Observations of the 2-Day Wave in UARS MLS Temperature and Ozone Measurements

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Abstract. Mesospheric ozone and temperature data obtained by the Microwave Limb Sounder (MLS) on board the Upper Atmosphere Research Satellite (UARS) have been analyzed to elucidate quasi-two day wave activity. Data from January 1993 were analyzed to investigate the evolution and structure of the two day wave. During this period, the wave amplitude in ozone attained its maximum value in late January near 30° in the summer hemisphere. The evolution of the wave amplitude indicates a shift of the peak amplitude to higher latitudes with increasing height. Correlation of the two day wave phase observed in MLS ozone and temperature measurements indicates that the perturbations are out of phase. During the same period, the amplitudes of the perturbations in temperature and ozone were positively correlated. The results suggest that the variations in ozone are photochemically driven in the mesosphere region via changes in reaction rates that are strongly temperature dependent.

Introduction

Studies by *Leovy et al.* [1985], *Fishbein et al.*, [1993], *Rosenlof et al.*, [1990], and *Randell* [1993] have shown that planetary wave events seen in the temperature data can strongly affect the distribution of ozone as a result of transport in the stratosphere where the ozone chemical life time is long. In the mesosphere region, where the chemical life time of ozone is relatively short, the ozone concentration is primarily driven by the photochemistry. The quasi-two day planetary wave in the middle atmosphere has been extensively studied in the temperature and wind fields [*Ward et al.*, 1996; *Palo at al.*, 1997; *Wu et al.*, 1996 - just to name few]. However, the response of ozone to two day wave perturbation in temperature in the mesosphere region has been relatively unexplored. Previous studies of the two day wave have indicated that it is most significant at midlatitudes during the two months following the solstice. The two day planetary wave event usually persists for about a 10-30 days duration. Recently, *Ward et al.* [2000] have shown the effects of transport and photochemistry on the ozone distribution in the stratosphere and mesosphere using a correlative study of the planetary wave signature in Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA) ozone and temperature data. Their study examined the wave two signatures with period of 12.5 days in the ozone and temperature fields and found them to be positively correlated in the dynamically dominated region (< 30 km) and negatively correlated in the photochemically driven region (> 40 km). A limitation of this study was that the CRISTA ozone data was available only up to ~60 km. Above this height the authors assumed that the negative correlation, characterizing the photochemically dominated region, between ozone and temperature perturbations would continue to exist.

In this paper, we present observations of ozone and temperature from the mesospheric region. These data were taken using the Microwave Limb Sounder (MLS) on board the Upper Atmosphere Research Satellite (UARS). Temperature and ozone data from UARS MLS during January 1993 were analyzed and are presented here.

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Data and Analysis

The MLS ozone and temperature data used in the present study are retrieved independently, mitigating the possibility of cross contamination between the fields. For details of the instrument the reader is referred to *Barath et al.* [1993]. The temperature data were retrieved using special research algorithms developed by the MLS science team [*Wu,* manuscript in preparation]. These algorithms improve the MLS temperature retrieval, particularly at high altitudes. This special MLS temperature data set is produced for 22 pressure surfaces ($P = 1000 \times 10^{(-i/3)}$ mb, where i = 0,1,2, ...) i.e. on every other standard UARS pressure surface. The Level 3, Version 5 ozone data, used in this study, were obtained from the 183 GHz radiometer. Initial (version 3) ozone data from this radiometer were discussed and validated by *Froidevaux et al.* (1996) and *Ricaud et al.* (1996); version 5 (and version 4) data are discussed in Livesey et al. [manuscript in preparation], but have not changed in a way that would significantly affect the results of this study. The height coverage of the ozone and temperature data used in the present study is ~20 - ~85 km. The latitudinal coverage of MLS measurements extends from 34° in one hemisphere to 80° in the other. Both the day and night side data during December 24, 1992 - February 10, 1993 (UARS days 470 - 520) are analyzed.

The two day wave amplitude and phase were obtained by fitting the MLS ozone and temperature data in the least squares sense to a sinusoidal model. Wave spectra (not shown here) of the MLS temperature and ozone data were used to identify the period and the wavenumber of the quasi-two day wave perturbation. The two day wave peaked near a period of 48 h and zonal wavenumber 3. The period and

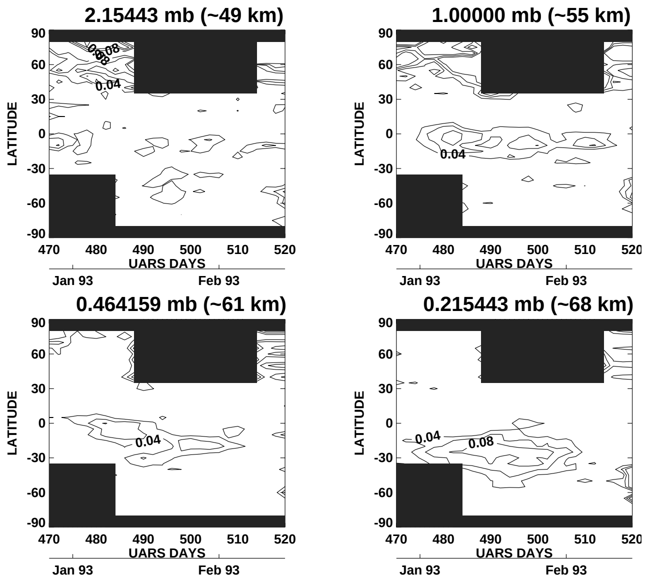

Figure 1. Amplitude (in ppmv) of the two day wave in the ozone during January 1993 at four different pressure surfaces. The plot covers December 24, 1992 (UARS day 470) - February 8, 1993 (UARS day 520) period.

wavenumber derived from the MLS wave spectra are consistent with previous observations of the two day wave (*Wu et al.*, 1996). A sliding window least squares fit is used to determine the latitudinal and temporal structure of the two day wave. Harmonic fits are produced at every 5° latitude bin and at 2 day interval. Uncertainties are given as the standard deviation for each fitted parameter.

Results and Discussions

Figures 1 and 2 show the amplitude of the two day wave in the ozone (ppmv) and temperature (K) data, respectively. A significant two day wave feature is seen in the ozone data above 2.154 mb and shortly after December 24, 1993 (see Figure 1). The two day wave signature is predominantly found in the summer hemisphere during this period and lasts for about 40 days. The amplitude of the wave perturbation increases with altitude and at the same time the peak amplitude of the wave shifts poleward. The observed two day wave perturbation in MLS temperature data is shown in Figure 2. The spatial patterns of the wave amplitudes seen in the temperature and ozone data are similar. For example, the temperature perturbation field also shows poleward shifting of the peak wave amplitude and wave amplitude enhancements with altitude. The latitudinal structure of both the ozone and temperature perturbation fields indicate amplitude peaks near 30° S. Care should be taken in interpreting the results poleward of 40 N since these amplitudes may represent an artifact of the data analysis near the MLS coverage boundary.

Figure 3 shows the variations in ozone and temperature perturbations at 30°S as a function of height. The left panels show the amplitude of the two day wave while the right panels show the phase of the wave. Results are shown for January 23, 1993 during which a significant two day wave feature was observed in the data. An increase in the wave amplitude above 1.46 mb is seen in both the ozone and temperature data. Wave amplitudes in ozone and temperature tend to track each other fairly consistently above 1.46 mb. Note that the apparent altitude shift between ozone and temperature perturbation peaks may be an artifact of different vertical resolution of the ozone and temperature measurements. On January 23, 1993, the peak amplitude of the two day wave seen in the ozone data is about 0.10 ppmv and occurs at about 0.2 mb (Figure 3a). A peak amplitude of 6 K is seen in temperature data which occurs at about 0.1 mb. Below 1 mb, the fit results are increasingly influenced by the noise level as the signal-to-noise ratio (SNR) decreases with decreasing height. The effect of decreasing SNR on the results is clearly visible in the phase plot (Figure 3b) which shows well defined phase profiles for both the ozone and temperature above 1 mb and a rather irregular phase behavior below this height. A comparison of the phase values of the wave perturbations in ozone and temperature indicates a difference of about 60±5 ° (phase is defined as the longitude of maximum amplitude) at altitudes above 1 mb. For a zonal wave number 3 signal, this difference in longitude translates to about half a period making the wave signatures in ozone and temperature out of phase as expected from the photochemical view point.

Figure 4 shows the time series of the two day wave phase in ozone and temperature at 30°S for two different altitudes (0.2154 mb and 0.1 mb). The relative phase of the wave signatures indicates an out of phase relation between ozone and temperature during the wave event. Since the ozone production rate is strongly temperature dependent and increases with decreasing temperature, the out of phase relation between ozone and temperature suggests that perturbations in the temperature may be the source of observed variations in ozone.

The high photolysis rate in the upper mesosphere region makes ozone extremely short lived at these heights. As a result, the perturbations seen in ozone are a direct response of photochemical coupling between ozone and temperature. The "pure" photochemical (no dynamical effects) consider-

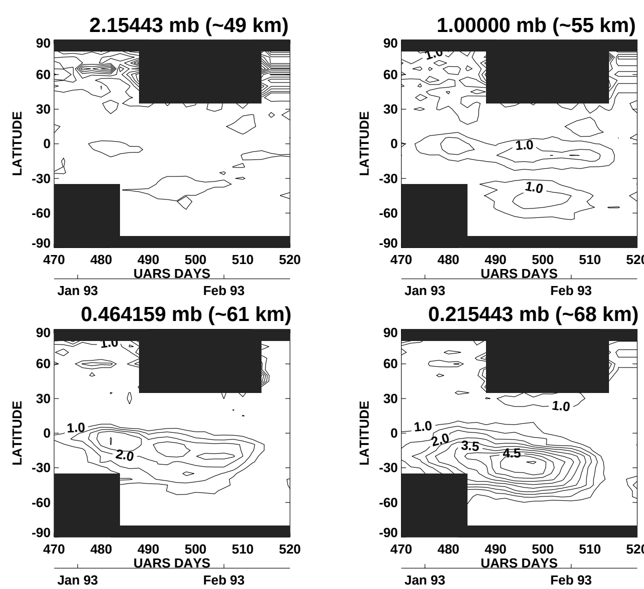

Figure 2. Amplitude (in K) of two day wave perturbations in the MLS temperature during January 1993. The duration covers December 24, 1992 (UARS day 470) - February 8, 1993 (UARS day 520) period. Four different pressure surfaces are shown.

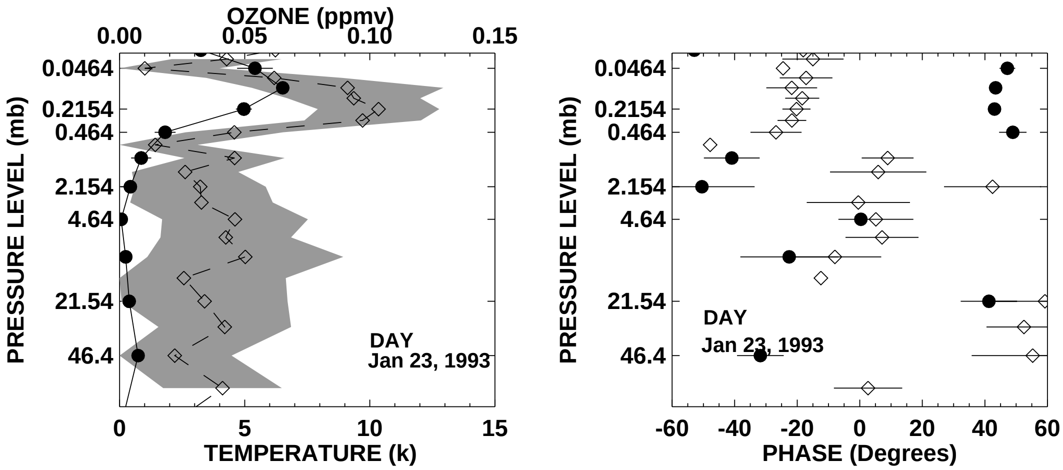

Figure 3. Height profile of the two day wave amplitude (left column) and phase (right column) in ozone and temperature. Solid circles connected with solid lines represent temperature data while diamonds connected with dashed lines represent ozone data. Results for January 23, 1993 (top row) and January 25, 1993 (bottom row) are shown. Shaded area represents uncertainty in ozone amplitudes.

ation of *Froidevaux et al.* [1989] is used to calculate the theoretical response of ozone to observed temperature perturbation with a 2 day period. For temperature perturbations of 5 K and 4.4 K seen on January 23, 1993 and January 23, 1993 at 0.2154 mb (see Figure 3), the amplitude of photochemical ozone perturbation is expected to be about 0.11 ppmv and 0.1 ppmv, respectively. These amplitudes are consistent with the observed ozone perturbation values. *Froidevaux et al.* [1989] studied the theoretical response of ozone to temperature perturbations and showed that there is a phase lag of 180° between ozone and temperature when the period of temperature perturbation is much longer than the ozone chemical relaxation time (2 hrs at 55 km). The two day wave results for the MLS ozone and temperature data show an identical phase relationship between the two fields in the mesospheric region.

Conclusions

In this paper, we have presented the results of the two day wave analysis of the UARS MLS ozone and tempera ture data from the January 1993 wave event. The two day wave feature is apparent in both the ozone and temperature fields and persists for about 40 days. Many similarities were observed between ozone and temperature. Both fields indicate a shift of the amplitude peak to higher latitudes with increasing altitude. The peak of the two day wave occurred in late January and was located near 30° in the summer hemisphere. The height variations in ozone and temperature perturbations show a positive correlation between the amplitudes and a phase lag of about 60° in the mesospheric region. These results provide verification of the assumption made by *Ward et al.* [2000] about the anti-correlation between ozone and temperature perturbations in the mesospheric region. The amplitude and phase of the observed ozone perturbations are in agreement with photochemical expectations suggesting that ozone in the mesosphere region is photochemically driven during this event. The results indicate that perturbations in the temperature lead to variations in ozone photochemistry via changes in the reactions rates which are strongly temperature dependent.

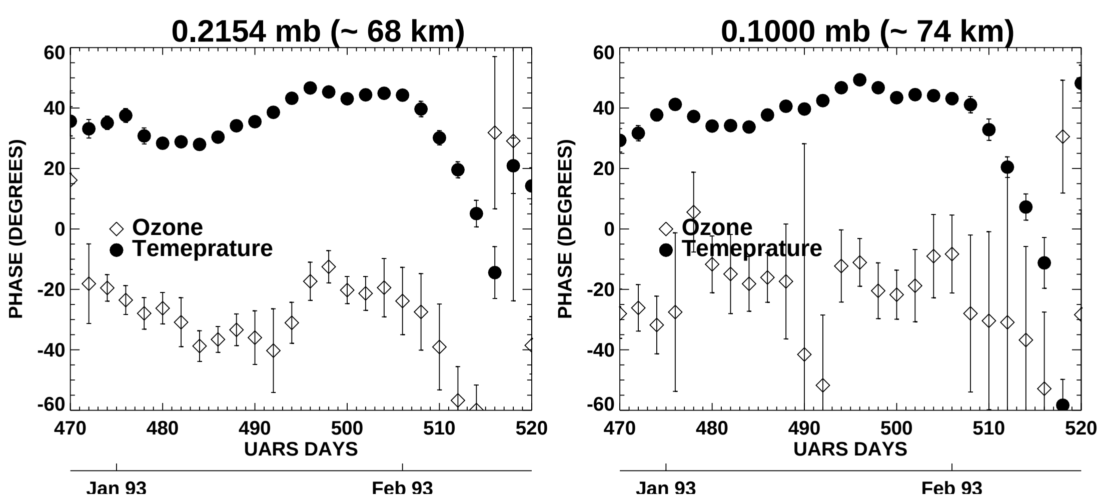

Figure 4. Time series of the two day wave phases at (a) 0.2154 mb and (b) 0.1mb.

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