Ionosphere-thermosphere coupling during the 22-23 June 2015 geomagnetic storm: Swarm and FPI coordinated observations above the Oukaimeden observatory

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Abstract

We investigate the response of the ionosphere-thermosphere coupled system to the 22-23 June 2015 geomagnetic storm in the region above the Oukaimeden observatory in Morocco with a Fabry-Perot interferometer and the Swarm satellites. The measured thermospheric neutral winds are strong enough to have two direct consequences. First, they create a strong asymmetry in the equatorial ionisation crests on both sides of the magnetic equator (actually, they make the southern hemisphere crest disappear). This asymmetry is explained by the southerly thermospheric neutral wind that was blowing during the storm and is shown to be favoured by the season. Second, within the northern hemisphere ionisation crest, Swarm A and C detect km-size electron density structures. Those may be ascribed to gradient drift instability.

1 Introduction

In this paper, we aim at better understand the coupling between the thermosphere and ionosphere at low latitude during geomagnetically disturbed times.

1.1 Neutral winds in the Moroccan sector

Neutral winds play an important role in the coupling between the neutral and ionised parts of Earth's upper atmosphere. This is particularly true at low latitudes were the dynamics of the thermosphere-ionosphere coupled system is actually dominated by these winds [1].

Kaab et al. [2] performed a statistical study of the quiet time neutral winds above the Oukaimeden observatory and showed some tendency during a typical night with a reversal of the wind direction in the middle of the night.

When the geomagnetic activity increases, the behaviour of the thermosphere is affected: the thermospheric winds tend to flow primarily towards the equator and towards the west under the Coriolis effect [3].

Semi-empirical models such as Horizontal Wind Model (HWM, [4]; [5]) have been widely used to estimate neutral wind speed and direction. There have been indications that the models only partly fit measurements made at Oukaimeden observatory though [2], especially in disturbed time [3].

1.2 Equatorial Ionisation Anomaly

At the magnetic equator, the geomagnetic field is horizontal, which leads to a vertical and upward plasma drift velocity. The ionospheric plasma outflows and then diffuses along the magnetic field lines to create two ionisation crests in the F-region on both sides of the magnetic equator: the so-called equatorial ionisation anomaly (EIA). It is quite common to observe two ionisation crests with very different level of ionisation, or in other words, with very different electron densities. Explaining these differences – or asymmetries – has been debated and even until recent times, two scenarios were put forward to explain the role of the meridional neutral wind in triggering this asymmetry [6]. In both of these scenarios, the neutral thermospheric wind plays a central role by pushing the ionised gas toward or away from the magnetic equator.

2 Instrumental configuration

In this work, we take the most of an overflight of the ESA Swarm constellation above the Oukaimeden observatory, in the Moroccan Atlas Mountains to document the thermosphere-ionosphere coupling during a geomagnetic storm. In this section, we briefly present the instrumentation used.

2.1 FPI at Oukaimeden observatory

Since 2009 the Oukaimeden observatory in Morocco (geographic coordinates: 31.206°N, 7.866°W; magnetic latitude: 22.84°N; elevation: 2700 m) has been equipped with a RENOIR set of instruments comprising a Fabry-Perot interferometer analysing the airglow of the atomic oxygen red (630 nm) and green (557.7 nm) lines, and an all-sky camera [7].

The FPI points towards 5 directions periodically: zenith, West, North, East and South (for the four later direction, the elevation is 45°). It takes measurements for 5 minutes in each directions. One can then consider the measurements in each direction separately or average the wind speeds measured in the west and east directions to obtain an average zonal wind; the same for the measurements made in the North and South directions to obtain an average meridional wind.

2.2 Instruments used on board Swarm

Swarm is the three-satellite constellation launched in November 2013 by the European Space Agency [8]. All three spacecraft are on a low- Earth polar orbit: about 460 k altitude for Swarm A and C, which fly almost side by side, and 530 km altitude for Swarm B.
In this work, we mainly make use of the Langmuir probes on-board the three spacecraft [9] that measure the electron density and temperature and of the GPS sensors that are used to calculate the total electron content (TEC) of the topside ionosphere.
To find good conjunctions, if any, we have used the Conjunction Search Tool, which included in the 3DView orbit visualisation tool [10] developed by the French data centre for space plasma physics, CDPP.

3 Observations and interpretation

3.1 Heliospheric and geophysical context

Figure 1 shows the external conditions from 22 June 2015 00:00 UTC to 24 June 2015 00 UTC. While a weak storm was developing after the arrival at Earth of a solar wind discontinuity (at around 06:00 UT on 22 June), a second a more intense pressure pulse hit the geospace around 18:30 UTC on the same day. The solar wind density then jumped from 15 cm^{-3} up to 40 and more cm^{-3}. In the meantime, the solar wind velocity increased abruptly from 450 up to almost 700 km.s^{-1}, and the Z component of the interplanetary magnetic field (IMF) reached -40 nT. All together, these conditions lead to a geomagnetic storm with a Sym-H reaching -200 nT slightly after 04:00 UT on 23 June.

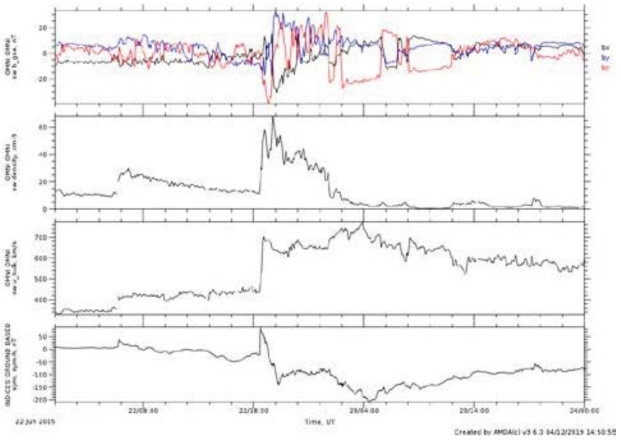

Figure 1. Heliospheric and geophysical context with, from top to bottom, the three GSE components of the IMF, the solar wind density and bulk velocity (all provided by OMNI via AMDA), and the Sym-H index.

3.2 Neutral winds above the Oukaimeden observatory

In the course of the night from 22 June to 23 June, the Fabry-Perrot interferometer (FPI) of the Oukaimeden observatory was operating and the sky was clear. The neutral wind measurements with the oxygen red line at 630.0 nm are shown in Figure 2.

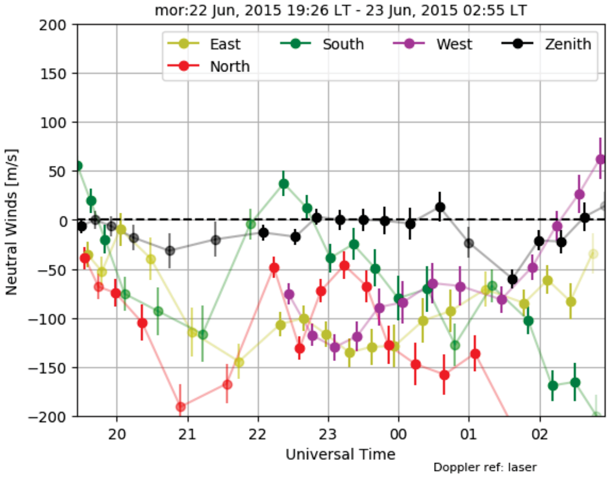

Figure 2. Line of sight component of the thermospheric neutral wind measured at 630.0 nm (oxygen red line), i.e., at ~250 km altitude, when pointing to 5 directions.

The data reveal that the velocity are rather high and correspond well to a disturbed period [3]. In particular, the wind component measured towards the north reaches -200 m.s^{-1} (the minus sign is indicative of a southerly wind) around 21:00 UTC on 22 June 2015, and goes even beyond after 01:30 UTC on 23 June.

3.3 Electron density at Swarm

A fortunate overflight of the Oukaimenden observatory area by Swarm A and C occurred around 23:10 UT on 22 June 2015. The two spacecraft were flying side by side with a longitude separation of about 1.5°, equivalent to 140 km at the latitude of the observatory.

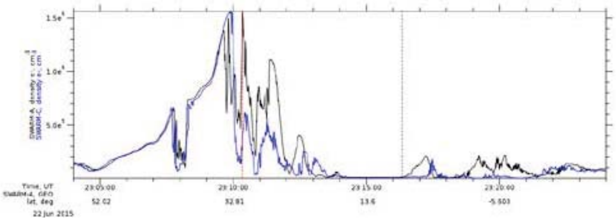

Figure 3. Electron density measured at Swarm A (black line) and C (blue line) versus universal time and geographic latitude. The black vertical dotted line marks the latitude of the magnetic equator; the red one marks the latitude of the FPI at the Oukaimeden observatory.

Figure 3 displays the electron densities [11] measured by the Langmuir probes on board Swarm A (black) and Swarm C (blue), versus universal time and geographic latitude. The latitude (and time of crossing) of the magnetic equator is marked by the vertical black line, those of the Oukaimeden observatory by a red dotted line.

A textbook case of such a crossing of the EIA would show two crests of ionisation [12]. Here, one can see a relatively dense ionisation crest, reaching almost 1.5×10^6 cm^{-3}, in the northern hemisphere, sitting right above the Oukaimeden observatory. However, in the southern hemisphere, there is no ionisation crest visible, at least not with the same level of ionisation.

Another interesting feature this figure shows is the good agreement between the recordings of the two Langmuir probes (black and blue lines) in the beginning of the plot and until about 23:09:30 UT; after, the data show significant differences that we shall address below.

4 Discussion and conclusion

Several features are striking in this data set.

First, the measured thermospheric neutral wind speeds are very large, especially its meridional component, exceeding 200 m/s southward. This is not common: Loutfi et al. [3] showed that around Summer solstice, the meridional wind is, in quiet times, rather weak and northward. This strong and southerly neutral wind is indeed the manifestation of a geomagnetically perturbed period.

Second, the ionisation crest in the northern hemisphere is particularly dense while the one in the southern hemisphere has completely disappeared. The dense northern ionisation crest is very likely due to the large southerly thermospheric wind [13] that pushes F-region dense plasma to the topside ionosphere [6], at the altitude of Swarm. However, to also explain the disappearance of the southern ionisation crest, this southerly meridional wind, measured only in the northern hemisphere, has to be trans-equatorial so that it pushes the ionospheric plasma down to lower altitudes. The season, may have favoured this effect as discussed by Loutfi et al. [3].

Last, it is interesting to note that although Swarm A and C fly practically side by side, their Langmuir probes make very different measurements, indicating that small scale ionospheric density structures are present. Those structures have typical zonal dimensions of the order of the cross track separation of the satellites (~140 km) and the meridional size of the order of a km (this is inferred by the time Swarm needs to cross those small structures and its velocity). The existence – and formation – of these density structures may be ascribed to small size plasma bubbles or, on the contrary, low density plasma regions. Given the large velocity of the zonal neutral wind, those small size density structures may be due to neutral wind-driven gradient drift instability [1]. This hypothesis will have to be verified with a statistical approach.

6 Acknowledgements

This project is financially supported by Campus France through the French-Moroccan bilateral program "PHC Toubkal 2019" (grant number 41409WJ). Swarm data were retrieved from ESA's Earth Online web-site: https://earth.esa.int/web/guest/swarm/data-access.

Line-of-sight wind data used in this study are freely available for use in the Madrigal database: http://madrigal.haystack.mit.edu/madrigal/.

Figures 1 and 3 were generated with AMDA, maintained by CDPP and CNES (http://amda.cdpp.eu). The conjunction between Swarm and the Oukaimeden observatory was found with the Conjunction Search Tool of 3DView, also maintained by CDPP and CNES (http://3dview.cdpp.eu).

7 References

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