Statistical plasma properties in relation to geomagnetic activity derived from Demeter data

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Abstract

The aim of this study is to derive statistical plasma properties by discribing various electron populations, characterizing them and relating their occurance to different geophysical conditions, including deep solar minimum.

We have investigated electron temperatures and wave acitivity. In such a way we intend to assign each electron population to certain types of waves in plasma, describe spatial and temporal scales of plasma turbulence and find apparent physical mechanism lying behind it.

In order to achieve it we have analysed measurements collected by Demeter microsatellite.

Introduction

Demeter is CNES microsatellite that was launched in 2004 in to sunsynchronous orbit at altitude of 660 to 715 km. The mission was operating until 2011. It consisted of various experiments:

- ISL: Langmuir Probe
- IAP: Plasma Analyzer
- ICE: 4 Electrical Sensor System
- IDP: Particle Detector
- IMSC: 3 Magnetic Sensors

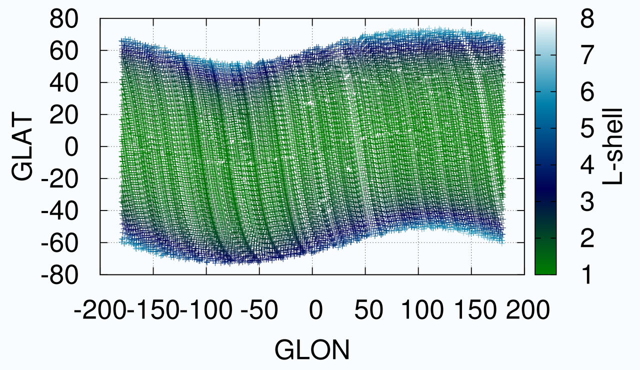

Figure 1: Projecton of the L-shell values on to the geocentric longitude-geocentric latitude plane.

Solar Conditions

Graphs below depict solar conditions expressed in the averaged solar flux density f10.7 (red dotted line) with regard to the day of year. Scale of the flux density is presented by the leftside vertical axis. Magnetic activity is showed by black solid line and expressed by the Dst index. Rightside vertical axis is the Dst index scale. First impression is that the solar, and thus magnetic activity decays from 2005 to 2010. However it is important to note that severe magnetic conditions are related with f10.7 index values more than $\mathbf{180 \times 10^{-22} Wm^{-2} Hz^{-1}}$ and in 2005 the maximum value reaches only $\mathbf{140 \times 10^{-22} Wm^{-2} Hz^{-1}}$.

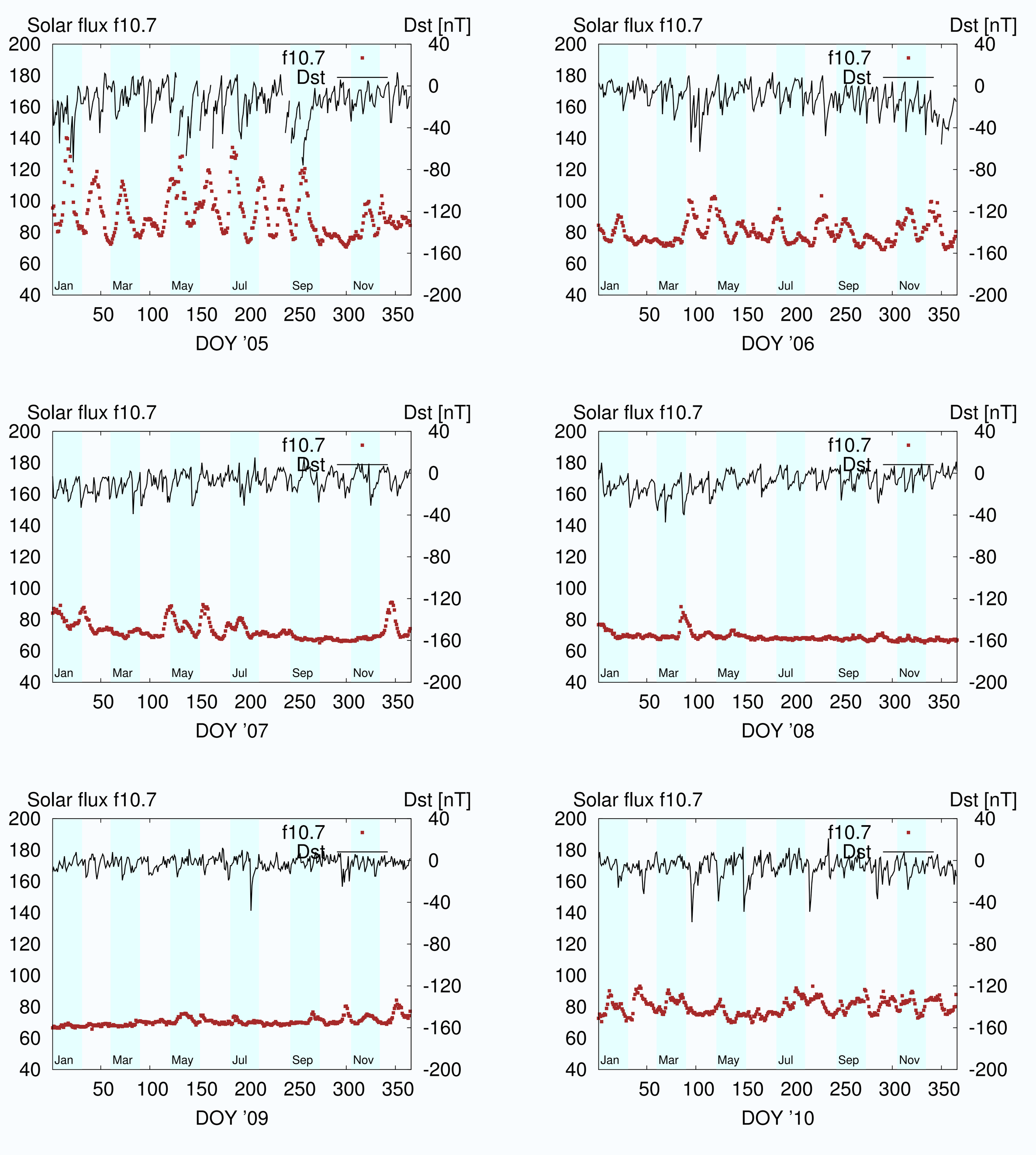

Figure 2: Daily avaraged solar flux registration during years 2005 - 2010 obtained from `http://omniweb.gsfc.nasa.gov/`

T_e comparison

Analysis of the electron temperature measurements taken during Januaries 2005 - 2010 reveal following characteristics:

- Southern Hemisphere electrons are hotter than the Northern Hemisphere electrons.
- The electron temperatures that exceeds 5000 K were mainly observed in January 2005 during days, when geomagnetic storms occured.
- Differences are specifically seen during nighttime observation. It may be due to the fact, that on the dayside ionosphere ionisation processes predominate the effects caused by geomagnetic conditions.

However it has to be noted that the temperature measurements taken by ISL probe are overestimated (private communication with J. P. Lebreton the PI of ISL).

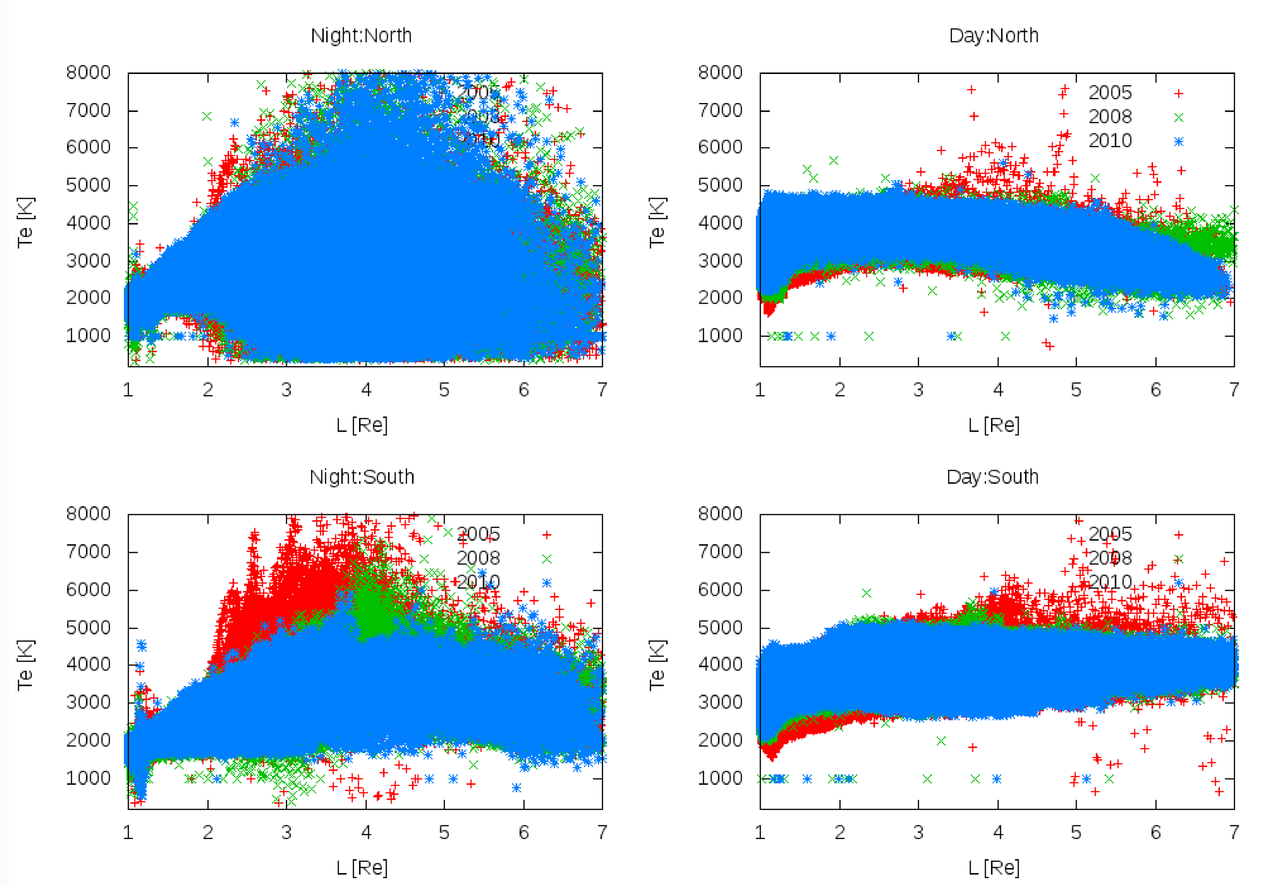

Figure 3: Pictures plot the electron temperatures in respect to the L shell value. Top and bottom panel present Northern and Southern Hemisphere respectively. Leftside pictures correspond to the nighttime measurements and rightside pictures present daytime measurements.

N_e to L relation

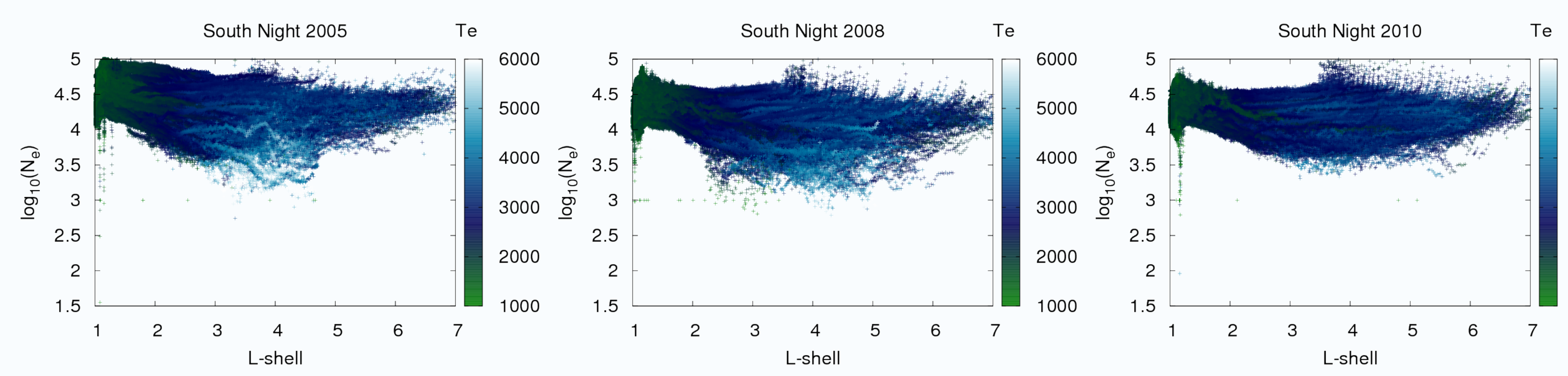

Figure 4: Electron density distribution in respect to the L-shell value. Color palette corresponds to the electron temperatures.

Comparison of electron density distribution for years 2005, 2008 and 2010 reveals that both the electron temperatures and electron densities are higher for enhanced solar activity. Enhancement in electron density can be observed at L=1:3 in 2005. One can also observed that the density minimum in 2005 is deeper than in other years. It is also located between L=3 and L=4 (equatorward: see Figure 1 for reference), while in 2008 the density minimum lies at L=4.

T_e to N_e relation

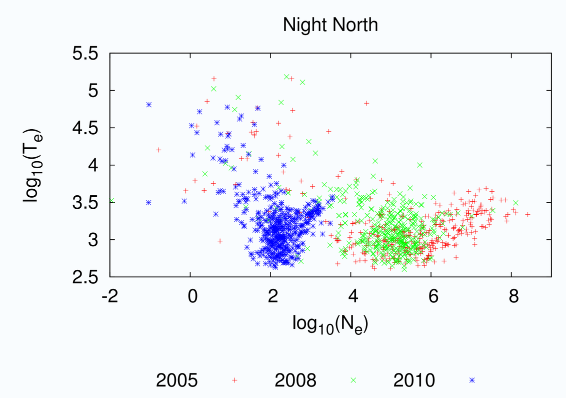

Figure 5: Te to Ne relation for North Hemisphere and night satellite passes.

Pictures from Figure 4 confirm the inverse temperature-density relation. However it is not as simple as linear dependence. Figure 5 presents the $\mathbf{\log_{10}(T_e)}$ with regard to the $\mathbf{\log_{10}(N_e)}$. Plot was calculated for the minimum value of the electron density at the Northern Hemisphere.

Trough

Trough is nighttime phenomenon best observed at dip latitudes $\mathbf{60^\circ - 70^\circ}$ [1]. It is a region of decreased plasma density that can be regarded as a boundary between the "mid-latitude" and "polar regions". During magnetic disturbances trough moves towards equator. As the magnetic storm go to recovery phase trough is also moving to higher latitudes. Calculation performed for the trough minimum location during storm in October 2008 shows that recovery phase is not very simple process. Picture below presents the trough minimum location. The rightside image presents auroral oval structures, and the arrow indicates the position of the trough minimum. The leftside graph was obtained with use of variuos measurements: electron density, electron temperature, electric field and TEC observations.

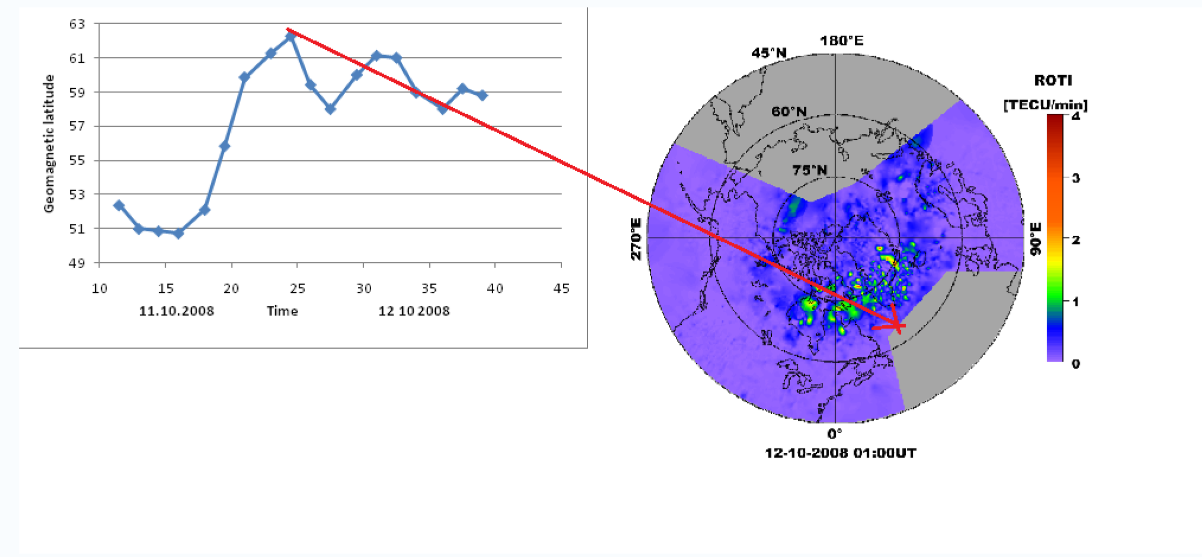

Figure 6: Credits: H. Rothkaehl & A. Krankowski

Wave activity

The presence of VLF and ELF emissions over storm recovery phase is imposed by the fact, that at the beginning of the disturbance a great amount of energy is deposited in the Earth's ionosphere, mainly in the polar cup region. Figure 7a presents condition of the plasma during magnetic storm. The trough is clearly visible just below the $\mathbf{60^\circ}$ latitude. The location of the mid-latitude trough is considered to coincide with plasmapause position [2]. The plasmapause is a storm-phase dependent structure that moves towards lower L-values during storm onset. That explains why trough is located at lower latitudes when the geomagnetic storm begins. Figures 7b and 7c relate to the recovery phase of the storm. At first one can notice that trough moved back to the higher latitudes (Figure 7b). On the Figure 7c the trough cannot be easily distinguished. It suggests that there is a turbulence, and more processes such as wave-particle interaction play a role in energy dissipation.

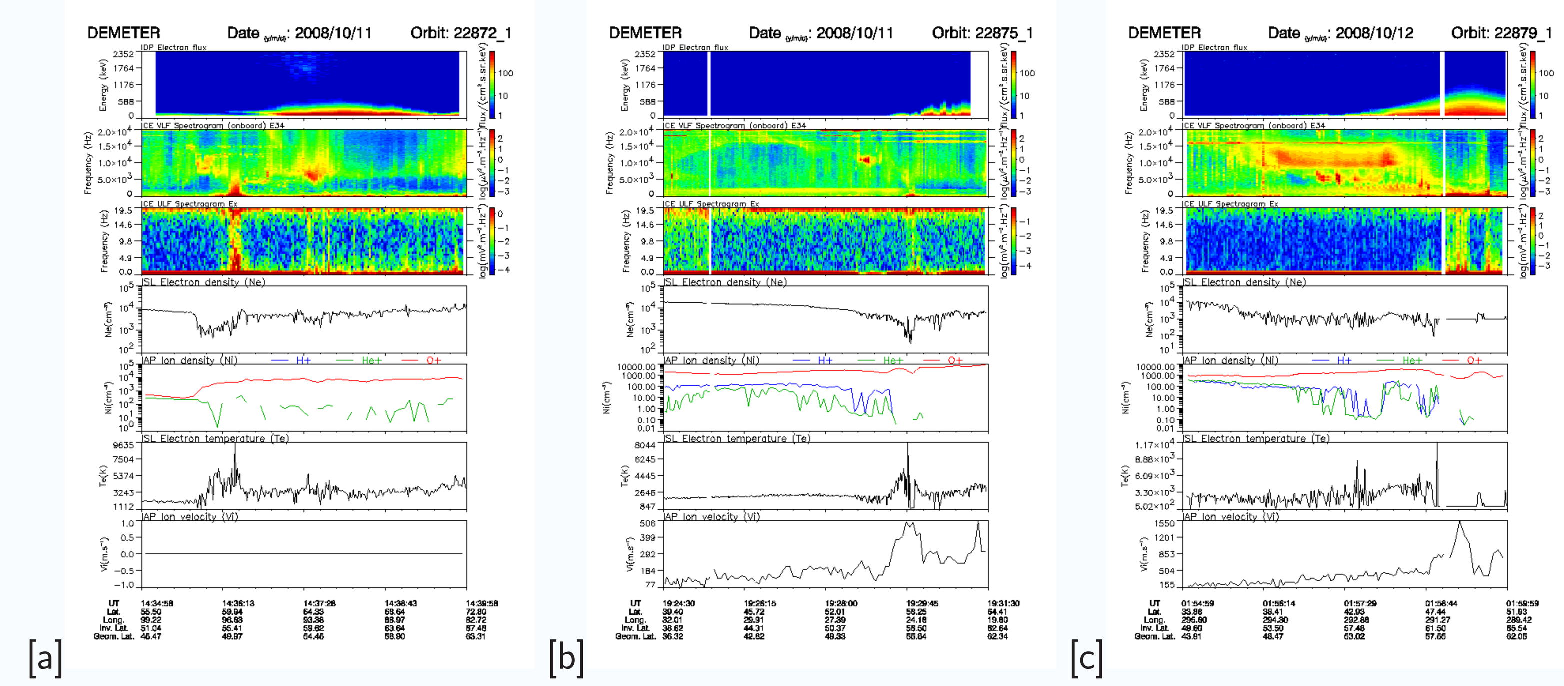

Figure 7: Graph above presents the DEMETER registration taken during magnetic storm in October.[a]-storm onset, [b],[c]-recovery phase.

Summary

The ionosphere during deep solar minimum seem to behave differently than while the Sun is active. Rather moderate geomagnetic storms cause observable changes in ionospheric plasma properties. The patterns are following:

- when the solar flux increases the electron temperatures and densities increases as well;
- the electrons with the higher temperatures are mainly located around the L=4, however they move towards lower L-shell values (equatorward) during magnetic disturbance;
- areas with the miminum electron density and maximum electron temperature can be related to the mid-latitude trough. That would explain why those features are located equatorward in years with enhanced solar (geomagnetic) activity.

Acknowledgements

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[2] Yizengaw, E., H. Wei, M. B. Moldwin, D. Galvan, L. Mandrake, A. Mannucci, and X. Pi (2005), The correlation between mid-latitude trough and the plasmapause, *Geophys. Res. Lett.*, 32, L10102