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Evolution of the Antarctic Polar Vortex in Spring: Response of a GCM to a Prescribed Antarctic Ozone Hole

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1. Introduction:

This study examines the possible effect of the Antartic ozone hole on the evolution of the polar vortex during late winter and spring using a general circulation model (GCM). The GCM is a version of the NCAR Community Climate Model whose domain extends from the surface to the mesosphere and is similar to that described in Boville and Randel (1986). Ozone is not a predicted variable in the model. A zonally averaged ozone distribution is specified as a function of latitude, pressure and month for the radiation parameterization. Rather than explicitly address reasons for the formation of the ozone hole, we postulate its existence and ask what effect it has on the subsequent evolution of the vortex.

The evolution of the model without an ozone hole is compared against observations in order to establish the credibility (or lack thereof) of the simulations. The change in the evolution of the vortex when an ozone hole is imposed is then discussed.

2. Experiments

A control and an ozone hole experiment are discussed here. Each experiment has been integrated through 4 separate realizations of Austral spring beginning in early August and ending in early January. The control experiment used an ozone distribution based on observations prior to the development of the ozone hole. In the ozone hole experiment, the ozone mixing ratios were altered poleward of 50°S based on the total column ozone observations in Stolarski and Schoeberl (1986) and the vertical column observations in Solomon et al. (1986).

Ozone mixing ratios for the fifteenth of each month are specified in the model and daily values are obtained by linear interpolation. The September and October values were altered in the ozone hole experiment. Thus, the hole develops from August 16 to September 15 then deepens slightly until October 15. The hole is gone on November 15 regardless of the state of the vortex.

The control experiment was integrated for 20 months beginning on May 1 to obtain two realizations of Austral spring. Ozone hole experiments were started in early August of

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each year. The other two realizations of each experiment were obtained by perturbing the original experiments in early August. This methodology results in 4 separate realizations for relatively modest cost.

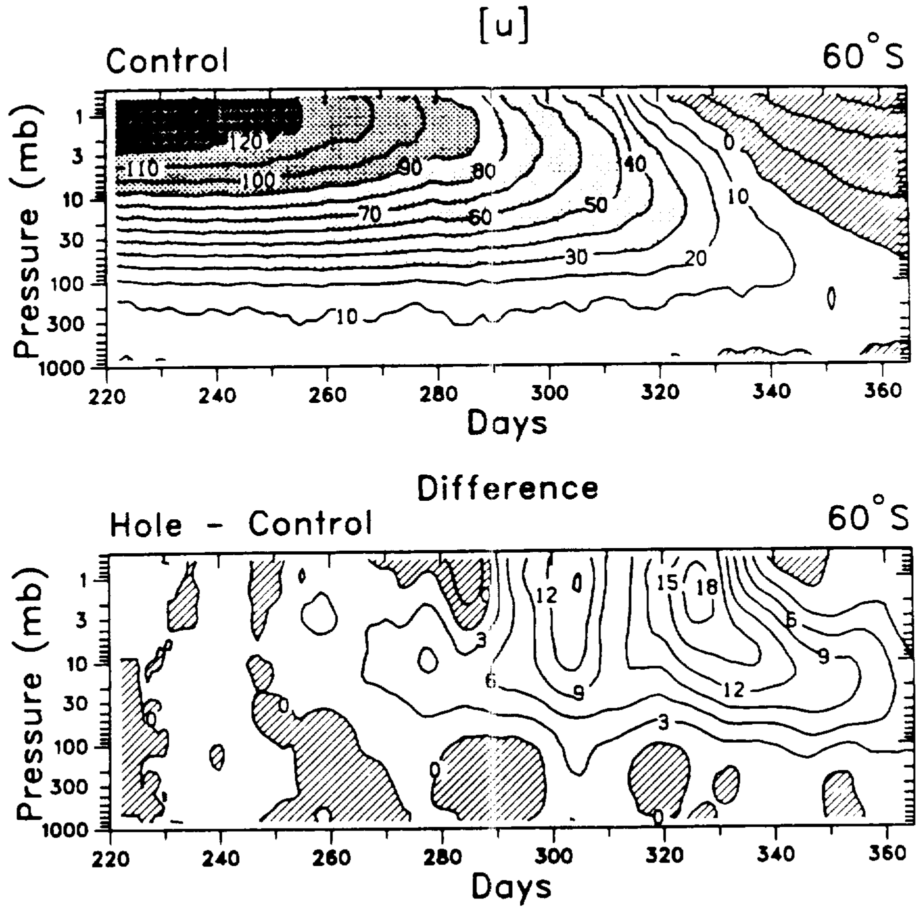

Figure 1. Time - pressure section of the zonally averaged zonal wind (ms^{-1}) at 60°S for the control simulation and the difference between the ozone hole and control simulations. Hatched region indicates negative values. Day numbers refer to day of the year (day 220 is August 8).

3. Results

The time evolution of the zonal wind is shown in Fig. 1 as a function of pressure and in Fig. 2 as a function of latitude. Ensemble means for the 4 realizations are shown. The polar night jet in the control simulation is stronger than observed during late winter, particularly at upper levels. At 10 mb and below the agreement with observations is much better (e.g. Randel, 1987) in late winter. The observed downward and poleward shift of the jet core through late winter and early spring can be found in the control simulation but is both too weak and too late. Note that this shift is the result of errosion of the jet at upper levels and low latitudes, not an acceleration at lower levels and higher latitudes. There appears to be insufficient dynamical forcing of the simulated polar vortex in early spring, resulting in an unrealistic persistence of the westerlies into December.

Imposing an ozone hole in September (days 244-273) and October (days 274-304) results in a colder and more stable vortex with a correspondingly stronger jet. Although the imposed ozone hole is gone by November 15, the lower stratospheric wind are almost 5 ms^{-1} stronger in the ozone hole simulation at the end of December. The large positive differences in November at upper levels in Fig. 1 result from a delay of about 10 days in the descent of the jet core in the ozone hole experiment compared to the control and a similar delay in the transition to easterlies. Below 10 mb the delay in the transition to easterlies is even longer, about 2 weeks. Westerlies persist until the end of December in the ozone hole simulation, although they are very weak.

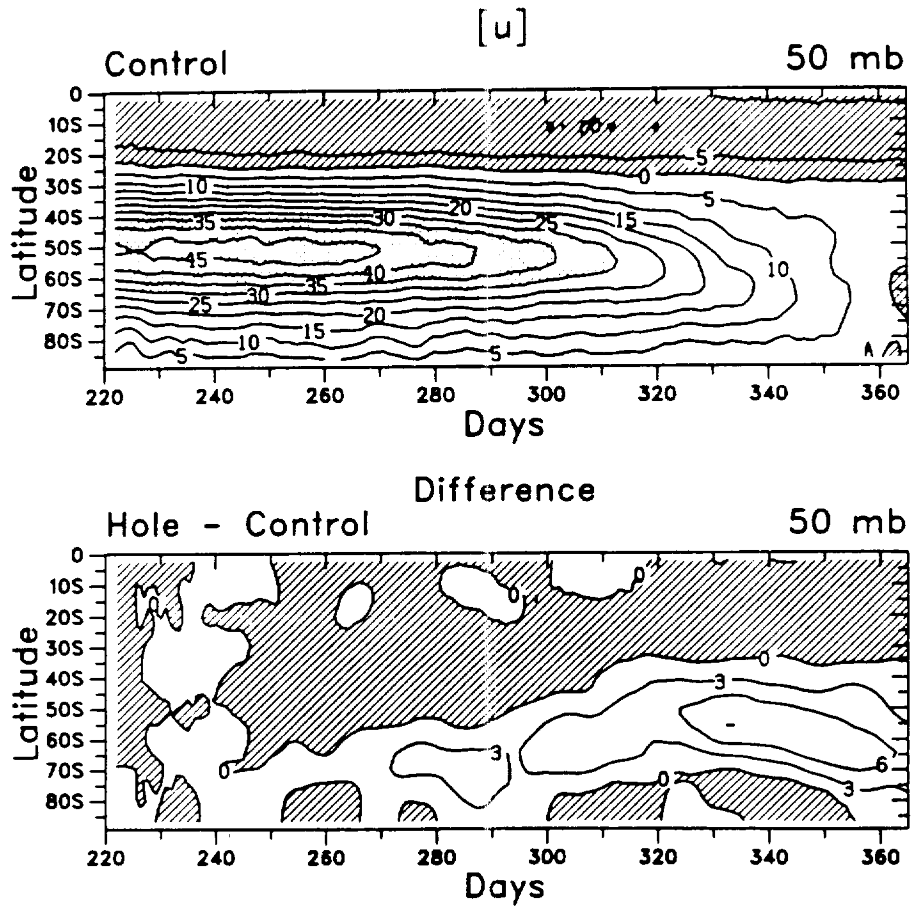

Figure 2. As in Fig. 1 except that a time - latitude section is shown at 50 mb.

4. Summary

The GCM results indicate that the presence of an ozone hole in September and October should result in a colder and more persistent polar vortex. This prediction is independent of the source of the hole, since the hole was simply imposed in the model. Whether a similar change in the persistence of the vortex can be observed in the atmosphere is uncertain. Even the control simulation of the GCM has weak dynamical forcing resulting in an overly persistent vortex. The stronger dynamical forcing present in the atmosphere in spring could swamp the tendency of the ozone hole to make the vortex persist longer.

References

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