

EVIDENCE OF GEOMAGNETIC STORM EFFECTS IN THE LOWER ATMOSPHERE: A CASE STUDY

GUSTAVO A. MANSILLA AND MARTA ZOSSI DE ARTIGAS

Departamento de Física, Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán, Consejo Nacional de Investigaciones Científicas y Técnicas, Tucumán, Argentina
(gmansilla@herrera.unt.edu.ar)

Received: July 15, 2009; Revised: October 28, 2009; Accepted: January 17, 2010

ABSTRACT

Disturbances produced by geomagnetic storms in the higher regions of the Earth's atmosphere, such as in the ionospheric F2 region and in the lower ionosphere, are relatively better known than those produced at lower altitudes, where the effects of geomagnetic storms have been little studied. During magnetically perturbed conditions, some changes in pressure and temperature at high latitudes have been observed, from the surface level to heights of around 30 km, but there are no morphological studies and/or patterns of behavior. Moreover, the physical mechanisms are still unknown and what exists is a matter of controversy. Thus, the aim of this paper is to contribute to the vertical profile of the effects of geomagnetic storms as observed in the lower sectors of the atmosphere. For that, we study the variations of two atmospheric parameters (temperature and wind speed) during an intense geomagnetic storm (minimum Dst = -300 nT), at heights between about 6 km and 20 km. The data used were obtained from weather balloon flights carried out at low, mid and mid-high latitudes in different longitudinal sectors of the northern hemisphere, which took place twice per day: 00:00 and 12:00 UT. Small, but statistically significant changes in temperature and in zonal component of the neutral winds are observed at mid-high latitudes, which can be linked to short-term geomagnetic forcing. However, the results show different atmospheric response to the geomagnetic storm in the different longitudinal sectors at tropospheric and stratospheric levels, which suggests a regional character of the geomagnetic storms effects at tropospheric levels.

Keywords: geomagnetic storm, temperature, wind velocity

1. INTRODUCTION

The impact of geomagnetic storms in the upper atmosphere, more precisely in the ionospheric F2 region ionosphere and the lower ionosphere, is relatively well understood. Basically, disturbances of the ionospheric F2 layer represent increase or decrease of the maximum electron density $NmF2$ from median or quiet-time values. However, the reaction of the ionosphere at different ionospheric stations may be quite different during the same geomagnetic storm depending on the station coordinates, local time of the geomagnetic storm onset, and some other parameters. The lower ionosphere contains

generally enhanced electron density in the auroral zone, but at middle and low latitudes the effect is opposite. The different behaviour is due to the differences in physical mechanisms responsible for the changes in the electron density (*Danilov and Lašovička, 2001*).

Electric fields, thermospheric meridional winds, a “composition bulge” and high latitude particle precipitation have been suggested as probable physical mechanisms to explain the ionospheric reaction to geomagnetic storms observed in the ionosphere at different latitudes and different stages of the storms (see for example *Fuller-Rowell et al., 1994; Prölss, 1995; Buonsanto, 1999; Danilov, 2001*, and references therein).

The effects of geomagnetic storms in the lower regions of the atmosphere are less known or controversial. Rocket measurements of temperature in the upper and middle stratosphere were summarized by *Lašovička (1988)*. The strongest influence on temperature was observed at high latitudes. The “height profile” is: lower thermosphere and upper mesosphere - heating; middle mesosphere (~ 70 km) - cooling; lower mesosphere (~ 60 km) - moderate heating; and upper stratosphere - positive, but rather marginal, correlation.

In the troposphere, although there is some evidence of geomagnetic storm effects, a mechanism enabling explanation of the observed correlations has not been established yet (*Lašovička, 1997*).

The purpose of this short paper is to provide an evidence for geomagnetic storm effects in the lower atmosphere to make a contribution to the vertical profile pattern of the geomagnetic storm effects in the Earth’s atmosphere. To do this, the latitudinal variation in two atmospheric parameters (temperature and wind speed) during an intense geomagnetic storm (minimum $Dst = -300$ nT) at heights from about 6 to 20 km was studied.

2. RESULTS

Fig. 1 shows variations of Dst and Kp geomagnetic indices for 12–21 July 2000. The magnetic storm considered exhibited two sudden commencements (SC). The first one occurred at 09:42 UT on 13 July. A gradual and irregular decrease was observed until about 14:00 UT on 15 July ($\Sigma Kp = 50$, $Ap = 164$), when Dst increase was observed; the

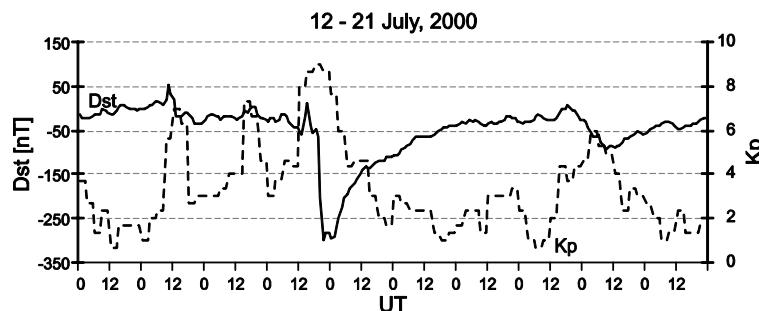


Fig. 1. Hourly Dst geomagnetic index and Kp index on 12–21 July 2000.

Table 1. List of geomagnetic stations, along with their Weather Bureau Army Navy (WBAN) identification numbers, used in the study. The stations are grouped into three longitudinal sectors.

Station	Latitude [°S]	Longitude [°W]	Geomag. Lat. [°S]
04102, Great Falls	47.5	-111.4	58.4
3198, Reno	39.6	-119.8	45.9
03020, Santa Teresa	31.9	-106.7	40.1
14898, Green Bay	44.5	-88.1	54.2
13723, Greensboro	36.1	-79.9	46.2
03937, Lake Charles	30.1	-93.2	39.6
12842, Tampa Bay/Ruskin	27.7	-82.4	37.8
11641, San Juan/Isla Verde	18.4	-66.0	28.7
40504, Ponape Island	7.0	158.2	0.36
40505, Truk Intl/Moen Island	7.4	151.8	-0.07
40309, Koror/Palau Island	7.3	134.5	-1.9

second sudden commencement took place at 14:38 UT. Thereafter, Dst sharply decreased and the main storm begun. At 22:00 UT Dst reached its minimum of -300 nT and after that a relatively rapid recovery started.

The data used were obtained from weather balloon flights carried out at low and mid latitudes in different longitudinal sectors of the northern hemisphere, which took place twice per day: 00:00 and 12:00 UT. The data are values of atmospheric temperature and velocity of the neutral wind (zonal and meridional components) taken at heights of isobaric surfaces one day before the start of the storm commencement and 6 days after it (12–21 July 2000). Measurements of temperature have an accuracy of $\pm 0.2^\circ\text{C}$ between 1080 and 100 mb and $\pm 0.3^\circ\text{C}$ below 100 mb while wind velocity measurements have an accuracy of ± 1 m/s. The stations used, and their geographic latitudes and longitudes are listed in Table 1.

For each longitudinal sector we select 10 magnetically quiet days outside the considered 12–21 July period and calculate average values and standard deviation σ for the analyzed parameters for 00:00 UT and 12:00 UT. The storm effects in the atmospheric parameters may be considered as significant if the deviation exceeds 2σ . This is an usual criterion normally used to demonstrate the existence of an effect in variations of any geophysical parameter. Only cases with statistically significant deviations ($> 2\sigma$) are shown in the paper.

Fig. 2 shows the variations in temperature (00:00 and 12:00 UT) at 500 mb level at the higher latitude station located in the longitude sector 105°W – 115°W together with the average value (line) and $\pm 2\sigma$ (dashed line). It can be seen statistically significant decreases in temperature about 4 days after the end of the main phase. At higher altitudes and at the rest of the stations no significant changes have been observed during the considered storm period.

Fig. 3 is representative of the behavior observed in the zonal component of the neutral wind at the higher latitude station of that sector. Statistically significant increases are observed also at the isobaric surfaces of 500 and 300 mb (not shown here), which take

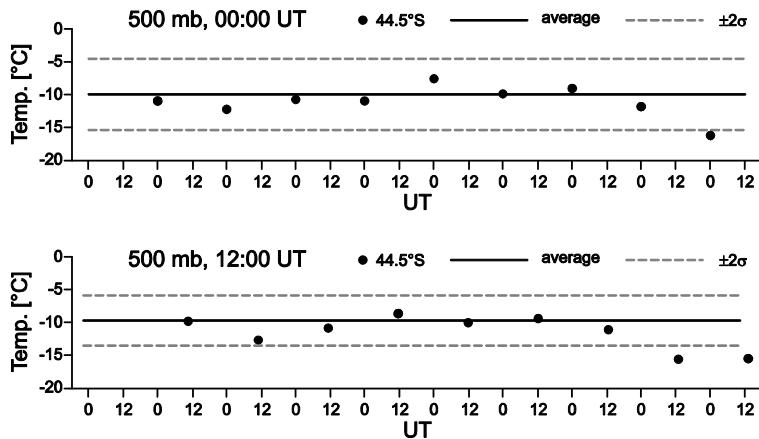


Fig. 2. Variation of temperature at 00:00 UT and 12:00 UT on the isobaric surface corresponding to 500 mb for the higher latitude station (44.5°S) located in the longitudinal sector 105°W – 115°W (dots). Full line: quiet time average of 10 days; dashed lines show its 2σ uncertainty.

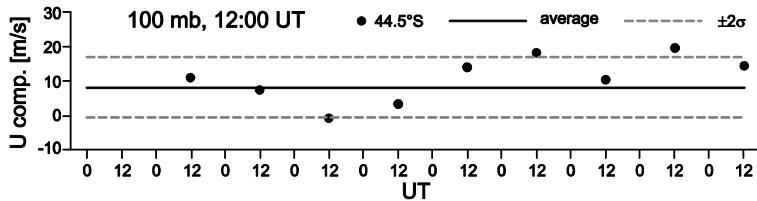


Fig. 3. Variation of the zonal component U (dots) on the isobaric surface corresponding to 100 mb (12:00 UT) at the higher latitude station (44.5°S) of the sector 105°W – 115°W . Full line: quiet time average of 10 days; dashed lines show its 2σ uncertainty.

place during the recovery phase of the storm. No significant effect is observed in the meridional wind component both at 00:00 UT and 12:00 UT.

Fig. 4 presents the variations of the meridional component v at 500 and 200 mb levels (00:00 UT) at the higher latitude station located in the longitude sector 66°W – 88°W . Increases can be seen, which are statistically significant during the recovery phase of the storm. Similar behaviour (not shown here) is observed at the isobaric surfaces of 300 and 100 mb, which suggests an important storm impact on the neutral wind. Temperature shows no significant deviations while they are sparse for the zonal component u . The rest of the stations in this sector show no significant effect either in the temperature or neutral wind components.

The stations located at sub-equatorial latitudes present practically no changes in temperature during the storm period while wind data at different altitudes present an irregular behavior, however the variation is not statistically significant.

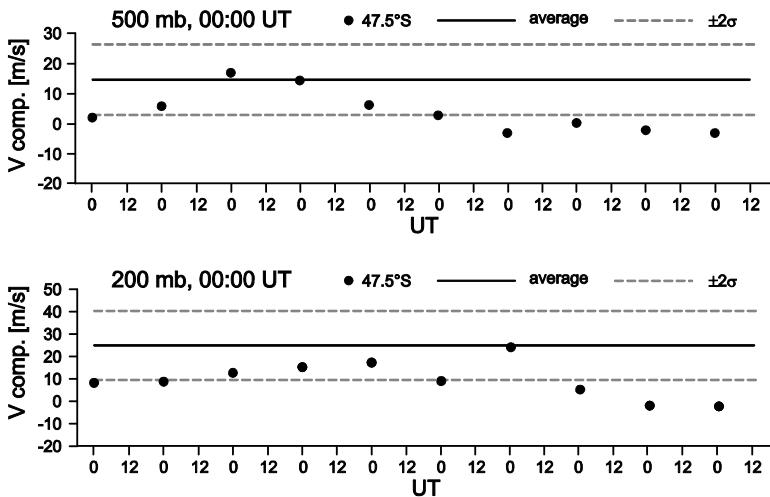


Fig. 4. Variation of the meridional component v (dots) on the isobaric surfaces corresponding to 500 mb and 200 mb for the higher latitude station (47.5°S) of the sector 66°W–88°W. Full line: quiet time average of 10 days; dashed lines show its 2σ uncertainty.

3. DISCUSSION AND CONCLUSION

This paper reports short-term variations observed in meteorological parameters at stratospheric and tropospheric levels of the terrestrial atmosphere during an intense geomagnetic storm. The results obtained suggest that the lower part of the atmosphere demonstrates a reaction to geomagnetic disturbances.

Considering stations located at mid-high, mid and low geographical latitudes, it is found that storm effects are statistically significant at mid-high latitudes.

No accuracy can be established in the response onset of the winds to the geomagnetic storm because the data present a temporal resolution of 12 hours, however some characteristics of the response of the neutral atmosphere to the geomagnetic storm can be described as follows:

During the last stage of the recovery phase at mid-high latitudes, statistically significant small changes in temperature are observed a few days after the storm onset at altitudes corresponding to 500 mb in the longitudinal sector 105°W–115°W, which seem to indicate a regional character of the disturbance. The variation in the meridional component v also shows a regional character because an intensification is observed in the longitude sector 66°W–88°W during the storm recovery phase. In this stage of the storm, v is reversed with respect to the quiet time values, blowing from north to south.

At low latitudes, statistically significant change is not observed either in temperature or in the components of the neutral wind, which seems to indicate no influence of the geomagnetic storm to the lower atmospheric processes.

It is well known that energy and momentum is transferred from the magnetosphere to the thermosphere/ionosphere system during geomagnetic storms. This energy, deposited in the high-latitude region of the upper atmosphere (thermosphere), gives rise to changes in wind and temperature profiles there. *Arnold and Robinson (1998)* postulate that these effects, in turn, affect the reflection and absorption of planetary and gravity waves. They have demonstrated that solar-cycle variations in the temperature and winds of the lower thermosphere can cause substantial variations in stratospheric temperatures. *Lam and Rodger (2003)* consider that this model did not extend into the troposphere; however, that work opens up the possibility that solar activity on a variety of scales may affect the stratosphere and possibly the troposphere via this mechanism.

Danilov and Lašovička (2001) exclude the possibility of direct downward transport of heat from the greatly heated auroral thermosphere down to the troposphere. The agent responsible for the tropospheric effects must basically skip across the stratosphere. They consider that only two agents fulfil this request, the galactic cosmic ray flux modulated by the geomagnetic storm and the global electric circuit and/or atmospheric electricity affected by in situ changes of conductivity and by ionospheric/magnetospheric electric fields and currents.

An energy deposition reflects itself in increasing temperature. The solar energetic particle (SEP) events are characterized by abrupt enhancements in the proton flux in the energy range of keV to MeV. On impacting the Earth's magnetosphere, the SEP events can lead to sudden disturbances of the Earth's magnetic field (geomagnetic storms). During SEP events energetic particles intrude into the Earth's magnetosphere and atmosphere more than 100 times during an 11-year solar cycle. Solar energetic particles behaviour in the magnetosphere and the atmosphere depends on solar energetic particles energy, height and latitude of observation site: most events do not penetrate below the altitude of 50 km and latitude lower than $\sim 60^\circ$; only 12–15 events per solar cycle can be recorded at the ground level (*Bazilevskaya, 2005*).

The SEP event considered here was one of the 4 major events of the solar cycle 23 (the maximum proton flux was ~ 24000 pfu). During strong SEP events (and intense geomagnetic storms), the solar protons and the auroral electrons possibly have sufficient energy as to penetrate to the height covered by the meteorological balloons and so, these charged particles could give rise to weak and disperse changes in temperature. Statistically significant increase in temperature is not observed in this case study. Further studies in different latitudinal sectors are necessary in order to determine whether there are temperature increases depending on the intensity of geomagnetic storm.

To explain some coolings observed at middle latitudes, a decomposition of stratospheric CO₂ was suggested to be a result of solar energetic particles. The removal of CO₂ in the stratosphere causes a cooling at tropopause levels (for details, see *Sekihara, 1979*).

Enhanced values of component u (zonal) were observed at low altitudes of the mid-high latitudes during the recovery phase depending on the longitude sector, which is indicative of an intensification of winds blowing from west to east (westerlies).

The existence of the quasi-biennial oscillation (QBO) in several solar-terrestrial parameters is well known. The zonal equatorial stratospheric winds show a well-defined QBO, in which the winds change between east and west. Although QBO is a tropical

phenomenon, it affects the stratospheric flow from pole to pole by modulating the effects of extratropical waves (for details see *Baldwin et al., 2001* and references therein). In 2000, the QBO was in their westerly phase (*Labitzke, 2005*). Although the QBO starts at about 100 mb, the increases seen during the recovery phase at mid-high latitudes at several height levels possibly affect the QBO. As before, further studies are required to obtain a better understanding of a possible influence of geomagnetic activity on the QBO.

During the recovery phase, the component v at mid-high latitudes reverses with respect to the reference values; these changes seem to be also of a rather regional character.

So, geomagnetic storms seem to cause changes in the lower stratospheric and tropospheric circulation, which remains an open and controversial topic (*Laštovička and Križan, 2005*).

In conclusion, the results presented here show evidence of possible atmospheric effects in association with a geomagnetic storm. Although the present results may be significant and could have important implications for the study of the behaviour of the atmosphere during geomagnetic storms, they still contain little statistical information. Since there are many unclear points about the details of various processes of atmospheric disturbances, more studies are required to draw definite conclusions about the geomagnetic storms effects in the lower part of the atmosphere and the involved mechanisms.

Acknowledgments: The authors wish to thank the reviewers for their usefull comments.

References

- Arnold N.F. and Robinson T.R., 1998. Solar cycle changes to planetary wave propagation and their influence on the middle atmosphere circulation. *Ann. Geophys.*, **16**, 69–76.
- Baldwin M.P., Gray L.J., Dunkerton T.J., Hamilton K., Haynes P.H., Randel W.J., Holton J.R., Alexander M.J., Hirota I., Horinouchi T., Jones D.B.A., Kinnersley J.S., Marquardt C., Sato K. and Takahashi M., 2001. The quasi-biennial oscillation. *Rev. Geophys.*, **39**, 179–229.
- Bazilevskaya G.A., 2005. Solar cosmic rays in the near Earth space and the atmosphere. *Adv. Space Res.*, **35**, 458–464.
- Buonsanto M.J., 1999. Ionospheric storms - a review. *Space Sci. Rev.*, **88**, 563–601.
- Danilov A.D., 2001. F2-region response to geomagnetic disturbances. *J. Atmos. Sol.-Terr. Phys.*, **63**, 441–449.
- Danilov A.D. and Laštovička J., 2001. Effects of geomagnetic storms on the ionosphere and atmosphere. *Int. J. Geomag. Aeron.*, **2**, 1–24.
- Fuller-Rowell T.J., Codrescu M.V., Moffett R.J. and Quegan S., 1994. Response of the thermosphere and ionosphere to geomagnetic storms. *J. Geophys. Res.*, **99**, 3893–3914.
- Labitzke K., 2005. On the solar cycle-QBO relationship: a summary. *J. Atmos. Sol.-Terr. Phys.*, **67**, 45–54.
- Lam M.M. and Rodger A.S., 2003. An investigation into the correlation of geomagnetic storms with tropospheric parameters over the South Pole. *Ann. Geophys.*, **21**, 1095–1100.
- Laštovička J., 1988. A review of solar wind and high energy particle influence on the middle atmosphere. *Ann. Geophys.*, **6**, 401–408.
- Laštovička J., 1997. Effects of geomagnetic storms-different morphology and origin in the upper middle atmosphere and the troposphere. *Stud. Geophys. Geod.*, **41**, 73–81.

- Laštovička J. and Križan P., 2005. Geomagnetic storms, Forbush decreases of cosmic rays and total ozone at northern higher middle latitudes. *J. Atmos. Sol.-Terr. Phys.*, **67**, 119–124.
- Prölss G.W., 1995. Ionospheric F-region storms. In: Volland H. (Ed.), *Handbook of Atmospheric Electrodynamics, Vol. II*. CRC Press, Boca Raton, 195–248.
- Sekihara K., 1979. The influence of solar corpuscular radiation on the meteorology of troposphere. A proposal of the mechanism. *Meteorol. Geophys.*, **30**, 141–151.