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THE ROLE OF CYCLONES IN THE DAILY VARIABILITY OF ANTARCTIC OZONE

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1. INTRODUCTION

Unusual meteorological events that occurred during the 1987 Antarctic spring have been correlated with strong ozone variability. For example, a storm that developed on 5 September 1987 along the periphery of Antarctica appears to be associated with more than 15% decrease in the total ozone content over the Palmer Peninsula. Fig. 1 (lower graph) shows the time evolution of total ozone concentration as estimated by satellite measurements (TOMS) and at the Argentine Station Marambio; in the upper graph of Fig. 1, the 200 mb geopotential heights for the same period and geographic location are shown. Notice that periods of large variability in the ozone content such as in the first days of September, around the 15th of the same month, early October, etc. seem to be correlated with variabilities in geopotential heights as well as other meteorological variables (200 mb vorticity and other geopotential heights) not shown here. These correlations can be noted throughout a large part of the planetary waves as seen in Fig. 2. The total ozone content derived from TOMS data and the 500 mb geopotential heights from the ECMWF analysis are shown for August 17, September 5 and 27 of 1987 respectively. Notice the high correlation between the position of the troughs and maximum ozone content and between minimum values and the ridges. The out-of-phase relation between geopotential contours and ozone content is also apparent. In particular see the sector between 40°W and 180°W on September 5.

Considering that the amount of ozone contained in the column below 500 mb is less than 20% of the total column content, it seems surprising that the 500 mb heights are a good indicator of the total ozone content. There are two possible explanations. One, the flow in the high latitudes of the Southern Hemisphere is highly barotropic, implying that the troughs and ridges of the upper level flow (say at 200 mb) are in phase with those at 500 mb. Second, since the large polar ozone depletion occurs mainly at 50 mb during the Southern Hemisphere spring, the relative amount of ozone in the troposphere for this period of time is becoming proportionally higher.

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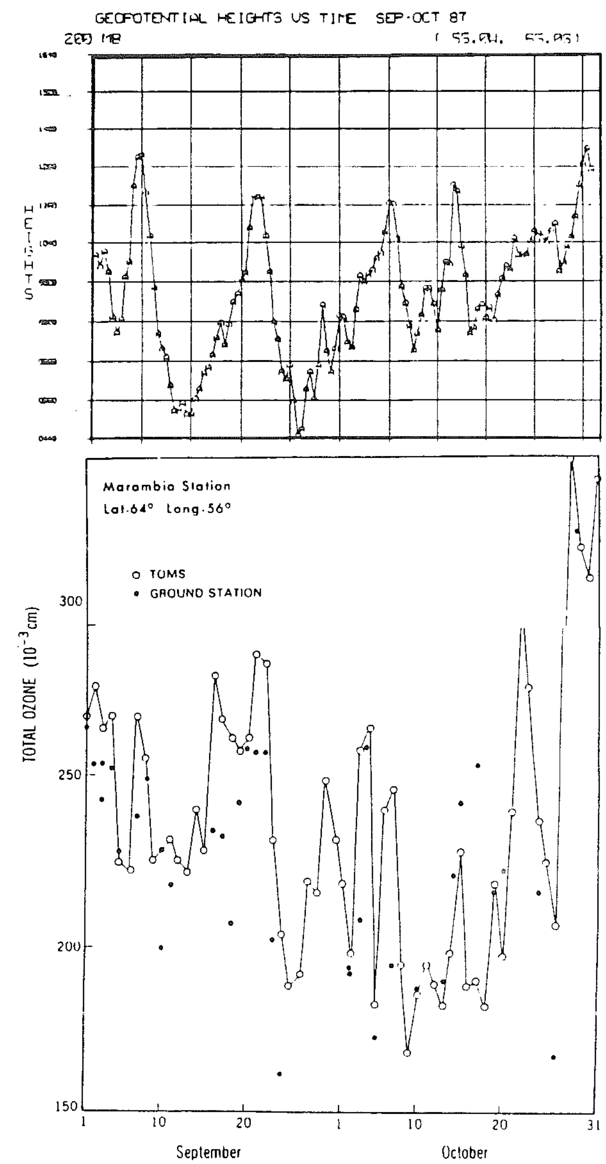

Fig. 1. The September-October daily record of ECMWF analyzed 200 mb geopotential heights at 55°W, 65°S (upper graph) and total ozone content (lower graph) from TOMS over the Palmer Peninsula (solid line) and ground measurements at Marambio Station (black dots).

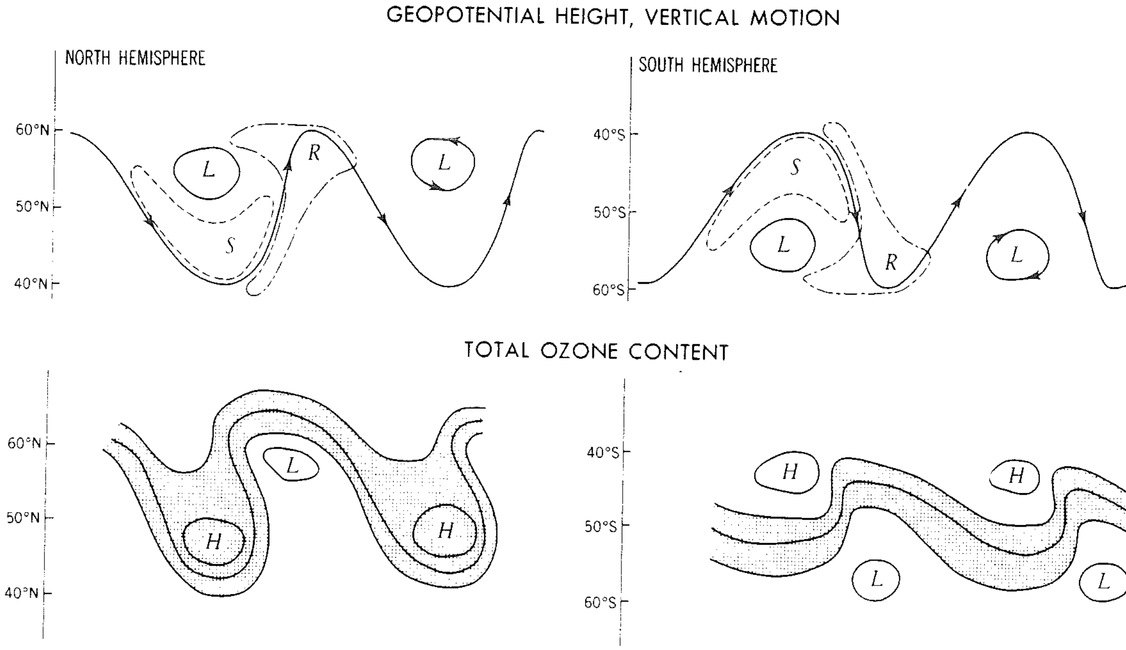

Fig. 3. Schematic of upper troposphere geopotential height (solid) and vertical motion (dashed) in a typical baroclinic wave (upper) and total ozone content (lower) for Northern Hemisphere (left) and Southern Hemisphere (right).

Reed (1950) is assumed here; however, the ozone concentration decreases toward the pole, as seen in the lower right. Whereas vertical advection has the same sign as in the previous case due to the positive stratification, the horizontal advection has a reversed effect. Flow equatorward advects low levels of ozone and conversely poleward flow advects high levels. The lower right graph shows the resultant distribution for both horizontal and vertical displacements. As explained before, this circulation will produce a maximum (minimum) over the trough (ridge) of the wave, but due to the reversed gradient as compared with the Northern Hemisphere the contours of ozone content will be out-of-phase with the geopotential heights. This effect is clearly seen in the analyzed fields of Fig. 2.

3. A CASE STUDY: 5 SEPTEMBER 1987

Now let us consider the case of 5 September 1987 that occurred over the Palmer Peninsula. On September 4, a deep trough developed over the southeastern Pacific (80°W, 50°S) with an intense surface front that was aligned in a north-south orientation. By 0100 UTC 5 September, a low pressure center developed at 90°W, 60°S with a cyclonic circulation. The system then moved southward to the Antarctic Peninsula and intensified. By 1200 UTC, satellite pictures showed a center located at 87°W, 62°S. The storm continued to intensify until it reached the Antarctic coast at 0200 UTC 6 September.

3.1 Analysis

Data from ECMWF have been used to analyze this circulation. The wind vectors at 300 mb, vertical velocity at 500 mb, and the total ozone content from TOMS at 1200 UTC 5 September 1987 are shown in the lower part of Fig. 4. Along the front, an intense upward vertical velocity field was observed extending up to 100 mb with a poleward circulation west of the peninsula and an equatorward and downward circulation on the east side. A maximum of vertical velocity over the Palmer Peninsula is well correlated with an absolute minimum of the total column-integrated ozone that was observed at this time. A broader minimum in the ozone concentration occurs in a north-south alignment ahead of the observed front and extends eastward, as a result of horizontal advection. Also, the maximum ozone content is well correlated with the area of sinking, equatorward motion. Note the similar pattern of low (high) ozone concentration over the ridge (trough) of the wave shown in the schematic graph of Fig. 3.

3.2 Tracer Simulation

A 48 hour simulation was completed using the nested, 9-level limited-area model (GFDL/LAHM, see Orlanski and Katzfey, 1987) using the September 4, 1987 ECMWF analysis as initial conditions. The simulation captured the full evolution of the storm. The results are reported elsewhere. A number of diagnostics have been applied to the model solution in order to understand the circulation associated with the storm. Basically, a trough moved eastward along the polar jet and intensified by pulling warm, moist air at low levels in mid-latitudes towards the Antarctic continent. Lagrangian trajectories showed particles starting at 850 mb and 50°S moved poleward and rose more than 500 mb in a period of 24 hours to near 350 mb. The maximum lifting occurred at 70°W and 70°S over the Palmer Peninsula. The rising air split into two branches, one which moved westward to the rear of polar regions to sub-polar latitudes. It has also been shown that the event on 5 September 1987, which is a classic example of a case of strong cyclonic development, exhibits a large correlation with low ozone content anomalies in the periphery of the Antarctic continent.

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