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MLS OBSERVATIONS OF STRATOSPHERIC WAVES IN TEMPERATURE AND O_3 DURING THE 1992 SOUTHERN WINTER

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Abstract. The Microwave Limb Sounder observed waves in stratospheric temperature and O_3 during the 1992 southern winter. Wave 1 intensifies three times from mid August through mid September, when a 9 day eastward traveling wave becomes in phase with the stationary wave 1. During the periods of wave intensification, minor sudden warmings and increased zonal mean O_3 are observed. The waves have a westward phase tilt which results in an intensified baroclinic zone when the waves are in phase. Waves in T and O_3 are positively correlated near 5 – 10 hPa, implying transport by planetary waves; this is supported by larger O_3 wave amplitudes than expected from photochemistry alone.

Introduction

An analysis of the LIMS data set [Leovy et al., 1985] showed that the ozone distribution is strongly affected by planetary waves, leading to poleward transport of ozone during sudden warmings. Also, the 1988 sudden warmings of the southern polar stratosphere led to an anomalously shallow ozone hole [Kanzawa and Kawaguchi, 1990]. The 1992 southern winter experienced several minor warmings at a time when increases in ozone (O_3) were associated with transport into the vortex [Manney et al. 1993]. It is expected that O_3 transport is related to the planetary waves associated with these warmings.

This letter describes observed wave activity associated with the 1992 southern winter warmings and its influence on the O_3 field. The data consist of Microwave Limb Sounder (MLS) measurements of temperature (T) and O_3 concentration during the period from 14 August through 20 September 1992, retrieved as described by Waters et al. [1993a]. The useful vertical coverage with current MLS algorithms (UARS version 0003 products) is 20 to 0.2 hPa for T, and 100 to 0.2 hPa for O_3. MLS temperatures are supplemented below 20 hPa by National Meteorological Center (NMC) 1200Z daily analyses sampled along the MLS measurement track. MLS data is currently undergoing validation activities, but results show zonal mean agreement with NMC temperatures of better than 5 K between 10 and 1 hPa, and with ozonesondes and SAGE O_3 measurements to better than 10% between 50 and 1 hPa. Fourier coefficients in time and longitude, are evaluated using the Salby method [1982] (L. Elson, personal communication). The measurement geometry allows resolution of zonal wavenumbers ≤ 7 and frequencies (periods) from 0.028/day (36.1 day) to 1.04/day (0.96 day).

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Observations and Discussion

Figure 1 shows T and O_3 zonal means at 5, 10 and 50 hPa. Three warmings, ~9 days apart are seen at 5 hPa and 10 hPa, and to a lesser extent at 50 hPa. The second warming has the largest temperature increase (18 K at 75S and 5 hPa) developing over 3 days starting on 2 September (DOY 246). Warming begins in the mid-stratosphere above 10 hPa and propagates into the lower stratosphere ~ 1 day later. The southern upper stratosphere between 60° S and 20° S experiences compensating cooling during the warmings. Zonal-mean O_3 mixing ratio south of 60° S increases at 5 and 10 hPa during the warmings with O_3 mixing ratio increasing most during the second warming, 1.5 ppmv increase at 75° S and 5 hPa. The zonal-mean "vortex boundary" as defined by Manney et al. [1993] is at ~ 60 S.

Figure 2 shows the power spectra of the time series of T and O_3 zonal waves 1 and 2 at 75° S over a vertical range from 50 to 0.2 hPa. The power spectra are typical for the southern winter, containing primarily stationary and eastward-propagating traveling waves [Mechoso and Hartmann, 1982; Manney et al. 1991]. Zonal wave 1 has most of its power in a stationary wave, and 9 and 4.5 day eastward traveling waves. Wave 2 has traveling components with the same periods as wave 1, but has no stationary component in T; its total amplitude is much smaller than wave 1.

At 20 and 50 hPa, the presence of ClO during this period [Waters et al., 1993b] indicates chemical loss due to processes triggered by heterogeneous chemistry. The dissimilarity of O_3 and T time series spectra at these pressures is consistent with the O_3 field transitioning from a transport–dominated regime to one dominated by O_3 loss.

In the Matsuno [1971] model of sudden warmings, the mean field is perturbed by waves having growing amplitudes. Figure 3 shows the amplitude of wave 1 at 75° S and 5 hPa during the period of observation. During each of the warmings, wave 1 intensifies in both T and O_3 but the intensification of wave 1 in O_3 lags behind the wave in T. The amplitudes of the 9 and 4.5 day traveling waves are also shown. The waves are extracted using a Gaussian bandpass filter with 0.04/day halfwidth (the contribution of the stationary wave to the 9 day wave amplitude is reduced by 7%). The 9 day wave, seen in both T and O_3, reaches a maximum amplitude during the second warming. The 4.5 day wave shows similar behavior, although the maximum is more localized near the warming. Al-

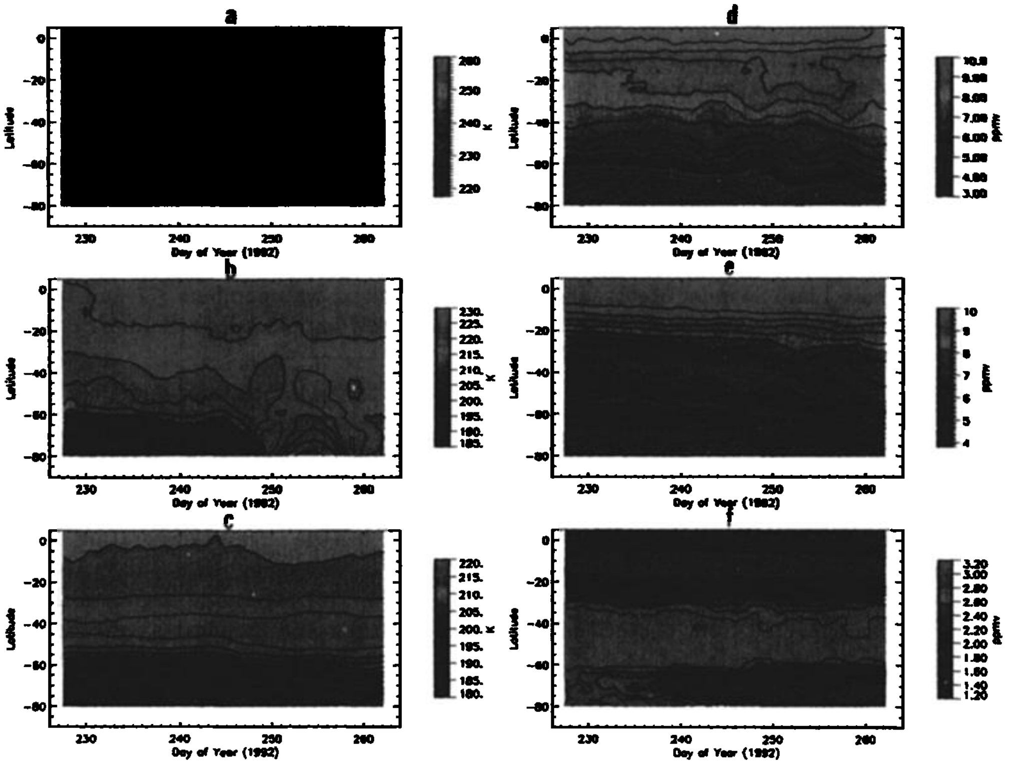

Fig. 1. Zonal means of T and O_3 versus time and latitude at 5 hPa (a,d), 10 hPa (b,e) and 50 hPa (c,f).

though the 4.5 day wave intensifies before the 9 day wave, there is no indication that the traveling waves in O_3 lag behind T.

Figure 3 also shows the amplitude of the sum of each traveling wave and the stationary wave (i.e. the waves are added taking into account their phases). Maxima occur when the traveling waves become in phase with the stationary wave, once every 9 days. These coincide with the warmings, showing that a major source of wave intensification arises from beating between the waves. The wave amplitudes in the O_3 field shows similar behavior, except that maximum amplitude occurs after the temperature waves.

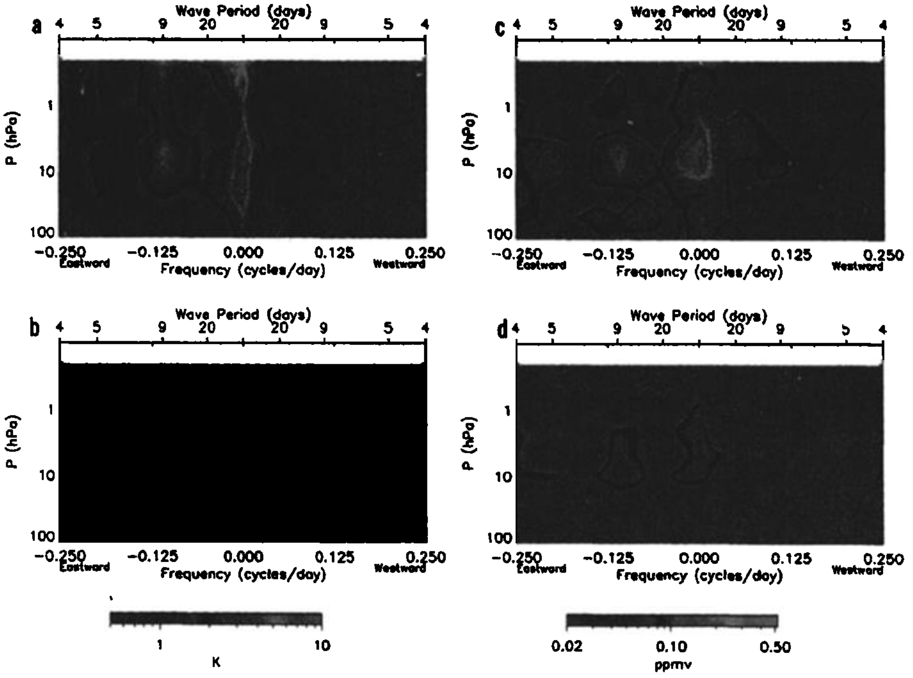

Fig. 2. Wave amplitude spectra versus frequency and height at 75° S for for T (a,b) and O_3 (c,d) for zonal wavenumbers 1 (a,c) and 2 (b,d).

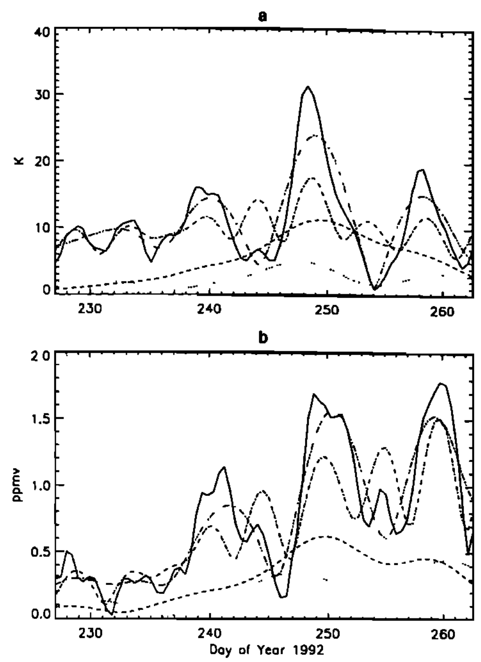

Fig. 3. Wave amplitude versus time for T (a) and O_3 (b) for zonal wavenumber 1 at 75° S and 5 hPa. Shown are: total amplitude (solid), 9 day wave (dashed), 4.5 day wave (dotted), stationary plus 9 day waves (3 dot-dash) and stationary plus 4.5 day waves (dot-dash).

The phase of the waves during the second warming (4 September at 0930Z) is shown in figure 4. The waves are approximately in phase as indicated by figure 3, but because the phase height relations are slightly different, the waves are in phase 1 day later at 50 hPa relative to 2 hPa; the same time delay is seen in the zonal mean warming. The amplitude of the O_3 wave 1 increases after T because the phases of the O_3 and T waves are slightly different, resulting in the waves in O_3 coming in phase later.

Ozone is transported across potential vorticity (PV) contours when the motion becomes diabatic. Fairlie et al. [1990] have shown that baroclinic zones (regions of strong vertical and horizontal T gradients tilting westward with height) which form during stratospheric warmings can lead to small-scale structure and increased dissipation. The traveling and stationary waves have westward phase tilt resulting in a baroclinic zone, and as the traveling wave moves into phase with the stationary wave, the baroclinic zone intensifies. Figure 5 shows temperature cross-sections during the second warming and 4.5 days later when the waves are out of phase. The baroclinic zone is strongest during the warming, but is almost absent 4.5 days later.

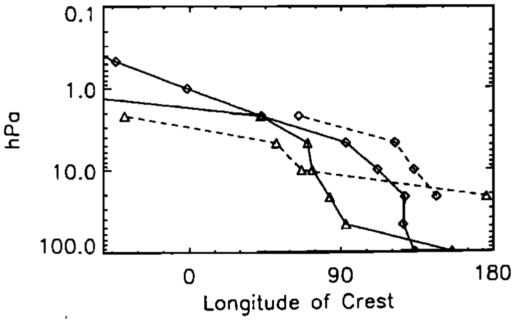

Fig. 4. Longitude of wave crest versus height for the stationary wave (diamonds) and the 9 day wave (triangles) for T (solid line) and O_3 (dashed line) on 4 September (DOY 248) at 0930Z.

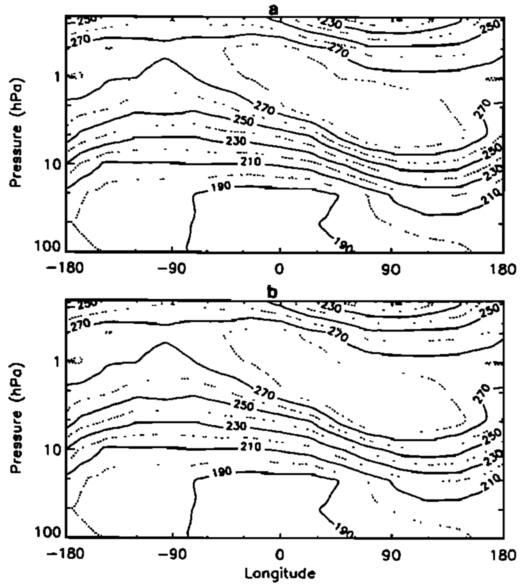

Fig. 5. Temperature cross-section at 75° S on (a) 4 September 1992 (DOY 248) at 1000Z and (b) 9 September 1992 (DOY 253) at 0000Z.

The question arises as to whether the O_3 waves result from photochemistry or transport. The photochemistry of O_3 is strongly temperature dependent and produces anticorrelations between T and O_3 concentration [Gille et al., 1980]. The correlation between O_3 and T waves is the cosine of the phase difference between the waves, which can be obtained from figure 4. Between 2 and 10 hPa, the stationary and traveling waves are positively correlated (>0.5 at 5 and 10 hPa), inconsistent with photochemistry. The amplitude of the photochemical O_3 response to a sinusoidal temperature perturbation is also much smaller than is observed. Following the linearized treatment of Froidevaux et al. [1989] , the O_3 perturbation froms a 6 K temperature perturbation with a 9 day period are approximately 90 and 5 ppbv at 5 and 10 hPa (using 10 day and 100 day photochemical timescales). These amplitudes are approximately 10 and 100 times smaller than observed, suggesting that dynamical terms not considered in the above are the source of the observed large O_3 variation.

Conclusions

Stratospheric wave activity in the south during August and September 1992 was dominated by zonal wave 1 consisting of stationary and 9 day eastward-traveling components. Consistent with the Matsuno model of stratospheric warming, wave 1 intensified during the warmings. Wave 1 was intensified primarily by wave interactions between the traveling and stationary components, but the individual traveling waves also intensified during the study period. This may have been caused by a baroclinic zone which was created by the waves and intensified whenever the waves were in phase. Wave 2 does not play a major role in the warmings.

Many similarities were seen between O_3 and T at 5 and 10 hPa. The zonal mean temperature and O_3 concentration were postively correlated. Both showed the same wave components, and in each, the waves intensified during the warmings. The correlation between T and O_3 waves and the ratio of spectra indicated that the waves in O_3 were not a result of normal photochemistry, but indicated O_3 transport. Calculations of particle displacement based on linear wave theory, to be presented in a future letter, show that at 5 hPa, both vertical and meridional motions contribute to the temperature wave, but only the horizontal displacements are important for the ozone wave. The effects of the baroclinic zone on transport have not been ascertained, but winds derived from it may have transported O_3 both horizontally and vertically.

Sudden warmings disrupted the vortex in late winter 1988 and 1992, but unlike 1988, the 1992 O_3 hole became stronger than the previous year [CAC, 1992]. In 1988, wave activity was anomalously strong [Manney et al., 1991] and the O_3 decline was halted soon after the warmings [Kanzawa and Kawaguchi, 1990]. As seen in figure 1, 46 hPa zonal mean O_3 continued to decrease through the remainder of the study period. In summary, the strength of wave activity, transport of O_3 and the depth and duration of the hole are related. Further study will address what kinds of wave activity lead to a weakened O_3 hole.

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