16.11 MODULATION OF THE SOUTHERN POLAR VORTEX AND TROPOSPHERIC VARIABILITY BY FORCING IN THE TROPICAL STRATOSPHERE AND IMPLICATIONS FOR OZONE

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1. INTRODUCTION

Following the eruption of Mount Pinatubo in 1991, a substantial mass of sulphate aerosol was injected into the stratosphere. These aerosols eventually affected a wide variety of elements within the climate system. Here, the changes in the stratospheric circulation are of particular concern and we focus on two aspects: 1) the role of aerosol induced change in the circulation by direct and indirect effects, and 2) the influence of stratospheric changes on the tropospheric variability via the so-called downward control. Because the stratospheric circulation is closely tied to the abundance of ozone, it is natural to consider the impact on this important trace gas. To explore these aspects, an atmospheric general circulation model is employed, and a sensitivity analysis performed for an idealized forcing that resembles the heating in the stratosphere similar to that which followed the Pinatubo eruption. In this study we focus on the wintertime (JJA) circulation.

2. MODEL CONFIGURATION

The NCAR-CCM3 atmospheric model is used with ocean temperature prescribed. The model is configured to have a horizontal resolution of 3.75°×3.75° transform grid, and 26 vertical levels. Of these, 13 are above the tropopause. The model top is at 0.28 hPa. A zonal mean forcing (Fig 1) is added to the thermodynamic equation at each time step to represent the additional heating associated with radiative effects of volcanic aerosols as computed in a previous study (Eluszkiewicz *et al.*, 1997). The radiative effects were realized in the region of the climatological thermal minimum, even though the aerosols became concentrated at the poles.

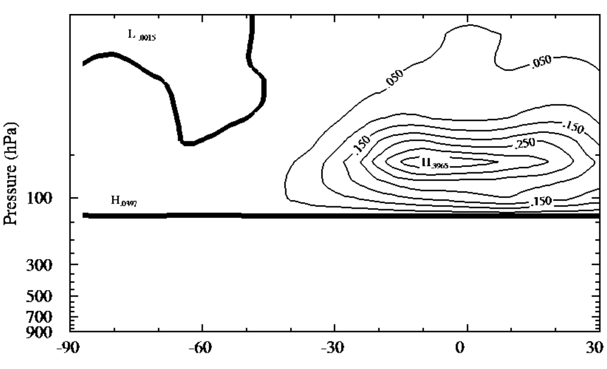

Fig. 1: Zonal JJA temperature forcing resulting from aerosol loading. Contours 0.5 K day^{-1}.

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3. RESULTS

Figure 2 shows a largely symmetric increase in the geopotential height at mid-latitudes and a stronger stratospheric vortex, which can be explained through balance conditions in the presence of the additional tropical heating. In the troposphere (500 hPa), the response of the stationary flow has zonal asymmetry

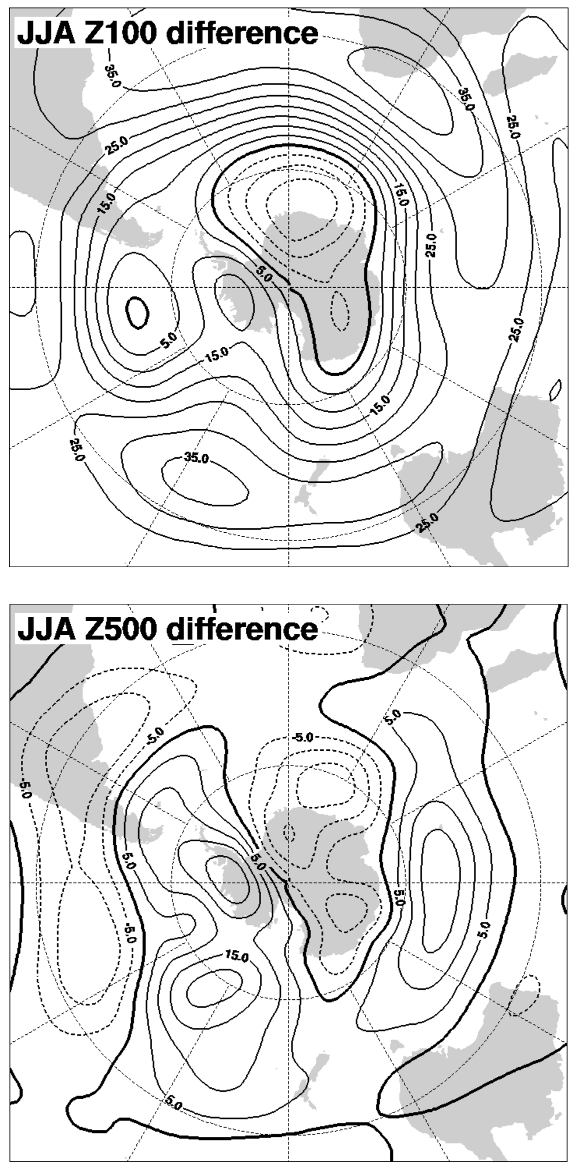

Fig 2: Difference in geopotential height at 100 (top) and 500 hPa. Contours at 5 hPa.

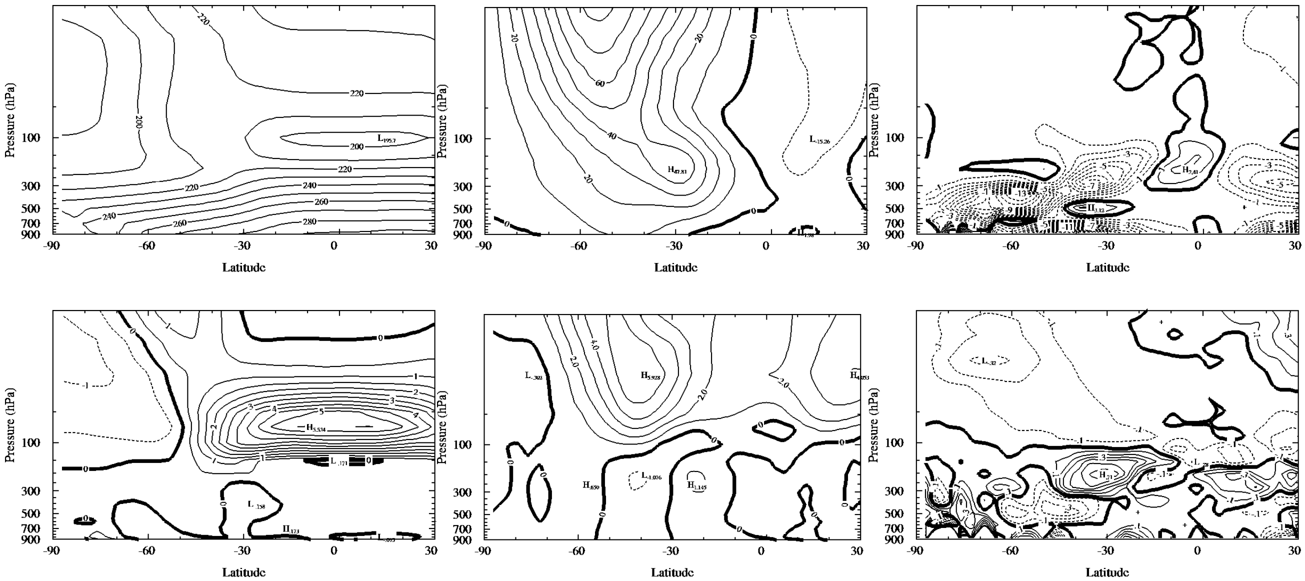

Fig 3: Zonal mean winter (from left) temperature (K), zonal wind (m/s) and EP flux divergence (m/s day^{-1}). Upper panels show control climatology and lower panels show aerosol experiment difference from control.

(particularly planetary wavenumber 1 and 2) and is associated with the downward control. For an atmosphere at quasi-equilibrium, the model indicates that the additional heat may be disposed from the tropical stratosphere by dynamical and radiative processes once the local temperature has increased by 5K (Fig 3). Following from geostrophy and thermal wind balance, these changes induce a reduction in the strength of the summer easterlies and, as shown, an increase in the wintertime westerly jet at mid-latitudes. This response equivalently describes an intensification of the nocturnal polar vortex, although the meridional location of the wind maximum remains fixed. Although additional heat has been added, the polar stratosphere becomes cooler. While there is a small imposed cooling near the pole, the cooler temperatures are largely due to an increase in the adiabatic expansion due to subsidence. The magnitude of the response in the mid-stratosphere is typical of that associated with variations in the Southern Annular Mode.

The tropospheric response is less substantial. The direct downward control of the zonally symmetric flow is small even though the stratospheric overturning has increased. Nonetheless, the intensity of the time mean zonal circulation is reduced across the hemisphere. Some of the changes in the tropics arise due to modification of the column heat budget and allow a reduction in the diabatic heating at the equator because of the need for increased longwave cooling aloft. The tropospheric changes increase the wave pumping (a drag) in the stratosphere (EP flux divergence in Fig 3), and acts to increase the residual circulation beyond a simple thermal wind analysis of the stratosphere. This is largely associated with the increase in the low wave number stationary waves, as seen in Fig 2, as the higher frequency waves more typical in the Southern baroclinic zone have limited influence on the stratosphere.

4. IMPICATIONS FOR OZONE

Increased residual circulation allows greater transport of tracers, such as ozone, to the high latitudes. In the case of ozone, however, the colder temperatures allow a greater likelihood of polar stratospheric clouds and more efficient photochemical destruction of ozone. Using a 2-dimensional chemical transport model, the net effect is in fact an increase in the polar ozone concentration. Changes in the abundance and seasonality of ozone modify the radiative flux of both incoming solar and, particularly, outgoing longwave radiation and provide impetus for additional thermal forcing in the troposphere beyond that expressed through the dynamic terms modeled here with a GCM. This study highlights the importance of the coupling between the ozone photochemistry and dynamics in modulating the climate of the high Southern latitudes, and the need for its inclusion in climate models.

5. REFERENCES

Eluszkiewicz J., D. Crisp, R. G. Grainger, *et al*., 1997: Sensitivity of the residual circulation diagnosed from the UARS data to the uncertainties in the input fields and to the inclusion of aerosols. *J. Atmos. Sci*., **54**, 1739-1757