THE QBO AND WEAK EXTERNAL FORCING BY SOLAR ACTIVITY:
A THREE DIMENSIONAL MODEL STUDY

M. Dameris and A. Ebel

Institute for Geophysics and Meteorology
University of Cologne
Albertus-Magnus-Platz
D - 5000 Cologne 41, F.R.G.

Introduction

The goal of this study is a better understanding of the physical mechanisms leading to significant correlations between oscillations in the lower and middle stratosphere and solar variability associated with the sun's rotation. A global 3-d mechanistic model of the middle atmosphere is employed to investigate the effects of minor artificially induced perturbations. The aim is to explore the physical mechanisms of the dynamical response especially of the stratosphere to weak external forcing as it may result from UV flux changes due to solar rotation. First results of numerical experiments dealing about the external forcing of the middle atmosphere by solar activity were presented in a paper by Dameris et al. (1986). Different numerical studies regarding the excitation and propagation of weak perturbations have been continued since then (Dameris, 1987; Ebel et al., 1988).

Description of experiments, Results

The model calculations presented in this paper are made to investigate the influence of the quasi-biennal oscillation (QBO) on the dynamical response of the middle atmosphere to weak perturbations by employing different initial wind fields which represent the west and east phase of the QBO. The initial wind fields used for this study are shown in figure 1: They are characterized by realistic, relatively strong vertical gradients in the tropics between 10 and 40 km height. The conditions at middle to high latitudes are the same for both cases (solstice conditions, north winter, south summer). The global 3-d numerical model taken for this study is the same as described in detail by Dameris et al. (1986) (fully nonlinear, primitive dynamical equations in flux form). Based on the experiments done in the past the external forcing function and the lower boundary conditions are chosen as follows: A weak standing temperature oscillation (zonal wave number 1) centred at 43 km height, 2.5°N is assumed with a maximum amplitude of 1.5 K. The amplitude decreases linearly to half its value in a distance of $\pm$ 5.4 km and $\pm$ 20°. A period of 13.6 days is employed. Stationary waves of geopotential height have been excited at the lower boundary (10 km). Their characteristics are: Zonal wave number one and two, maximum amplitudes of 100 gpm and 30 gpm, respectively, centred at 60°N (winter), decrease of

amplitudes to zero at 30°N and 80°N. Transient zonal waves are simulated at the lower boundary assuming the latitudinal structure of free westward travelling modes. The following modes were used: (1,4), 16-day wave (max. amplitude 50 gpm); (1,3), 10-day wave (20 gpm); (1,2), 5-day wave (2 gpm).

In the following results of the two model experiments are presented which differ only by the definition of the initial wind fields representing the west and the east phase of the QBO. The external forcing and also the lower boundary conditions are the same for both experiments. For a better presentation of the effects of the weak external forcing, control runs without external forcing were also made for otherwise identical conditions. Here only the differences between the experiments with weak external forcing and the respective control run are shown.

Figure 2 shows the horizontal structure of temperature perturbations at 26 km height due to the periodic temperature forcing for both cases (QBO-west, QBO-east) for model day 80, where the differences between the two calculations are most obvious: For the west case two regions of significant response to the assumed temperature perturbation are observed, one in the equatorial region (0.4 K) and the other at high latitudes of the winter hemisphere (0.5 K). The results for the east case indicate significantly stronger amplitudes of the temperature perturbation at high latitudes of the winter hemisphere up to 2.5 K. A similar result is found for the perturbation of the geopotential height field (not shown). For model day 80 maximum amplitudes of 6 gpm are found for the west case instead of 30 gpm for the east case, also observed at high latitudes of the winter hemisphere.

An important tool to analyse the model results and to get an indication why the model reacts in such a way is given by the Eliassen Palm (EP) flux diagnostics. The results shown in figure 3 indicate that there is little or no transport of wave energy across the critical wind line ($u=0$) into regions where the mean wind is easterly. At model day 76 (here also differences with respect to control run) the meridional cross section of the EP-vector for the west case indicates relatively strong activity at the tropics lower than 30 km height in comparison to the results of the east case. This effect is probably caused by the westerly winds in this region: The wave energy can directly penetrate from the region of main forcing (43 km, 2.5°N) to lower levels. At middle to high latitudes of the stratosphere the EP-vectors (transport of wave energy) are significantly enhanced for the east case. Most of the perturbation energy is bend into the region of westerly winds (winter hemisphere).

Conclusion

The model results show significant differences of the dynamical response of the middle atmosphere to weak external forcing by assuming different initial conditions representing the west and the east phase of the QBO. If the QBO has its easterly phase, solar induced perturbations, which are generated near the equatorial stratopause, lead to stronger

variations in the middle and lower stratosphere than during the west phase of the QBO. Up to now no statistical analysis is available for a comparison with our model results. Statistical analyses which were made in the past, for example by Ebel et al. (1986) must be repeated, but now with regard to the different QBO phases, to get indications if the real atmosphere reacts similar.
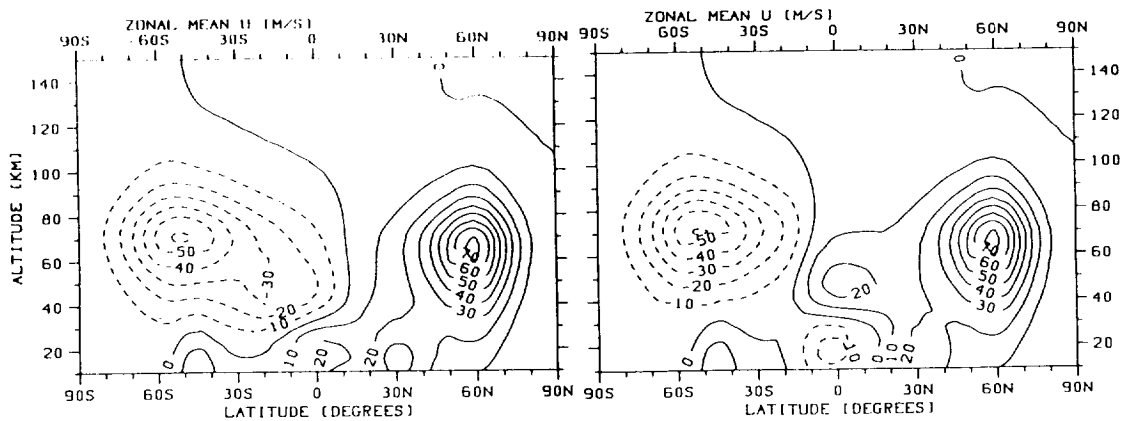

Figure 1: Initial stage of the mean zonal wind field used for the numerical experiments, representing the west phase of the QBO (left), representing the east phase of the QBO (right). Positive and negative values indicate eastward and westward motion, respectively. Units are m/s.
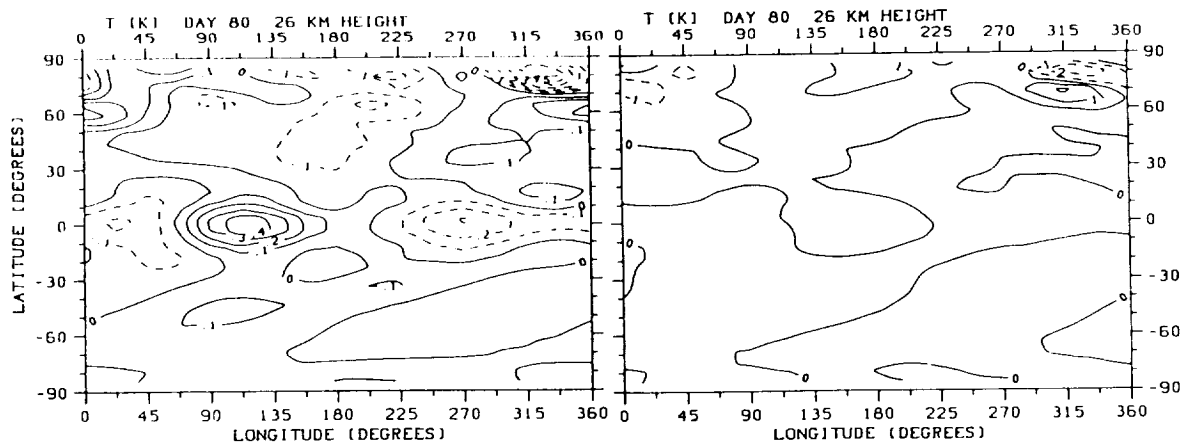

Figure 2: Horizontal structure of the response to periodic temperature forcing centred at 43 km height, 2.5°N with a zonal wave number 1 structure. Temperature perturbations (differences with respect to control run) in K at 26 km height for model day 80.West-case (left-hand side) and East-case (right-hand side). Attention, the contour lines are different for the two cases.
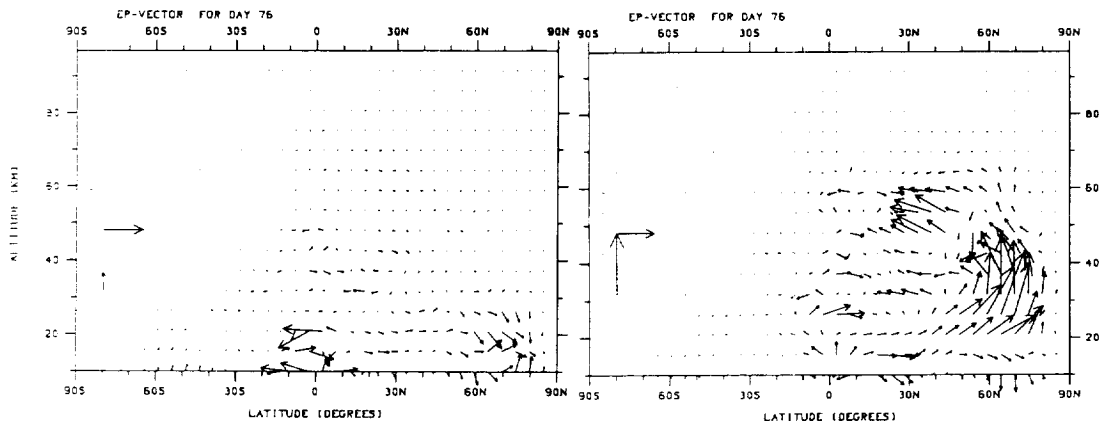
Figure 3: Differences of the EP-vectors (differences with respect to control run) for the West-case (left-hand side) and East-case (right-hand side) for model day 76. The distance occupied by $10°$ of latitude represents a value $2 \pi a^2 \rho_s \cdot 7.0 \cdot 10^{-3} m^2 s^{-2}$ of F_ϕ and that occupied by 10 km of pressure-altitude z represents a value $2 \pi a^3 \rho_s \cdot 6.2 \cdot 10^{-5} m^2 s^{-2}$ of F_z.

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