GROUND AND IONOSPHERIC SIGNATURES OF SOLAR WIND-MAGNETOSPHERE INTERACTION AT MID-LATITUDES

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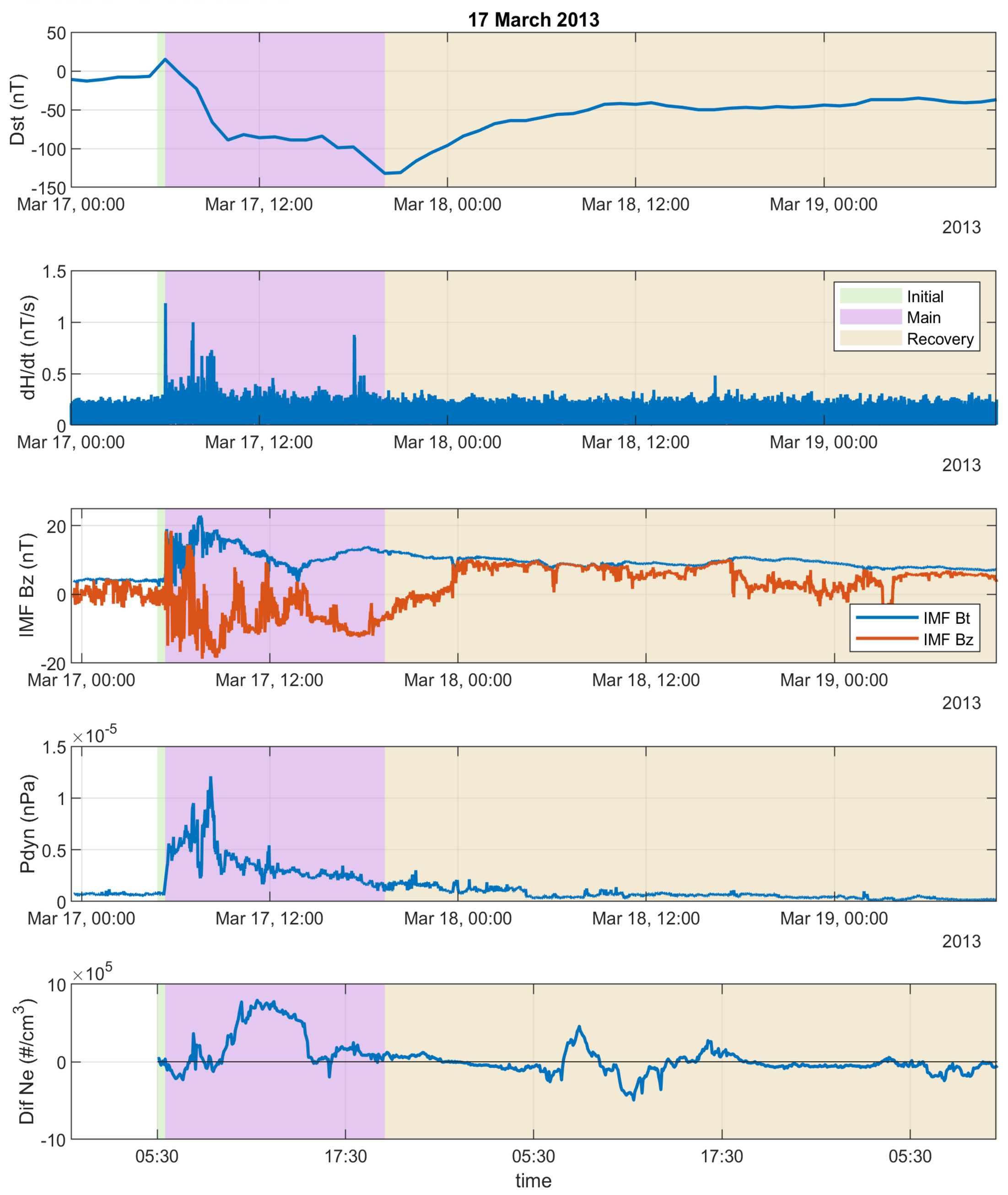
UPPER ATMOSPHERE

Abstract

As we enter the increasing solar activity epoch, the space weather phenomena and predictions become crucially important to avoid the effects on our lives and technology which is becoming more space-dependent every day. One of the key issues in space weather is to determine the worldwide signatures of the solar wind-magnetosphere-ionosphere coupling. While the response of the high and low latitude regions on Earth to the space weather phenomena is well established, the signatures at the mid-latitudes comparatively are less explored. Being farther from both the auroral and the equatorial latitudes, mid-latitude signatures of the solar wind-magnetosphere interaction can be more complex and may not be so straightforward. In this study, the effects of the geomagnetic activity are investigated using observational tools which are unique to its geographical region, north-west Turkey. Dynasonde radar measurements (Dynasonde at ITU Campus, 41°N, 29°E), magnetotelluric measurements of ground electric field (Magnetotelluric station at Bozcaada, 39.5°N, 26°E), and geomagnetic field variations (Geomagnetic observatory at Iznik, 40.43°N, 29.72°E) are combined to obtain a global perspective of the space weather effects in this mid-latitude region. Magnetically active periods were determined using Dst index and the variations in the corresponding ionospheric electron density and the geomagnetically induced currents (GICs) were analyzed based on the case studies as well as statistical tools. More than 20 indicators such as differences in the fields, extreme values, averages, and storm durations were analyzed and their relations to magnetic storms as well as solar wind and interplanetary magnetic field (IMF) connections were studied. GICs were investigated based on the variations in the horizontal magnetic field. The dependence on the magnetic storm phases was revealed. One of the most intriguing results from both case studies and statistical analysis is that stronger GICs were found in our region during the recovery phase of the geomagnetic storms. The electron density variations indicated both positive and negative effects during the storms. The magnitudes of the variations for both GICs and electron density variations were determined. While the case studies indicate close relations with geomagnetic indices, solar wind, and IMF variations, statistical results resulted in small correlation coefficients. This emphasizes and further indicates the importance of the statistical indicator that is used in the correlation analysis. In this presentation, solar wind-magnetosphere connection to the ionosphere and to the ground will be discussed in view of our findings. It is believed that these results will improve our understanding of the cause-and-effect of the space weather phenomena at mid-latitudes while at the same time, it will give support to global space weather modeling studies.

Case Studies



Three cases from 3 different years have been thoroughly analyzed. The solar origins of the storms have been determined via various coronagraph and solar imagery obtained from NASA SDO and LASCO. The geomagnetic effects of these cases have been investigated with geomagnetic indices and different model outputs. For each case, the time series of dH/dt and electron density differences, and solar wind parameters are analyzed.

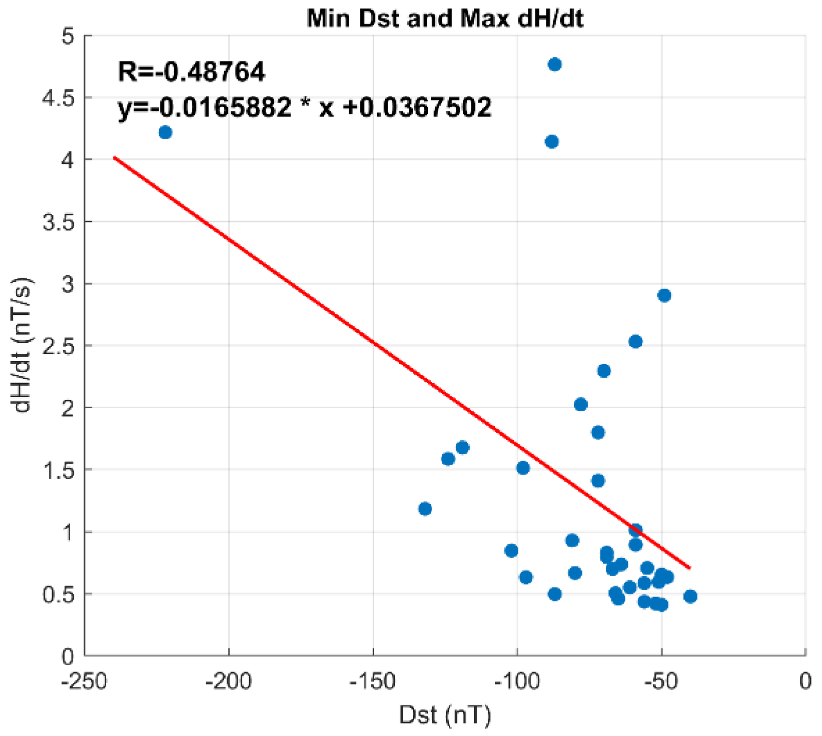
In the figure on the left, time series for St. Patrick Storm 2013 can be seen. The greatest variations are seen during the main phase of the storm including dH/dt, IMF Bt and Bz, dynamic pressure, and the difference in electron density. The changes in dH/dt seem almost perfectly aligned with Dst, and IMF Bz. Yet on the other hand, as expected ionosphere does not respond to the changes in geomagnetic conditions quickly. The electron density starts to increase a few hours after the storm starts. The most significant effect on the first day of the storm also shows alignment with the other parameters but with a natural delay.

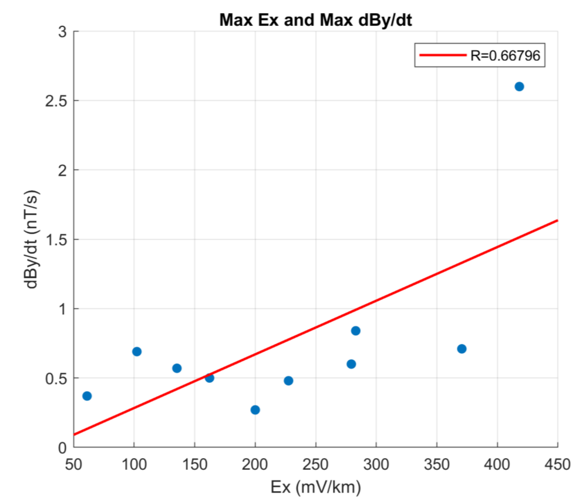
Correlations

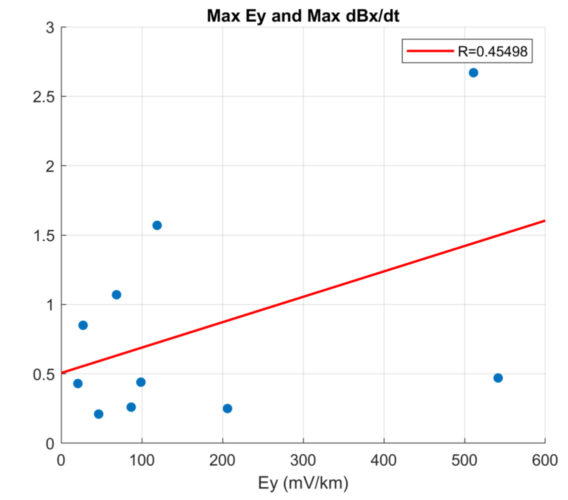
Linear relationships between 69 physically meaningful pairs is found. Pearson correlation coefficient is calculated for this analysis. Student's t-test for 95% significance level is applied for the pairs. According to the test, the correlations coefficients smaller than 0.36 are statistically insignificant. Among the 69 pairs, 22 of them are statistically significant.

Some of the most important relationships is the correlation between geomagnetic indices and the maximum dH/dt of each storm. Maximum Dst is chosen to investigate the effect of the sudden commencement as well as the other indices minimum Dst, maximum AE, and maximum Kp.

- Minimum Dst → -0.48
- AE → 0.42
- Kp → 0.37
- Maximum Dst → Statistically insignificant







Faraday's law has been tested for mid-latitudes. According to Faraday's law, Ex is closely related to dBy/dt, and Ey is closely related to dBx/dy. In order to test this, the maximums of each parameter for 10 cases have been analyzed.

- Ex and dBy/dt → 0.67
- Ey and dBx/dt → 0.46

Data and Methodology

Faraday's induction law $\nabla \times \vec{E} = -\frac{\delta \vec{B}}{\delta t}$

- **SOLAR WIND**
  - ACE
  - WIND
- **GEOMAGNETIC STORM**
  - Dst < -40 nT

Time derivative of the horizontal geomagnetic field

$$\frac{dH}{dt} = \sqrt{\left(\frac{dB_x}{dt}\right)^2 + \left(\frac{dB_y}{dt}\right)^2}$$

Relationship between electric and magnetic field components

$$\vec{E_x} \propto -\frac{dB_y}{dt} \qquad \vec{E_y} \propto -\frac{dB_x}{dt}$$

Equation to find electron density with critical frequency

$$n_{e_{max}} = \left(\frac{f_{critical}}{0.0091}\right)^2$$

- **GROUND LEVEL MAGNETIC FIELD DATA**
  - 2013-2015
  - 37 events, 1 second
  - İznik (40°N, 29°E)
  - Fluxgate Magnetometer
- Bx, By, Bz
- Max $\frac{dH}{dt}$

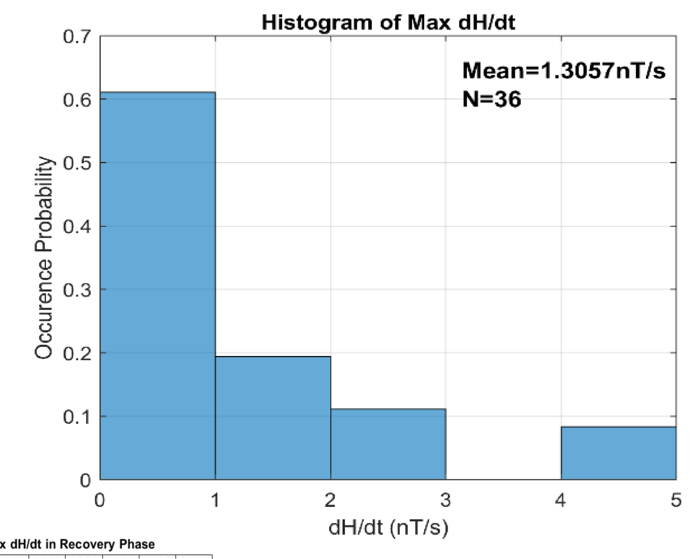
- **GROUND LEVEL ELECTRIC FIELD DATA**
  - 2013-2014
  - 10 events, 1 second
  - Bozcaada (39°N, 26°E)
  - LEMI MT
- Bx, By, Bz
- Max $\frac{dH}{dt}$
- Ex, Ey

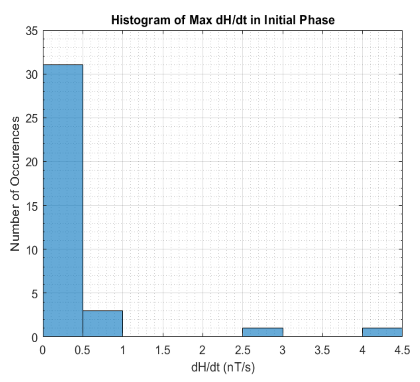
- **IONOSPHERIC LEVEL ELECTRON DENSITY**
  - 2013-2015
  - 36 events, 4 minutes
  - İstanbul (41°N, 28°E)
  - Dynasonde
- **Ne**
- foF2

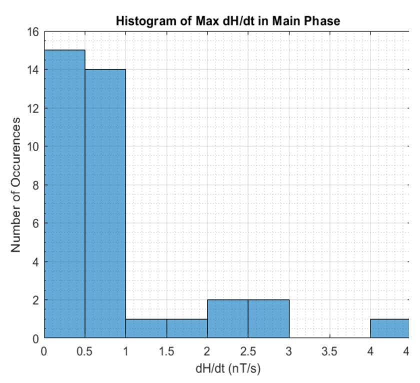
Statistical Analysis and Histograms

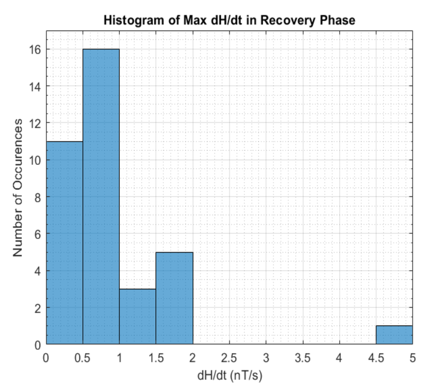
27 histograms have been formed to see the general distribution of parameters and understand the general behavior expected over mid-latitudes.

The threshold for the GICs have been chosen as 1 nT/s. The maximum dH/dt value of every storm period is considered and the result is approximately in 40% of the storms, GICs ocur over mid-latitudes.



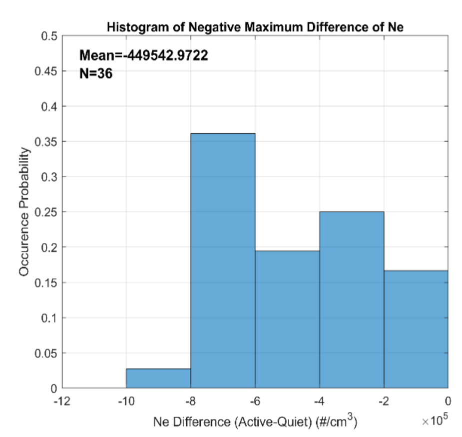


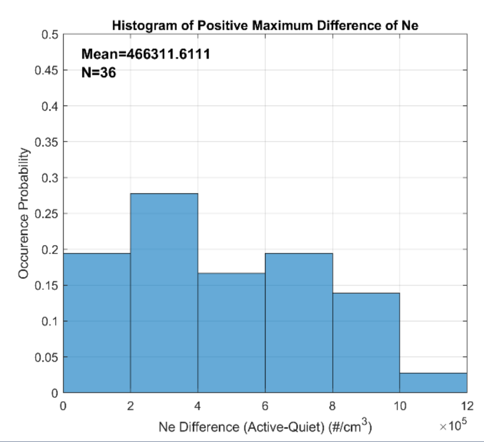


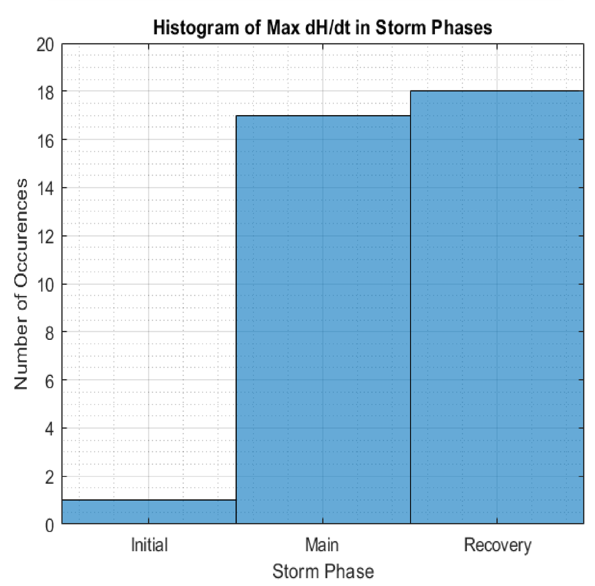


The maximum dH/dt in every phase is found and the result is that the maximum dH/dt is seen in the recovery phase the most.

Ionospheric Electron Density, the negative and positive maximums of each storm is found to see which effect is more frequent. → **EQUAL**







Conclusions

- The main dH/dt fluctuations for the 17 March 2013 storm start with the sudden commencement and last throughout the main phase, and the maximum dH/dt is greater than 1 nT/s. Ionospheric electron density increases (positive effect) during the main phase.
- The case studies Show great alignment with the solar wind parameters especially with IMF Bz and dynamic pressure, even though the same relationship is not seen in the statistical study.
- In 40% of the cases the maximum dH/dt is greater than 1 nT/s.
- In half of the storms, the maximum dH/dt is seen during the recovery phase. In only one case the maximum dH/dt occurs during the initial phase.
- In half of the cases, the maximum electron density difference is negative, and in the other half, it is positive. Thus; in mid-latitudes possibility of seeing positive and negative effects on ionospheric electron density is equal. Additionally, the possibility of seeing a greater difference is higher when the effect is negative.
- Maximum dH/dt corralates with minimum Dst the most, and maximum Dst relation is insignificant.
- Faraday's law is acceptable at mid-latitudes based on the correlation coefficients.

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