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A search for an association between the equatorial stratospheric QBO and solar UV irradiance

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[1] The QBO of the zonal wind in the equatorial stratosphere between 15 and 70 hPa is analyzed in connection to the solar UV flux. F10.7 is used as a UV proxy after filtering out its long-term variations. A running correlation between F10.7 filtered values and the equatorial zonal wind was estimated. A clear oscillation of around 11 years can be noticed in the running correlation coefficients, with maximum negative and positive values around maximum and minimum solar activity respectively, between 50 and 15 hPa. In coincidence with other authors, during maximum solar activity, higher (lower) UV levels occur during the QBO easterly (westerly) phase. During minimum solar activity this relationship is reversed. A link between these results and the association between the equatorial QBO and the polar winter is suggested together with a mechanism of association between the UV QBO and the zonal equatorial wind in the stratosphere. *INDEX TERMS:* 3334 Meteorology and Atmospheric Dynamics: Middle atmosphere dynamics (0341, 0342); 3399 Meteorology and Atmospheric Dynamics: General or miscellaneous; 7536 Solar Physics, Astrophysics, and Astronomy: Solar activity cycle (2162). **Citation:** Elias, A. G., and M. Zossi de Artigas, A search for an association between the equatorial stratospheric QBO and solar UV irradiance, *Geophys. Res. Lett.*, *30*(16), 1841, doi:10.1029/2003GL017771, 2003.

1. Introduction

[2] The quasi-biennial oscillation, QBO, with a period varying from about 26 to 30 months, is the main variation of the mean zonal wind in the equatorial stratosphere and also a feature of many processes in the Earth's atmosphere [*Naujokat*, 1986; *Holton*, 1992; *Baldwin et al.*, 2001]. The wind QBO, which prevails over seasonal variation at heights between 15 and 30 km (200 to 10 hPa), descend with time in alternating series of easterlies and westerlies that attain speeds of 20 to 30 m/s.

[3] *Troshichev and Gabis* [1998] have shown that the UV irradiance undergoes a quasi-biennial periodicity correlated with quasi-biennial oscillations in the Earth's atmosphere, rising in years of east QBO phase and dropping in years of west QBO phase. They use the Mg II index as a solar UV irradiance proxy and eliminate long-period variations with $\tau \geq 26$ months and short-term fluctuations with $\tau < 27$ days.

[4] They noticed that for east QBO phases the filtered Mg II index is predominantly positive (greater flux than average) at the first 2/3 of the QBO length, and tends to be negative by the end of the interval. The opposite is observed in west QBO phases. This regularity is noticed in years of solar maximum and almost blurred during solar minimum conditions. On average, west QBO phase in the Earth's stratosphere is observed in connection with the Mg II index minimum (lower solar flux), whereas east QBO phase is observed when the Mg II increases up to maximum (higher solar flux).

[5] *Soukharev and Hood* [2001] have also reported a possible response of the equatorial quasi-biennial wind oscillation to solar variability occurring at periods of 25–30 months. They apply a cross-spectral analysis to F10.7 and equatorial zonal wind for levels from 50 to 1 hPa and find a significant coherency at the QBO period at all pressure levels.

[6] In this work we take up the idea of the QBO in the solar UV flux using F10.7 as a UV proxy, and apply a running correlation analysis to F10.7 and equatorial zonal wind data.

2. Data Analysis

[7] In order to analyze the association between the QBO and solar UV flux suggested by *Troshichev and Gabis* [1998] during a longer period, we use F10.7 as an EUV proxy instead of Mg II.

[8] The 10.7 cm solar radio flux (F10.7) is widely used to estimate the intensity and relative temporal variations of solar EUV and UV radiation [*Donnelly et al.*, 1983; *Barth et al.*, 1990]. In fact, the linear correlation between the monthly mean values of the Mg II index, available from November 1978 to date, and F10.7 is 0.98. Since F10.7 records begin in 1949, the QBO and UV association analysis can be brought backwards until this date.

[9] The monthly mean zonal wind in the equatorial stratosphere, which define the phases of the QBO, was taken from a compilation by Naujokat (http://dss.ucar.edu/cdroms/karin_labitzke_strat_grids/data/qbo/qbo_53-01.dat) for the levels 70, 50, 40, 30, 20, and 15 hPa. The 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 supposed to be representative of the equatorial belt since all studies have shown that longitudinal differences in the phase of the QBO are small.

[10] Figure 1 presents F10.7 band pass filtered with frequency bounds corresponding to periods of 12 and 39 months, and the mean zonal equatorial wind at 40 hPa, almost the same level used by *Troshichev and Gabis* [1998].

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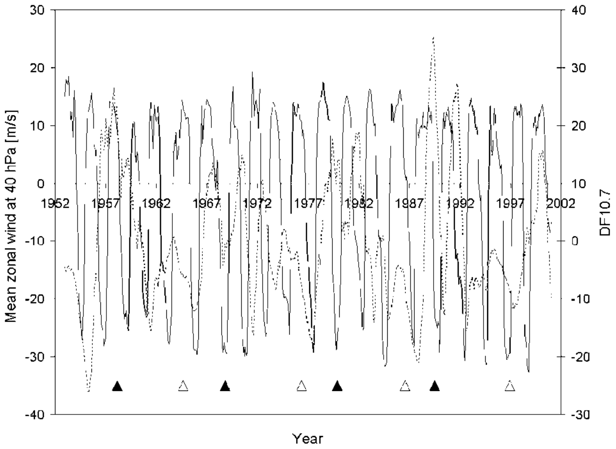

Figure 1. F10.7 band pass filtered with frequency bounds corresponding to periods of 12 and 39 months (dotted line) and the monthly mean zonal equatorial wind at 40 hPa (solid line). Filled and empty triangles correspond to maximum and minimum solar activity level dates respectively.

It can be noticed that around periods of maximum solar activity (filled triangles in Figure 1), the wind and F10.7 oscillates with almost the same frequency. During periods of low solar activity there is a phase shift and also a change in the amplitude of the oscillation. In order to take into account these changes a running correlation between F10.7 and the mean zonal wind 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:

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

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

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

[12] Figure 2 shows the running correlation time series for the six pressure levels between 15 and 70 hPa with $M = 4$ years. An oscillation of around 11 years can be noticed in all of them with maximum negative correlation around solar maximum and maximum positive correlations at solar minimum for 15 to 50 hPa. In the case of the wind at 70 hPa, the maximum negative and positive correlations take place during minimum and maximum solar activity respectively. During the ascending and descending phases of the solar cycle, r, in all cases, approaches zero and changes sign. 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.

[13] In other words, 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. 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. Now, assuming that there is a physical connection between solar variability and equatorial zonal wind on the 25–30 month timescale, how can the transition from solar minimum to solar maximum change the sign of the association between them?

3. Discussion and Conclusions

[14] Quasi-biennial oscillations were revealed in solar activity at the beginning of the 20th century by *Schuster* [1906] who detected a period of 2.69 years in sunspot number but considered it "in all probability only sub-period of the 11 years' variation", and then by *Shapiro and Ward* [1962]. This initially led to a controversy about whether solar forcing could be responsible for the equatorial wind QBO. Finally, *Lindzen and Holton* [1968] successfully explained the key features of the QBO by invoking the

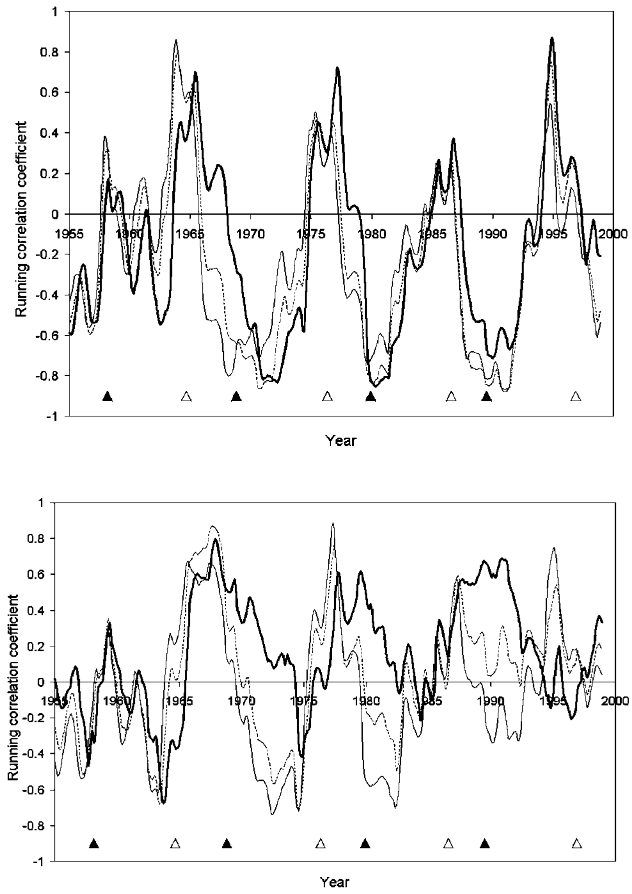

Figure 2. Running correlation coefficient time series with a 4-year window width for (a) pressure levels 15 hPa (solid line), 20 hPa (dashed line), 30 hPa (enhanced line) and (b) 40 hPa (solid line), 50 hPa (dashed line) and 70 hPa (enhanced line). Filled and empty triangles correspond to maximum and minimum solar activity level dates respectively.

mean flow effects of gravity waves forced in the troposphere, propagating into the stratosphere. The mechanism was further explained by *Plumb* [1977].

[15] The correlation between the winter-time average polar temperature and the phase of the QBO in the lower stratosphere was noted over twenty years ago by *Holton and Tan* [1980]. They found that polar winter stratospheric warmings (and higher polar temperatures) tended to occur mainly during the easterly phase of the equatorial QBO. The explanation was that the QBO winds in the lower stratosphere determine the position of the zero wind line near the equator. This results in enhanced poleward heat transfer during an easterly QBO phase and weaker transfer during a westerly phase. But, this mechanism does not always hold up. *Labitzke* [1982, 1987] showed that the Holton-Tan result only remains valid under solar minimum conditions. Under solar maximum conditions, stratospheric warmings tend to occur in the westerly QBO. These warming events result in both temperature and ozone increases at high winter latitudes.

[16] *Labitzke and van Loon* [1988, 1995, 2000] have extensively documented the observational evidence for the combined effect of the QBO and the solar cycle on temperature, geopotential height, and ozone at high winter latitudes.

[17] *Soukharev* [1997, 1999] showed that total ozone data over Northern Europe are consistent with both the Holton-Tan result for solar minimum and the Labitzke and van Loon results for solar maximum.

[18] *Troshichev and Gabis* [1998] were the first to show that the quasi-biennial periodicity in solar UV irradiance (monitored using the Mg II index) correlates with the stratospheric wind QBO such that QBO maxima in the UV flux tend to occur in the easterly QBO phase and vice versa. This result led them to suggest that the solar UV QBO determines the QBO phase in the Earth's equatorial stratosphere.

[19] *Salby and Callaghan* [2000] first presented evidence that some properties of the QBO vary with the 11-year solar cycle. They did not, however, consider forcing by a QBO periodicity in the solar UV flux.

[20] *Soukharev and Hood* [2001] presented further evidence that the QBO varies with the 11-year solar cycle. In addition, they showed that band-pass filtered F10.7 data show a QBO periodicity. Independently of Troshichev and Gabis (whose work was unknown to them), they also found that F10.7 and equatorial zonal winds show significant coherencies at the QBO period at all available pressure levels. This again suggests that QBO variations in the UV flux may be modifying the equatorial wind QBO, which is still mainly driven by tropospheric waves.

[21] This paper extends the analysis of Troshichev and Gabis over a longer time interval using F10.7 instead of the Mg II index. Like *Soukharev and Hood* [2001], we find that the QBO variations in solar UV flux are larger under solar maximum conditions. We confirm the conclusion of Troshichev and Gabis that QBO UV maxima tend to occur during the easterly QBO wind phase under solar maximum conditions. Under solar minimum conditions, the opposite is true but the amplitude of the solar QBO UV variations is much lower anyway (and may be inconsequential) near solar minimum.

[22] Under solar minimum conditions, the relationship between polar temperature/ozone and the equatorial wind QBO is explained by the Holton-Tan model. At solar maximum, the QBO UV variations are larger and, given the results of Labitzke and van Loon, it can be argued that they apparently do perturb the winter stratosphere into a strong vortex mode during the wind QBO easterly phase. However, the fastest polar night jet, associated to a stronger vortex, is not simply dependent on radiative forcing alone but is determined through interaction with atmospheric waves propagating up to the stratosphere and with the mean flow [*Kodera and Kuroda*, 2002].

[23] Even at solar maximum, the UV variations are still too small (±20 F10.7 units) to directly strengthen the vortex through enhanced equatorial radiative heating. Qualitatively, solar radiative heating due to the absorption of solar UV by ozone in the upper stratosphere would create a large temperature gradient during winter, inducing a strong westerly polar night jet and thus a stronger polar vortex. If this mechanism is correct, the slightly higher UV fluxes near maxima of the solar QBO under solar maximum conditions are able to push the winter stratospheric circulation over a threshold that forces it into an undisturbed vortex. How this happens is not well understood theoretically. It may involve effects of ozone concentrations, which change with solar forcing, and the stability and propagation characteristics of free Rossby waves in the winter stratosphere [*Nathan et al.*, 1994].

[24] In addition we suspect that there may be a physical link between the UV QBO and the equatorial wind QBO. The altered ultraviolet radiation will primarily affect ozone-rich regions receiving appreciable solar insolation (i.e., lower latitudes in the upper stratosphere), changing the thermal gradients and thus wind fields, which may then affect wave propagation and wave/mean flow interactions [*Shindell et al.*, 1999]. These perturbations would propagate to lower levels [*Kodera et al.*, 1990] and affect Kelvin, Rossby-gravity waves, and gravity wave generation in the equatorial troposphere.

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