Space Weather of the Heliosphere: Processes and Forecasts
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The Space Weather through a Multidisciplinary Scientific Approach

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Abstract. Space weather encompasses understanding how the near-space environment responds to forces from lower-atmosphere weather systems as well as conditions on the Sun. Although the specific effects of space weather (including power grid failures, communication outages, and navigation errors when using space-based navigation systems such as GPS) are local in nature, understanding and predicting their occurrence requires a global view of the environment. Here we initiated a first attempt to link one solar event which occurred on 2014 February 25, and affected the Earth's upper atmosphere.

Keywords. Ionosphere, Airglow, Solar Eruption

1. Introduction

We adopted a multidisciplinary approach at the Cadi Ayyad University in Morocco to better understand the Sun-Earth interaction. Our objective is to identify the various correlations, which may exist between the phenomena observed by various instruments. For this we have deployed an experiment dedicated to the study of the Ionosphere - RENOIR - with the cooperation of the University of Illinois, USA. We also have installed a GPS station in cooperation with MIT and have started cooperation with the LESIA of Paris Observatory for the study of solar eruptions through the RHESSI satellite in particular. We present here a first attempt to combine the observations from these various facilities in the context of a solar event which occurred on February 25, 2014 in order to find a causal relationship between the solar activity and the disturbances of the upper layer of the terrestrial atmosphere. We explore here the ionospheric and thermospheric responses to the February 27-28 geomagnetic storm. We assume that this storm was caused by a flare-associated Coronal Mass Ejection (CME) that occurred on February 25 2014.

2. The Solar Event

The X4.9 flare of February 25, 2014 took place in a newly numbered sunspot region NOAA 11990 (S12^o E82^o) which was the sunspot region NOAA 11967 during the previous rotation studied in detail by Chen *et al.* (2014). Figure 1 shows shows the continuum image map of NOAA 11990 observed on February 25, 2014 with the Helioseismic and Magnetic Imager (HMI) instrument onboard Solar Dynamic Observatory (SDO; Schou *et al.* 2012). The Helioseismic and Magnetic Imager is a filtergraph with the full−disk coverage by two CCD cameras of 4096×4096 pixels. NOAA 11990 produced only one X−class flare during that day. The Geostationary Operational Environmental Satellite (GOES) Data indicates that the X-ray flare started at 00:39 UT, peaked at 00:49 UT, and ended at 01:03 UT.

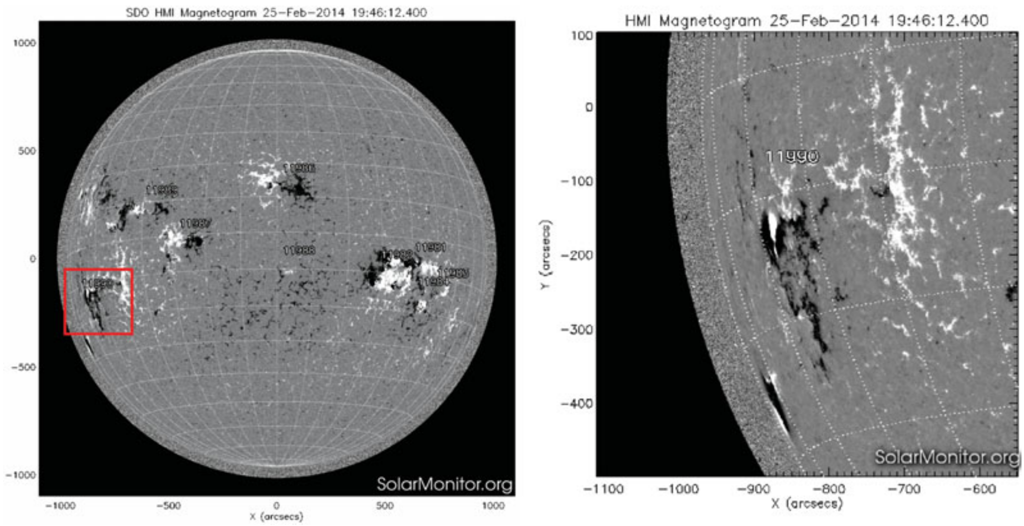

Figure 1. Left: SDO HMI Magnetogram of the solar disk obtained with HMI/SDO on February 25, 2014 at 19:46 UT. Active Region AR 11990 is indicated by the orange square. Right: Image centred on AR 11990 observed with HMI/SDO.

The X4.9 flare, corresponding to a 1−8 SXR produced an energy flux of 4.9×10^{-4} W/m^2 measured at Earth, assuming isotropic emission from the flare source. This represents an instantaneous luminosity of $\sim 1.1\times10^{26}$ ergs/s, or $\sim 3\times10^{-8}$ of the total solar luminosity from the SXRs alone.

3. Thermospheric and Ionospheric Response

Using GNSS measurements and prediction models Bergeot *et al.* (2014) classified the February 27, 2014 ionospheric storm as moderate based on the value of Dst index.

3.1. *RENOIR @ Oukaimeden*

The RENOIR (Remote Equatorial Nighttime Observatory of Ionospheric Region) experiment consists of a Fabry−Perot (FPI) interferometer and wide angle viewing camera. The FPI makes measurements of the thermospheric neutral wind velocities and neutral temperatures using observations of the 630.0 nm emission caused by the dissociative recombination of O_2^+. The wide−angle imaging system uses the same airglow emissions to provide measurements of ionospheric structures and irregularities. The main goal of this experiment is to characterize the mid-latitude ionosphere and thermosphere by establishing the climatology of both the neutral winds and the instabilities taking place in the ionosphere as well as the coupling between the ionosphere and thermosphere during quiet time conditions and during geomagnetic storms. The thermospheric storm, induced by high latitude heat input drives a global circulation of winds flowing from high to low latitudes creating large scale of atmospheric waves that propagates in a global scale. The local impression of this global picture of the storm was captured during the February 27^{th} event. Figure 2 shows the meridional and zonal winds measured with the Fabry−Perot interferometer (FPI) during the 24, 25, 27 and the February 28^{th}, 2014. The February 26 measurements are missing. The FPI winds are estimated from the 630 nm airglow emission caused by dissociative recombination of O_2^+. The red line refers to the monthly average of the nights with Kp strictly less than four. The blue line shows the meridional

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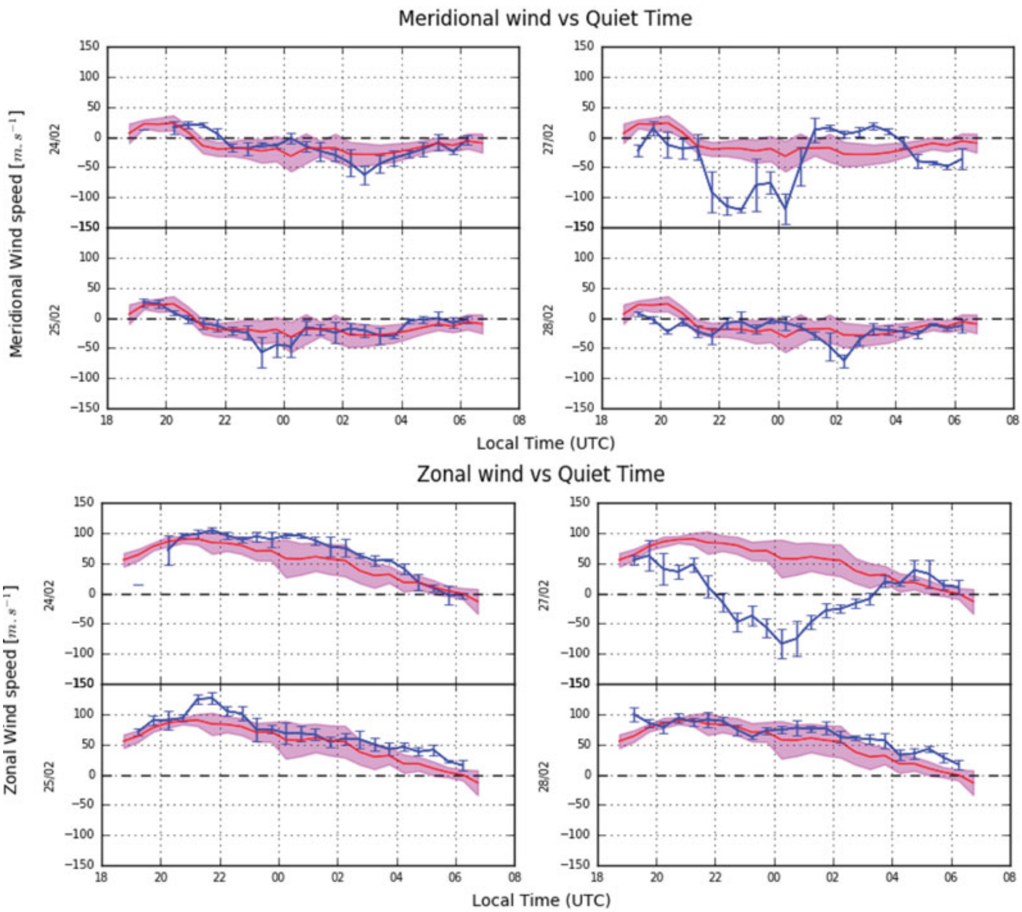

Figure 2. Thermospheric meridional and zonal winds measured by the the Fabry-Perot interferometer (FPI) over Oukaimeden Observatory (31°12′ 23.3″N, 7°51′ 58.8″ W).

(zonal) measurements during the night and the magenta area denotes the daily variability during February 2014. The average quiet time is in red color and the quiet time daily variability is illustrated as the shaded purple area.

3.2. *GPS Observations*

The estimated total electron content (TEC) measured from a GPS station installed in Rabat (33.998°N; 353.1457°E,geographic) is illustrated in Figure 3. This figure contains the TEC for the February 27-28, 2014 and the average of the quiet days (Kp<3). We can notice some oscillation of the 27th TEC between 14 LT and 00 LT and in the early hours of the 28th which correlate positively with NmF2 peak (the F2-layer peak electron density which is derived from the F2-layer critical frequency). As the meridional wind plays an important role in the electrodynamics of the ionosphere, we present in Figure 3 the evolution of the TEC along with the north and south component of the winds. We can notice as well that the positive storm on February 27 with a maximum TEC of 65 TECU (around 13 UT), remaining high for some hours and achieving 50 TECU at 00 UT. On the early hours of 28th, from 01 to 04 UT, the decrease is steep with an approximate rate of 8,3 TECU/hour. During the 28th, the TEC was still higher than

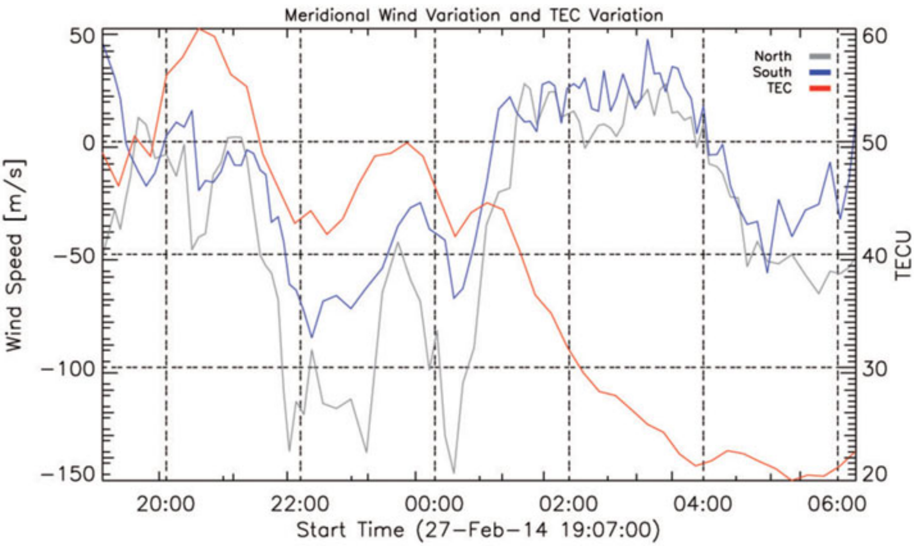

Figure 3. Temporal variation of the Total Electron Content measured over Rabat (33.998°N; 353.1457°E, geographic) overlay thermospheric meridional and of the thermospheric meridional and zonal winds measured by the the Fabry-Perot interferometer (FPI) over Oukaimeden Observatory ($31°12' 23.3''$ N, $7°51' 58.8''$ W).

quiet time behavior. The observed gap during the early hours was about 40 TECU, and about 20 TECU during the day and diminishes to 10 TECU during the night.

4. Conclusion

The effect of the X4.9 flare of the February 25, 2014 solar event on the thermosphere and the ionosphere is investigated. Thermospheric winds and temperature were inferred from Fabry-Perot interferometer measurements deployed at Oukaimeden observatory. The ionospheric response of the storm was also analyzed with the VTEC (Vertical Total Electron Content) data and a wide-angle imaging camera. Attention was paid to the conditions on the Sun, interplanetary medium and geomagnetic indices that impacted the thermosphere-ionosphere coupling during that storm. This is the first time that a case study of a geomagnetic storm has been achieved in north Africa by using Fabry-Perot interferometer data of the thermosphere. Additionally, this is the first coincident study of a storm using a ground-based FPI and an all-sky imager in this sector. The African sector is lacking data and it is important to see how the thermosphere/ionosphere system reacts to geomagnetic storms in this area. Furthermore, the comparison with models is useful for validation or improvement. Our perspective is to address the variable ways in which the thermosphere-ionosphere system reacts to geomagnetic storms in this region. We are about to publish more detailed results concerning this event in a forthcoming paper.

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