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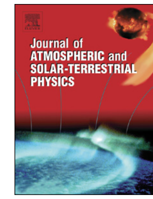

A link between high-speed solar wind streams and explosive extratropical cyclones

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ABSTRACT

A link between solar wind magnetic sector boundary (heliospheric current sheet) crossings by the Earth and the upper-level tropospheric vorticity was discovered in the 1970s. These results have been later confirmed but the proposed mechanisms remain controversial. Extratropical-cyclone tracks obtained from two meteorological reanalysis datasets are used in superposed epoch analysis of time series of solar wind plasma parameters and green coronal emission line intensity. The time series are keyed to times of maximum growth of explosively developing extratropical cyclones in the winter season. The new statistical evidence corroborates the previously published results (Prikryl et al., 2009). This evidence shows that explosive extratropical cyclones tend to occur after arrivals of solar wind disturbances such as high-speed solar wind streams from coronal holes when large amplitude magneto-hydrodynamic waves couple to the magnetosphere-ionosphere system. These MHD waves modulate Joule heating and/or Lorentz forcing of the high-latitude thermosphere generating medium-scale atmospheric gravity waves that propagate energy upward and downward from auroral zone through the atmosphere. At the tropospheric level, in spite of significantly reduced amplitudes, these gravity waves can provide a lift of unstable air to release the moist symmetric instability thus initiating slantwise convection and forming cloud/precipitation bands. The release of latent heat is known to provide energy for rapid development and intensification of extratropical cyclones.

1. Introduction

The relation between the solar wind magnetic sector structure and the winter mid-latitude upper-tropospheric vorticity was first suggested by Wilcox et al. (1973, 1974, 1975, 1976). These authors used the vorticity area index (VAI) that was introduced by Roberts and Olson (1973) and evaluated it for the 300-and 500 hPa levels. The statistical significance of the "Wilcox effect", namely a decrease in VAI about one day after the sector boundary crossing (SBC), was confirmed by Hines and Halevy (1977). The effect, with some variations, was frequently revisited with positive (e.g., Shapiro, 1976; Larsen and Kelley, 1977; Burns et al., 1980; Rostoker and Sharma, 1980; Arora and Padgaonkar, 1981; Lundstedt, 1984; Tinsley et al., 1994; Kirkland et al., 1996) and sometimes negative (Bhatnagar and Jakobsson, 1978; Williams, 1978; Williams and Gerety, 1978) results. Other studies presented evidence of an intensification of cyclonic activity in the North Atlantic correlated with energetic solar proton events (Veretenenko and Thejll, 2004, 2005). More recently, Lam et al. (2013) demonstrated a previously unrecognized influence of the interplanetary magnetic field (IMF) B_y component on mid-latitude surface pressure.

These observations underline the need to find an acceptable mechanism to explain possible solar influences on tropospheric vorticity. Several mechanisms were proposed (e.g., Park, 1976; Tinsley et al., 1994; Kirkland et al., 1996; Rycroft et al., 2000; Carslaw et al. 2002) and the subject of solar wind influence on weather was reviewed (e.g., Taylor, 1986; Tinsley and Deen,1991; Tinsley 2000; Harrison and Carslaw, 2003). The "Wilcox effect" was verified for both the northern and southern hemisphere winters

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using the European Center for Medium-Range Weather Forecasts ERA40 re-analysis dataset (Prikryl et al., 2009a). It was shown that, on average, VAI is modulated by high-speed solar wind streams flowing from coronal holes, with a minimum in VAI one day after SBC followed by a maximum a few days later during the peak activity of the stream. Also, a tendency for severe extratropical winter storms to occur within a few days after the high-speed solar wind arrival was found. In a companion paper, Prikryl et al. (2009b) suggested that auroral atmospheric gravity waves (AGWs) could be a link between the solar wind and tropospheric weather. They postulated that auroral AGWs may release instabilities, such as moist symmetric instability, thus initiating (seeding) convection that leads to cloud/precipitation bands and intensification of extratropical cyclones.

In this paper, we use storm track data base obtained from two sets of meteorological reanalysis data to present new statistical evidence that explosively developing extratropical cyclones tend to occur after arrivals of high-speed solar wind streams from coronal holes. Possible mechanisms to explain these results are discussed.

2. Data sources and methods

Iwao et al. (2012) studied explosively developing extratropical cyclones over the winter months from 1979 to 2011 in the northwestern Pacific (Yoshida and Asuma, 2004; Kuwano-Yoshida and Asuma, 2008; Yoshiike and Kawamura, 2009) using reanalysis data from the Japanese 25-yr Reanalysis/Japan Meteorological Agency Climate Data Assimilation System (JRA-25/JCDAS) (Onogi et al., 2007). Iwao et al. (2012) adopted two commonly used methods based on the sea level pressure (SLP) and the low-level (850 hPa) vorticity fields to detect and track extratropical cyclones. They compared the JRA-25 climatological results with those based on the ERA-40 and ECMWF Interim Re-Analysis (ERA-Interim) (Simmons et al., 2007). In the present paper we use their database of extratropical cyclone tracks for the Northern Hemisphere obtained for the JRA-25 and ERA-40 re-analyses.

Solar wind data were obtained from the Goddard Space Flight Center Space Physics Data Facility CDAWeb and OMNIWeb (King and Papitashvili, 2005). The OMNIWeb data set of interplanetary magnetic field and solar wind plasma parameters have combined the data from available solar wind monitors. Hourly averages of solar wind plasma parameters, including the velocity, V, the interplanetary magnetic field (IMF) magnitude, B, the standard deviation, σ_{Bz}, of IMF B_z and proton density, n_p, are used to identify co-rotating interaction regions (CIRs) at the leading edges of high-speed streams from coronal holes. As the CIR passes by a spacecraft solar wind density rises to a maximum and then drops sharply within a narrow interface while the magnetic field

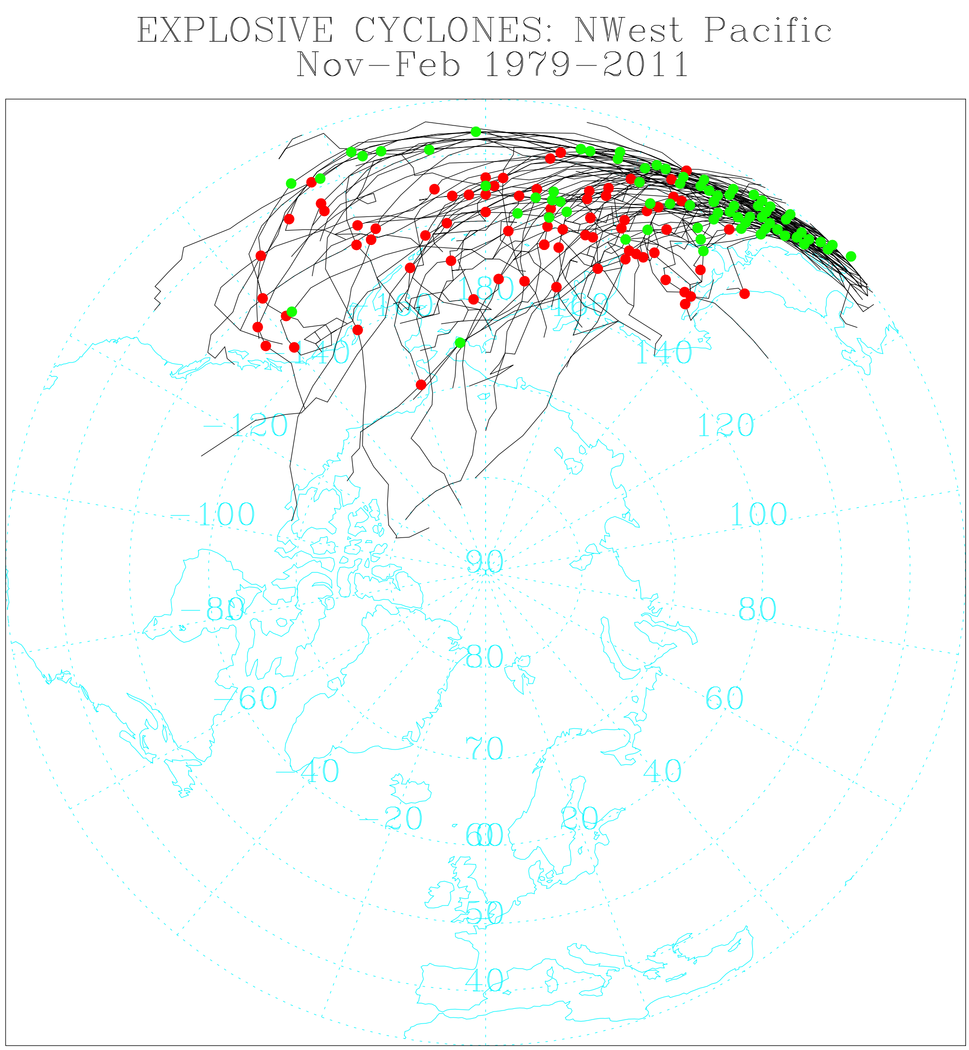

Fig. 1. Explosive cyclone tracks with locations of the maximum deepening rate (green) and the storm lowest SLP (red) are shown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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