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ASPECTS OF PLANETARY WAVE TRANSPORTS IN THE MIDDLE ATMOSPHERE

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ABSTRACT

The heat and momentum flux due to standing planetary waves in the stratosphere has been calculated on the basis of satellite data. The convergence of these fluxes has been investigated and show an apparent heating and acceleration of the mean zonal state. The Eliassen-Palm flux divergence calculation shows that the mean zonal state is effectively decelerated. Furthermore the interaction between ultra-long waves and waves k = 4 - 15 in the troposphere has been investigated for a winter period and has been discussed in connection with the geopotential wave one amplitude, which increases before a stratospheric warming event occurs.

The investigation of processes which determine the deviation of the zonally averaged temperature and wind field from radiation equilibrium is a central question in stratospheric dynamics. LEOVY (1964), HOLTON and WEHRBEIN (1980) in their model calculations take into consideration a linear drag that produces a deceleration proportional to the mean zonal wind, while SCHOEBERL and STROBEL (1978), DETHLOFF and SCHMITZ (1982) additionally consider the momentum transport by planetary waves. On the basis of a stationary model. Dethloff and Schmitz showed that the planetary wave influences on the mean state are small above the stratopause. In the following at first the standing momentum and heat flux and the divergence of the Eliassen-Palm flux is investigated. Furthermore the wave k = 4 - 15 projection on the ultra-long waves in the troposphere preceding the occurrence of a stratospheric warming has been calculated.

The data basis is the monthly mean standard 500, 200 mb topographies of the European Meteorological Bulletin, the 100, 50, 30, 10 mb topographies from Obninsk, the synoptical bulletin and the 5, 2, 0.4 mb data source are the NOAA NMC maps for the winter 1974/75 where meteorological rocketsonde and satellite radiance data are used for analyses. The high topographies are given once a week only. The momentum and heat fluxes are calculated from the planetary wave amplitudes and phases. In the following the mean December values for the two years will be discussed. In Figure 1 the amplitude of planetary wave one is shown. The maximum of wave one appears at 70°N at a height of about 35 km with 800 gpm. Figure 2 shows the meridional standing momentum transport due to the sum of waves k = 1 - 3. The momentum transport has high values in the jet region of the upper troposphere and at a height of 50 km in middle latitudes. The meridional heat transport of the waves k = 1 - 3, given in Figure 3, also has largest values in the stratosphere, the two fluxes being essentially determined by the wave one contribution.

These shortly discussed fluxes are the basis for a determination of the interaction between ultra-long waves and mean zonal circulation, according to the Eulerian zonally-averaged momentum and thermodynamic equation. The interaction of the zonally averaged state with the planetary waves is explained through the convergence of momentum and heat fluxes. The effective acceleration and heating rates, resulting from these terms, have been calculated for the monthly mean December of the years 1974, 1975. The largest acceleration appears in high latitudes at 35 km with about 12 ms^{-1}/day. The convergence of the meridional heat flux seems to give strong heating rates of about 4°K/day at high latitudes and at a height of 40 km, but cooling in middle latitudes. These

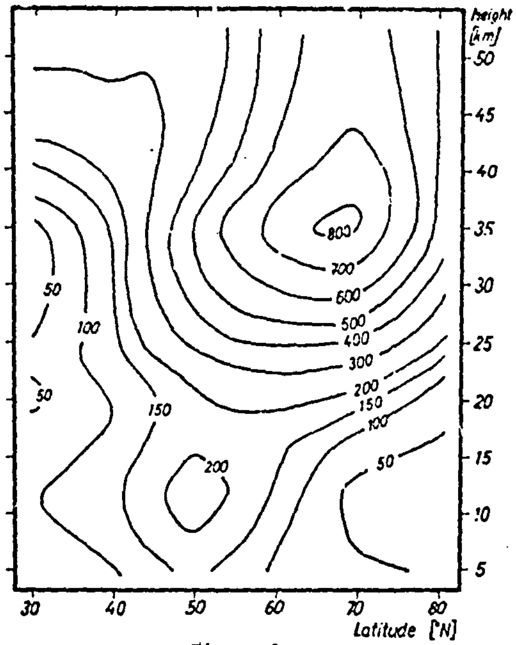

Figure 1.

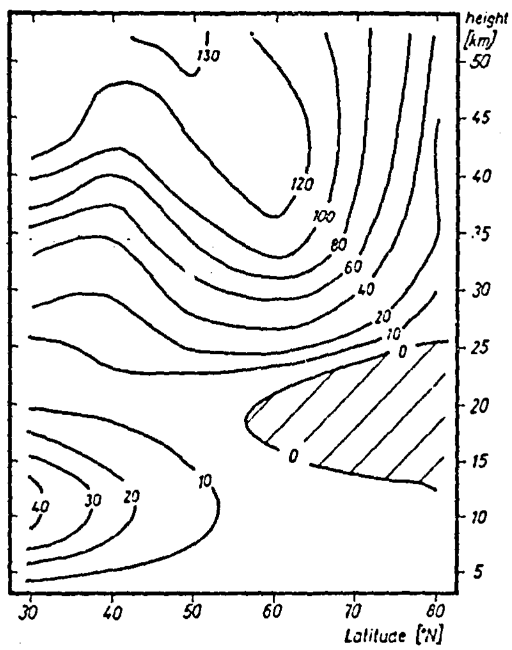

Figure 2.

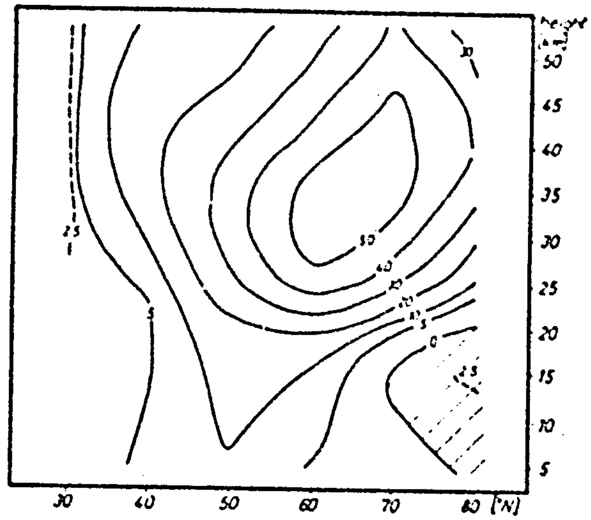

Figure 3..

values are lower than those given by GELLER (1982), because here we discuss the standing part of fluxes only. The calculated effective dynamical heating rates in the stratosphere are approximately equal to the diabatic heating rate. From the nonacceleration theorem of CHARNEY and DRAZIN (1961) and ANDREWS and MCINTYRE (1976) is known that one obtains misleading physical information when discussing the influences of the planetary wave momentum or heat fluxes alone, because steady planetary waves without dissipation or internal forcing do not force the zonal mean state. EDMON et al. (1980) propose the use of residual mean equations for a discussion of the net effect of planetary waves fluxes on the mean flow. The waves are introduced into this system only through the divergence of the Eliassen-Palm flux in the residual zonal momentum equation. Figure 4 shows the Eliassen-Palm flux divergence for the standing waves as a mean value of December 1974/1975. The EPF divergence has negative values at a latitude of 40°-60°N of the stratosphere, whereas the divergence term of the Eulerian zonal momentum equation is positive so that the mean zonal state is effectively decelerated, in contrast to an acceleration in the Eulerian picture. GELLER (1982) discussed this relation for the data of January 1979 where he found a zonal mean state acceleration which is reduced by a factor 2 when calculated from the EPF divergence. If we discuss the December mean consisting of only 8 weekly values at 5, 2, 0.4 mb as a stationary solution, then the residual meridional flow is induced to balance the EPF divergence.

Furthermore we have investigated the connection between standing and transient fluxes and their spectral characteristics on the data basis of the winter period 1970/71. The results suggest a relation between the zonal mean ultra-long k = 1 - 3 and the k = 4 - 15 wave transport. One possibility for such a relation is that this process is conducted via the mean zonal state, the other is the nonlinear interaction between ultra-long waves and waves k = 4 - 15. We shortly discuss the latter conception further, because it seems that the time variability of ultra-long waves in the stratosphere is also connected with this process. Furthermore the question arises whether the high increase of the amplitudes of geopotential wave one or two in the troposphere before a stratospheric warming is related to the interaction between ultra-long and waves k = 4 - 15. This question has been investigated by calculating the projection of

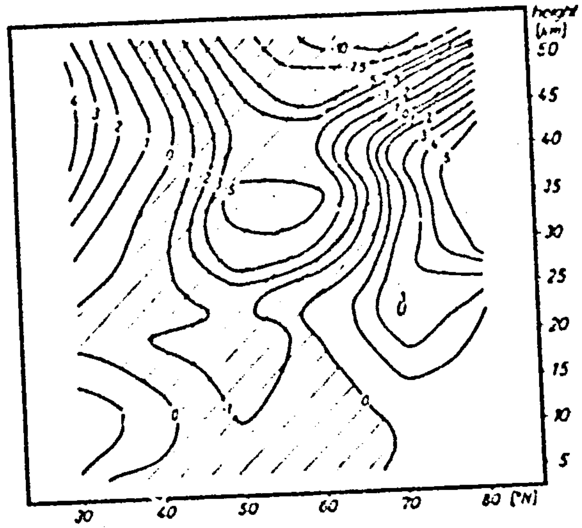

Figure 4.

nonlinear interaction of baroclinic waves with wavenumbers 4 - 15 on the ultra-long waves at 200 mb.

The wave transport terms $\overline{u^*v^*}$, $\overline{v^*v^*}$, $\overline{u^*u^*}$ have been investigated. These transports appear in the momentum equations and excite or dissipate ultra-long waves. The symbol ($\overline{\quad}$) stands for the waves 1, 2, 3 and ( )* for the baroclinic wave k = 4 - 15 contributions. So we discuss for example $(\overline{v^*v^*})_1$ as the interaction between the waves k = 4 - 15 and the wave k = 1. Figure 5 gives the standing plus transient wave k = 4 - 15 projection on the wavenumbers k = 1, 2 for the transport $\overline{v^*v^*}$. The interaction with wave 1 appears much stronger than that for wave k = 2. It will be interesting to determine the importance of this source for an interpretation of standing ultra-long waves in models.

Figure 6 shows the geopotential wave one amplitude in the period from December 1970 to January 1971 at 200 mb. Around 5-8th December at 55°N, 20th December at 50°-70°N, and about 15th January at 75°N we observed an acceleration of wave-one amplitude. For the winter 1970/71 the warming was observed around 10th January and it seems that this warming was stimulated by the amplitude acceleration at about 25th December. This acceleration is a necessary prerequisite for the development of a stratospheric warming. Figure 7 shows the baroclinic wave projection ($\overline{v^*v^*}$) on the wavenumber k = 1 at 200 mb. The thickened isolines for the wave projection terms are larger than the monthly mean total value by a factor of two. Comparison of the curves shows that in middle or high latitudes periods of strong baroclinic wave interactions with wave 1 correspond with periods of large wave amplitude accelerations. Furthermore the net acceleration of geopotential wave amplitudes was estimated on the basis of the divergence of the transports $\overline{u^*v^*}$ and $\overline{v^*v^*}$ in the meridional momentum equation. For the mentioned time periods one obtains at 50°N an acceleration of about 50-100 gpm/day which is a reasonable value in mechanistic models to describe a stratospheric warming.

In summarizing, it seems that the time variability of ultra-long waves in the stratosphere is also determined by interaction with baroclinic waves in the upper troposphere.

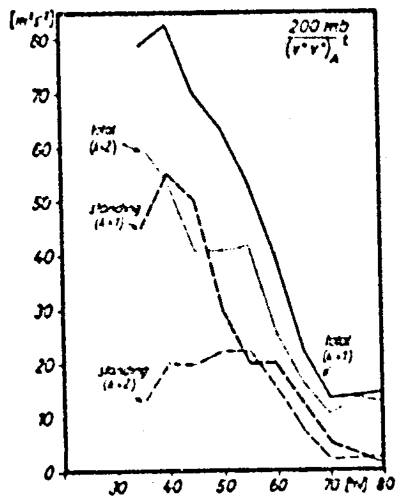

Figure 5.

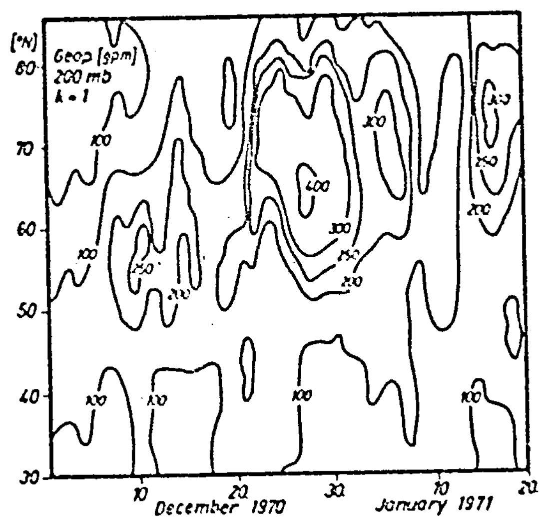

Figure 6.

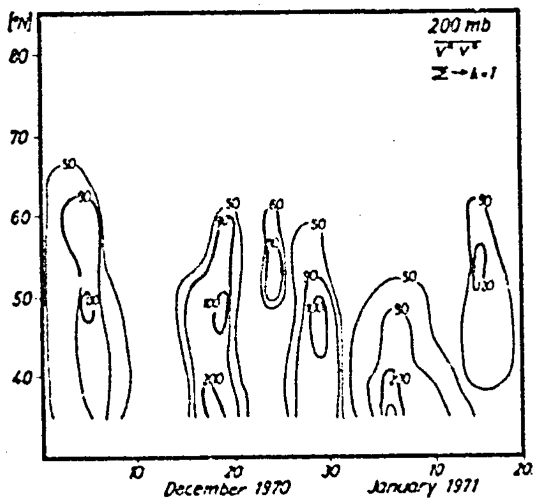

Figure 7.

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