

A SEARCH FOR FREE ROSSBY WAVES AND FOR VAN LOON'S TEMPERATURE VARIATIONS IN THE SOUTHERN HEMISPHERE STRATOSPHERE

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ABSTRACT

Thirty years ago, Harry van Loon published a paper describing out-of-phase temperature variations at middle and high latitudes of the Northern Hemisphere stratosphere (van Loon et al., 1975). They are a regular feature there, and their typical time scale is one to three weeks. It has been argued that at least some of these variations can be explained by similar variations in horizontal heat transport from middle to high latitudes which result from the interference of forced, stationary waves and free, traveling Rossby waves (Madden and Labitzke, 1981). If this interpretation is correct, one might expect similar variations in the Southern Hemisphere stratosphere since the free Rossby waves are global modes. Variations are smaller in the Southern Hemisphere (Randel and Newman, 1998), but large oscillations in temperature gradient and eddy heat transport do occur occasionally, and good examples are those during the southern winter of 2002 (J. Atmos. Sci.,

March 2005). The Southern Hemisphere oscillations have been connected to the interaction between a stationary wave-1 and an eastward traveling wave-2. Free Rossby waves of large scale such as wave-2 should move westward so this latter wave is not a free Rossby wave. Indeed the predominant propagation of large-scale waves in the Southern Hemisphere stratosphere is eastward (e.g. Randel and Newman, 1998), although there is some evidence based on Southern Hemisphere data alone (as opposed to projections of global data) for westward propagating free Rossby waves (e.g. Rodgers, 1976; Mechoso and Hartmann, 1982; Hirota and Hirooka, 1984). To learn if the interference of forced, stationary waves and free, traveling Rossby waves as proposed for Northern Hemisphere oscillations may play a role in some Southern Hemisphere stratospheric ones, we search for Southern Hemisphere temperature variations of the van Loon type and for manifestations of accompanying, free Rossby waves

1. INTRODUCTION

Harry van Loon described out-of-phase temperature variations at middle and high latitudes of the Northern Hemisphere stratosphere (van Loon et al., 1975). It was argued that large-scale free, Rossby waves played a role in fluctuating horizontal heat transports across 60N that drove the temperature variations (Madden and Labitzke, 1981). Here we look for similar variations in the Southern Hemisphere stratospheric temperature and manifestations of related free, Rossby waves. Data are from

channel 4 of the microwave sounding units (MSU) flown on a series of NOAA satellites, that from the ERA40 analyses from the ECMWF Data Server, and also 300hPa streamfunction data based on NCEP/NCAR Reanalysis.

2. MSU DATA

Figure 1 shows the weighting of MSU Channel 4 data. Zonal averages of the Channel 4 MSU data for a four month period are shown in Fig. 2a (50N and 70N) and 2b (50S and 70S).

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CHANNEL 4 WEIGHTING FUNCTION

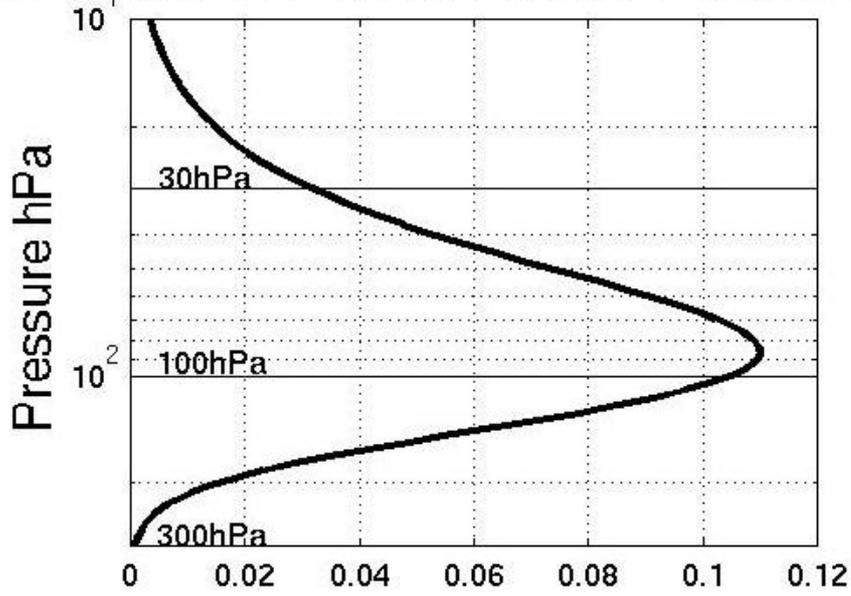
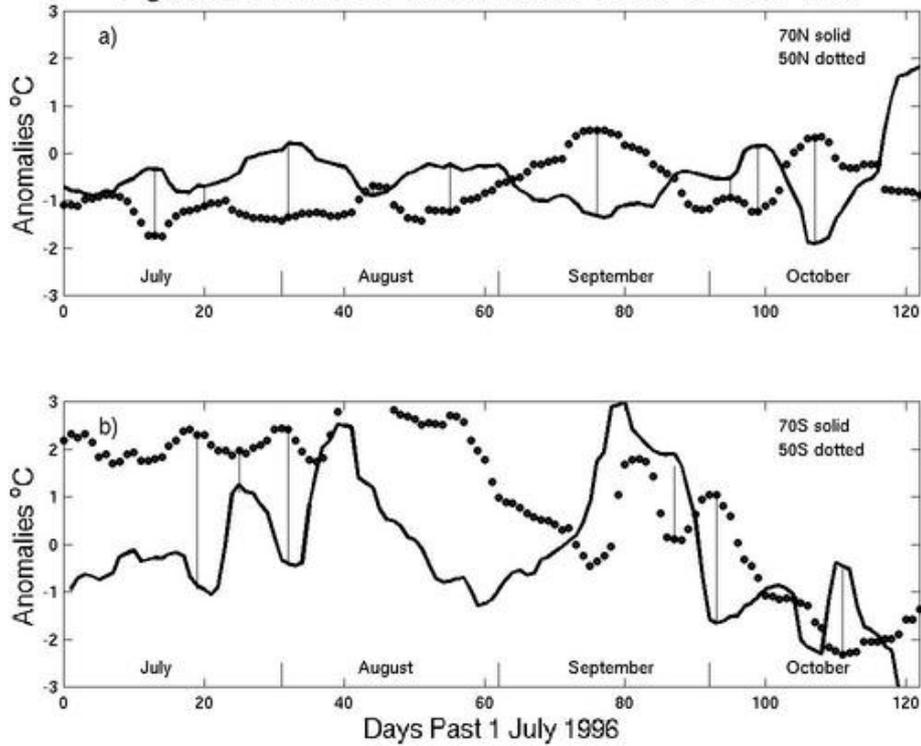


Figure 1

Figure 2: CHANNEL 4 MSU DATA 1 JUL - 31 OCT 1996



Some of the out-of-phase variations are highlighted by the vertical lines. Figure 3 shows the coherence and the phase angles from cross-spectra estimated with 13 years of data from 1992 through 2004. Degrees of freedom are about 198 (99 adjacent periodogram values have been averaged). The horizontal dashed line marks the approximate 95% significance level. Frequency resolution is 0.02 cycles/day (99/4749).

Coherence is high from about the lowest resolved frequencies (.01 cycles/day) to about .20 cycles/day. Negative phase angles indicate that the polar values lead the more midlatitude ones by two to three radians at very low frequencies. At periods shorter than about 25 days (10 days for the Southern Hemisphere) 50 and 70 degrees latitude are, as one might expect from Fig.2, out-of-phase.

3. ERA40 DATA

In order to compare the temperature variations with eddy heat transports, we need meridional winds. To that end, ERA40 data were extracted for 365 days from 1 April 1996 through 31 March 1997 at 100 hPa, a level where the MSU weighting is large. Newman and Nash (2000) compared vT estimated from ERA40 and from NCEP/NCAR Reanalysis and found that they agreed within about 15%. A further check of the ERA40 data reliability is a cross-spectrum

between them and the MSU data, though it should be recognized that they are not totally independent (Uppala,2005). Figure 4 shows the coherence squared between zonally averaged data at 50S and 70S. At periods longer than about six days coherence is high and the phases are very nearly zero (not shown), so we conclude for periods longer than this the ERA40 data are good estimates. For Fig. 4, 11 adjacent periodogram estimates were averaged giving approximately 22df and a resolution of 0.03 (11/365)

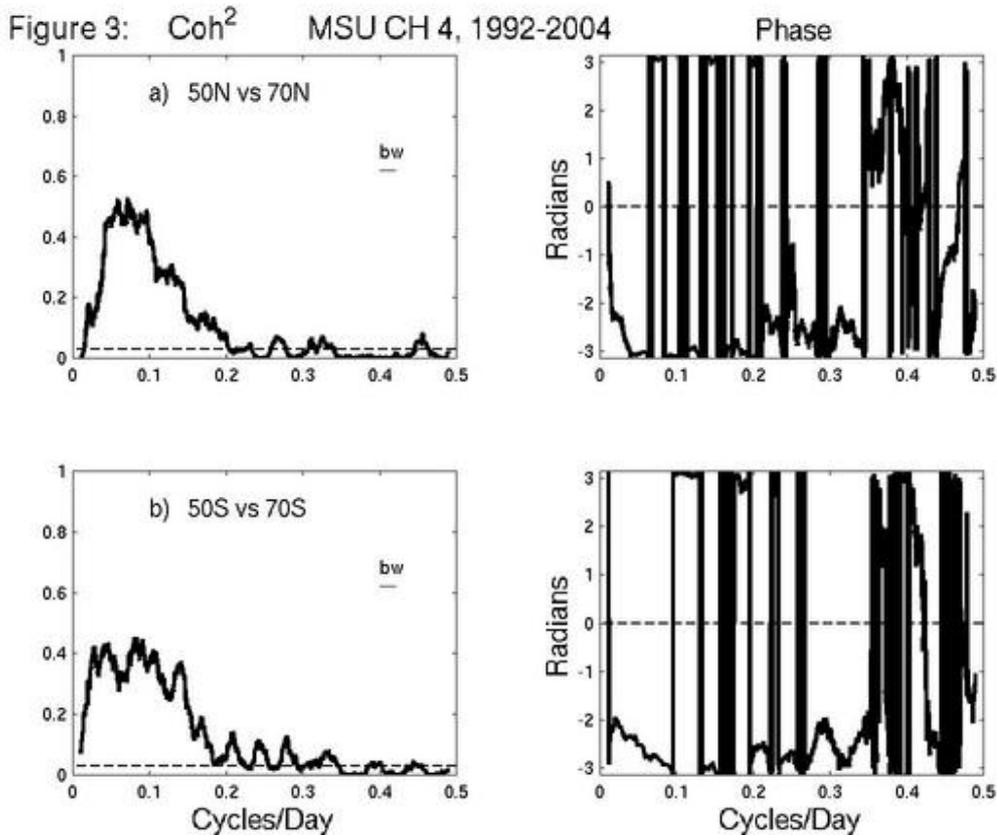
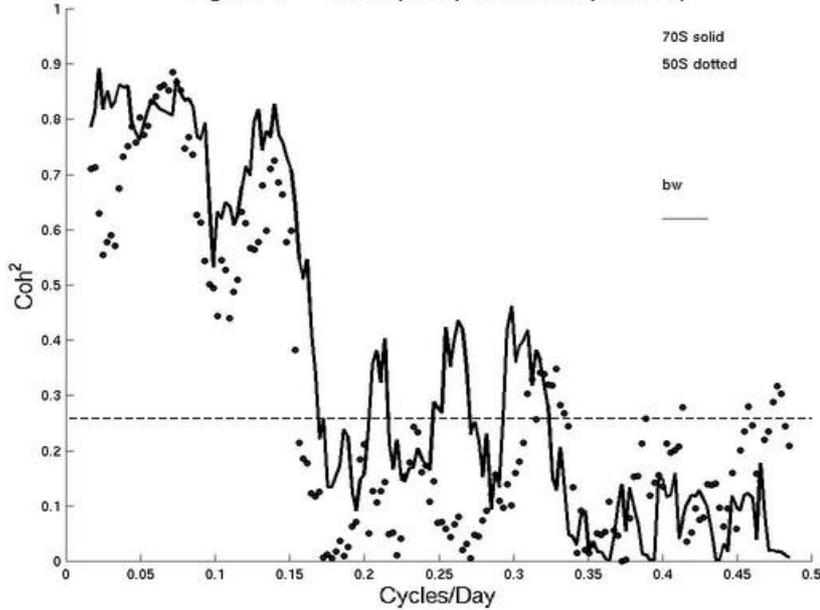


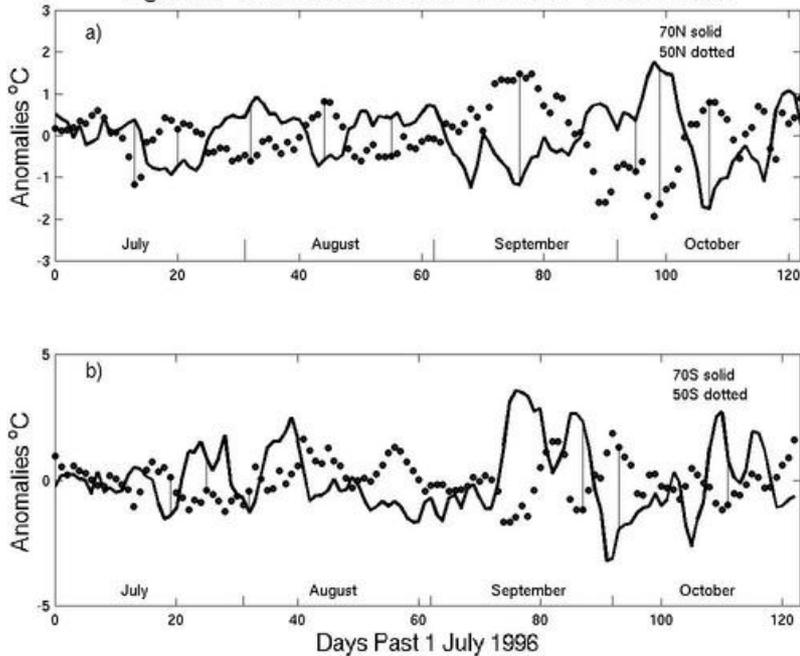
Figure 4: MSU (Ch 4) vs ERA40 (100hPa)

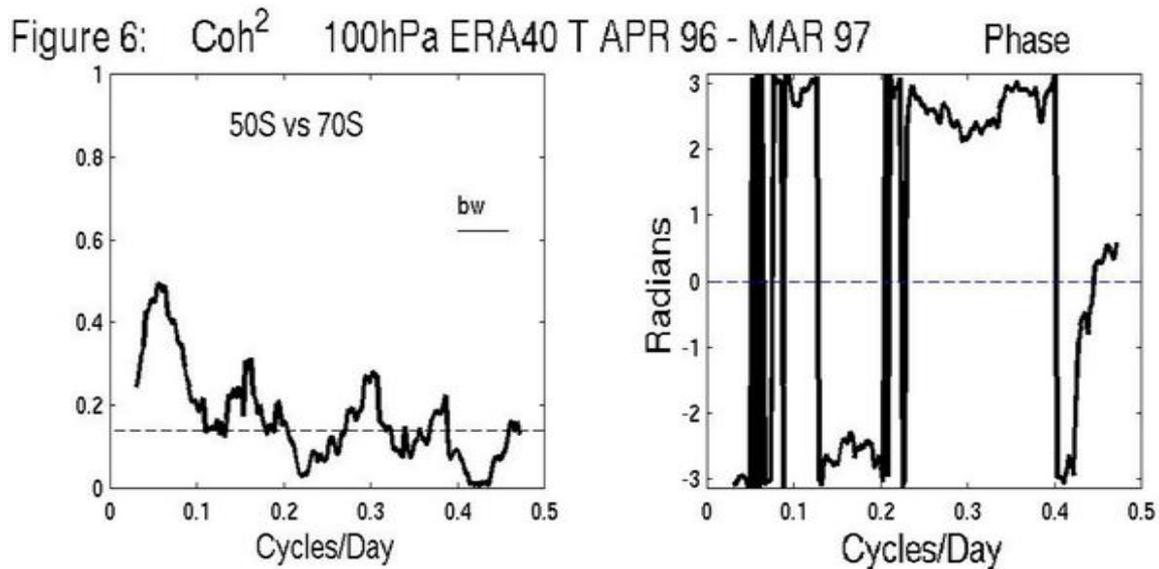


In order to minimize the seasonal variation, a third order polynomial fit was subtracted from the ERA40, 100hPa temperature data to give Fig. 5. Out of phase variations similar to those of Fig. 2 are often evident. Vertical lines in Fig. 5 are at the same dates as those of Fig. 2 for comparison. Figure 6 is like Fig. 3 but for the Southern

Hemisphere ERA40 100hPa data. Relatively high coherence and out-of-phase phase angles are evident between 50S and 70S. From Fig. 4 we conclude that coherences and phases of Fig. 6 are not reliable at periods shorter than six days (0.17 cycles/day).

Figure 5: 100hPa ERA40 DATA 1 JUL - 31 OCT 1996





4. HORIZONTAL HEAT TRANSPORTS

The above shows that out-of-phase temperature variations occur across 60S as they do across 60N. Now we verify that eddy heat transports are related to these temperature variations as they are in the Northern Hemisphere. The top of Fig. 7 shows the same data of Fig. 5 (bottom), but only for the Sep-Oct 1996 time period. The bottom panel of Fig. 7 shows the total eddy heat transport across 60S for all waves and for that of zonal wavenumber 1 and 2. There is a regular variation

on a time-scale of a several days that is dominated by wave-2 from about 10 Sep. to 20 Oct. Heat transports tend to lead relative maxima (minima) in the 50S (70S) temperatures. Figure 8 is the coherence and phase between heat transport by wave-2 across 60S and the 50S

zonal mean temperature minus that at 70S, showing that variations evident in Sep-Oct were not uncommon during the year. If wave-2 heat transport were the only contributing factor, the phase angle would be .25 cycle (1.57 radians). Again, we assume that coherences and phases are not reliable at periods shorter than six days (0.17 cycles/day).

There is at least one large excursion in wave-1 transport between about 10 and 20 September, but a cross-spectrum between it and the 70-50S temperature gradient doesn't show any significant low frequency coherence so we conclude wave-1's role was much less important than that of wave-2 during 1996.

Figure 7: 100hPa ERA40 DATA 1 SEP - 31 OCT 1996

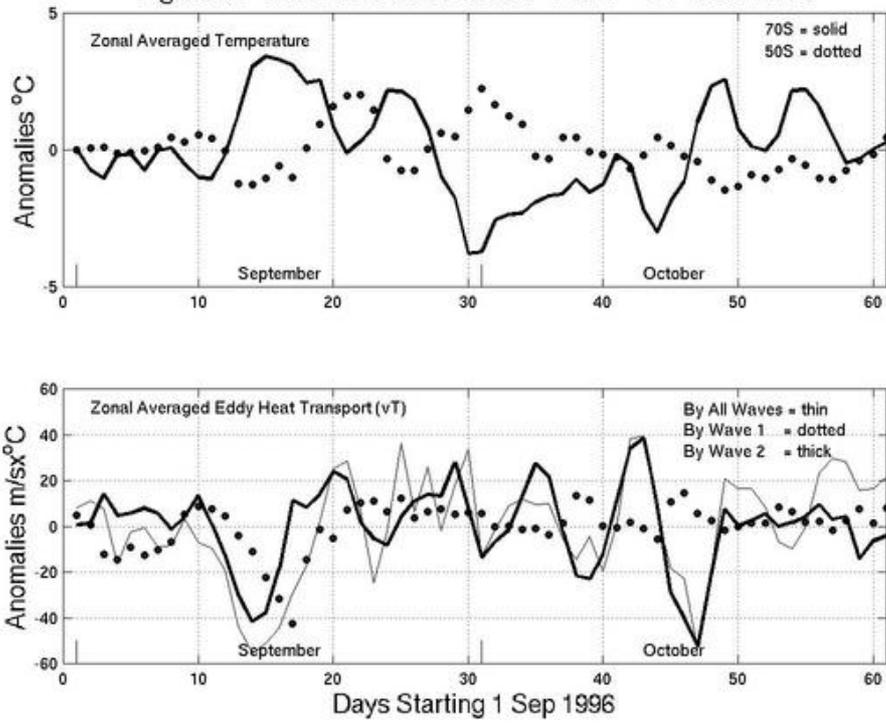
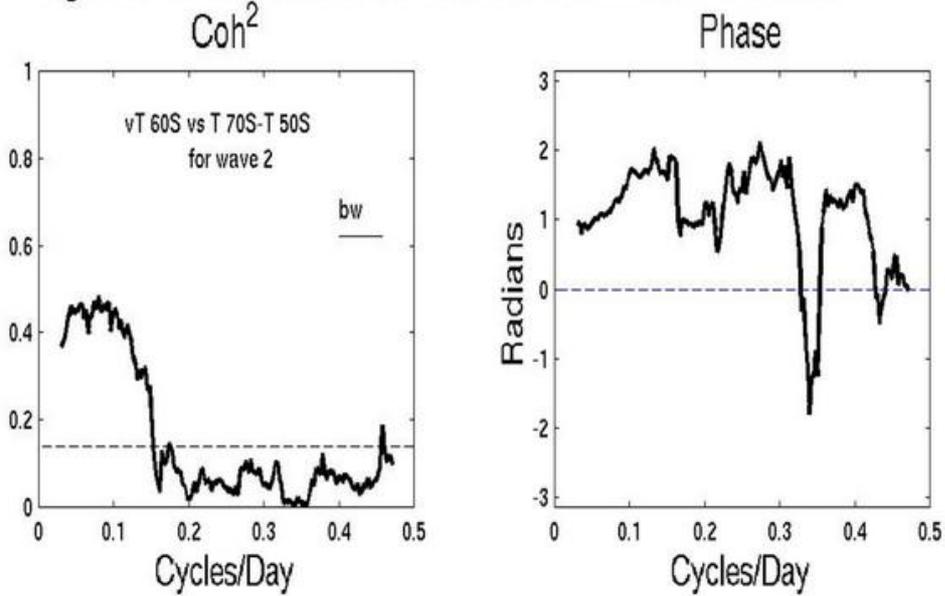


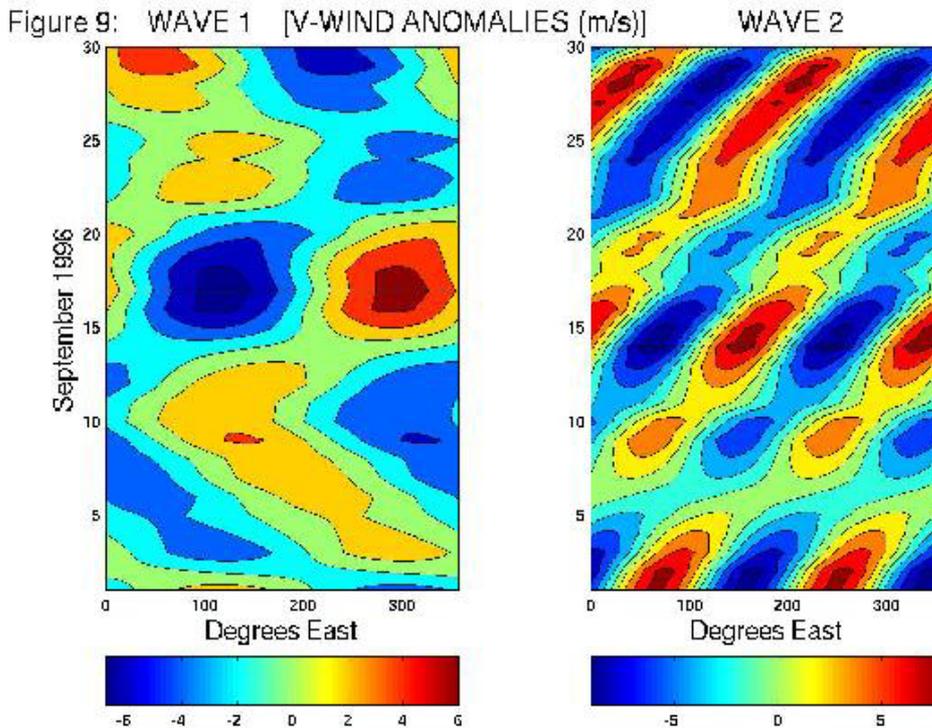
Figure 8 100hPa ERA40 vT vs T50S-T70S APR 96-MAR 97



5. WAVE MOTIONS

Figure 9 is the September 1996 time-longitude section of the v-wind anomalies (from the 30-day mean) for wave-1 (left) and wave-2 (right) at 60S. Clearly the wave-2 variations in v-wind and in resulting heat transport are associated with an eastward propagating wave. The eastward wave-2 is well known (see Manney et al., 1991 and references therein), and its role in southern stratosphere oscillations has been examined (eg. Hirota et al., 1990 ; Hio and Yoden,2004). The eastward propagation rules out the possibility that this disturbance is a free Rossby wave. Westward propagation of wave-1 in early September, and possibly in the second half of the month (with a 6 or 7-day modulation) might be related to the “16-day” Rossby wave.

We have attempted to identify free Rossby waves in NCEP/NCAR Reanalysis data in another study which will be reported on elsewhere. Figure 10, below, is taken from that study. The two left panels are the leading Eigenvectors of 16-day band-pass filtered, 300 hPa streamfunction (ψ) data, from 40 years of NCEP/NCAR Reanalysis. Patterns are consistent with the 16-day wave (second symmetric, free Rossby wave). The right hand panel shows the principal components of the two EOFs during September 1996. There are values for 00 and 12 GMT. The counter clockwise rotation, especially from about 3 to 23 September, is consistent with the expected westward propagation.



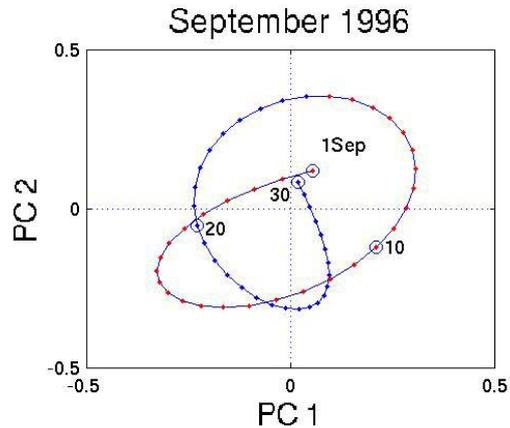
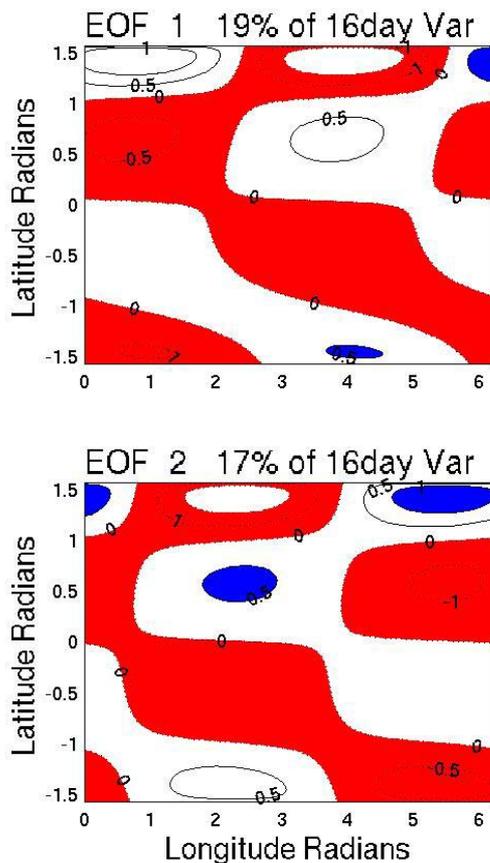


Figure 10:

Leading EOFs of 16-day, filtered, 300hPa streamfunction data - left; PCs (amplitudes) of the EOFs during September 1996 (first 15 days in red; last 15 days in blue) - above. Data are from NCEP/NCAR 00 and 12 GMT Reanalyses. Units are arbitrary.

The left panel of Fig.11 shows the wave-1 v-wind anomalies (the September 1996 average values subtracted) at 60S and 100hPa based on the ERA40 data (same as left panel of Fig. 9). The right panel is $d\psi/dx$ (nondivergent v-wind component) at 60S determined from the EOFs and PCs of Fig.10. There is good qualitative ($d\psi/dx$ units are arbitrary) agreement between the two panels of Fig.11 during the first 10 days of the month with little vertical slope between 300 (right panel) and 100 hPa (left panel). In the second

half of September the agreement is not as good. The 16-day wave continues regular westward propagation as determined by the EOFs and PCs (right panel of Fig. 11) but westward movement of the ERA40 v-wind is not so regular. It is necessary to point out that isolation of the 16-day wave in the right panel of Fig. 11 is not certain. Of special importance is the fact that the filtering process involves many weights so that a single strong episode will be reflected in the filtered data before and after the event.

6. SUMMARY

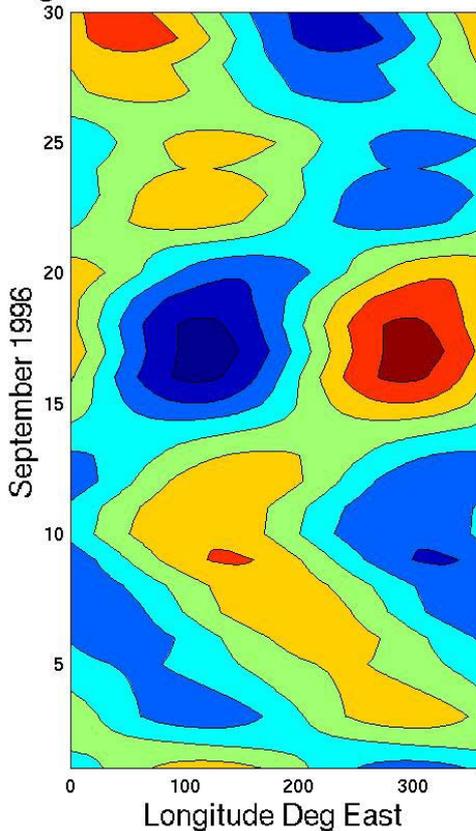
Out-of phase lower stratospheric temperature variations occur across 60S similar to those across 60N that were discussed earlier by van Loon. They are related to heat transport across 60S. The well known eastward propagating wave-2 plays an important role in the varying

heat transport. In mid-September 1996, there was a large fluctuation in wave-1 heat transport which may have been related to the westward, 16-day free Rossby wave, but further work is needed to determine if free Rossby waves are important there.

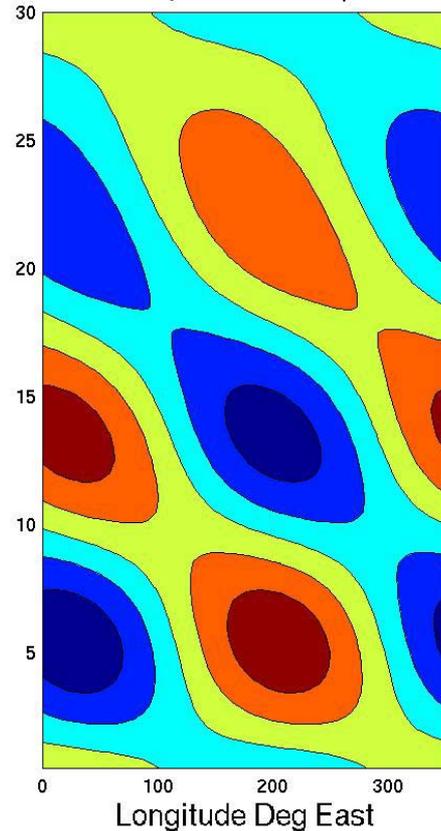
Acknowledgements:

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Fig. 11: Wave 1 V-Wind Anom.



16 Day Filtered $d\psi/dx$



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