# A SYNOPTIC VIEW OF THE ECMWF STRATOSPHERIC FORECASTS

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## 1. INTRODUCTION

The Berlin Stratospheric Research Group has been involved in stratospheric synoptics since the first description of a midwinter warming by *Scherhag* in 1952. Daily height and temperature fields have been analyzed since respectively 1957 and 1964 at various stratospheric levels. During the winter and spring months, we monitor the stratospheric circulation and prepare daily STRATALERT messages, mandated by the WMO and distributed by the Global Telecommunication System. These messages describe the state of the stratospheric circulation over the northern hemisphere and provide a forecast of the large-scale features such as "undisturbed, cold vortex" or "progressing warming" or "break-down of the vortex". The stratospheric alert system was introduced in 1964 to coordinate detailed measurements for the further study of stratospheric warmings. More recently, the information on extremely low temperatures has become more important in connection with the possibility of ozone destruction by heterogeneous chemistry in polar stratospheric clouds. Therefore, we have provided additional meteorological support to various measurement campaigns.

For these purposes, in winter 1983/84 we started to receive ECMWF products (via the DWD Offenbach); at first 3-day and 5-day forecasts of the spectral components of the planetary waves 1, 2 and 3 for 30-hPa heights at 60°N, which were later supplemented by the 8-day forecasts. We then changed to receive the northern hemispheric 30-hPa height and temperature fields which were finally supplemented by the same charts for 50 hPa. Since the European Arctic Stratospheric Ozone Experiment (EASOE) in the winter 1991/92 we also have access to the ECMWF forecasts of temperature and potential vorticity at various isentropic levels.

In the following, I will show some examples from our 10 years of experience with the ECMWF stratospheric forecasts. Comparisons are made with the Berlin analyses, in the first section for the amplitudes and phases of the long planetary waves and in the second for the temperature and height fields. The discussion will be focused on the 5-day forecasts, which we use regularly. The 8-day forecasts have only been used to indicate the tendency because they often overestimate the development.

## 2. ECMWF FORECASTS AND BERLIN ANALYSES

### 2.1 Planetary waves

The knowledge of the development of the long planetary waves is essential to diagnose a developing stratospheric warming because they are responsible for the stratospheric midwinter disturbances through wave-wave and wave-mean flow interactions (*Matsuno*, 1971, *Andrews* and *McIntyre*, 1976, *Plumb*, 1981).

We have therefore compared the amplitudes of the 30-hPa height waves 1 and 2 at 60°N (where the amplitudes are largest) during the past 10 winter periods (December to March) from the Berlin analyses and the ECMWF forecasts, published in our regular winter reports. A collection of these reports, starting with the winter 1974/75, is available as a STEP Handbook (*Naujokat* and *Labitzke*, 1993). An example of such a comparison is shown in figure 1, including the correlation coefficients for the linear regressions between the analyses and the 3- and 5-day forecasts.

Figure 2 summarizes the correlation coefficients of the 5-day forecasts of the amplitudes of 30-hPa height waves 1 and 2 (neglecting the phases) for all winters. The different quality does not only reflect changes in the forecast model but depends also on the strength and variability of the waves during the respective winters. The amplitude of wave number 1, predominant in the stratosphere in winter, is in general well predicted with correlation coefficients around 0.9, except in the winter 1984/85 (the reason will be shown later). The correlations for wave number 2, with its lower amplitudes, are slightly worse. Figure 3 shows the maximum values of amplitudes during the winters, the means of the periods December through March and their standard deviations, as analyzed by Berlin and forecast by the ECMWF for 5 days. In most of the winters, the amplitudes of both waves are underestimated by the 5-day forecast (or overestimated by our subjective analyses). Combining figures 2 and 3, it is obvious that strong wave activity results in high correlations, but it can also be seen that low amplitudes of wave 1 are better represented since 1988 and those of wave 2 since 1990.

Considering the specific circulation features during the 10 winters (*Naujokat* and *Labitzke*, 1993), the strong amplification of wave 1 in connection with stratospheric warming events was always well predicted, as were the retrograde movement of this wave and the following rapid development of wave 2 in the case of major warmings. Even during the winter 1984/85 the developing major warming was well predicted but it was unusually connected with an amplification of wave 2, as shown by figures 4 and 5. The 5-day forecast did not realize the rapid decrease of the amplitude of wave 1 after the Canadian warming at the beginning of December. Together with the weakness of wave 1 during the rest of the winter, this resulted in the above mentioned low correlation coefficient for wave 1, in contrast to that for wave 2. The phases of wave 2 also agree much better than those of wave 1 (Fig 6).

An example of a well predicted retrograde movement of the planetary wave 1 is shown in figure 7 for the period 11 January to 10 February 1984. Following the ideas of *Madden* and *Labitzke* (1981), the westward movement of wave 1 can be interpreted as the movement of a free wave which starts to intensify when it moves into phase with the quasi-stationary wave. This happened in the beginning of February 1984, leading to a warming event and finally to the transition into summer conditions. The ECMWF 3- and 5-day forecasts show a good agreement with the Berlin analyses, although the amplitudes were somewhat too strong.

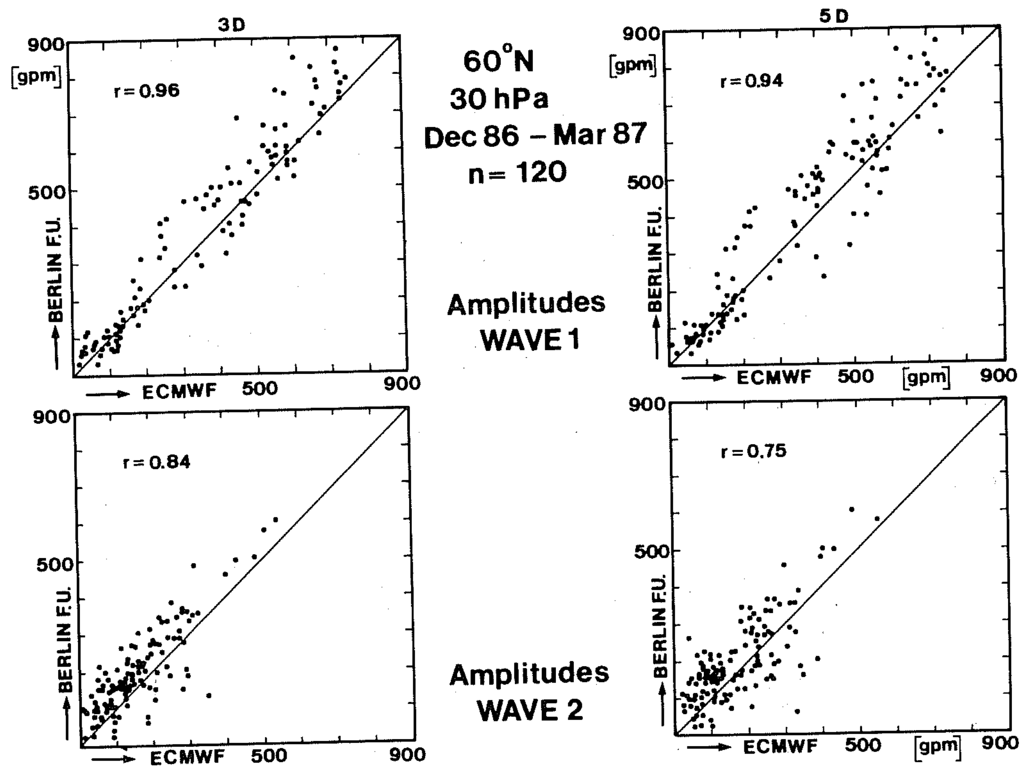


Fig 1 Comparison of amplitudes (gpm) of 30 hPa height waves 1 and 2 at 60°N between the Berlin analyses and the ECMWF 3- and 5-day prognoses for the winter 1986/87. r are the correlation coefficients.

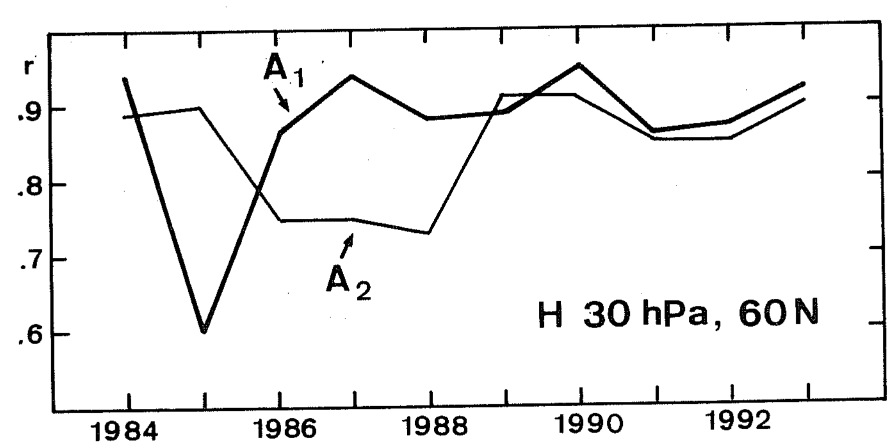


Fig 2 Correlation coefficients between Berlin analyses and ECMWF 5-day prognoses of the amplitudes of 30 hPa height waves 1 and 2 at 60°N (A1, A2) in the winters (December-March) 1983/84 - 1992/93.

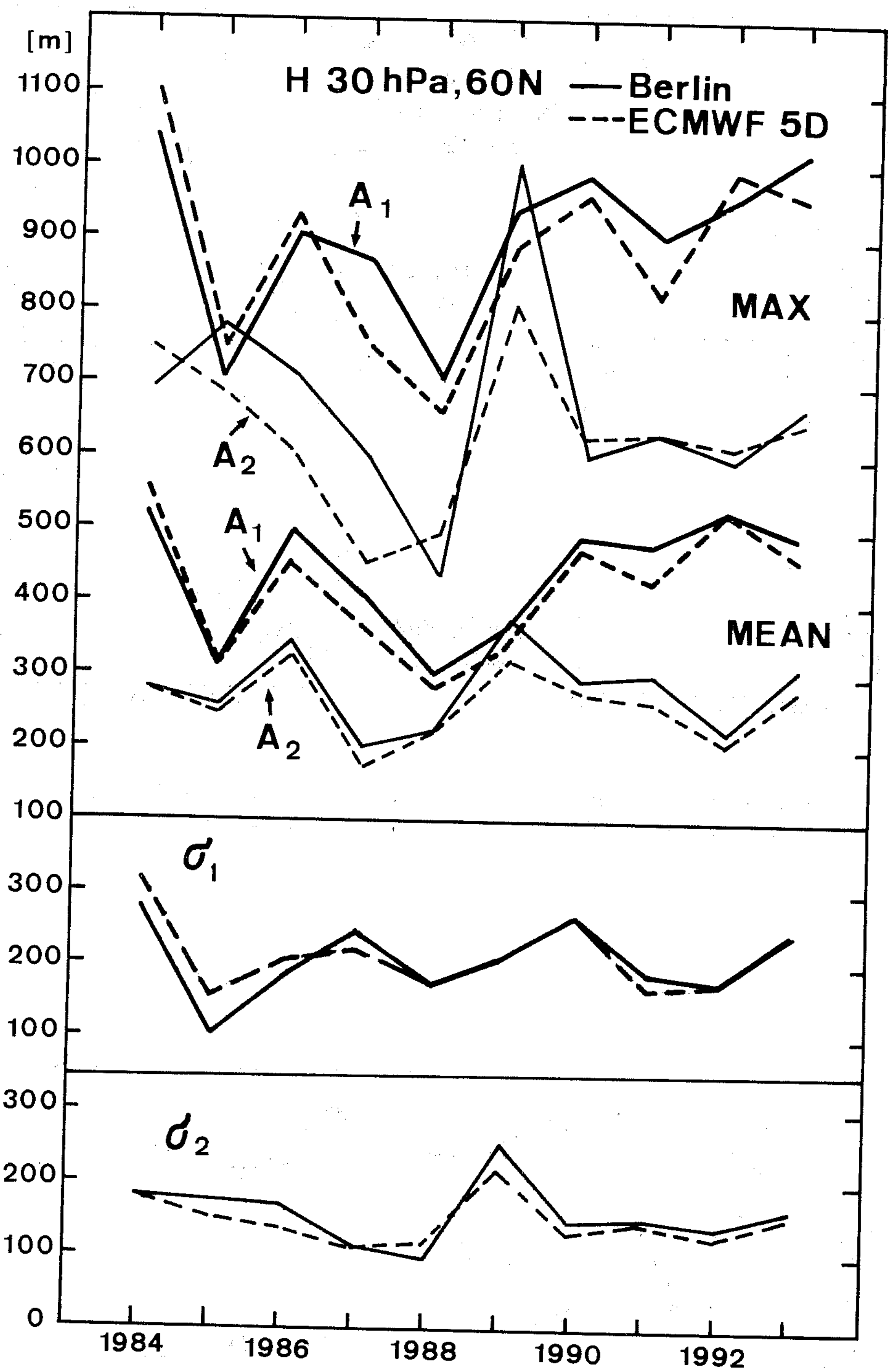


Fig 3 Amplitudes of 30 hPa height waves 1 and 2 (gpm) at 60°N (A1, A2) in the winters (December-March) 1983/84 - 1992/93 from Berlin analyses and ECMWF 5-day forecasts: absolute maxima, means, and standard deviations.

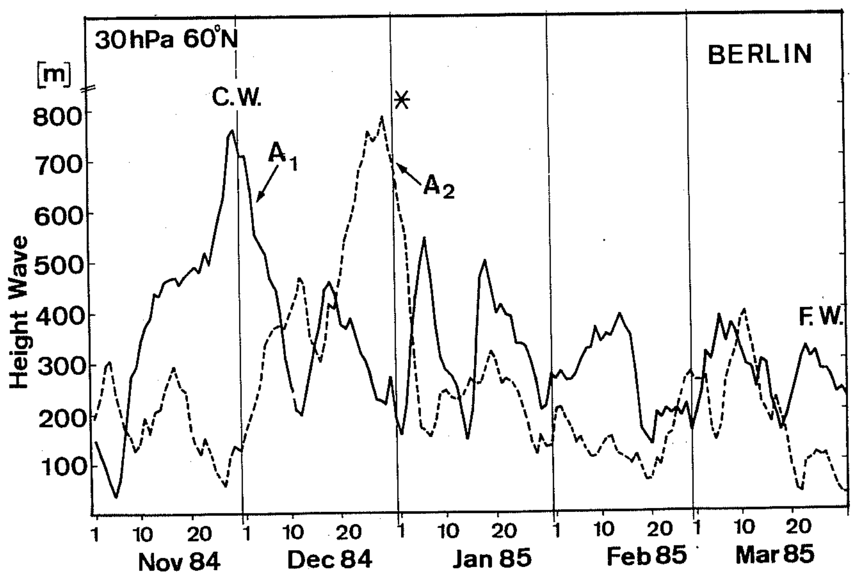


Fig 4 Amplitudes of 30 hPa height waves 1 and 2 (gpm) at 60°N (A1, A2) from November 1984 to March 1985 from Berlin analyses.

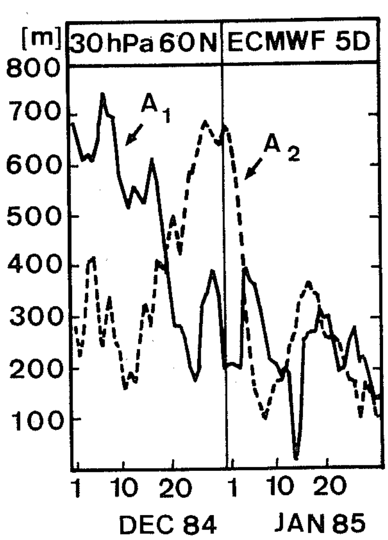


Fig 5 Amplitudes of 30 hPa height waves 1 and 2 (gpm) at 60°N (A1, A2) from December 1984 to January 1985 from ECMWF 5-day forecasts.

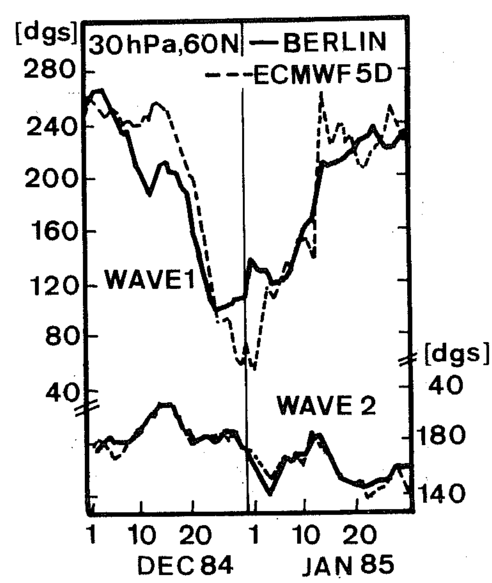


Fig 6 Phases of 30 hPa height waves 1 and 2 at 60°N from December 1984 to January 1985 from Berlin analyses and ECMWF 5-day forecasts.

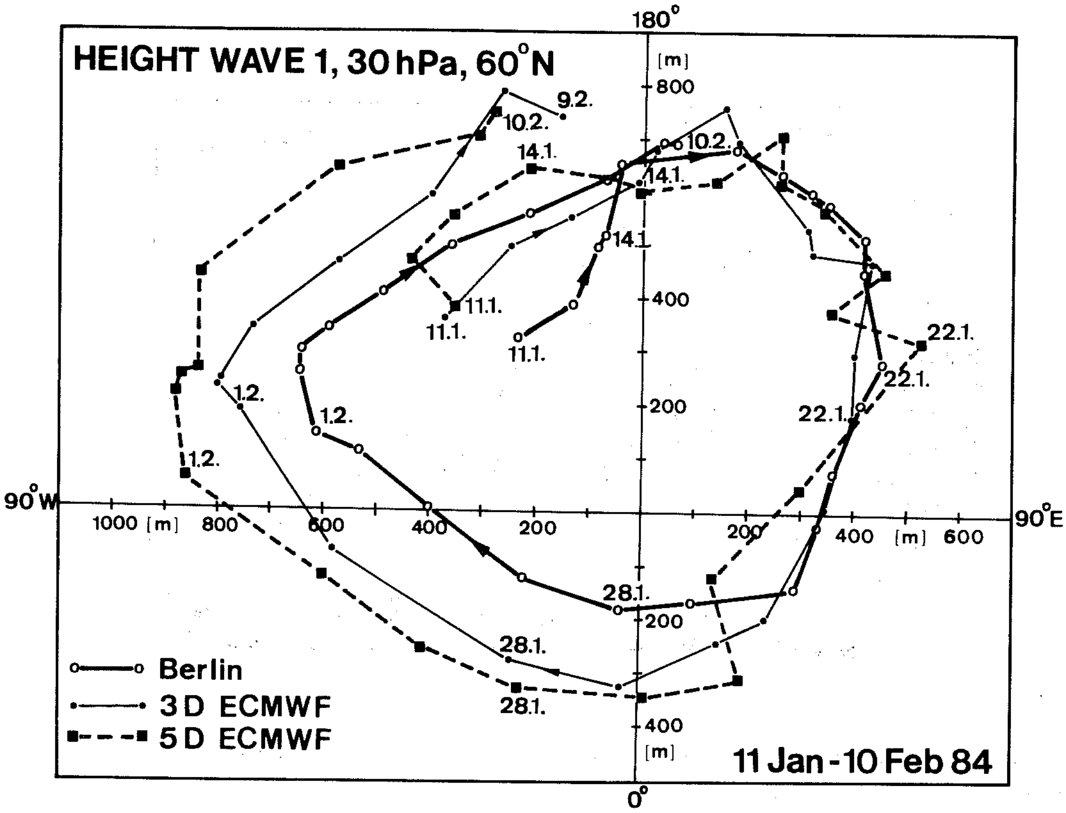


Fig 7 Polar diagram of 30 hPa height wave 1 at 60°N for the Berlin analyses and the ECMWF 3- and 5-day forecasts from 11 January to 10 February 1984. Plots illustrate the amplitude (m) and the phase of the ridge at the indicated date.

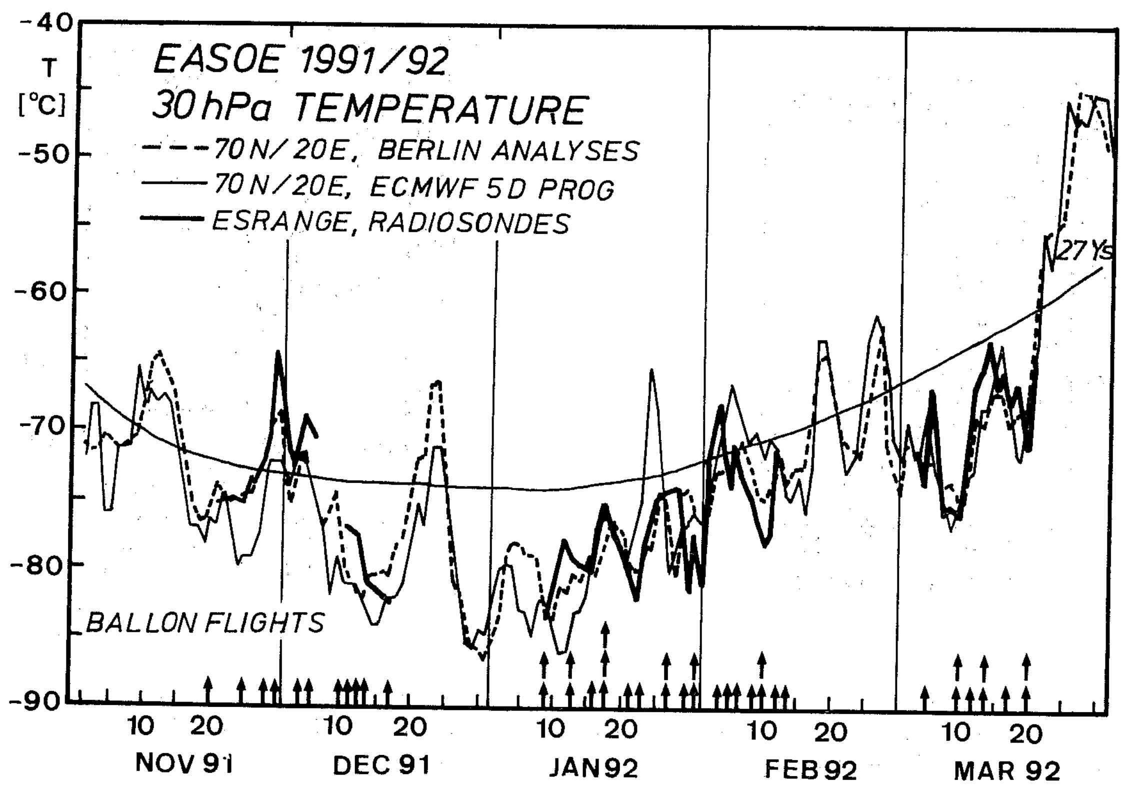


Fig 8 Daily 30 hPa temperatures (°C) at 70°N/20°E from November 1991 to March 1992 from Berlin analyses (the smooth line is a 27-year mean), ECMWF 5-day forecasts, and radiosonde measurements at ESRANGE/Kiruna (68°N/21°E). Arrows at the bottom indicate days of balloon experiments.

## 2.2 Temperature and height fields

In the winter 1989/90 we received, for the first time, ECMWF forecasts of stratospheric height and temperature fields for the entire northern hemisphere which gave information not only on the planetary wave activity but also on the expected spatial distribution of the centres of action. It was possible now to see the temperature development at specific locations, for instance the southward movement of the cold air towards northern Europe in February 1990 and the connected 10 degrees temperature decrease to values around -85°C over Scandinavia, where a balloon campaign took place.

Figure 8 shows the temperature development (measured, analyzed and forecast) in the winter 1991/92 at the experimental site of the European Arctic Stratospheric Ozone Experiment (EASOE) at ESRANGE/Kiruna, Sweden. In general, there is a good agreement, especially during the cooling periods in early winter and during the final warming at the end of March. The effect of the minor warming at the end of January was overestimated over northern Europe. The first cooling period over Scandinavia around mid-December, connected with a developing warming over northeastern Asia, is shown in more detail in figure 9. The Berlin analysis of 8 December 1991 shows that the polar vortex was split (as predicted by ECMWF) and northern Scandinavia was situated within a pronounced ridge outside the polar vortex. The ECMWF 5-day forecast from 8 December for the 13 December shows the re-establishment of a single vortex centre and the displacement of the cold air towards northern Europe. Kiruna was expected to be near the cold centre and inside the polar vortex, as shown by the forecast of the potential vorticity. The verification is demonstrated by the analysis of 13 December 1991. This asymmetrical temperature distribution, due to the adiabatic cooling induced by the intensified rising motions in the upwelling branch of an enhanced planetary wave, may have strong implications to the ozone content, as shown by *Petzoldt et. al* (1993).

## 3. CONCLUSIONS

The ECMWF forecasts provided excellent guidance for the preparation of the STRATALERT messages during the last 10 winters and they were a great support during measurement campaigns to help with the decision for the deployment of balloon experiments and aircraft flights.

Improvements may be possible, but one should keep in mind that the forecasts cannot be better than the analyses. Figure 10 shows an example of different temperature analyses during the minor warming event in January 1992. Shown are daily 30-hPa temperatures within the warm and the cold regions and at the North Pole as analyzed by Berlin (at 00 UT), the ECMWF, the National Meteorological Center (USA), and the Japanese Meteorological Agency (all three at 12 UT). Only the subjective analyses of Berlin incline to extreme values, however, the general agreement is satisfying with regard to the warm and the cold centres.

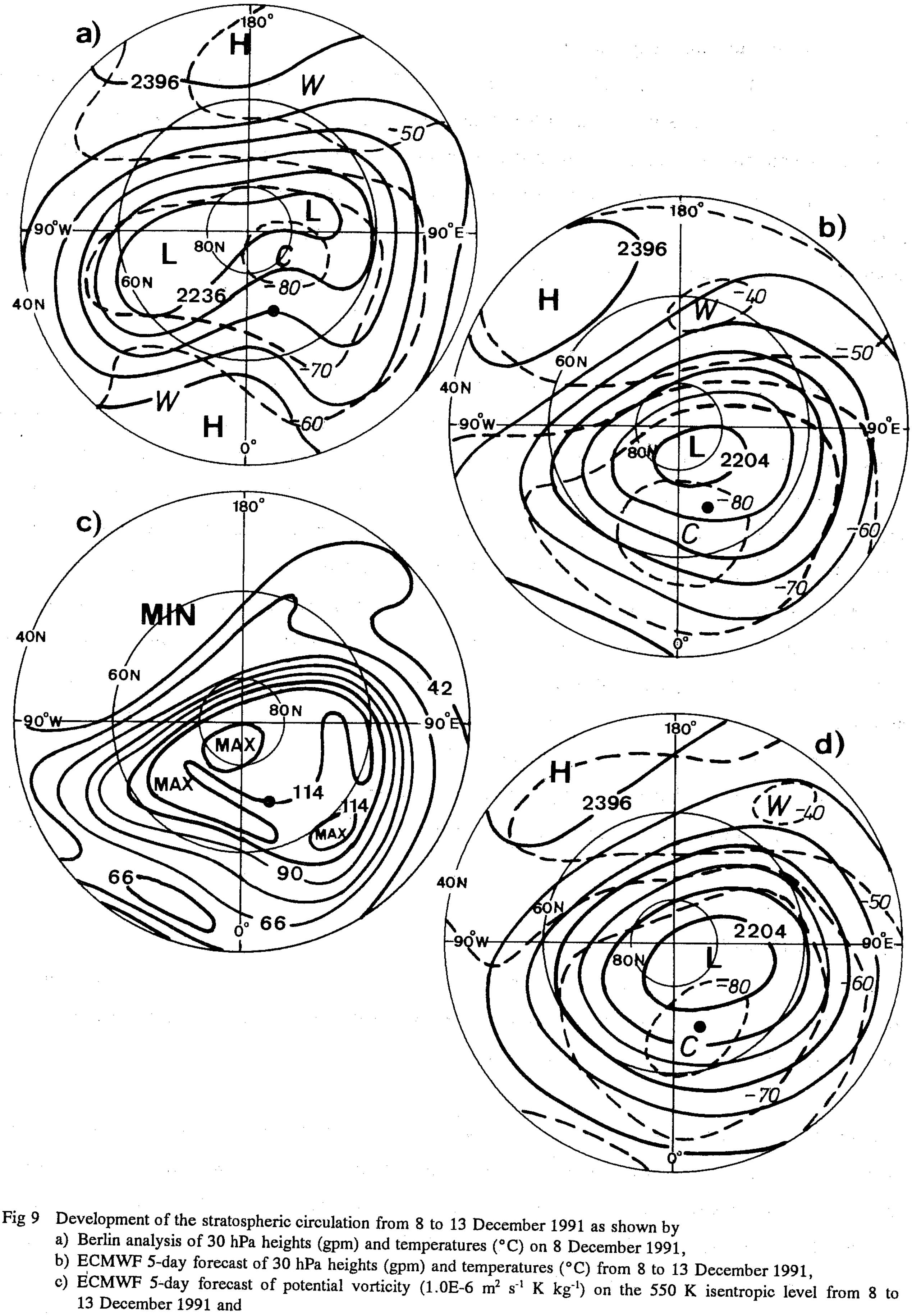


Fig 9 Development of the stratospheric circulation from 8 to 13 December 1991 as shown by
a) Berlin analysis of 30 hPa heights (gpm) and temperatures (°C) on 8 December 1991,
b) ECMWF 5-day forecast of 30 hPa heights (gpm) and temperatures (°C) from 8 to 13 December 1991,
c) ECMWF 5-day forecast of potential vorticity (1.0E-6 $m^2$ $s^{-1}$ K $kg^{-1}$) on the 550 K isentropic level from 8 to 13 December 1991 and
d) Berlin analysis of 30 hPa heights (gpm) and temperatures (°C) on 13 December 1991.

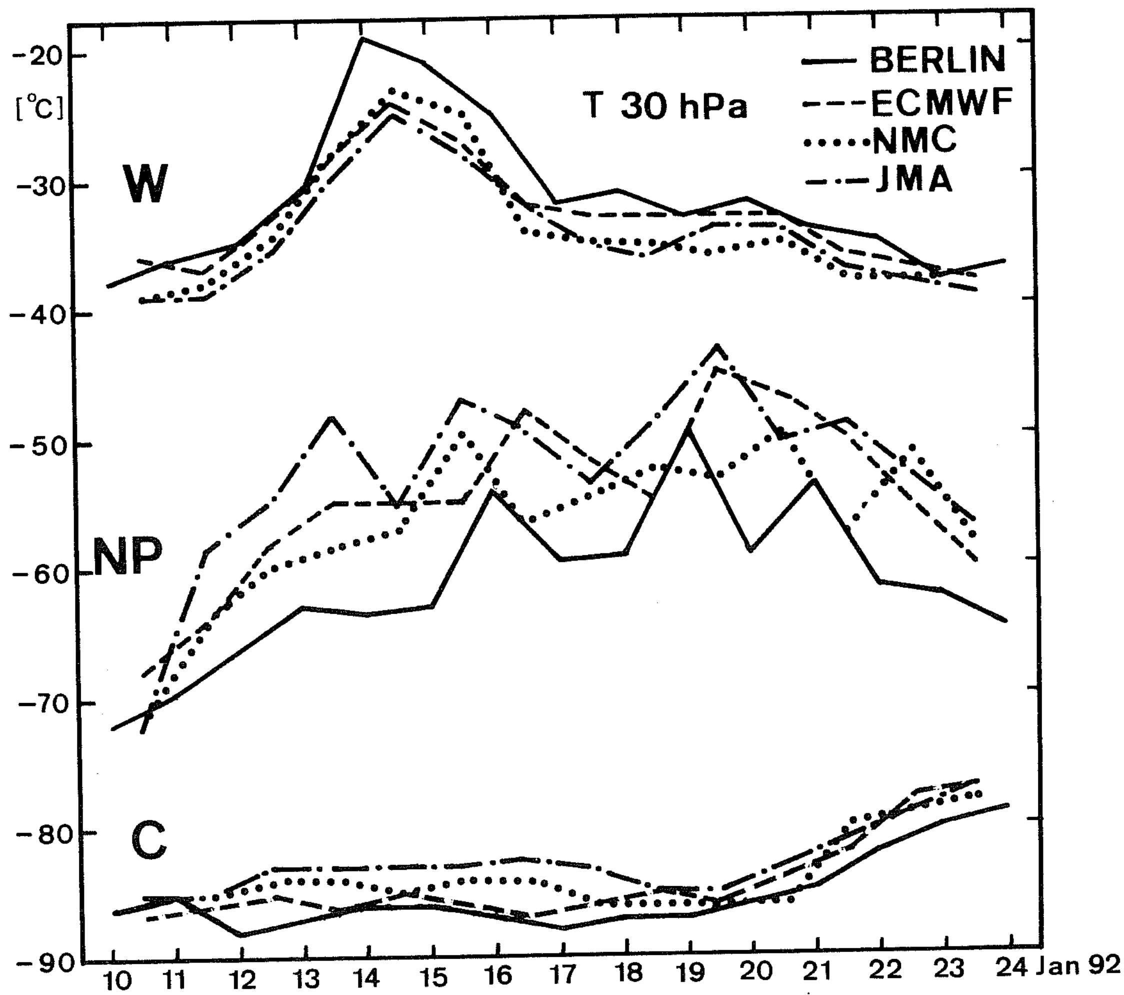


Fig 10 March of 30 hPa temperatures (°C) from 10 to 24 January 1992 as analyzed by different analysis centres (Berlin, ECMWF, NMC, JMA) in the warm region (W), at the Northpole (NP), and in the cold region (C).

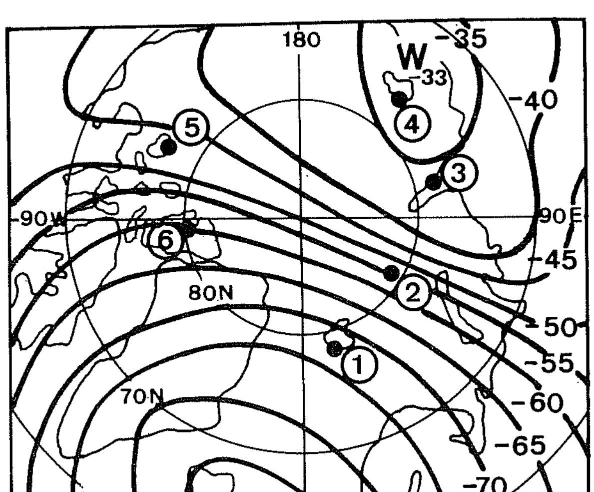


Fig 11 30 hPa temperature field (°C) on 19 January 1992, Berlin analysis. The numbered dots mark the northernmost radiosonde stations.

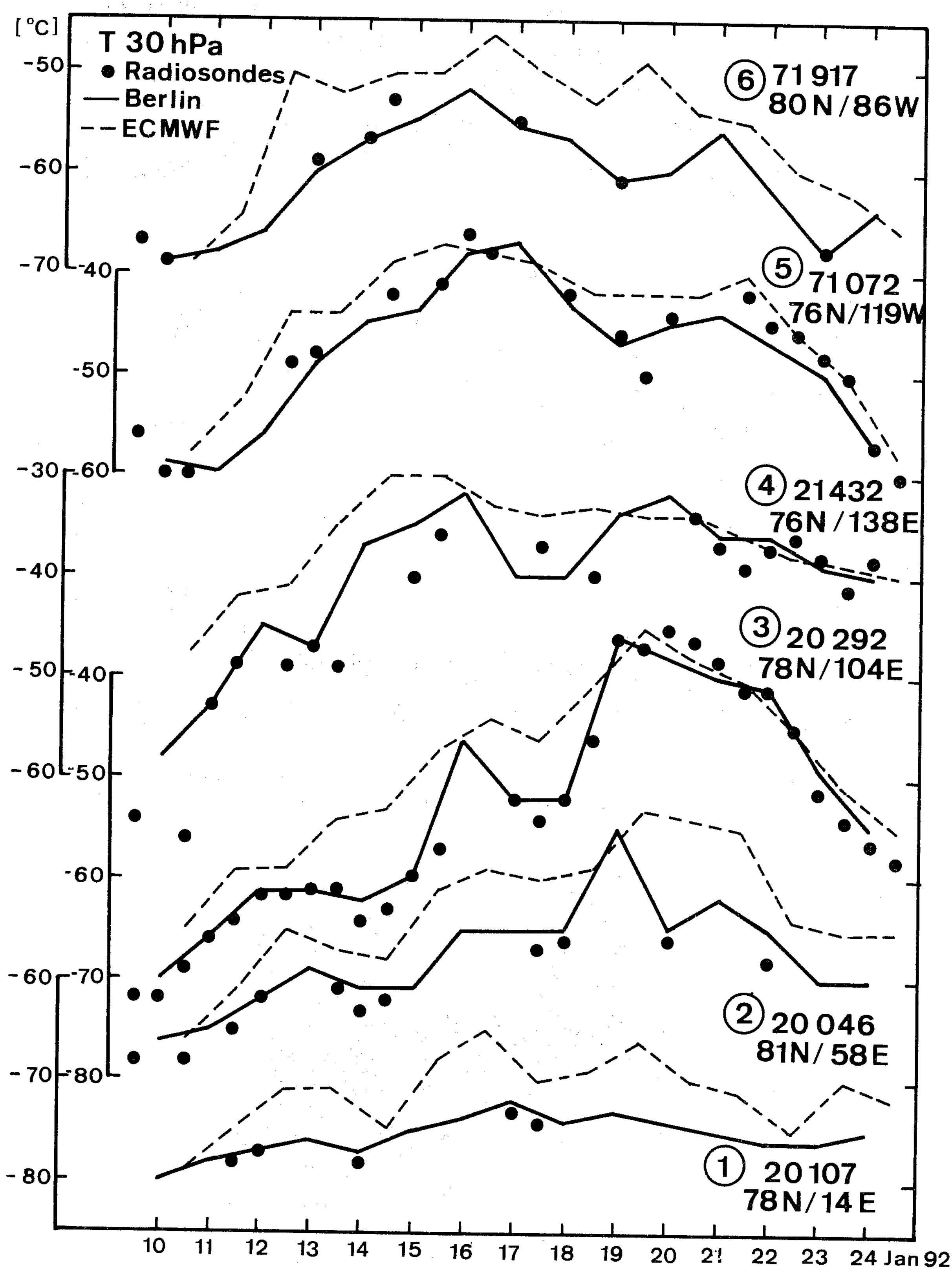


Fig 12 Comparison of 30 hPa temperatures (°C) in the polar region from 10 to 24 January 1992, measured by radiosondes and analyzed by Berlin and the ECMWF at the locations marked in Fig 11.

The discrepancies at the North Pole, reaching 15 degrees on some days, are not acceptable. They result from the strong temperature gradient over an area with insufficient data coverage, as shown by figure 11. The six northernmost radiosonde stations are far away and, moreover, they did not measure regularly at this height. Figure 12 compares the available radiosonde temperatures with the analyses of Berlin and of the ECMWF, the latter being systematically warmer than the first.

Finally, even if the initial fields are known accurately and all physical relations are taken into account, some uncertainties will remain due to the chaotic behavior of the atmosphere. Probability forecasts would be helpful in evaluating the prediction.

## 4. REFERENCES

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