilities, such as the polar front in winter, are present. For this timescale there is little ambiguity as to which responses are due to which of several solar wind inputs. In contrast with such day-to-day responses, in this paper we are concerned primarily with responses on the inter-annual and decadal timescales, for which so far there has been no reliable way to infer the responsible solar input.

1.2. *Responses in the North Atlantic*

The North Atlantic region seems to be favored for many of the observed responses, as found in the correlation of atmospheric geopotential height (GPH) with solar wind geo-effective electric field (GEF) (Boberg and Lundstedt, 2003); of GPH with solar wind speed (SWS) (Zhou et al., 2014); and of surface air temperature (SAT) with energetic electron precipitation (EEP) and the geomagnetic activity that accompanies it (Seppälä et al., 2009; Baumgaertner et al., 2011; Maliniemi et al., 2013). The NAO is a regional measure of atmospheric response, and is a mode of variation in atmospheric parameters that is largely coherent from Florida to Greenland and from northwestern Africa to Europe. It is defined by the normalized pressure differences between a low latitude station (e. g., Lisbon) and a high latitude station (e.g., Stykkisholmur, Iceland). The causes of its variability, especially on decadal and longer timescales, are not completely understood, and there seems to be a role for ocean circulation changes and external forcing, with even a suggestion that the “observed inter-annual and longer time scale NAO fluctuations could entirely be a remnant of the energetic weekly variability” (Hurrell et al., 2003). A pattern of SST changes associated with the atmospheric NAO is described by Visbeck et al. (2001).

Large scale dynamical responses to the 11-year cycle of solar activity in the north Atlantic region have been found, for example, by Kodera (2002), Thejll et al. (2003), and Huth et al. (2006, 2009). The strongest North Atlantic responses to the solar wind inputs have been found in the extended northern winter months (November-March) when atmospheric dynamics are strongest and the energy conversions (including cloud processes) are thought to be more easily perturbed by external energy and ionization inputs.

A strong association between stratospheric dynamics and seasonal changes in SST has been found with a coupled atmosphere-ocean model by Reichler et al. (2012), through a dynamic linkage that propagates from the stratosphere to the troposphere, with wind stress affecting ocean dynamics and sea surface temperature. The model had no external forcing, and the authors state that it is most likely that the stratospheric energy that propagates down is related to initial stochastic forcing from the troposphere. This raises the possibility that upward wave propagation from day-to-day tropospheric responses to the solar wind cause stratospheric dynamical changes that feed back into tropospheric SST responses on the seasonal and longer timescales.

In this context it is of interest that the study of Thejll et al. (2003) found significant positive correlations between winter (DJFM) sea level pressure and the geomagnetic Ap index (which is a measure of short term solar wind variability) in the North Atlantic from 1973–2001. Earlier than 1973 the pressure/Ap correlations were weaker, and in 1949–1950 were weakly negative. They note that prior to about 1970 the polar vortex was also weaker, and that downward coupling in general is weaker with a weaker vortex. However, for correlations between stratospheric geopotential height and Ap, a significant connection was found by Thejll et al. (2003) both before and after 1970. Upward coupling is not found to be affected by the vortex strength (Perlwitz and Graf, 2001). Graf and Walker, (2005) noted that the polar vortex controls the downward coupling not only to the atmosphere but also to the ocean, as characterized by the NAO.

All this is consistent with a scenario in which day-to-day tropospheric responses to solar wind inputs are propagating upwards to the stratosphere and affecting the vortex strength, with downward coupling on a timescale of weeks to months affecting the large scale circulation.

A response of surface pressure in the Arctic and Antarctic to changes in ionospheric potential on a timescale of about a week (the Mansurov effect) has recently been shown to be part of a geopotential height anomaly extending over the whole of both high latitude regions and out into mid-latitudes (Lam et al., 2013), which propagates upwards in altitude (Lam et al., 2014) through the troposphere. It is statistically significant within the troposphere, rather than above it. The changes in ionospheric potential were deduced from radar and spacecraft measurements, and are driven by the product of SWS and the B_y component of the solar wind magnetic field. The only candidate mechanism consistent with the electrical input involves J_z and cloud microphysics, which is also a candidate for the other day-to-day responses to space weather noted above. Both the IMF B_y component and SWS vary on the 11-year solar cycle.

That relativistic electron (2–15 Mev) precipitation (herein REP) could play an important role in coupling solar wind and magnetospheric variability as far down as the middle atmosphere was found by Baker et al. (1987, 1993). The connections between REP and SWS have been demonstrated by Li et al. (2001a, b) and Reeves et al. (2011). The REP can penetrate down to the upper stratosphere levels in the sub-auroral zone (magnetic latitude of 45°–65°), and Bremsstrahlung radiation is produced at the same time, which can impact stratospheric ozone chemistry as for EEP. In addition, the ionization produced by the REP and the Bremsstrahlung can alter the electric conductivity down to lower stratosphere levels, so that the stratospheric electrical column resistance is changed, and also J_z. The electrical link through J_z provides immediate coupling between the ionosphere and the troposphere. On the day-to-day timescale a response of the NAO index to REP has been found (Zhou et al., 2014). However, the strength of the response in terms of atmospheric vorticity was found to depend on the amount of volcanic sulphate aerosol in the middle atmosphere (Kirkland et al., 1996; Kniveton and Tinsley, 2004; Mironova et al., 2012b). Because of its dependence on irregular episodes of volcanic aerosol the REP/electrical influence on the NAO is not a good candidate for the decadal SST responses.

In this paper, we analyze data on the effects of SWS, GEF, and the QBO on SST, both globally and with respect to season. We use a large data set from 1963 to 2011, and look at effects in high and low speed ranges of SWS.

2. Data analysis and methods

The data sources whose description follows all have URLs specified in the Acknowledgments section. The interplanetary magnetic field (IMF) and SWS monthly data are from the OMNI time series (King and Papitashvili, 2005) from 1963 to 2011. The SWS data are intermittent from 1964 to 1994, continuous from 1995 to 2011, and the data gaps have small influence on the monthly data (Finch and Lockwood, 2007). The solar wind geo-effective electric field (GEF) is defined by B_sV, where V is the solar wind speed and B_s is the southward component of the

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