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# The equatorial stratospheric QBO and geomagnetic activity

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**Abstract**

The quasi-biennial oscillation (QBO) of the zonal wind in the equatorial stratosphere is analyzed in connection to geomagnetic activity as measured by the disturbance storm time (Dst) index. A running correlation between Dst band pass filtered values, and the equatorial zonal wind at 15, 20 and 30 hPa was estimated. Although not as clear as in the case of F10.7 analyzed in a previous work, an oscillation of around 11 years can be noticed in the running correlation coefficients, with maximum positive and negative values during maximum and minimum solar activity levels, respectively. Taking into account that higher negative Dst values correspond to stronger geomagnetic storms, this means that during maximum solar activity, there is higher (lower) geomagnetic activity during the QBO easterly (westerly) phase. During minimum solar activity this relationship is reversed. A link between these results and geomagnetic activity effects over atmospheric dynamics in the Northern Polar stratosphere is suggested.
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*Keywords:* Geomagnetic activity; Quasi-biennial oscillation; Ring current; Dst; Solar activity; Stratosphere

## 1. Introduction

The discovery of the quasi-biennial oscillation (QBO) in equatorial stratospheric winds by Reed (Reed et al., 1961) and Ebdon (1960) induced researchers to look for this oscillation in meteorological and geophysical parameters (for a comprehensive review of the QBO see Baldwin et al., 2001). Several authors have identified a QBO in geomagnetic field perturbations during quiet days analyzing data from low- and mid-latitude stations. Among them, Stacey and Westcott (1962) attributed this oscillation to the extension of the equatorial stratospheric QBO to ionospheric heights; Yacob and Bhargava (1968) argued that its source was a biennial periodicity in solar UV radiation; Raja Rao and Joseph (1971) suggested an association between its mechanism and the equatorial electrojet; and Olsen (1994) and Olsen and Kiefer (1995) postulated that the observed QBO in geomagnetic variations could be caused by a dynamo action of a QBO in lower thermospheric winds. Jarvis (1996) arrived at conclusions similar to Olsen's analyzing data of a high latitude station. Kane (1996) results indicate a strong geomagnetic QBO in the equatorial electrojet region only. He suggests that it may be related to the 50 hPa wind QBO and rules out a solar origin.

Sugiura and Poros (1977) found a QBO in the disturbance storm time index (Dst) highly correlated

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with a QBO in Rz. According to them, the most likely cause for this oscillation is a solar modulation of the rate of plasma injection into the magnetosphere. Rangarajan and Araki (1997) detect a QBO in Dst of 22-month periodicity, although different in quasi-period to the QBO in stratospheric winds, and suggest also a solar cause.

The Dst index monitors the disturbance of the horizontal component of the geomagnetic field (*H*) at the dipole equator on the Earth's surface (Mayaud, 1980). This disturbance field is originated by ions injected into the inner magnetosphere, which, by the geometry of the geomagnetic field, drift around the Earth forming a westward ring current. When a typical storm occurs, a substantial ring current develops over a few hours and then recovers over several days. A comprehensive analyses of magnetic storm morphology has been made by Gonzalez et al. (1994). The range of observed Dst is approximately +100 to −600 nT. Quiet time (undisturbed) conditions are represented by a Dst of 0, but this is not typical. Following the terminology of Sugiura and Chapman (Gonzalez et al., 1994) intense storms are those with a peak Dst of −100 nT or less, moderate storms fall between −50 and −100 nT, and weak storms are those between −30 and −50 nT.

In this work, we analyze geomagnetic activity as measured by Dst index in order to detect if, as in the case of solar UV radiation, there is an association with the equatorial stratospheric QBO (Elias and Zossi de Artigas, 2003). While geomagnetic activity is caused by corpuscular radiation carried by the solar wind, solar UV is electromagnetic radiation. Through this analysis, which is made applying the running correlation method to Dst and the equatorial zonal wind between 15 and 30 hPa, we intend to add one more hint to the controversial theme of solar influences on climate, especially to the link between solar effects on the stratosphere including the link to the QBO in equatorial stratosphere. Solar-terrestrial relations have become an important subject after the detection of the global warming. Many papers have appeared trying to determine if the long-term increase in global temperature is of anthropogenic or solar origin. Evidence for an enhanced role of the Sun in forcing climate has been shown through correlations between solar or geomagnetic activity indices and atmospheric parameters. The detection of solar forcing at the stratosphere is less straightforward due to the shorter records of stratospheric parameters in comparison to tropospheric ones.

## 2. Data analysis

Monthly mean Dst data, obtained from hourly data available at the World Data Center-C2 of the Kyoto University, Japan, were band pass filtered with frequency bounds corresponding to periods of 12 and 39 months. The band pass filter was constructed as the difference of a low pass filter with a cutoff frequency of 12 months and another filter with a cutoff frequency of 39 months. Both of them are Boxcar filters (running means) with finite impulse response (FIR filter). The filter was applied to the raw monthly Dst data and the resulting series was called DDst. Fig. 1 shows the monthly mean Dst and DDst series. While the raw Dst presents the semi-annual and solar cycle as important periodicities, the filtered series has almost eliminated them. The amplitude of DDst variation is, on average, 20% of Dst amplitude (maximum departure from the mean). Fig. 2 presents DDst estimated with another filtering technique: wavelet analysis. The band pass filtered series was estimated as the level 5 detail of the multiresolution analysis of the raw Dst monthly mean series using Daubechies 6 wavelet. Both filtered series (DDst estimated with the Boxcar filter and DDst obtained after a wavelet analysis) are quite similar.

We have chosen the monthly mean of Dst since we needed a series with the same frequency of observations as that of the equatorial stratosphere zonal wind data, which is a data per month. But, due to the nature of the Dst index, a monthly average may not be the correct monthly statistic to use. However, if the Boxcar band pass filter is applied to the daily series, the same DDst series as that estimated with monthly data is obtained. This result is not surprising due to the nature of the filtering process used, which involves averages with equal weights.

The monthly mean zonal wind in the equatorial stratosphere, which define the phases of the QBO, was taken from a compilation by Naujokat (1986) (http://dss.ucar.edu/cdroms/karin_labitzke_strat_grids/data/qbo/qbo_53-01.dat) for the levels 15, 20 and 30 hPa. The

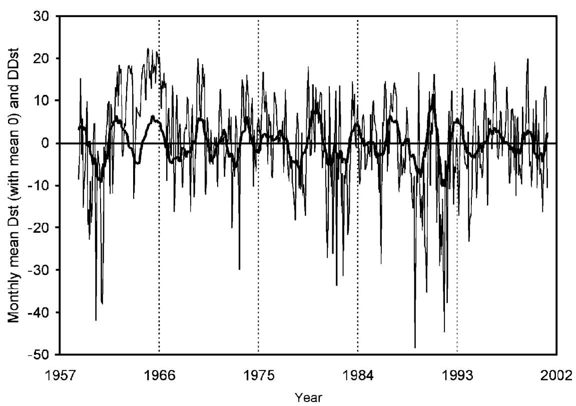


Fig. 1. Monthly mean Dst index minus the average value of the whole period (solid thin line) and Dst band pass filtered with frequency bounds corresponding to periods of 12 and 39 months (enhanced line).

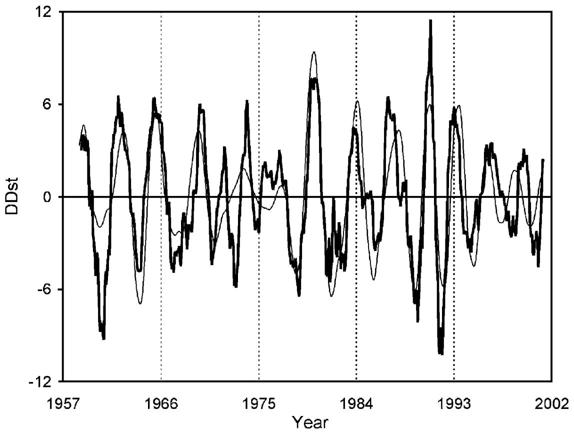


Fig. 2. Dst band pass filtered with frequency bounds corresponding to periods of 12 and 39 months (enhanced black line) and detail 5 of a multiresolution analysis of Dst with Daubechies 6 wavelet (thin line).

data set, going from 1953 to the present, combines the observations of the radiosonde stations Canton Island (3°S, 172°W), Gan/Maledive Islands (1°S, 73°E), and Singapore (1°N, 104°E). This data set is representative of the equatorial belt since all studies have shown that longitudinal differences in the phase of the QBO are small (Naujokat, 1986).

Fig. 3 presents Dst band pass filtered values (DDst) and the mean zonal equatorial wind at 15, 20 and 30 hPa. It can be noticed periods where the wind and DDst oscillates in phase with almost the same frequency, and periods where there is a phase shift. In order to take into account these changes a running correlation between DDst and the mean zonal equatorial wind at 15, 20 and 30 hPa was performed. According to Kodera (1993) a change in the relationship between two variables, $X$ and $Y$, can be investigated by calculating the running correlation $r$ for year $i$ as follows:

$$r_i = \frac{\frac{1}{M}\sum_{n=i-m}^{i+m} X'_n Y'_n}{\sqrt{\frac{1}{M}\sum_{n=i-m}^{i+m} X'^2_n \frac{1}{M}\sum_{n=i-m}^{i+m} Y'^2_n}},$$

where $M = 2m + 1$ is the window width and primed quantities are deviations from the $M$ year mean, that is

$$X'_i = X_i - \frac{1}{M}\sum_{n=i-m}^{i+m} X_n.$$

Fig. 4 shows the running correlation coefficient time series for 15, 20 and 30 hPa with $M = 4$ years together with the smoothed sunspot number, Rz. An oscillation of around 11 years can be noticed in all of them with maximum positive correlation during maximum solar activity and maximum negative correlations during minimum solar activity except for solar cycle 20 where

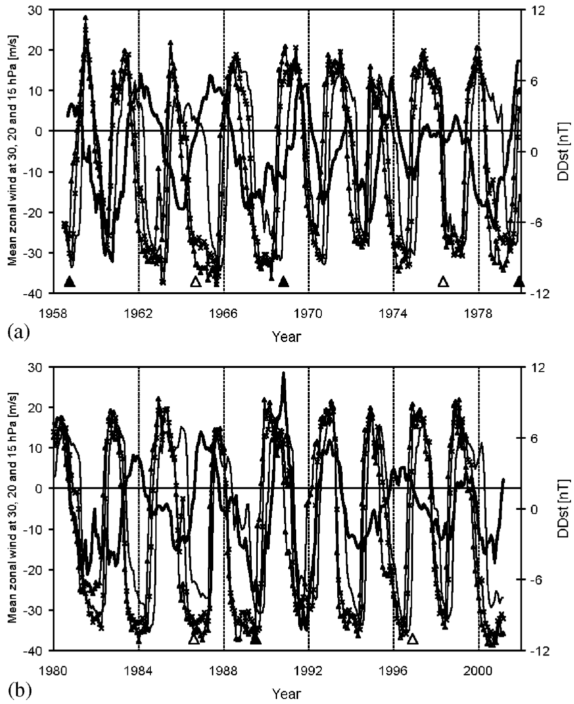


Fig. 3. Dst band pass filtered with frequency bounds corresponding to periods of 12 and 39 months (enhanced black line), monthly mean zonal equatorial wind at 30 hPa (thin black line), at 20 hPa (line with crosses) and 15 hPa (line with empty triangles). Filled and empty triangles correspond to maximum and minimum solar activity level dates respectively.

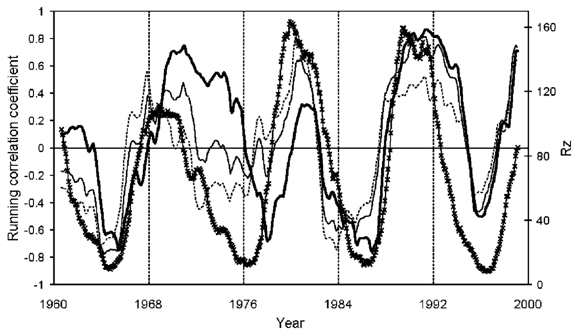


Fig. 4. Running correlation coefficient time series with a 4-year window-width between DDst and monthly mean zonal equatorial wind at 15 hPa (solid line), 20 hPa (dashed line), and 30 hPa (enhanced line), and Rz after a 12-month running mean (line with crosses).

the maximum correlation occur during the declining phase. This solar cycle is a special one due to its very low activity. Changes in the window width ($M$) up to 5 years affect the results only by decreasing the amplitude of the 11-year oscillation of $r$.

Taking into account that higher negative Dst values correspond to stronger geomagnetic storms, it can be said that during maximum solar activity levels, higher geomagnetic activity coincides with the easterly phase of the QBO, and lower geomagnetic activity with the westerly phase. During minimum solar activity levels higher geomagnetic activity coincides with the westerly phase of the QBO, and lower geomagnetic activity with the easterly phase.

There are numerous assumptions and errors involved in Dst calculations and as a consequence, the index contains systematic and random errors (Mayaud, 1980). The Dst index is defined to be linearly proportional to the total energy of particles drifting in the radiation belts (symmetric ring current) but since it is estimated from surface measurements of $H$, it is affected by many electrical currents other than the symmetric ring current, such as Sq which results from ionospheric currents. This current flows in the E region, where dynamo electric fields are generated as the neutral drag ions across geomagnetic field lines. The Sq current is driven by solar EUV radiation, which not only produces the ionization in the E region but also heats the atmosphere and causes the wind (Schunk and Nagy, 2000). One may think that through Sq the EUV QBO suggested by Elias and Zossi de Artigas (2003) may affect Dst, but it is assumed that Sq effects on Dst are eliminated by the algorithm that calculates the Dst index, and that the residual variations due to an insufficient elimination of Sq are probably small (Mayaud, 1980). Nevertheless, Sugiura (1976) already argued that the quasi-biennial geomagnetic variations he observed cannot be from similar variations in the ionospheric Sq current. If as a geomagnetic activity index aa is used instead of Dst, which is most probably free of any Sq contamination, the results are similar taking into account that there is an inverse association between aa and Dst. This can be seen in Fig. 5 which shows the running correlation coefficients between aa filtered time series and mean zonal equatorial wind at 15, 20 and 30 hPa. Here again, there is an exception during cycle 20 since the maximum correlation, instead of occurring during a minimum, it takes place during the declining phase.

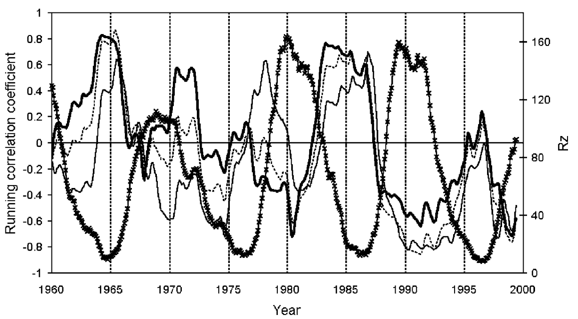


Fig. 5. Running correlation coefficient time series with a 4-year window-width between Daa and monthly mean zonal equatorial wind at 15 hPa (solid line), 20 hPa (dashed line), and 30 hPa (enhanced line), and Rz after a 12-month running mean (line with crosses).

*2.1. Correlation between filtered Dst and solar activity parameters (Rz and F10.7).*

Sugiura (1976) and Sugiura and Poros (1977), based upon a correlation analysis between geomagnetic and solar activity indices, suggested the possibility that quasi-biennial variations observed in the geomagnetic field and stratospheric parameters are produced by a common cause on the sun. For the period 1958–1973, they found highly correlated quasi-biennial variations in the geomagnetic field and in solar activity analyzing Dst and Rz. In order to extend their analysis until 2000 the lag correlation between DDst and filtered Rz and F10.7 (DRz and DF10.7) using our filtering technique, was estimated. Since DRz and DF10.7 behave very similarly we will discuss only the association of DDst with DRz.

The series have been divided into two periods: 1958–1973, which is the period analyzed by Sugiura and Poros, and the most recent period 1973–2000. At lag 0, the correlation coefficient is around $-0.36$ in both cases, close to the value $-0.4$ obtained by Sugiura and Poros. For the period 1958–1973, the maximum correlation $-0.57$ occurs at a lag of $-5$ months (Rz 5 months ahead Dst). The maximum positive correlation is 0.3 at a lag of $+11$ months (Dst 11 months ahead Rz). The maximum correlations obtained by Sugiura and Poros are $-0.79$ at a lag of –4 months and 0.75 at a lag of $+8$ months that would imply a half cycle of 12 months (or a 24-month cycle) in the correlated series. In our case this cycle would be around 32 months.

If the band pass filter used in this work is narrowed, being closer to the filter used by Sugiura and Poros, the correlation coefficients at lag 0 are now $-0.39$ during 1958–1973 and $-0.31$ during 1974–2000. For the first period, the maximum correlation, which is again $-0.57$, occurs now at a lag of $-4$ months as in the case analyzed by Sugiura and Poros, followed by the maximum positive correlation 0.28 at a lag of $+9$ months. As can be seen in Fig. 6(a) when Dst is lagged ahead Rz the correlation coefficients are much lower during the period 1974–2000 and during 1958–2000 than those obtained by Sugiura and Poros. When Rz is lagged ahead Dst, for periods 1974–2000 and 1958–2000 using the broad and narrow filters, there seems to be a cycle of around 29 months in both series, DRz and DDst. This periodicity in Rz would be 3–4 months ahead the periodicity in Dst. Fig. 6(b) shows the Student $t$ value together with the 95% and 99% significance level. The 4-month time lag is shown to be present also when the raw monthly Dst and Rz are correlated for the period 1958–1973. The same

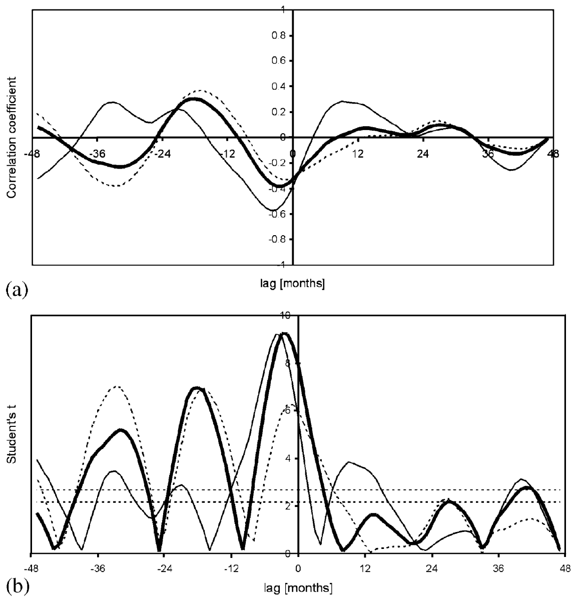


Fig. 6. (a) Cross-correlation coefficient between DDst and DRz for the periods 1958–1973 (solid line) 1974–2000 (dotted line) and 1958–2000 (enhanced line). (b) Student's t value as function of time lag. Straight dotted lines are t values for a 95% (upper) and 99% (lower) significance level.

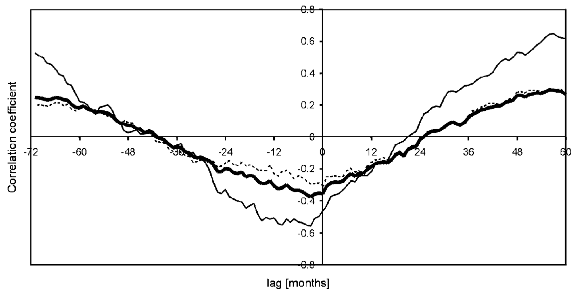


Fig. 7. Cross-correlation coefficient between Monthly mean Dst and Rz for the periods 1958–1973 (solid line) 1974–2000 (dotted line) and 1958–2000 (enhanced line).

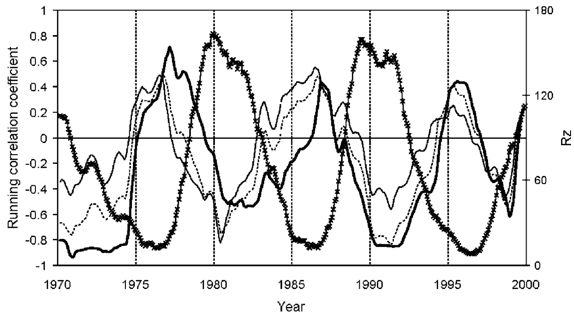


Fig. 8. Running correlation coefficient time series with a 4-year window-width between DB (filtered IMF magnitude B) and monthly mean zonal equatorial wind at 15 hPa (solid line), 20 hPa (dashed line), and 30 hPa (enhanced line), and Rz after a 12-month running mean (line with crosses).

result is obtained here analyzing the period 1974–2000 and 1958–2000 but with a lower correlation value as can be seen in Fig. 7. Sugiura and Poros (1977) suggest that it is likely that the cause for the 4 month time lag in the Dst QBO relative to the QBO in Rz is the same cause by which the unfiltered monthly Dst lag behind the unfiltered monthly Rz, but, they do not know about its origin neither the nature of the highly correlated solar and geomagnetic QBO. Using our filtering technique we do not obtain such a high correlation, and in addition, it even decreases when Sugiura's period is extended until 2000.

Sugiura and Poros (1977) suggested also that an oscillation in the southward interplanetary magnetic field, IMF, could give rise to the observed geomagnetic QBO but their preliminary study could not confirm it. Following this suggestion we filtered, together with the southward component of IMF Bz [nT], the IMF magnitude B [nT], the solar wind velocity $v$ [km/s] and the solar wind proton density $\rho$ [cm$^{-3}$]. All these data series were obtained from the NSSDC OMNI database for the period 1965–2000. The correlation coefficient between each of these filtered series and DDst is 0.05 for Bz, $-0.70$ for B, $-0.50$ for $v$ and $-0.14$ for $\rho$. The cross-correlation between each series and DDst do not improve much the coefficients, as is the case with DRz. From these results we would say that it is B, and not Bz, the IMF parameter most linked to the geomagnetic QBO. However a detailed analysis of this association, if it really exists, remains to be done.

If a running correlation between the mean zonal equatorial wind and the filtered parameters of the solar wind and IMF is performed, only B presents the 11-year oscillation, as can be seen in Fig. 8, in agreement with the behavior of DDst.

## 3. Discussion and conclusions

Regarding the origin of the QBO in Dst we cannot make any speculation yet. Olsen (1994) and Olsen and Kiefer (1995) suggested that the QBO in $H$ daily variations ($\Delta H =$ maximum $H$–minimum $H$ for each day) could be caused by a dynamo action of a QBO in the lower thermospheric prevailing winds. According to them, $H$ noon values are greater than midnight values during a given phase of the QBO. Half a QBO cycle later the noon values are lower than the midnight values by the same amount. We do not think that this process is the cause of the QBO observed in Dst. In our case the daily variation is averaged out since we use monthly means estimated from daily means. There would be a difference between the daily mean corresponding to each QBO phase only if $\Delta H$ is different in each QBO phase.

In a previous work, following the analysis of Troshichev and Gabis (1998) and Soukharev and Hood (2001) about a QBO in solar UV irradiance, we found that during maximum solar activity, higher UV levels are seen during the easterly phase of the QBO at levels between 15 and 50 hPa, and lower UV levels during the westerly phase (Elias and Zossi de Artigas, 2003). During minimum solar activity, this relationship is reversed and is accompanied by a decrease in the amplitude of the QBO periodicity in the UV flux. In this work, analyzing geomagnetic activity through Dst, a similar behavior pattern is obtained.

Combining our results with those of Labitzke and Van Loon (1988, 1995, 2000), Soukharev (1997, 1999) and Varotsos (1989) concerning ozone content and temperature in the Northern Polar stratosphere, it could be said that during maximum solar activity, higher geomagnetic activity and UV levels coincide with the easterly phase of the QBO together with lower temperatures and less ozone in the Northern Polar cap, while the westerly phase coincide with lower geomagnetic activity and UV levels together with stratospheric warming and more ozone in the Northern Polar cap. During minimum solar activity levels this relationship is reversed.

These results would imply that stratospheric warming, with consequent higher ozone content over the Northern Polar stratosphere, are more likely to occur during low geomagnetic activity. In fact, it has been shown (Bucha and Bucha, 1998; Bucha 2002) that the enhancement of physical processes in the auroral oval due to geomagnetic storms leads to an enhancement of the zonal flow in the Northern Hemisphere troposphere strengthening the polar vortex. At times of low geomagnetic activity, the amplitudes of planetary waves increase again as a result of the effects of topography and surface heating, prevailing over the effects of processes in the auroral oval.

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