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Observation of the two-day wave near the southern summer stratopause

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Abstract. Temperature and H_2O measurements from the Upper Atmospheric Research Satellite Microwave Limb Sounder (UARS MLS) data sets during the southern hemisphere summer of 1991-92 are analyzed using the asynoptic mapping method. Results show a prominent wavenumber 3 two-day wave confined to latitudes between 60˚S and 4˚N and to altitudes above 2 hPa. The temperature wave amplitude increases upward to the upper limit of the observations and maximizes at 2.0 K near 0.465 hPa. The H_2O wave amplitude reaches a maximum of 0.25 ppmv near 1 hPa. Evidence suggestive of wave breaking and meridional mixing associated with the interaction between this wave and a lower frequency wavenumber 1 is shown.

Introduction

The two-day wave is a zonal wavenumber three oscillation that migrates westward with a (quasi) two day period. The wave signature can be found in the upper stratosphere and above in the vicinity of the summer easterly jet. Its presence has been well documented in past data sets. From studies in the 1970's using radar observations of meteor winds to the more recent studies using satellite observations, a consistent structure of this wave has emerged. *Salby* [1981] and *Plumb* [1982] provide excellent reviews of these observational results. The wave's remarkable feature is its regular seasonal recurrence: January/February in the southern summer hemisphere, June/July in the northern summer hemisphere.

In this study, new evidence of the two-day wave in the Upper Atmospheric Research Satellite (UARS) temperature and H_2O data will be presented. The wave identification and structure are based on spectral evidence and simple band-pass filtering of the data. To our knowledge, this is the first reported evidence of the two-day signal in a long-lived tracer.

Data and Analysis

The temperature and H_2O data are from soundings retrieved by the Microwave Limb Sounder (MLS) instrument aboard the UARS satellite. These data sets are from the version 3 "level 3AT" files in which the sounding profiles are given at about every 65.5 seconds. The independent sounding levels used are at 21.54, 10.00, 4.64, 2.15, 1.00, and 0.46 hPa. This level separation corresponds to a profile height resolution of approximately 5.4 km. At these altitudes, the precision of individual MLS measurements ranges from 0.1-0.3 ppmv for H_2O [*Lahoz et al*., 1994] and 1-3 K for temperature [*Fishbein et al*., 1994]. The period of data analyzed is January 14, 1992 (UARS day 125) to February 13, 1992 (UARS day 155). During this period, the instrument was looking south and providing data coverage from 80˚S to 30˚N.

At each level, the data are first interpolated in space and time onto an evenly spaced latitudinal grid at 4˚ intervals, from 68˚S to 28˚N. The data are then divided into separate ascending and descending node streams. Missing data are linearly interpolated and the resulting data series are smoothed with a 0.25-0.50-0.25 filter.

The time series are tapered with a split Cosine window and analyzed by the asynoptic method [*Salby*, 1982b]. The Fourier transforms of the ascending and descending time series are weighted with the satellite orbital parameters and linearly combined to resolve the wave signatures. These signals are represented by Fourier coefficients for each zonal wavenumber with a corresponding frequency range (within the interval of 1 cycle per day, cpd, eastward to 1 cpd westward). The maximum resolvable zonal wavenumber is six. The frequency resolution is about 0.0357 cpd. By Fourier summing over all allowable wavenumbers and frequencies, twice daily synoptic maps are obtained.

The "raw" power spectra presented in this study are defined as $0.5(A^2+B^2)$, where A and B are the Fourier coefficients. Cross-spectral calculations are computed using the formulation of *Hayashi* [1971]. The spectra are smoothed with a normalized Gaussian filter as in *Randel* [1993]. The method of *Blackman and Tukey* [1958, p.24] was used to evaluate the number of degrees of freedom (DOF) of the individual spectra at each latitude. Approximately five DOF is attained, and the corresponding 95% confidence level for the coherence square (COH^2) is about 0.55.

Two-day wave in the temperature field

Figure 1 shows the smoothed temperature wavenumber 3 power spectra at 0.465 hPa. Significant energy is concentrated at a westward period of 2.1 days (0.48 cpd) throughout the southern hemisphere. The spectral peak is near 12˚S. Some two-day signal is also present in the winter hemisphere although not significant (see Figure 3).

Figure 2 shows the time series of the two-day wave variance at 1 hPa. The wave variance is defined as the square of the zonal mean wavenumber three perturbation. The perturbation is computed by summing the wavenumber three Fourier coefficients over the frequency range between 0.35 cpd (2.86 days) and 0.60 cpd (1.67 days), as indicated in Figure 1. This frequency range covers most of the spectral peak. The duration of the wave is roughly from January 22 to February 4, 1992. The variance is mainly confined between 20˚S and 4˚N. Some weak local extrema can be seen around January 24 near 28˚S and 20˚N. In late-January (between UARS day 138-140) the two-day wave variance intensifies to a maximum of 4 K^2 while propagating slightly southward to 12˚S.

The meridional cross-section of the wave structure is shown in Figure 3. The wave amplitude is presented as the square root of

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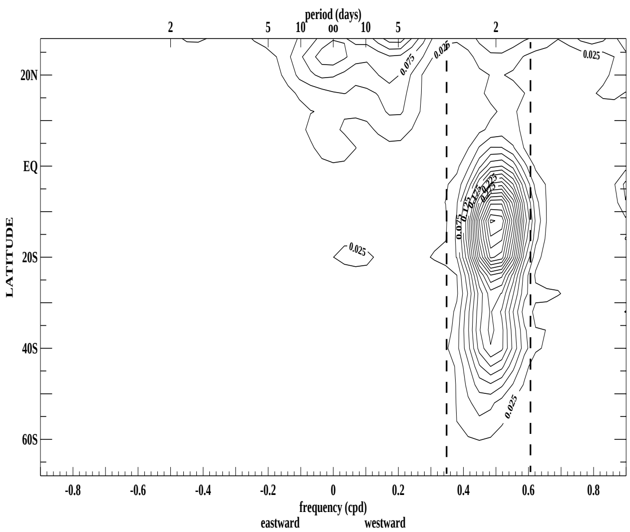

Figure 1. Temperature wave number 3 power spectra versus latitude at 0.465 hPa. Contour interval is 0.025 K^2.

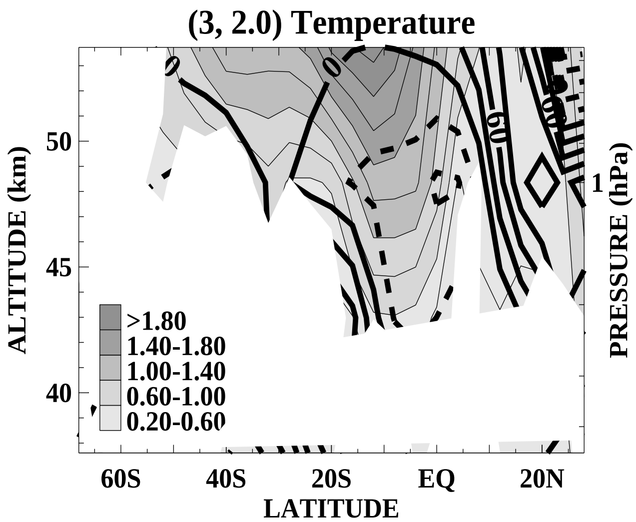

Figure 3. The meridional cross-section structure of the temperature two-day wave. The wave amplitude is represented by shaded contours given in intervals of 0.2 K. The phase lines are shown as heavy solid and dashed contours, in increments of 30˚.

twice the sum of the power spectra over the mentioned frequency range. The wave phase lines (with respect to 12˚S and 0.465 hPa) are shown approximately where the COH^2 is significant at the 95% level or greater. The striking feature of the wave amplitude is the growth in latitudinal extent with height. The axis of maximum amplitude tilts slightly poleward with height. Near 12˚S, the wave phase tilts slightly westward with height to about 1 hPa and then eastward above 1 hPa. In the same region, there is a slight eastward phase tilt toward the South. The weak phase tilt with altitude reveals the approximate barotropic nature of the two-day wave.

Two-day wave in the H_2O field

The two-day wave is evident in Figure 4 which shows the smoothed H_2O wavenumber 3 power spectra at 1 hPa. The signal peaks at a westward period of 2.1 days (0.48 cpd). The entire wave signature is embedded in the summer hemisphere and has its maximum near 20˚S. The period of the wave is nearly identical to that of temperature. However, this two-day H_2O feature is centered at lower altitude and further south than the temperature feature (see Figure 3 and 6).

The two-day H_2O wave variance is displayed in Figure 5 at 1 hPa. As with the temperature data, the frequency range between 0.35 cpd (2.86 days) and 0.60 cpd (1.67 days) was used to compute the perturbation. The variance evolution indicates two separate pulses of the two-day H_2O wave. The first event lasts from January 17-24, reaches a maximum of 0.07 $ppmv^2$ around January 20 (UARS day 131), and coincides with a weak temperature wave signal. The longer-lasting, stronger second event starts around January 25, reaches maximum variance of about 0.11 $ppmv^2$ around January 29 (UARS day 140), roughly the same time as the temperature two-day wave, and dies out by February

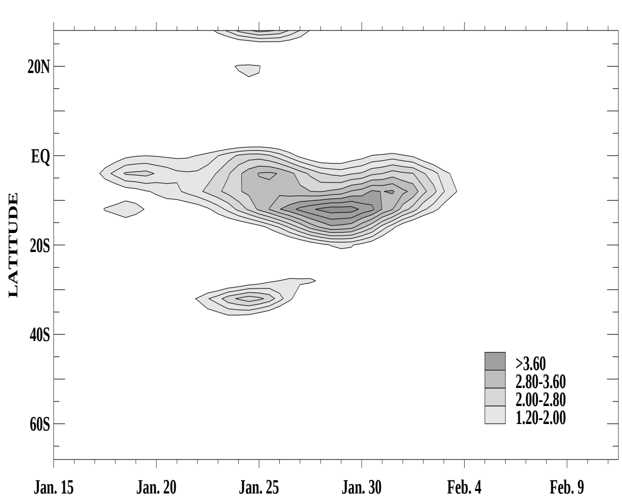

Figure 2. Latitude-time plot of the temperature two-day wave variance at 1.0 hPa. The variance contours are given in increments of 0.4 K^2.

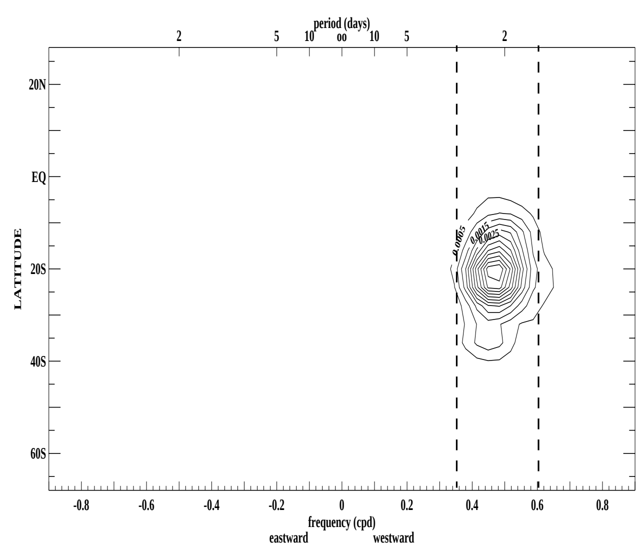

Figure 4. H_2O wavenumber 3 power spectra versus latitude at 1.0 hPa. Contour interval is 0.0005 $ppmv^2$.

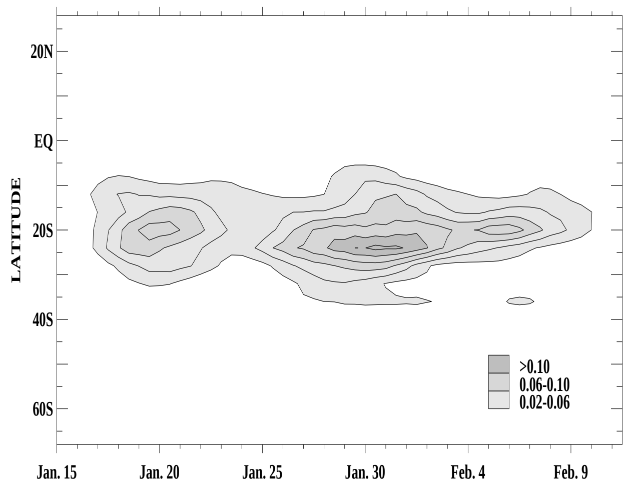

Figure 5. Latitude-time plot of the H_20 two-day wave variance at 1.0 hPa. The variance contours are given in increments of 0.02 $ppmv^2$.

7. For both events, the variance is mainly confined between 36˚S and 4˚S.

The meridional cross-section of the H_2O two-day wave structure is shown in Figure 6. Phase lines (with respect to 20˚S and 1 hPa) are shown approximately where the COH^2 is statistically significant above the 95% level. The wave phase generally tilts slightly westward with height to about 1 hPa and then eastward above 1 hPa. The wave also tilts westward toward the North at all heights. The H_2O amplitude peaks further south and at lower elevation than its counterpart temperature wave.

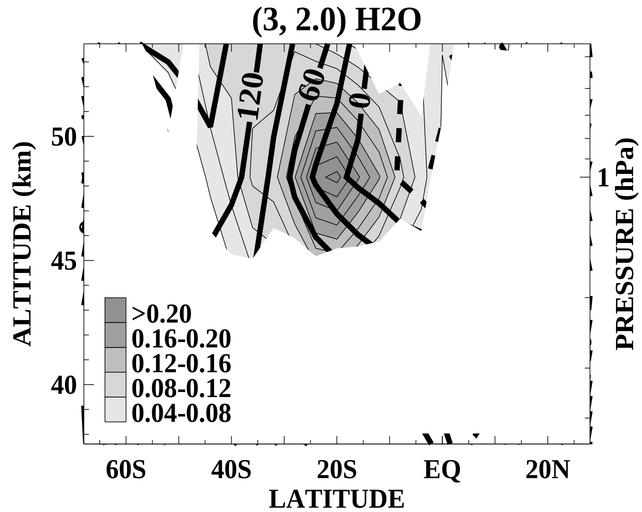

Figure 6. The meridional cross-section structure of the H_2O two-day wave. The wave amplitude is represented by filled contours given in intervals of 0.02 ppmv. The phase lines are shown as solid and dashed contours, in increments of 30˚.

Discussion

The temperature two-day wave structure generally agrees well with the case study of *Burks and Leovy* [1986] using Limb Infrared Monitor of the Stratosphere (LIMS) temperature data. In both analyses, the axis of maximum amplitude tilts slightly poleward with height so that the shape of the amplitude contours exhibits a similar downward and equatorward pointing wedge-like feature, confined between 20˚S and 4˚S. Both studies suggest that a larger two-day amplitude occurs higher in the mesosphere. Despite the

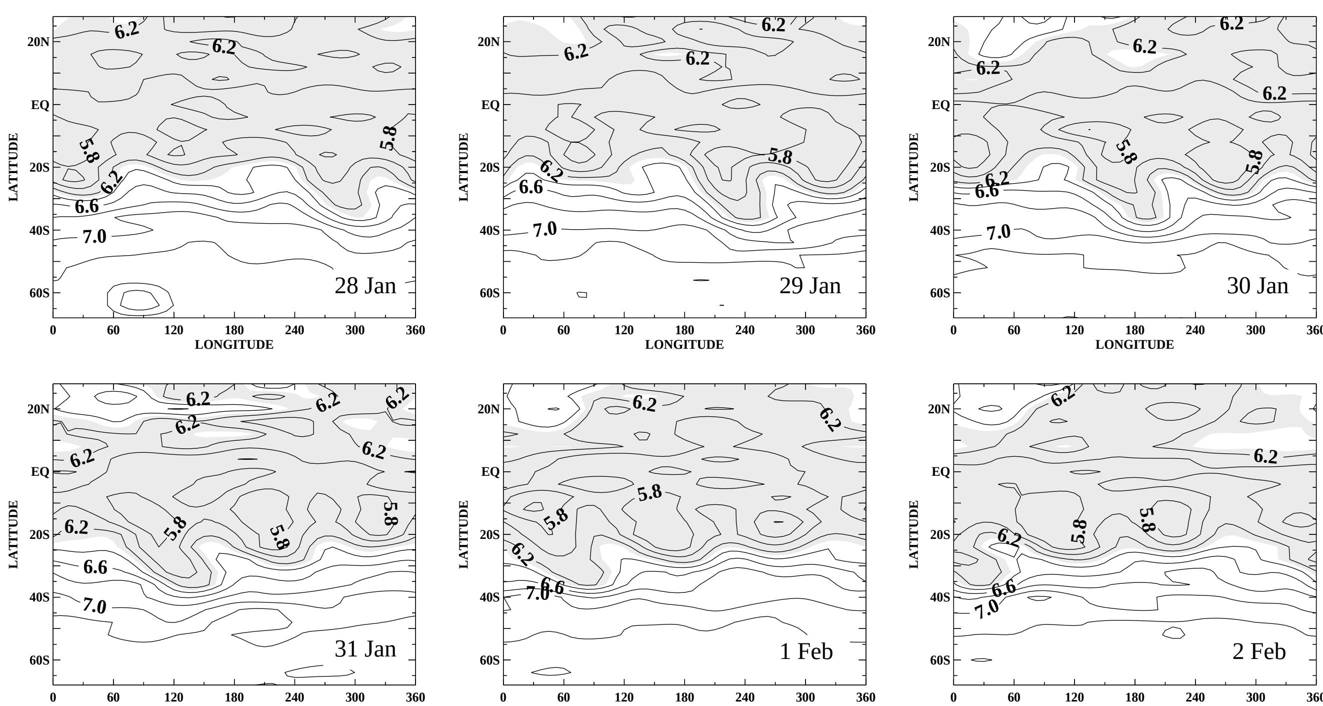

Figure 7. Synoptic maps of H_2O on 1800 K isentropic surface (approximately 1 hPa). Contours are given in increments of 0.2 ppmv with values less than or equal to 6.3 ppmv shaded.

complexity of the phase structure, both studies generally find very weak phase tilt with height. Our amplitude is, however, slightly larger. It is unclear whether this is due to differences between UARS MLS and LIMS data and retrievals or to true interannual differences.

Our results and that of *Burks and Leovy* [1986] show that significant two-day wave signatures reside in the summer hemisphere. However, others studies [e.g. *Randel*, 1994, and *Wu et al.*, 1993] have found the two-day disturbance to penetrate significantly well into the winter hemisphere. The discrepancy in these findings needs to be addressed in future work.

To our knowledge, this is the first observation of the two-day wave signature in H_2O. Since tracer variance is probably controlled mainly by wave meridional advection, which is not directly measured by satellites, the tracer structure provides valuable information about the two-day wave behavior.

Large meridional wind variations dominated by two-day period have been observed in the middle atmosphere. Recent observational example of such strong wind perturbation is shown in *Harris* [1994]. Given this, there is a possibility of the two-day wave breaking in the summer hemisphere, and the response of long-lived tracer might be expected to be dramatic. *Plumb et al.* [1987] suggested that transport by the two-day wave may be the most effective latitudinal transport process in the summer middle atmosphere. Using reasonable assumptions, they performed a simple calculation showing that meridional parcel displacement associated with a two-day event can be on the order of 1000 km in the mesosphere.

Figure 7 shows synoptic maps of the H_2O distribution on 1800 K potential temperature surface (approximately 1 hPa). Since the synoptic maps are created by summing the Fourier coefficients over all allowable wavenumbers and frequencies, planetary waves other than the wavenumber 3 two-day wave are present in Figure 7. In particular, disturbances of wavenumber one (with westward period between 5-10 days) and wavenumber four (with westward period between 1.8-2.0 days) were observed in the summer hemisphere at 1 hPa. *Burks and Leovy* [1987] also reported the presence of these waves in conjunction with the two-day wave.

The selected time for Figure 7 corresponds to the beginning of the strong second two-day event shown in Figure 5. A pronounced two-day (wavenumber 3) signature is clearly seen near 20˚S. Tongues of dry low latitude air can be seen to perturb the transport “barrier” region where the tracer distribution shows a strong latitudinal gradient between 20˚S and 35˚S. The westward motion and evolution suggestive of breaking of the pattern, associated with the dry intrusion located near 60˚W on January 28, are evident. This supports *Plumb et al.'s* conjecture of strong wave mixing in the region but shows that modulation of the wavenumber 3 two-day wave by other waves in the region is an important contributing factor.

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