Equatorward large-scale travelling ionospheric disturbances of high latitude origin during quiet conditions

*Golekamang Thaganyana[1,2], John Bosco Habarulema[1,2]
[1] South African National Space Agency (South Africa) ,
[2] Rhodes University (South Africa)
cthaganyana@sansa.org.za

Abstract

This study presents observations of large-scale travelling ionospheric disturbances (TIDs) originating from high latitudes, and crossing the equator into the opposite hemisphere in the African-European sector, during geomagnetically quiet conditions within the period of 2010-2018. During the study period, four geomagnetically quiet days were selected each month. The Global Navigation Satellite Systems (GNSS) total electron content (TEC) data were used to obtain the two dimensional (2-D) TEC residuals. We have identified 7 interhemispheric equatorward TIDs out of 384 days that were analysed with most of them originating from the southern hemisphere. TIDs propagation velocities and periods are in the range of 270-322 m/s and 48-80 minutes, respectively. Analysis of the space weather environment and conditions rules out space weather as a source of the TIDs. However, observations of the 4.3 µm brightness temperature (BT) from the Atmospheric Infrared Sounder (AIRS) instrument on board the NASA Aqua satellite point to AGWs of troposphere-stratosphere origin as the likely source of these TIDs.

Introduction

- Atmospheric gravity waves (AGWs)/travelling ionospheric disturbances (TIDs) have been comprehensively reported for over decades (Hines, 1960; Habarulema et al., 2018, and references in). AGWs are formed when buoyancy push air up, and gravity pulls it back down.
- It is generally believed that TIDs are signatures in the ionosphere of the propagating atmospheric gravity waves.
- TIDs are wave-like perturbations in the ionospheric measurements, such as plasma density, temperature, electron concentration and drift.
- Large-scale TIDs have periods that range between 30 minutes to 3 hours, horizontal velocities greater than 400 m/s, wavelength of more than 1000 km, and generally propagate equatorward from both hemispheres (Hocke et al., 1996).

Purpose of study

The existing literature on equatorward large-scale TIDs is extensive and conducted particularly during geomagnetically disturbed conditions (Hocke et al., 1996; Habarulema et al., 2018, and references in). However, there has been no detailed investigation of equatorward propagating large-scale TIDs of high latitude origin, which can be observed across different hemispheres during geomagnetically quiet conditions. There are numerous articles reporting on large-scale TIDs during quiet conditions, but none have reported on large-scale TIDs originating from high latitude and crossing the geomagnetic equator into the opposite hemisphere. In this study, we report on observations of large-scale TIDs launched from high latitudes during geomagnetically quiet conditions with unique properties of being observable in both hemispheres.

Data selection and Method

- For the analysis, the geomagnetic quiet (maximum kp<3) days were obtained from the World Data Center for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/qddays/).
- For each month during the period 2010-2018, the four quietest days were selected.
- Observations of equatorward large-scale TIDs are made using Global Navigational Satellite System (GNSS) data over the African-European sector.
- Firstly. the outliers from VTEC of each PRN were removed by using the median (M) together with median absolute deviations (MAD). Huber (1981) defined MAD as follows:
  $$\text{MAD} = b\text{M}(|\ x - \text{M}(x)|) \quad (1)$$
  were b = 1.4826 is a constant for normally distributed observations, x represent the time series observations. Outliers were removed using the following criterion:
  $$\text{M} - 2.5 \times \text{MAD} < VTEC < \text{M} + 2.5 \times \text{MAD} \quad (2)$$
- In the next step, vertical TEC was detrended by using fourth-order polynomial to produce a residual TEC (ΔTEC) time series for each PRN.
- Data was considered within latitude and longitude coverages of 90° S-90° N and 20° -40° E, respectively.

Atmospheric Hyperspectral Infrared Spectrometer

- Observations from the Atmospheric Infrared Sounder (AIRS) (Aumann et al., 2003), a hyperspectral infrared spectrometer, on-board the NASA Aqua satellite provide data for gravity waves, clouds and deep convection.
- AIRS has 2378 channels collecting measurements at different wavelengths, including 3.74-4.61 µm, 6.20-8.22 µm, and 8.8-15.4 µm.
- It makes cross-track scans every 2.67 s with 90 footprints on the ground.
- AIRS views the same area on Earth twice per day; once during a descending pass which occurs at 01:30 LT and once during the ascending pass at 13:30 LT.

Results and discussions

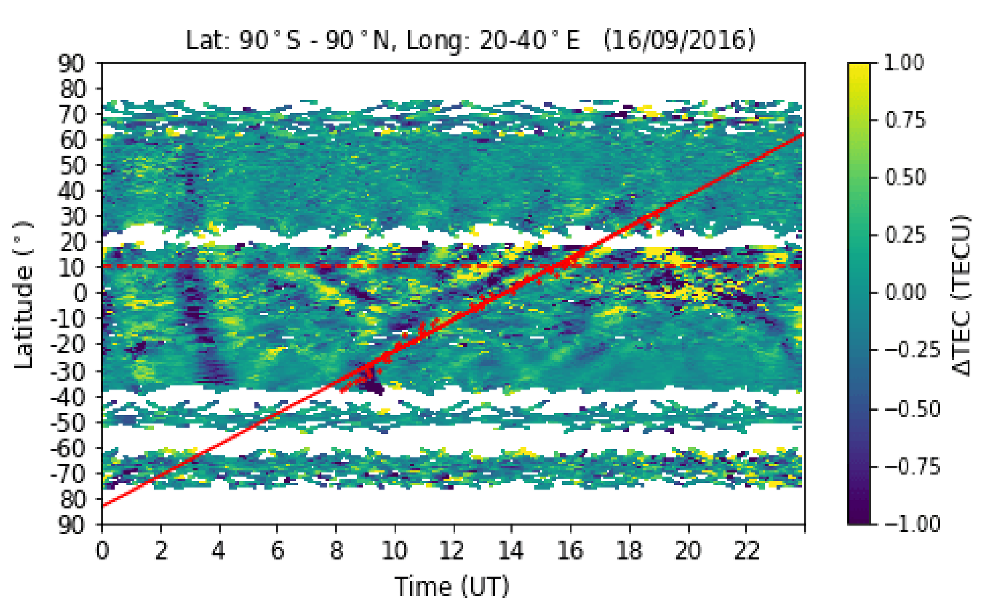

Figure 1. Latitude-Time plot of TEC perturbations for the 16 September 2016.

- TIDs appear to have originated from high latitudes as shown in Figures 1 in the southern hemispheres.
- Figures 1 show a detailed example of least-square fitting method (Liu et al., 2019) with the ΔTEC (time and latitude) maps. The linear least-square method is used to fit maximum ΔTEC in interval of the bin of 1 degree by 40 min. Keeping the interval constant, time was incremented by 10 min.
- The meridional speed and propagation direction for the TIDs can be derived based on the gradient of the fitted lines.
- The propagation velocities for the TIDs is 309 ± 23 m/s.
- The propagating azimuth of TIDs are 32.1° (clockwise from north).
- We suggest that the sources of these equatorward large-scale TIDs are tropospheric processes such as deep convections.
- To support our hypothesis, Figure 2 shows the 4.3 µm brightness temperature (BT) perturbations derived from the Atmospheric Infrared Sounder (AIRS) (Hofmann et al., 2017) and at approximate times when large scale TIDs is thought to have originated from high latitudes as revealed by the 2D ΔTEC maps.

Acknowledgments

We are grateful to the following organizations for providing data: UNAVCO (GPS RINEX data, www.unavco.org/), Trignet (GPS RINEX data, ftp://ftp.trignet.co.za/) and World Data Center for Geomagnetism, Kyoto (Kp index, http://wdc.kugi.kyoto-u.ac.jp/qddays/index.html). AIRS data used in this study is available from the following website: https://datapub.fz-juelich.de/slcs/airs/gravity_waves/index.html.

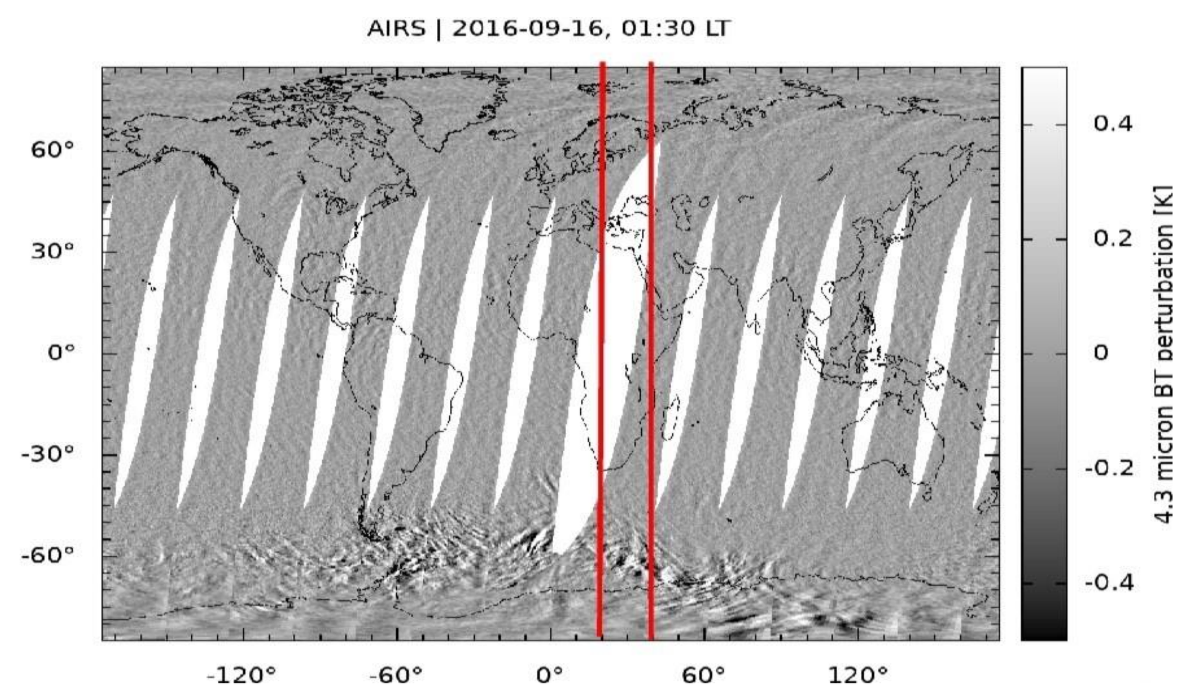

Figure 2. Global AIRS derived 4.3 µm brightness temperature perturbations on 16 September2016 at approximate times when TIDs were identified to have originated in high latitudes in GPS data. The red vertical solid lines show the region of 20°-40° E longitude sector used in GPS data.

- Observation of the presence of AGWs in AIRS 4.3 µm BT perturbations at southern hemisphere high latitudes in Figure 2.
- It is worth noting that there are no visible AGWs presence in northern hemisphere high latitude.

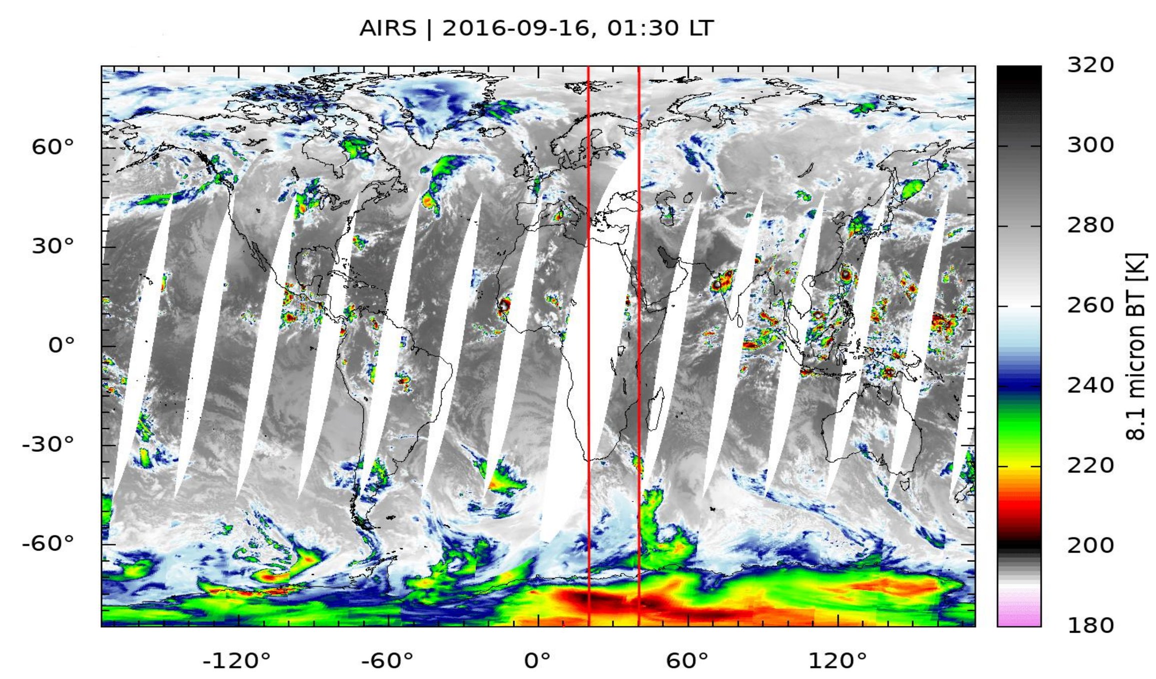

Figure 3. Global AIRS cloud imagery derived 8.1 µm brightness temperature perturbations on 16 September 2016 at approximate times when TIDs were identified to have originated in high latitudes in GPS data. The red vertical solid lines show the region of 20°-40°E longitude sector used in GPS data analyses.

- Figures 3 show that deep convection may have contributed to the observed equatorward TIDs on 16 September 2016.
- These clouds have dominant temperature less than 220 K, which indicate that deep convection did occur making observations of convective AGWs possible (Hoffmann et al., 2017).

Table 1. Properties of TIDs launched from high latitude and crossing geomagnetic equator during quiet conditions as indicated by the red solid fitted lines in Figures 1. First column: dates of occurrence of large scale TIDs; Second column: maximum kp index; third column: propagation direction of the large scale TIDs wavefront (clockwise from north); Fourth column: propagation velocities obtained using wave least-square fitting method; Fifth column: the periods of large scale TIDs.

Date	Maximum Kp index	Prop. direction (°)	Velocity (m/s)	Period (min)
13.07.2012	1	31.5	270 ± 22	80 ± 13
27.07.2012	2	44.2	311 ± 11	64 ± 9
16.01.2014	1	127.2	322 ± 12	63 ± 17
29.01.2016	1	116.5	273 ± 20	49 ± 8.3
19.04.2016	1	31.1	320 ± 47	48 ± 9.7
04.06.2016	1	36.2	251 ± 14	55 ± 10.5
16.09.2016	2	32.1	309 ± 23	53 ± 14.2

Summary

- This study presented observations of large scale TIDs possibly launched in high latitude and crossing geomagnetic equator into other side of hemisphere over the African-European sector during quiet conditions.
- For each month, four geomagnetically quiet days based on data from the World Data Center for Geomagnetism, Kyoto were selected.
- 7 interhemispheric equatorward TIDs were identified out of 384 days that were analyzed, with most of them originating in the southern hemisphere.
- TIDs propagation velocities and periods are in the range of 270-322 m/s and 48-80 minutes.
- The observations of the 4.3 µm brightness temperature (BT) from the AIRS instrument on board the NASA Aqua satellite point to AGWs of troposphere-stratosphere origin as the likely source of these TIDs.

References

Aumann, H. H., Chahine, M. T., Gautier, C., Goldberg, M. D., Kalnay, E., McMillin, L. M., et al. (2003). AIRS/AMSU/HSB on the Aqua mission: Design, science objectives, data products, and processing systems. IEEE Transactions on Geoscience and Remote Sensing, 41 (2), 253–264. https://doi:10.1109/367 TGRS.2002.808356

Habarulema, J. B., Yizengaw, E., Katamzi-Joseph, Z. T., Moldwin, M. B., & Buchert, S. (2018). Storm time global observations of large-scale TIDs from ground-based and in situ satellite measurements. Journal of Geophysical Research: Space Physics, 123 (1), 711–724. doi: https://doi.org/10.1002/2017JA024510

Hines, C. O. (1960). Internal atmospheric gravity waves at ionospheric heights. Canadian Journal of Physics, 38 (11), 1441–1481. doi: https://doi.org/10.1029/GM018p0248

Hocke, K., & Schlegel, K. (1996). A review of atmospheric gravity waves and travelling ionospheric disturbances: 1982–1995. Annales Geophysicae, 14 (9), 917. doi:435 10.1007/s00585-996-0917-6

Hoffmann, L., Spang, R., Orr, A., Alexander, M. J., Holt, L. A., & Stein, O. (2017). A decadal satellite record of gravity wave activity in the lower stratosphere to study polar stratospheric cloud formation. Atmospheric Chemistry and Physics, 17 (4), 2901–2920. doi: https://doi.org/10.5194/acp-17-2901-2017

Huber, P. (1981). Robust statistics. New York: Wiley online Library.

Liu, J., Zhang, D.-H., Coster, A. J., Zhang, S.-R., Ma, G.-Y., Hao, Y.-Q., & Xiao, Z. (2019). A case study of the large-scale traveling ionospheric disturbances in the eastern Asian sector during the 2015 St. Patrick's Day geomagnetic storm. Annales Geophysicae, 37 (4), 673{687. doi: https://doi.org/10.5194/angeo-37-673-2019