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A REVIEW OF THE 11-YEAR SOLAR CYCLE, THE QBO, AND THE ATMOSPHERE RELATIONSHIP

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1. Introduction

The papers published by LABITZKE (1987) and by LABITZKE and VAN LOON (1988, hereafter referred to as LvL) indicated that the separation of Winter stratospheric data according to the phase of the Quasi-Biennial Oscillation (Q.B.O.) led to a largely improved relationship with the 11-year solar cycle. Since then, this possible relationship has been studied and extended from the surface to the lower thermosphere and its extension to other seasons is in progress. This workshop provides an opportunity to review the state of the problem and to attempt to give a general view of the experimentally observed responses of the atmosphere to solar activity, when considering the phases of the Q.B.O. After a brief recall of the relationship firstly discovered in the winter stratosphere, its extension downwards, upwards and to the other seasons will be successively reviewed.

2. The winter stratosphere and high troposphere

The separation of the stratospheric data according to the phase of the QBO (defined at 40-50 mb) during winter (January and February) first introduced by LABITZKE (1987) for the North Pole and by LVL for the Northern Hemisphere, was at the start of a regained interest in the field of solar terrestrial relationship. It is assumed that the reader is familiar with these now two famous papers, in which was pointed out for the first time a high correlation with solar activity in the low atmosphere (correlation coefficient above 0.8 at 30 mb at the North Pole. However the major results are briefly recalled :

- The data set (consisting on monthly mean temperature and geopotential height) starts in 1953 and cover then three complete solar cycles for the Northern Hemisphere. There is no way to characterize the QBO phase beyond that year, and therefore no direct way to extend the period of study in the past; but it is worth mentionning that data from the two recent winters are in agreement with the above mentionned association. They are used to update figure 1 of LvL and presented in the Figure 1 of this paper (from LABITZKE private communication).
- The signs of the correlation with solar activity are found to be opposite between the polar region and the mid and low latitudes and between the westerly and easterly phases of the QBO. This last point explains why the effect had been masked when considering the whole data set without separating the data according to the phase of the QBO.
- The atmospheric response at the different atmospheric levels from 500 to 30 mb, though variable in shape, have a pattern very similar with quasi-stationary planetary waves.
- While the first papers only dealt with the Northern Hemisphere, it was shown recently, (LABITZKE and VAN LOON 1989a), that the same high level of positive correlation is found for the South pole, but only for the easterly phase of the QBO. Recent results from the Southern high latitude rocket station of Molodezhnaya (69°S 46°E) seem to indicate that the correlation become negative in the high stratosphere for both phases of the QBO (MOHANAKUMAR, 1989). This is confirmed by the study of KIDIYAROVA and FOMINA (1989).

3. The surface and low troposphere

Using the same approach, VAN LOON and LABITZKE (1988) extended the correlation down to the surface, with significant correlation for sea level pressure and surface air temperature

(R ~ 0.6) which were proved to be statistically meaningful (figure 2). The correlation pattern at 700 mb was found to be similar to the teleconnection pattern and this was interpreted as a sign that the observed effect was related to atmospheric internal dynamics. The suggestion that the solar cycle modulates the weather, attracted, as expected, some scepticism even though it was submitted successfully to the adequate statistical tests; but several other results of solar related dependences have been obtained on storm tracks (TINSLEY 1988) and tropical sea surface temperature (BARNETT 1989) which may bring more confidence in this result and help to understand the mechanism involved.

4. Extension to the upper atmosphere

Using two regions which according to LvL presented an opposite behaviour at 30 mb : Heyss Island (81°N, 58°E) and 2 close-by sites in France (44°N, 6°E and 45°N, 2°E)), a study of the solar dependence of the temperature was performed first up to 80 km (LABITZKE and CHANIN 1989) and later up to the lower thermosphere (CHANIN et al. 1989). It showed that the response of the upper atmosphere, even though already present when using the whole data, was amplified by sorting out the data set according to the QBO. It also put into a new light some already published results indicating a negative solar dependence in a region of the atmosphere which was though to be positively related with solar activity. The alternance of positively and negatively correlated regions extending from ground level to 150 km, with vertical structures of the order of 40 km, as seen on figure 3, strongly suggest an influence of planetary waves generated at the surface or in the low troposphere and modulated by the QBO. In the region above 50 km we interpret the observed results as a superposition of a direct radiative effect due to the UV absorption and a dynamically induced effect related to the pattern observed at lower levels.

5. Extension to other seasons

Because of the filtering of upward propagating planetary waves by stratospheric winds, it is expected that the dynamically induced contribution will maximize in winter, while the radiative contribution should present a maximum in summer (~ 70 km). Then the relative importance of both contributions should vary with the seasons and one could expect the response of the stratosphere to solar activity to be weaker in summer than in winter. On the other hand in the mesosphere a positive response is expected for all seasons; it has been observed from a number of sites with a solar dependence of much larger amplitude than predicted from radiative models (see review in CHANIN et al. 1987).

The results of LABITZKE and VAN LOON (1989b) in the Northern summer stratosphere indicate that it was not necessary to group the data according to the QBO to obtain a statistically significant response to solar activity : this response was found to be positive at 30 mb for all the north hemisphere and mostly significant in a belt between 20 and 45 N. Recent results pointed out that a significant negative response is found in the height range 30-50 km and that the correlation with solar flux is amplified for some sites if separating the data according to the QBO. This is observed in summer and autumn at the French lidar station (44°N, 6°E) for easterly QBO (KECKHUT and CHANIN 1989) and during summer in THUMBA (8°N, 77°E) for westerly QBO as reported by MOHANAKUMAR (1989) in this workshop. On the other hand the QBO do not seem to play any role in this altitude range at the site of Molodezhnaya (69°S, 46°E) where the correlation is strongly negative for both phases of the QBO and at Volgograd (49°N, 44°E) where it is below significance for both phases during summer.

The common feature in all of these results is that the responses to solar activity at some levels within the altitude ranges 20-40 km and 60-80 km are found to be of opposite signs at all sites and independently of the season: i.e negative in the stratosphere and positive in the mesosphere. The altitude of the reversal of sign, the importance in the role of QBO and the amplitude of the solar dependence are anyhow variable from onesite to another.

6. Discussion

Before the LABITZKE (1987) paper, the solar influence on atmospheric parameters was searched for by averaging data either globally or on zonal mean, by using all available years independently of the QBO, and in some case by restricting the data set to summer periods to avoid the high winter variability. The experimental results could be summarized as follows :

- no conclusive result in the troposphere
- a small amplitude effect (1 to 2 K) around 40 km for a solar cycle
- a positive relationship with up to 10 K amplitude around 70 km

a well documented positive dependence in the high thermosphere which was thought to start around 120 km, as included in the empirical models.

On the other hand, the radiative photochemical models, taking into account the effect of a change in UV flux and its consequences on the ozone distribution and the radiative budget, predicted changes for a solar cycle of + 2 to + 2.5 K at the most with a maximum effect at 70-75 km (GARCIA et al. 1984, BRASSEUR et al. 1987). Results from one-dimensional radiative transfer model indicates an even smaller effect (0.8 K at 50 km). Such changes are difficult to differenciate from trends of other origins. However the predictions of the models were known to disagree with the data which in the mesosphere led to an amplitude around 5 to 10 K.

The fact to look at data locally, their separation according to QBO, and furthermore the selection of winter data where the effect was found to be stronger, brought a completely new set of results which could be summarized as follows :

- in winter periods, strong correlations with solar activity of opposite signs for easterly and westerly QBO and from pole to mid and low latitude in the region below 30 km and down to the surface
- a reversal of the sign of the correlation between part of the stratosphere and the mesosphere, with the influence of the QBO decreasing with altitude
- a planetary-wave type structure both horizontally and vertically in the atmospheric response to solar activity
- in all the height range the amplitudes of the solar dependence much larger than any model prediction by at least one order of magnitude.

7. Conclusion

The existing models are not adequate rightnow to represent the solar influence as they only take into account the change in UV flux, but before being able to take into account the large scale dynamics in a coupled radiative-photochemical model, one needs to understand the mechanism able to explain the forcing from the lower atmosphere or the surface which could be induced by a change in solar activity. Some of the possible mechanisms are described in this issue (EBEL, 1989).

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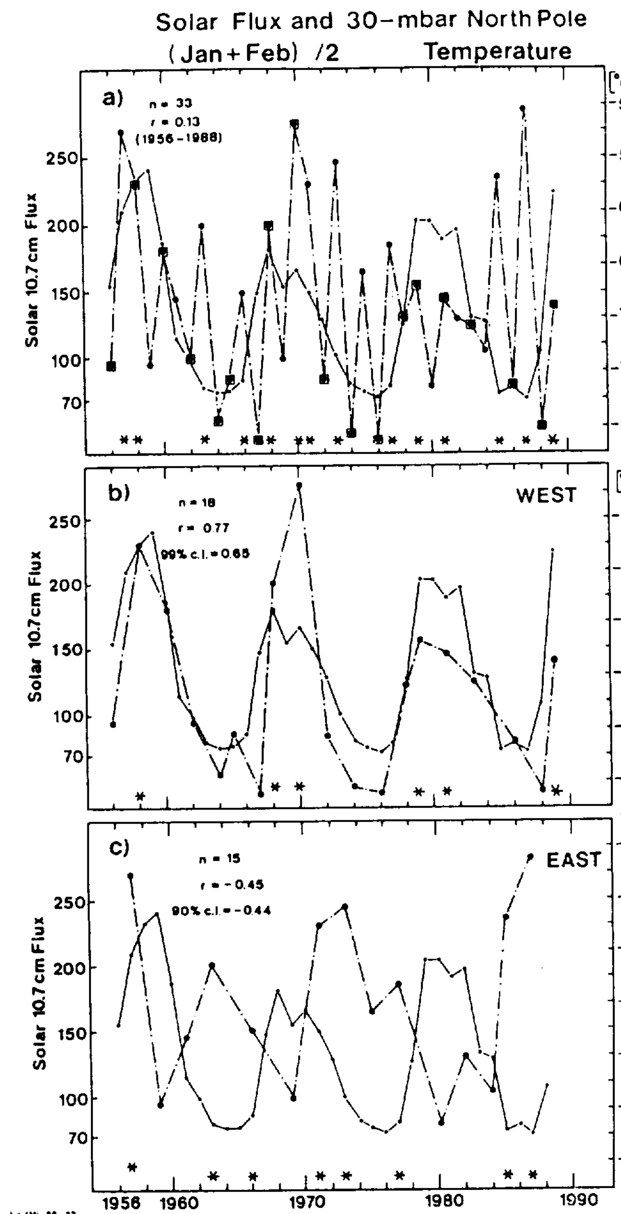

Figure 1: Time series of the 10.7 cm solar flux (units are 10 -22 W m-2 Hz-1) for (Jan.+ Feb./2; and of the mean 30mb temperature (°C) at the North Pole for (Jan. + Feb.)/2. From LvL, updated 1989 (LABITZKE, Private communication)

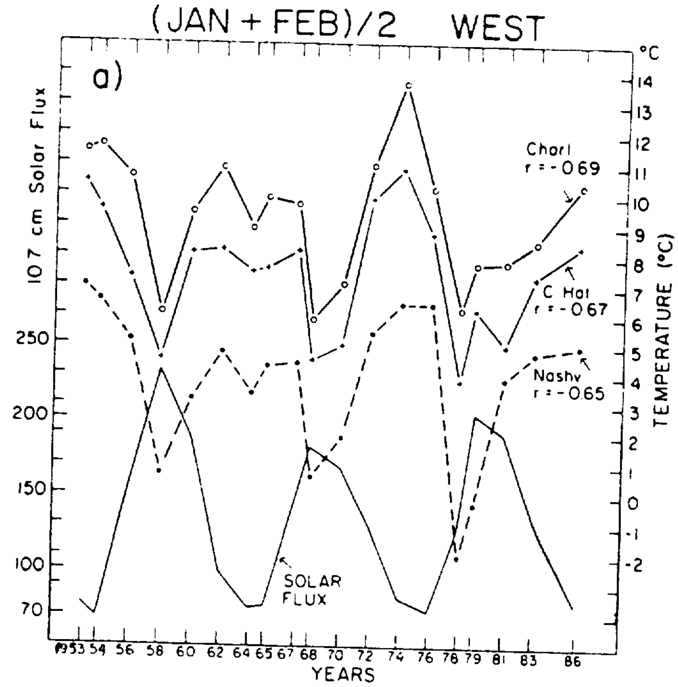

Figure 2: Time series for January-February in the West phase of the QBO of the 10.7 cm solar flux for all years (dashed line) and of surface air temperature at 3 U.S. stations. The correlation coefficiets r are indicated. (VAN LOON and LABITZKE 1988)

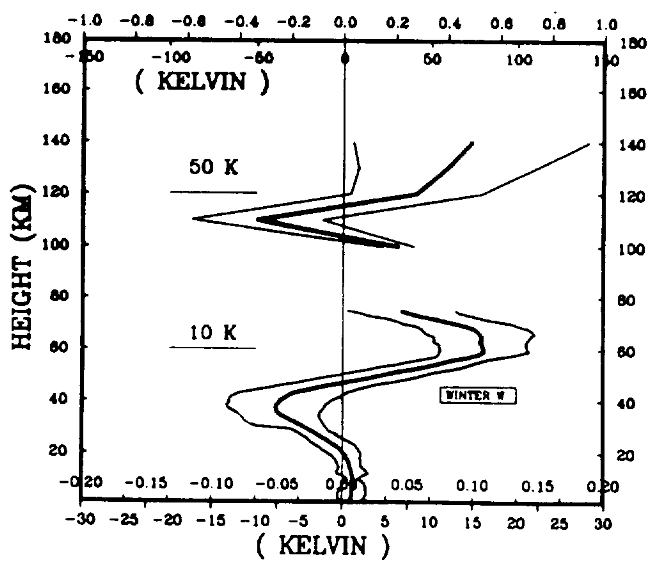

Figure 3: Amplitude of the solar temperature dependence over Southern France expressed in Kelvin and in Kelvin by unit of solar flux. (Note the different scale for top and bottom part). From CHANIN et al. 1989.