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CHANGES IN THE OZONE CONTENT OVER CENTRAL EUROPE DURING REVERSALS OF STRATOSPHERIC CIRCULATION IN LATE WINTER

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A superposed-epoch analysis during late winter zonal wind reversals was carried out from 18-year observation series (1963-1980) of the meridional geopotential height gradient in the 30 mb level (latitude mean) and of the ozone content over central Europe.

Figure 1a gives the mean seasonal variation of the meridional geopotential height gradient between 50°N and the North Pole. This parameter is positive during winter, indicating west wind, whereas it is negative during summer, indicating east wind. In some late winters the meridional gradient breaks down to low, sometimes even to negative, values, as for 1977 (dotted curve). Such break-downs are connected with stratospheric warmings. The beginning of these decreases of the meridional gradient, exactly the first day of decreasing during a period which later attains negative values, was taken as key day of the subsequent superposed-epoch analysis. Figure 1b gives the variance of the geopotential height along the 50°N latitude circle. It represents in an integral form the deviation of the wind from a circumpolar zonal flow

$$\sigma = \left[1/2 \sum_{k=1}^{\infty} (A_k)^2\right]^{\frac{1}{2}}$$

(with A_k = the amplitude of the k-th planetary wave) i.e., a measure which we may call planetary wave activity. Because the amplitudes of waves $k > 3$ can be neglected, σ describes mainly the activity of the first 3 modes of planetary waves.

Figure 2a shows the result of the superposed epoch-analysis of 8 cases as given in Table 1.

Table 1. Key days of the superposed epoch analysis.

January 14, 1963	January 5, 1971
February 12, 1966	January 19, 1973
January 2, 1968	January 3, 1977
December 26, 1969	February 14, 1979

The curve through the dots represents the deviation of the meridional height gradient between 50°N and the North Pole from its mean seasonal variation. The gradient decreases and about 12 or 13 days after the key day it attains a minimum of 20 geopotential metres per degree latitude below the normal mean value. The curve of open circles represents the same parameter but between 40° and 60°N, it attains 11 gpm/deg.lat. below normal, about 20 days after the key day. If we formally convert the meridional gradient into zonal wind, we get a reduction of the west wind by 13 m/s and 10 m/s for the mean latitudes of 70°N and 50°N, respectively. After a recovery phase normal values are obtained

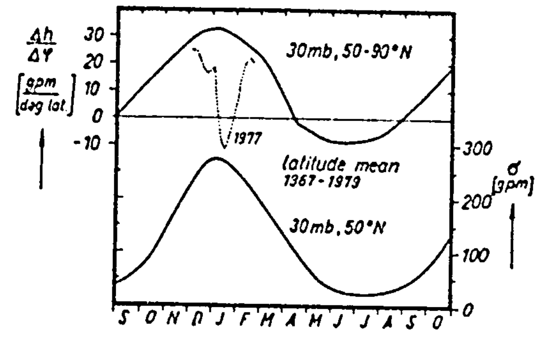

Figure 1. Mean seasonal variation at the 30 mb level (1967 - 1979) of
a) the meridional geopotential height gradient between 50° N and the North Pole;
b) the variance of the geopotential height along the 50° N latitude circle.

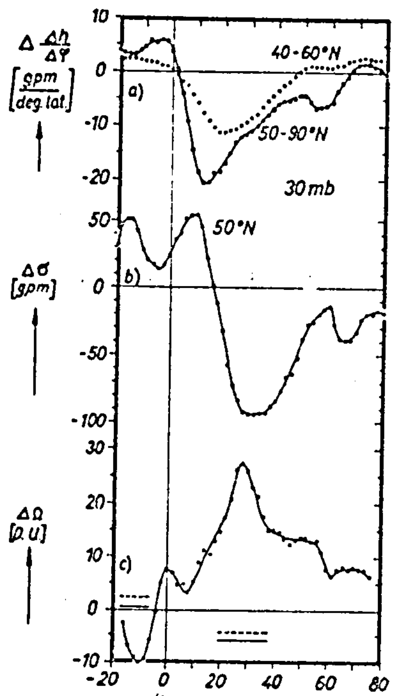

Figure 2. Superposed-epoch analysis of 8 cases of late winter zonal wind reversals between 1963-1980.
a) deviation of the meridional height gradient at 30 mb between 50°N and the North Pole from the mean seasonal variation (dots) and between 40° and 60°N (open circles);
b) deviation of the variance (planetary wave activity) from the mean seasonal variation;
c) deviation of the ozone content over Central Europe from the mean seasonal variation (curve); deviation of the monthly mean of the 8 cases from the long time monthly mean of the ozone content over the tropics (Kodaikanal: dashed horizontal bar, Huancayo: full horizontal bar).

between the 50-th and 60-th day after the key day. Figure 2b shows the behaviour of planetary wave activity. About ten days before the peak of the zonal wind reduction, o attains a relative maximum and then decreases till the 30-th day, reducing the normal planetary wave activity by almost 100 geopotential metres. Figure 2c gives the deviation of the ozone content over Central Europe from its mean seasonal variation (mean latitude of the 8 stations used: 50°N). It increases and attains a maximum of 27 D.U. (i.e. about 8 per cent) above the normal value, about one month after the key day. This ozone maximum occurs 10 days after the zonal wind minimum and almost simultaneously with the minimum of the planetary wave activity. Because the key days concentrate between the end of January and the middle of February, the ozone effect must be detectable in the seasonal variation, too. Figure 3 gives the seasonal variation of the ozone content over Central Europe with and without zonal wind reversals. In the mean of January to April the ozone content is indeed higher by 18.6 D.U. in years with zonal wind reversals than in the years without. According to the t-test this difference is significant by more than 99.9 percent.

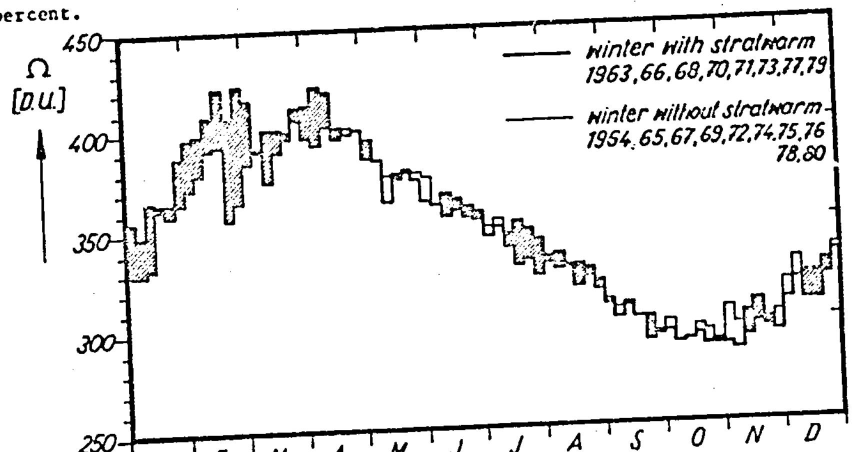

Figure 3. Seasonal variation of the ozone content over Central Europe with and without late winter zonal wind reversals.

In Figure 2c the deviation of the monthly mean from the long time monthly mean of the ozone content over the tropics (stations Kodaikanal 12°N and Huancayo 10°S) is given for the month before and for the month with the wind reversal at medium latitudes. In the month before the wind reversal, there is no significant difference to the normal value, but in the month with wind reversals the ozone content is significantly (on the 95% level) reduced at both stations by 5 D.U. in the mean, i.e., 2.1 per cent below normal. This result can be interpreted as an increase of meridional ozone transport from the tropics to middle latitudes during late winter zonal wind reversals. We have already found such opposite behaviour of the ozone content between the tropics and middle latitudes in the long-time ozone trend of the sixties and seventies, in the solar cycle and in the quasi-biennial-oscillation (ENTZIAN and GRASNICK, 1981). Now it is shown also in periods of some weeks, and in all these cases the meridional transport seems to be the connecting link.

After a theoretical investigation by ROOD (1982) the meridional ozone transport by diabatic circulation is supported by planetary wave transport during stratospheric warmings. In the case of a strong stratospheric warming, Rood expects a decrease of the tropic ozone content by more than 15 per cent,

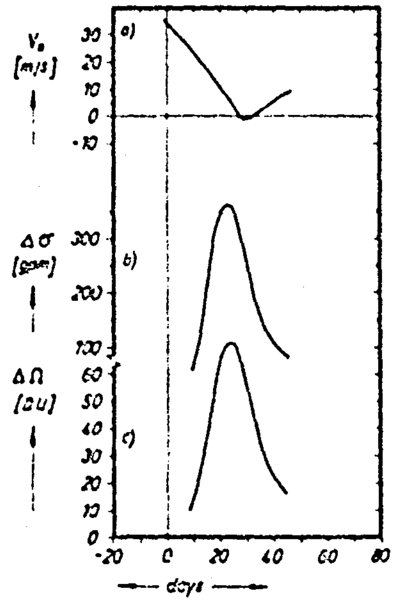

Figure 4. Kawahira's theoretical results of an adopted wave disturbance at 22.5 km beginning at the day zero, converted into parameters comparable with our Figure 2.
a) change of zonal wind at 22.5 km as a result of interaction between waves 1 and 2 and the mean flow;
b) planetary wave activity (k = 1 and 2) at 22.5 km;
c) ozone content between 10 and 40 km perturbed by planetary waves (k = 1 and 2).

which is qualitatively in agreement with our experimental result. Generally in contemporary theories the ozone increase in middle latitudes during stratospheric warmings is explained by enhanced efficiency of planetary wave transport, e.g., KAWAHIRA (1982). Figure 4 shows Kawahira's theoretical results converted into a form comparable with our results. After a disturbance at the zero day, planetary waves k = 1 and 2 at 22.5 km (near the 30 mb level used by us) reduce the zonal wind by more than 30 m/s, the minimum of zonal wind being reached at the 30th day, i.e., about 10 days later than our experimental result for 50°N. One week before the zonal wind minimum, Kawahira's planetary wave activity at 22.5 km (waves k = 1 and 2) attains a maximum and simultaneously the ozone content attains also a maximum of about 70 D.U. above normal. As to the time of ozone maximum, Kawahira's results are in good agreement with ours, though his maximum is twice or three times larger. Our experimental data on planetary wave activity, however, lead to a theoretically unexpected result, because we find, that the ozone maximum is attained during a minimum of that parameter. Therefore it may be suggested that, if planetary waves are responsible for the additional meridional ozone transport during stratospheric warmings, this transport has to take place at heights other than those up to the ozone maximum in the middle latitudes.

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The 30 mb data were taken from Meteorologische Abhandlungen, Tagliche Hohenkarten der 30 mb Flache, Institut fur Meteorologie der Freien Universitat, Berlin.

The ozone data were taken from Ozone data for the world, publ. by the Atmospheric Environment Service, Dept. of the Environment, in co-operation with the WMO, Downsview, Ontario, Canada.