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AN OBSERVATIONAL STUDY OF THE FINAL WARMING IN THE SOUTHERN HEMISPHERE STRATOSPHERE

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Abstract. The final warming in the Southern Hemisphere stratosphere during the period 1 September - 30 November for the years 1978-1983 is studied. The change in zonally averaged temperatures during that period is almost the same for each year. However, there is substantial interannual variability in the time evolution of the warming as events of enhanced wave, mean-flow interaction associated with bursts of upward propagating planetary waves develop at different times in different years. Polar temperatures in the middle stratosphere can increase as much as about 20 K in 4 days during these events. Such dynamical processes can play a significant role in the interannual variability of stratospheric ozone and other constituents.

Introduction

For the Southern Hemisphere stratosphere, in the absence of major mid-winter warmings, the most outstanding events of wave, mean-flow interaction occur during the spring and fall seasons. The former period, during which the final warming develops, was studied by Hirota et al. [1983] and Shiotani and Hirota [1985] for 1981 and by Yamazaki and Mechoso [1985] for 1979. These authors used the U.S. National Meteorological Center (NMC) 1200 GMT analyses of temperature and geopotential fields between 1000 and 0.4 mb which start on October 1, 1978.

In this paper, we use the same dataset for the period 1 September - 30 November during the years 1978-1983 to compile a climatology of the final warming in the Southern Hemisphere stratosphere, investigate its interannual variability and analyze episodes of strong wave, mean-flow interaction. Ozone decreases reported by Farman et al. [1985] and Stolarski et al. [1986] have local and temporal features since they are most pronounced over Antarctica during early spring. These features suggest that dynamical processes, such as those studied in this paper, play a significant role in the development of the phenomenon, particularly in its interannual variability.

Climatology

The mean for the years 1978-1983 of the difference in zonally averaged temperatures between 30 November and 1 September is shown in Figure 1. Except for the subtropical lower stratosphere where there is weak cooling, all other regions show warming with a maximum of about 55 K in the polar region between 30 and 50 mb. The corresponding plots for each of the individual years look almost identical to Figure 1 despite interannual differences at corresponding dates. The deviation of the mean temperature difference from its zonal average at 30 mb (see Figure 2) shows that maximum and minimum warmings are over the South Atlantic and South Pacific Oceans, respectively. The pattern in Figure 2 primarily reflects deviations from zonal symmetry at the beginning of the period (1 September) rather than at the end of the period (30 November) when they are small. The mean time evolution of temperature averaged between 70 and 80°S is shown in Figure 3. The height of the location with minimum temperatures descends in time from about 70 mb to 250 mb. Below about 10 mb, temperatures increase monotonically at all heights. In association with the temperature changes, the mean zonally averaged geostrophic zonal wind at 10 mb (see Figure 4) decelerates becoming easterly at all latitudes towards the end of November.

Interannual Variability of Polar Temperatures

The evolution of the flow in individual years departs significantly from its mean as events of wave, mean-flow interaction develop at different times in different years. The time evolution of

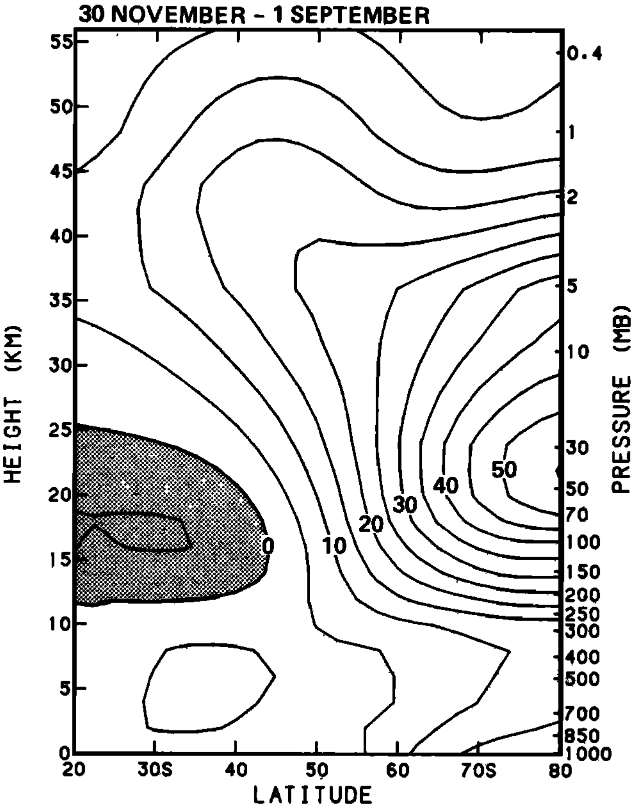

Fig. 1. Mean for the years 1978-1983 of the difference in zonally averaged temperatures (K) between 30 November and 1 September.

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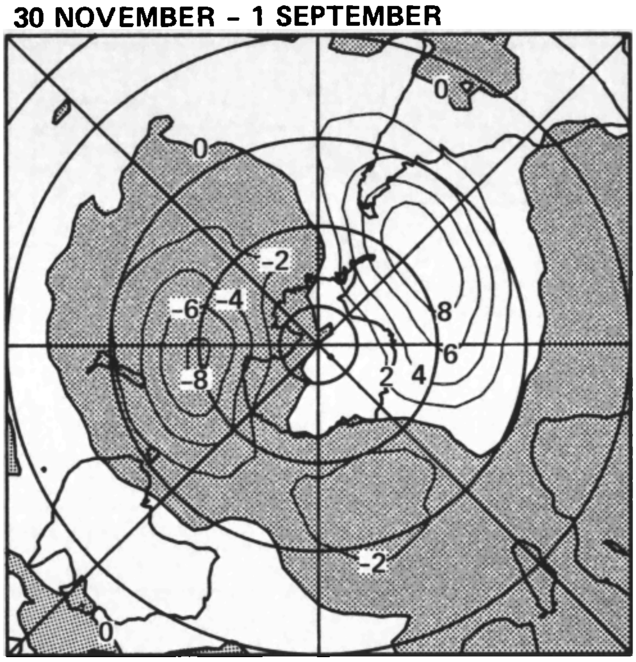

Fig. 2. As in Fig. 1, except for the deviation from the zonal average at 30 mb.

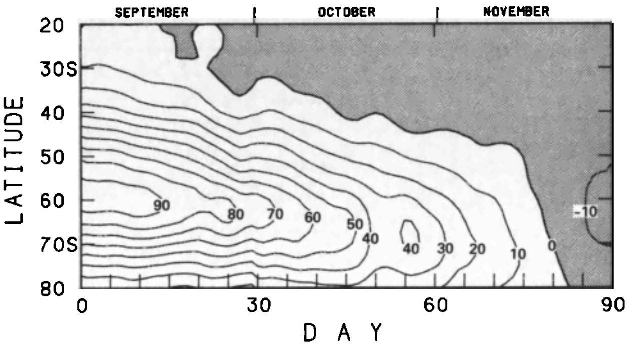

Fig. 4. Mean for the years 1978-1983 of zonally averaged geostrophic zonal wind (m/s) at 10 mb from 1 September to 30 November.

temperature at 30 mb averaged between 70 and 80°S for the individual years of this study is shown in Figure 5. Largest interannual differences appear in October and early November when some years (1978, 1979, 1982, 1983) appear significantly warmer than others (1980, 1981). Yamazaki and Mechoso [1985] showed that there were rapid changes in the stratospheric circulation during mid-October 1979 in association with a burst of upward propagating planetary waves. The changes consisted of a rapid deceleration in high latitudes and a simultaneous warming of the polar region. The time evolutions of the temperature for 1978 and 1982 are somewhat similar to that for 1979, particularly after mid-October. The final warming in 1982 will be discussed in the next Section. In 1983, an enhancement in the warming rate occurred around the end of October. On the other hand, wave, mean-flow interactions were weaker in 1980 and 1981, although there was a burst of upward propagating planetary waves in early October 1980. Interestingly, temperatures at the beginning and end of the period do not differ significantly from year to year and, in this short sample, there is no apparent relation between temperatures in early September and the occurrence of subsequent warming events.

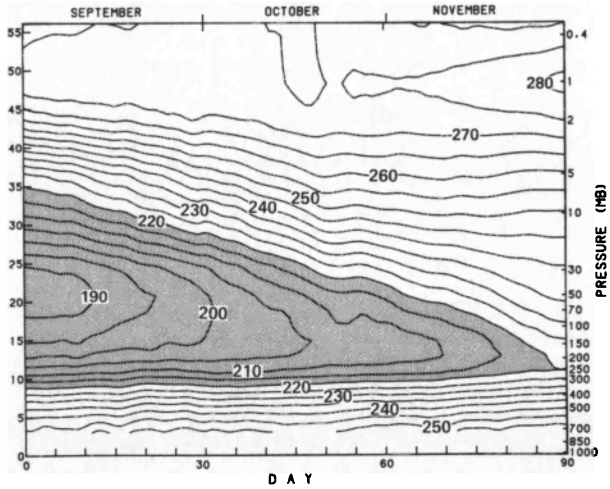

Fig. 3. Mean for the years 1978-1983 of temperature (K) averaged between 70 and 80°S from 1 September to 30 November.

The Final Warming in 1982

The strongest event of wave, mean-flow interaction during the analysis period occurred in October 1982. For this year, Figure 6a shows the 4-day change in temperature averaged between 70 and 80°S, and Figure 6b shows the northward eddy heat flux averaged between 50 and 70°S. There is a clear correspondence between episodes of enhanced wave activity and those of larger changes in polar temperatures. Later episodes affect lower levels, so that effects on polar temperatures at 30 mb become apparent in October (see Figure 5). In particular, the episode of enhanced poleward heat transport during 16-20 October is associated with 4-day increases of about 20 K in polar temperatures at around 10 mb and decreases of the same magnitude at upper levels. Such a temperature decrease at upper levels is not found in previous episodes. The latitudinal extent of the temperature change between 16 and 20 October is illustrated in Figure 7.

Eliassen-Palm fluxes computed geostrophically [Mechoso, et al., 1985] and averaged for the period 16-20 October are shown in Figure 8. They are predominantly upwards throughout the atmosphere at middle and high latitudes indicating upward energy propagation by planetary waves at this time. Convergences in the upper stratosphere at high latitudes are associated with decelerations observed there. Corresponding plots for the previous and subsequent periods show similar characteristics as those before and after the October 1979 event discussed by Yamazaki and Mechoso [1985], namely E-P fluxes that are almost equator-

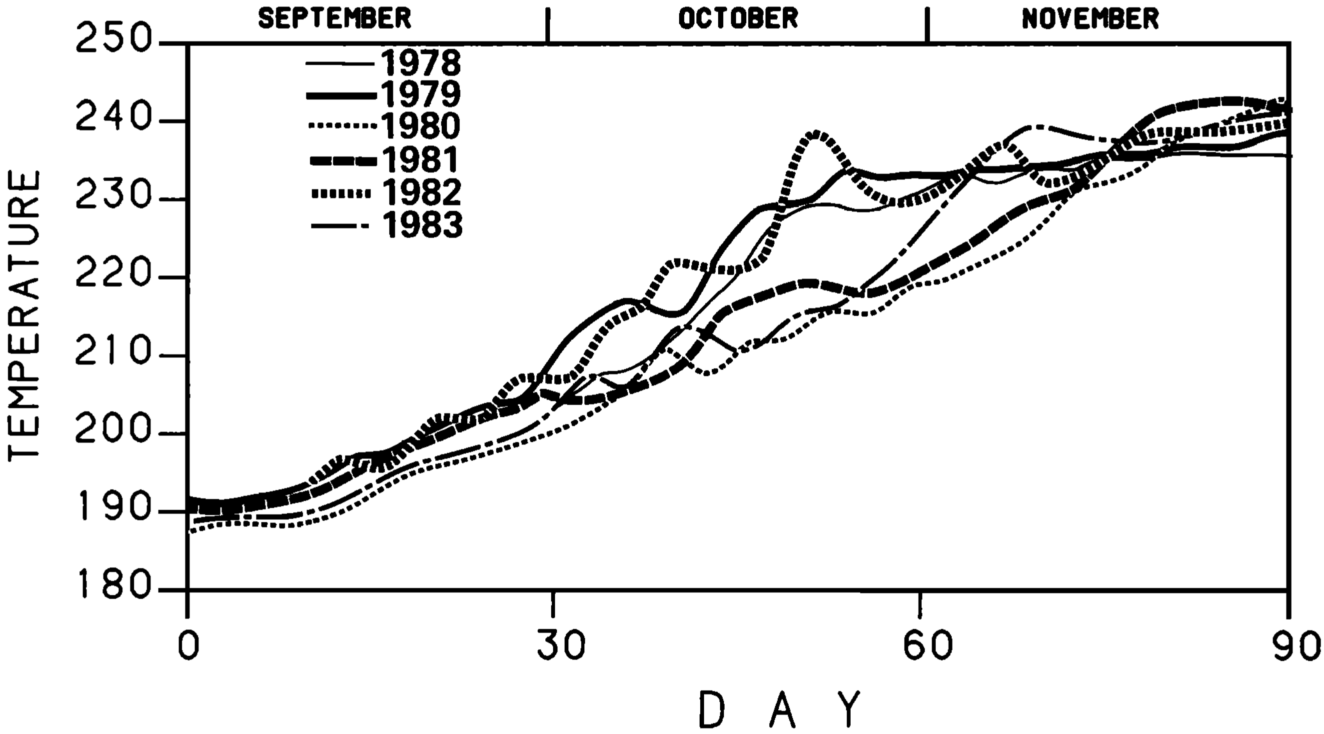

Fig. 5. Temperature (K) at 30 mb averaged between 70 and 80°S from 1 September to 30 November for each of the years in this study.

ward both before and after the event and upward during the event.

Conclusions

An analysis of the warming for the stratosphere of the Southern Hemisphere during the period 1 September - 30 November for the years 1978-1983 reveals that it is almost the same for each year despite interannual differences at corresponding dates. The time evolution of the warming, on the other hand, shows substantial interannual variability in relation with that in events of enhanced wave, mean-flow interaction associated with bursts of upward propagating planetary waves. As a consequence of such events, polar temperatures in the

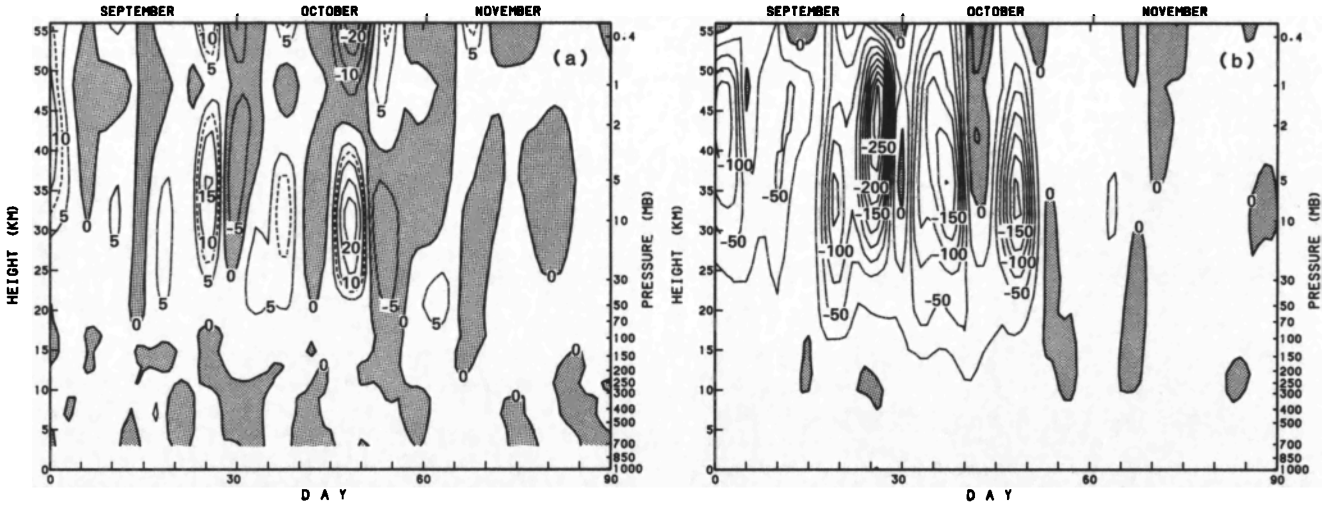

Fig. 6. As in Fig. 3, except for the 4-day change in 1982 (a), and northward eddy heat flux (mK/s) averaged between 50 and 70°S for 1982 (b).

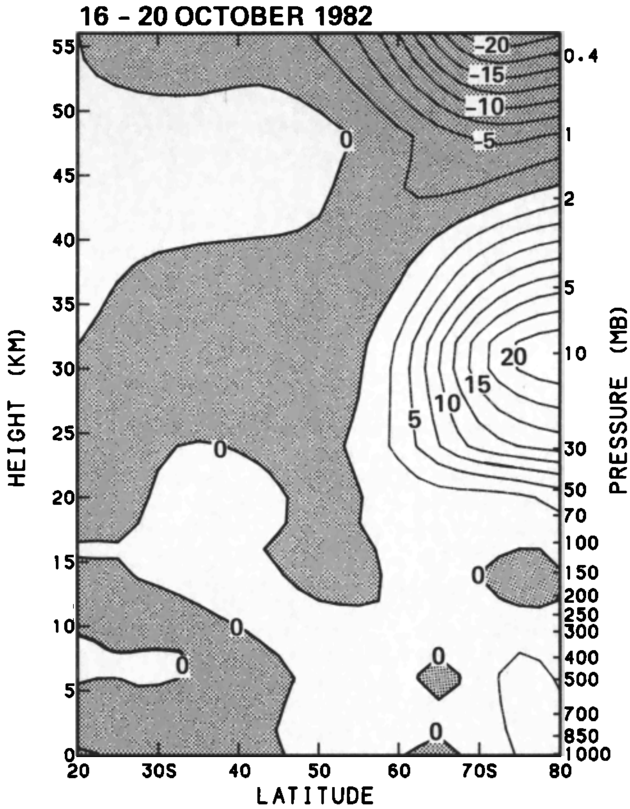

Fig. 7. Difference in zonally averaged temperatures (K) between 20 and 16 October 1982.

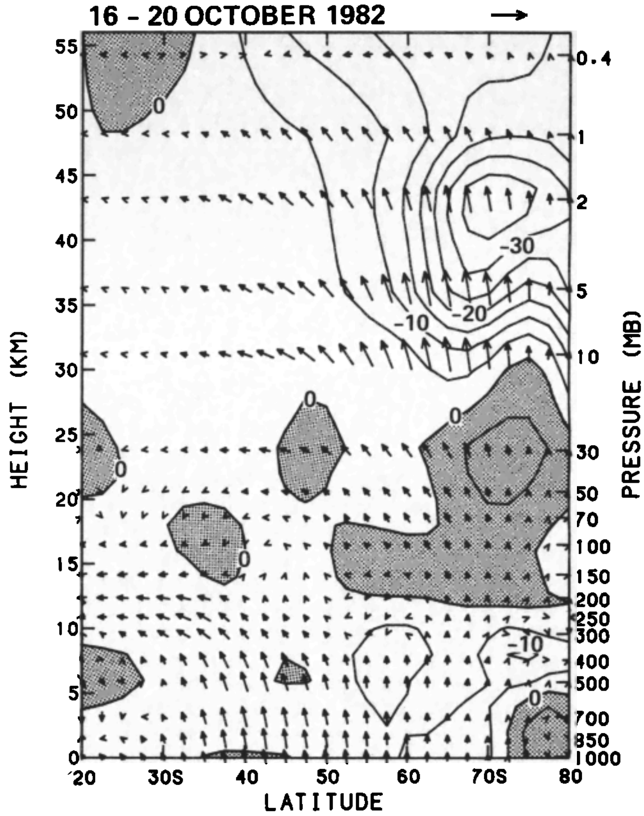

Fig. 8. Mean for the period 16-20 October 1982 of the Eliassen-Palm cross sections. Contour interval is 5 (m/s)/day.

middle stratosphere can increase as much as 20 K in a 4-day period. During October and early November of the years with stronger events, temperatures in the lower polar stratosphere are significantly higher than in those years with weaker events.

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References

Farman, J. C., B. G. Gardiner and J. D. Shanklin, Large losses of total ozone in Antarctica reveal seasonal ClO_X/NO_X interaction, Nature, 315, 207, 1985.

Hirota, I., T. Hirooka and M. Shiotani, Upper stratospheric circulations in the two hemispheres observed by satellites, Quart. J. Roy. Meteor. Soc., 109, 443, 1983.

Mechoso, C. R., D. L. Hartmann and J. D. Farrara, Climatology and interannual variability of wave, mean-flow interaction in the Southern Hemisphere, J. Atmos. Sci., 42, 2189, 1985.

Shiotani, M. and I. Hirota, Planetary wave, mean-flow interaction in the stratosphere: A comparison between the Northern and Southern Hemisphere, Quart. J. Roy. Meteor. Soc., 111, 309, 1985.

Stolarski, R. S., A. J. Krueger, M. R. Schoeberl, R. D. McPeters, P. A. Newman and J. C. Alpert, Nimbus 7 satellite measurements of the springtime Antarctic ozone decrease, Nature, 322, 808, 1986.

Yamazaki, K. and C. R. Mechoso, Observations of the final warming in the stratosphere of the Southern Hemisphere during 1979, J. Atmos. Sci., 42, 1198, 1985.

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