Water vapour : stratospheric variability - I

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Cargèse International School
Water Vapour in the Climate System (WAVACS)
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Lecture 2 of 4

Types of variability of significance for stratospheric water vapor

1) annual

2) semiannual

3) interannual
   ie: QBO, ENSO

4) long term changes (trends)

(There is also spatial variability, but really only important in the lowermost stratosphere and will not be discussed here. New satellite data sets with increased horizontal resolution should eventually allow detailed analysis of stratospheric spatial variability)

Processes that impact stratospheric water vapor variability.

1) tropical cold point variations

2) variations in the strength of the Brewer-Dobson circulation

Other possibilities: In polar regions, variations at locations near saturation and variations in the input of methane into the stratosphere.

The entry of water vapor into the stratosphere is largely a function of the temperature at the tropical cold point.

This induces variability that can spread throughout the stratosphere.

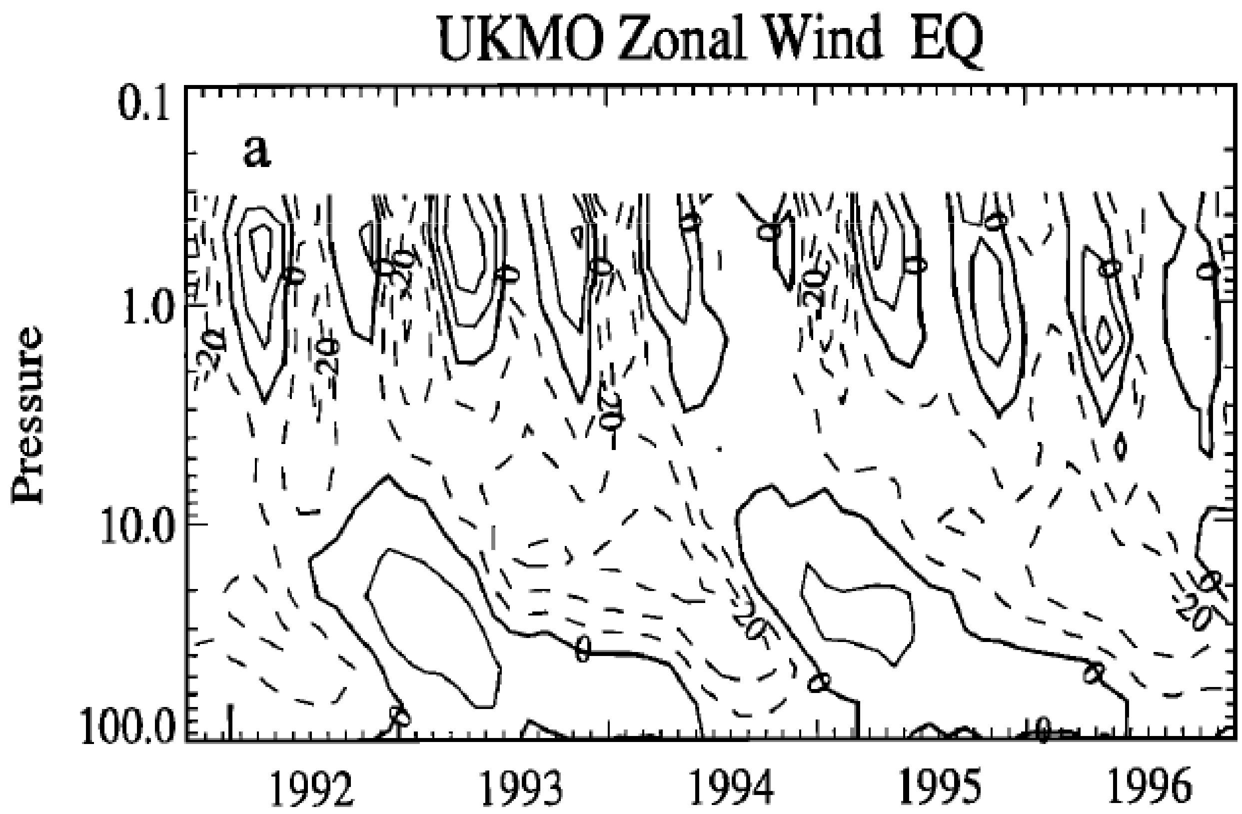
In the middle and upper stratosphere, water vapor is largely a function of how long the air has been in stratosphere (how much methane has oxidized).

Variability in vertical and horizontal motions can then induce variability in stratospheric water vapor.

Semi-annual Oscillation

The semi-annual oscillation is one mode of dynamical variability that also impacts stratospheric tracers. This is largest significant mode in the tropical stratosphere above 30 km.

RAY ET AL.: EQUATORIAL SEMIANNUAL OSCILLATION IN ZONAL WIND



The bottom line is that variations in vertical velocity associated with the SAO gives variations in tracer species. This was seen in SAMS measurements (in Holton and Choi, 1988.

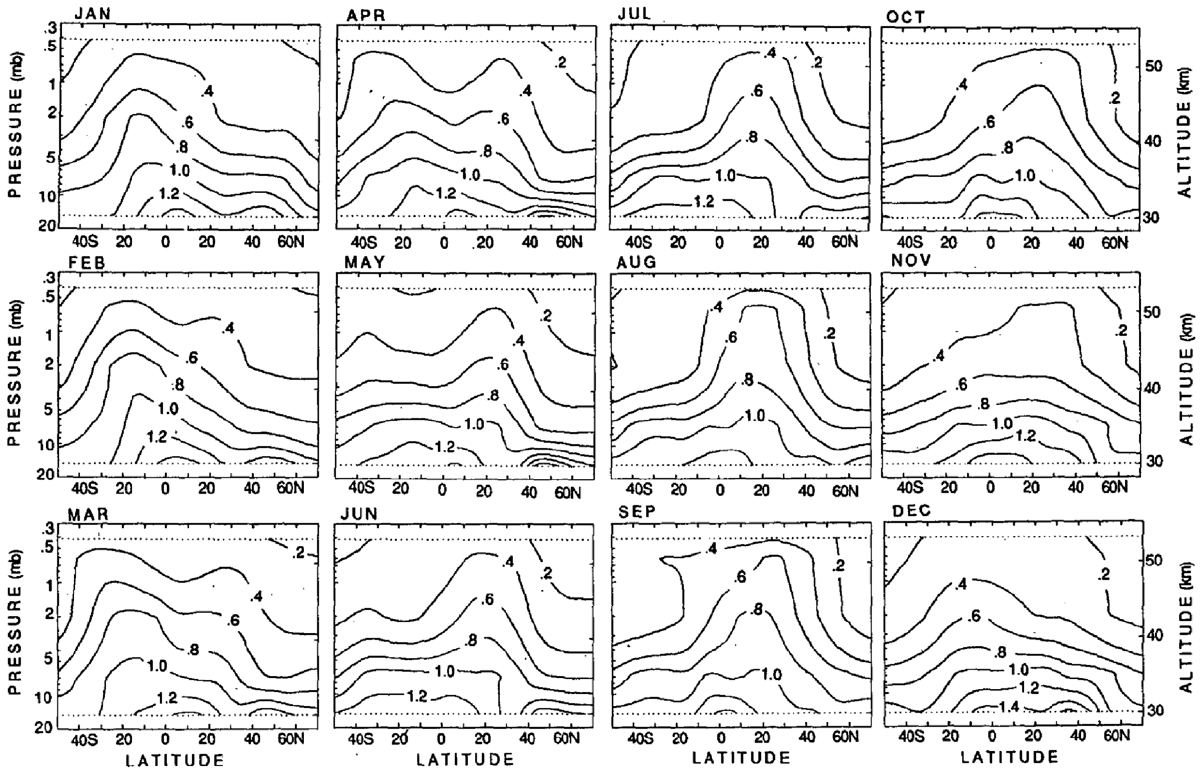
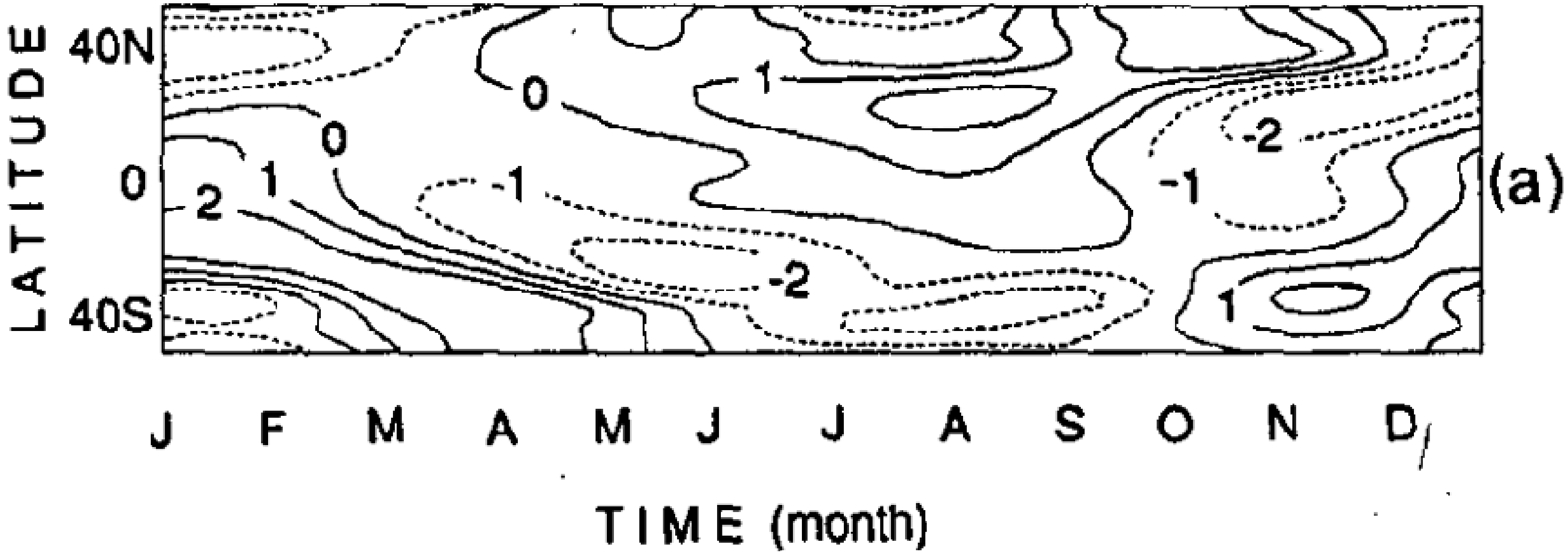


FIG. 2. As in Fig. 1 but of CH_4 (ppmv).

Methane example



Estimated vertical velocities at 1mb based on SAMS methane analysis...shows SAO in vertical velocities. From Holton and Choi, 1988

Ray et. al 1994 discuss the SAO in temp and ozone. Variations in downwelling in the upper part of the stratosphere produces a signal in tracers. G-waves and Kelvin waves provide westerly accelerations, planetary waves and advection provide easterly acceleration.

SAO in UARS MLS water, from Eluszkiewicz et al, 1996.

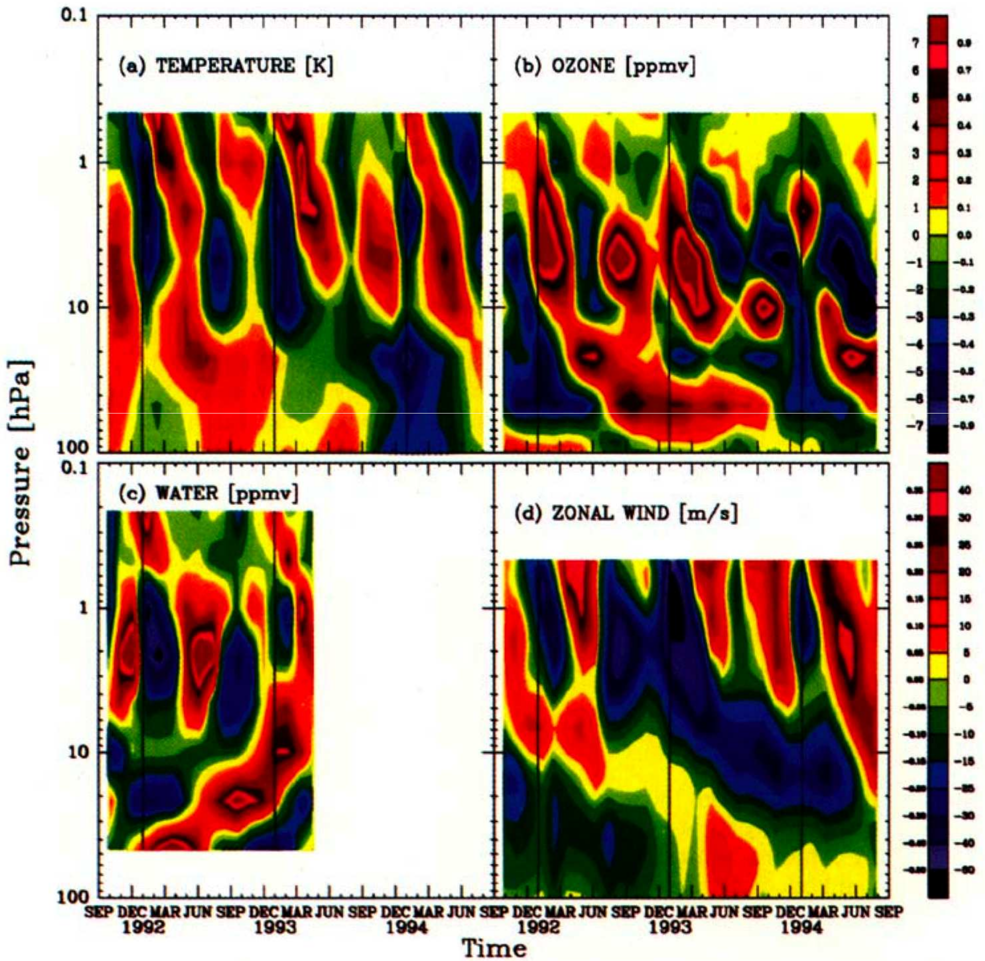


FIG. 12. Zonally averaged equatorial time–height sections of (a) temperature, (b) ozone, (c) water vapor, (d) zonal wind, (e) net diabatic heating, (f) $\bar{w}^*$, and (g) $\bar{v}^*$. In panels (b) and (c) the time mean has been taken out. Vertical lines indicate year boundaries. The negative (or generally low) heating rates at 46 hPa are artifacts of the neglect of Mt. Pinatubo aerosols (cf. the lower left hand panel in Fig. 3) and of the systematic underestimate in the tropical O_3 mixing ratios at 46 hPa in MLS version 3 retrievals (Froidevaux et al. 1994a,b).

SAO variations in the upper stratosphere in trace species a result of variation in the mean meridional circulation in the tropics.

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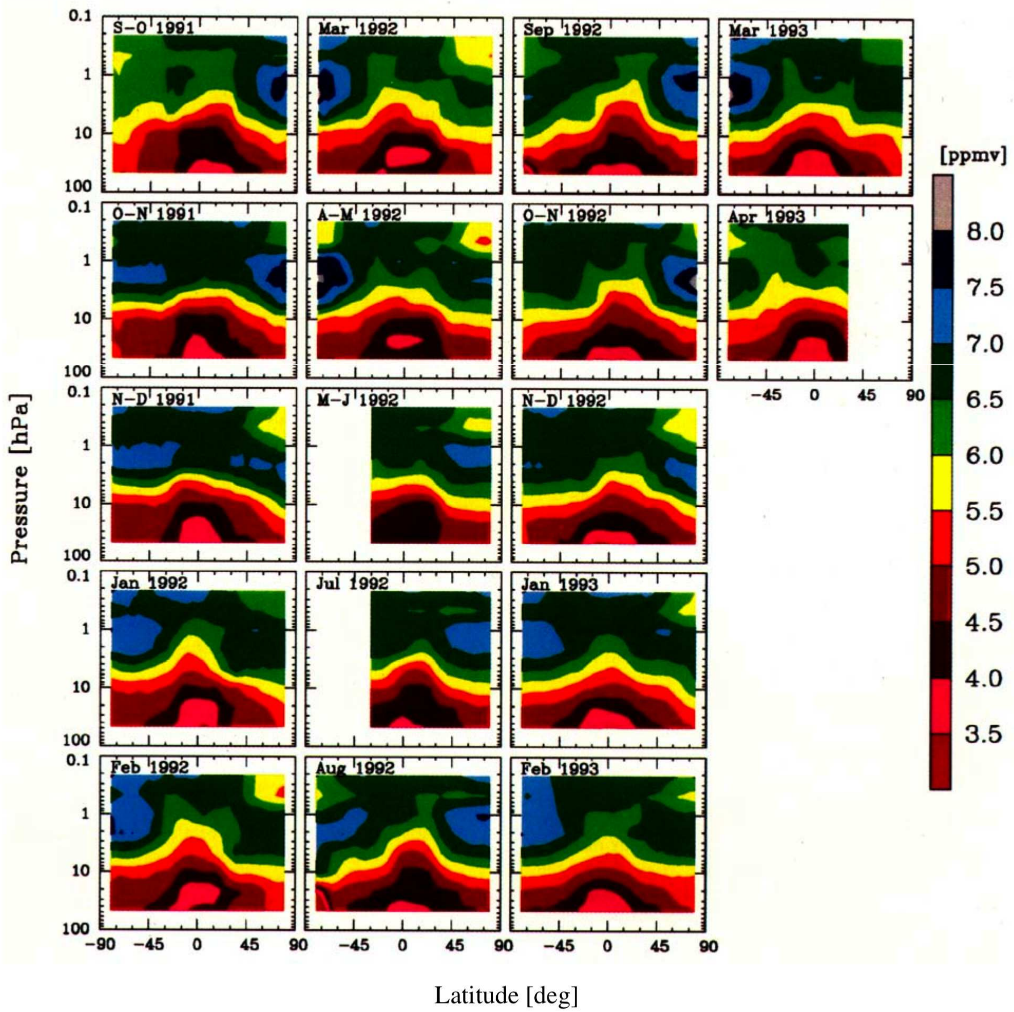


FIG. 13. Latitude–height sections of the water vapor mixing ratio (in ppmv). MLS water vapor data are not available for the period 1 June–16 July 1992 and after 25 April 1993.

Quasi-biennial Oscillation

The Quasi-biennial Oscillation (QBO) is another significant mode of variability in the stratosphere.

Baldwin et. al (Reviews of Geophysics, 2001) gives a comprehensive overview of the QBO and its effects on tracer distributions.

It is a tropical phenomena, but it affects the stratosphere from pole to pole by modulating the effects of extratropical waves.

It is believed to be driven by a spectrum of upward propagating tropical waves (both eastward and westward) interacting with the mean flow.

It is currently not well represented in many climate models.

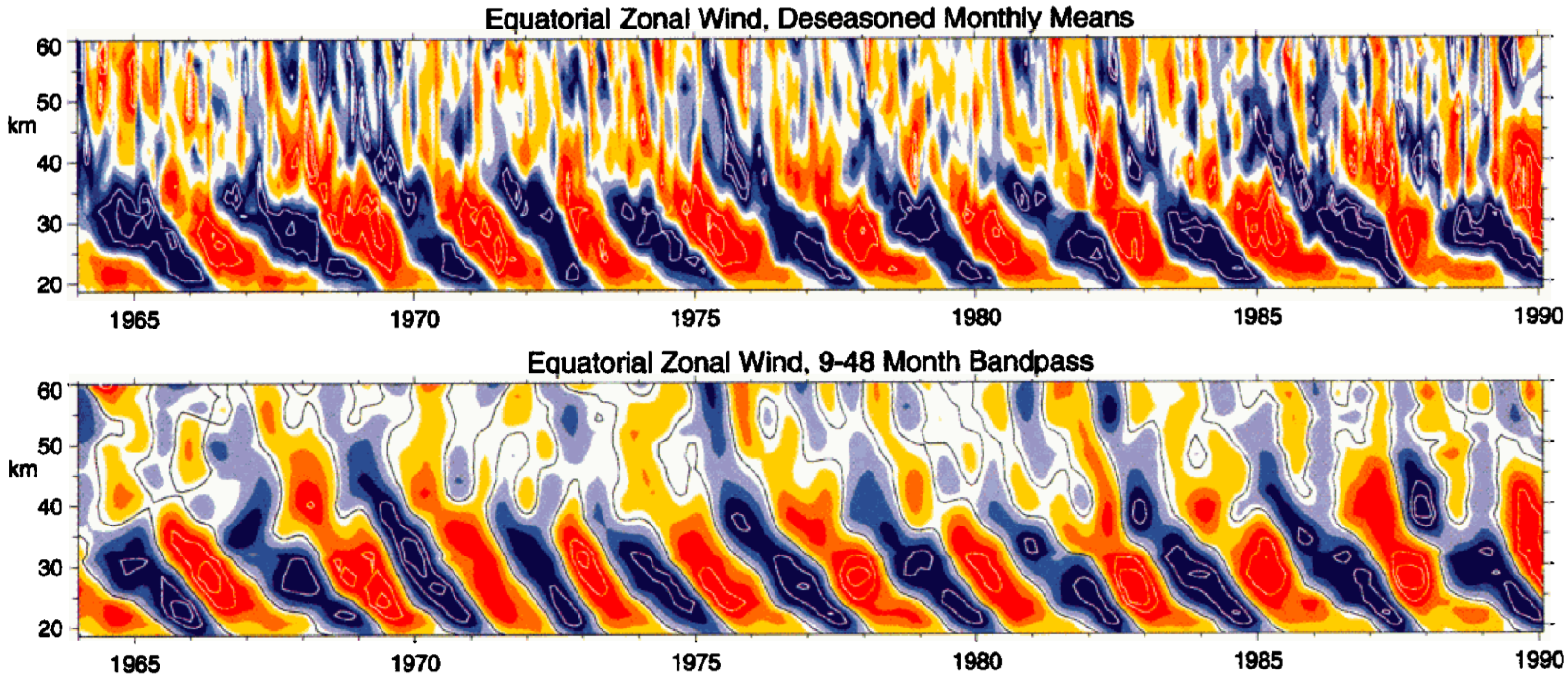


Plate 1. (top) Time-height section of the monthly-mean zonal wind component (m s^{-1}), with the seasonal cycle removed, for 1964–1990. Below 31 km, equatorial radiosonde data are used from Canton Island (2.8°N, January 1964 to August 1967), Gan/Maledive Islands (0.7°S, September 1967 to December 1975), and Singapore (1.4°N, January 1976 to February 1990). Above 31 km, rocketsonde data from Kwajalein (8.7°N) and Ascension Island (8.0°S) are shown. The contour interval is 6 m s^{-1}, with the band between -3 and $+3$ unshaded. Red represents positive (westerly) winds. After *Gray et al.* [2001]. In the bottom panel the data are band-pass filtered to retain periods between 9 and 48 months.

From Baldwin et al, 2001

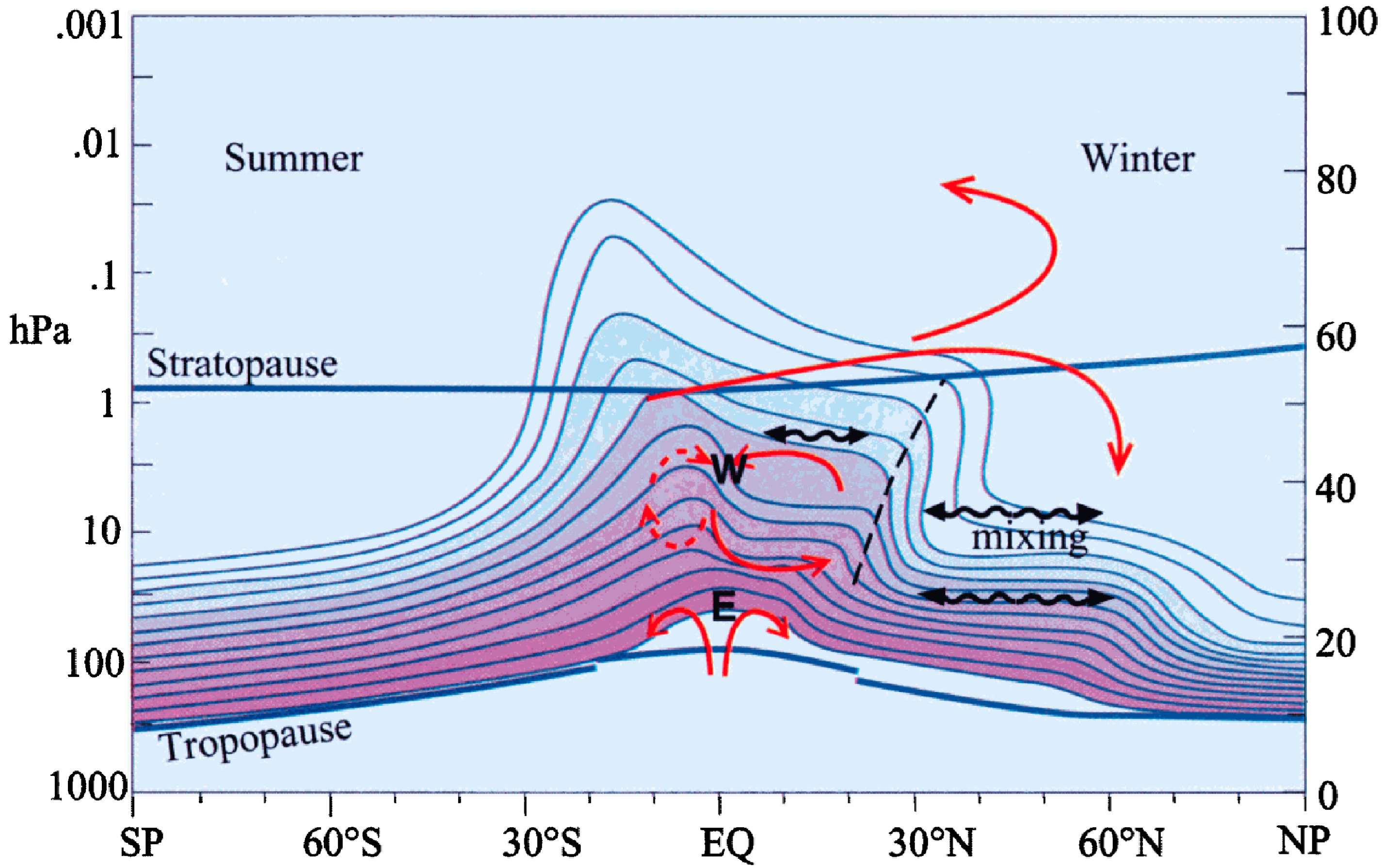


Plate 3. Overview of tracer transport by QBO wind anomalies and mean advection. Contours illustrate schematically the isopleths of a conservative tracer during northern winter when the QBO is in its easterly phase at 40 hPa (matching Plate 2). Tropical upwelling causes the broad maximum in tracer density in the middle to upper equatorial stratosphere, while the QBO causes deviations from hemispheric symmetry near the equator. Red arrows near the equator depict circulation anomalies of the QBO. The circulation anomaly in the equatorial lower stratosphere is approximately symmetric, while the anomaly in the upper stratosphere is much stronger in the winter hemisphere. The descent near the equator (~5 hPa) and ascent to the north (~5 hPa, 10°N) combine to produce a "staircase" pattern. A second stairstep is formed in midlatitudes by horizontal mixing.

Schematic showing impact of QBO on stratospheric tracers

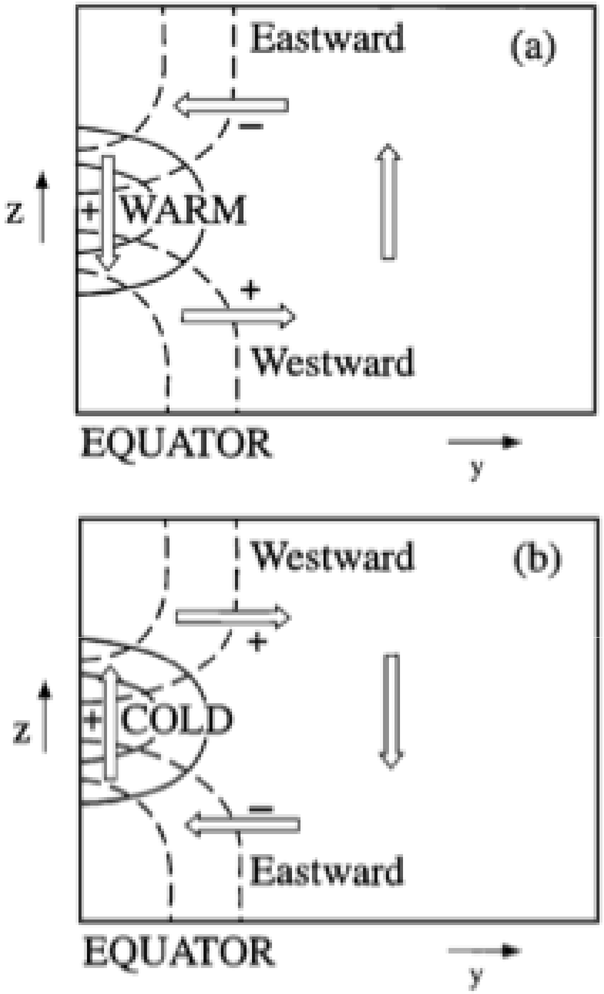
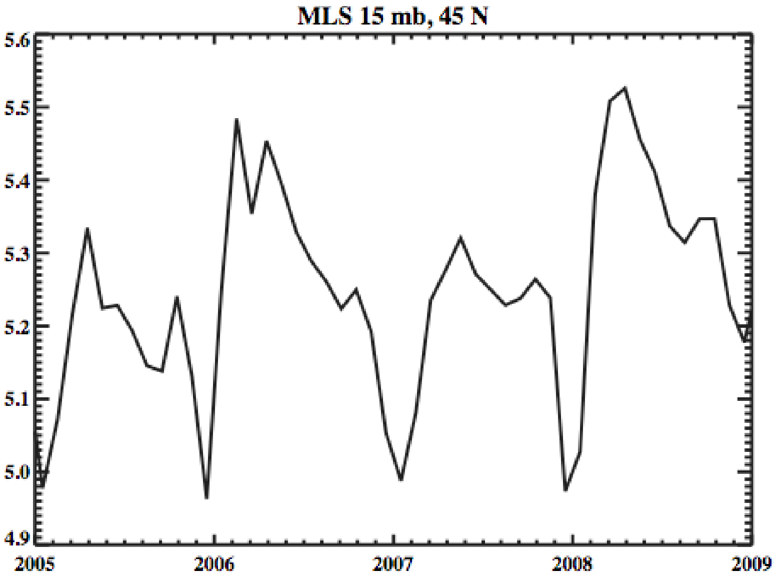
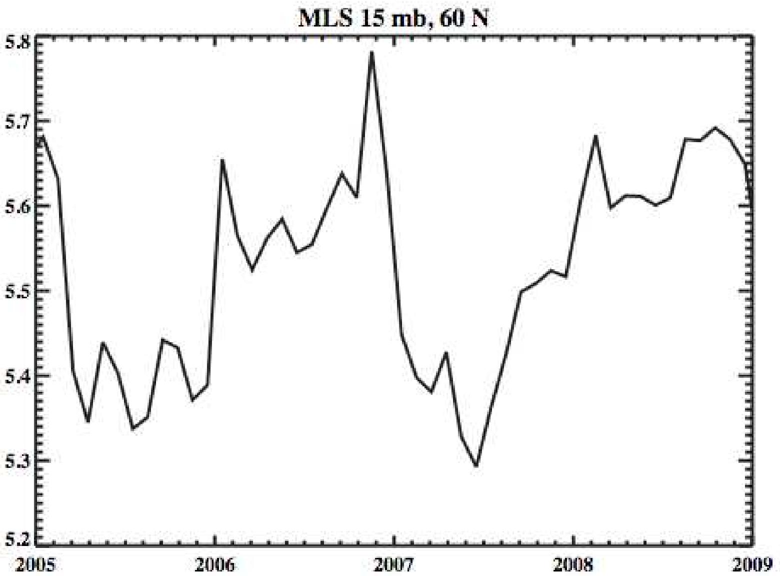


Figure 13. Schematic latitude-height sections showing the mean meridional circulation associated with the equatorial temperature anomaly of the QBO. Solid contours show temperature anomaly isotherms, and dashed contours are zonal wind isopleths. Plus and minus signs designate signs of zonal wind accelerations driven by the mean meridional circulation. (a) Westerly shear zone. (b) Easterly shear zone. After *Plumb and Bell* [1982b]. Printed with permission from the Royal Meteorological Society.

secondary circulation associated with the QBO...impacts tracer distributions, from Plumb and Bel, 1982 (JAS)





mid to high latitude, transport dominated QBO in water tropics (from Randel 1998), upper stratosphere, transport dominated QBO signal, lower stratospehre, see upward propogation, temperature dominated.

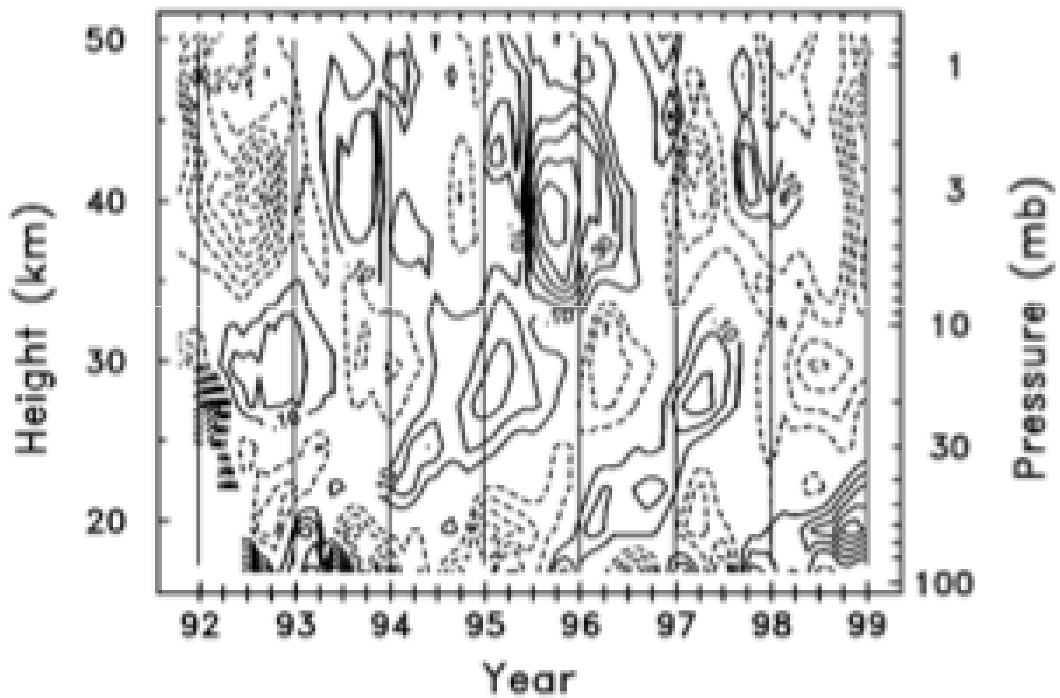


Figure 27. Time-height cross sections of interannual anomalies in H_2O over the equator from the Halogen Occultation Experiment (HALOE) instrument. The contour interval is 0.1 ppmv, with 0 contour omitted. Updated from *Randel et al.* [1998].

The lower stratospheric component of QBO variability in tropical water vapor is associated with changes in cold point temperatures.

Zhou, Geller and Zhang (2004) developed an dehydration index, and used that to show QBO variations in entry of water vapor into the stratosphere.

This includes other effects on tropical cold point temperature besides the QBO, but note the QBO signal is prominent at times.

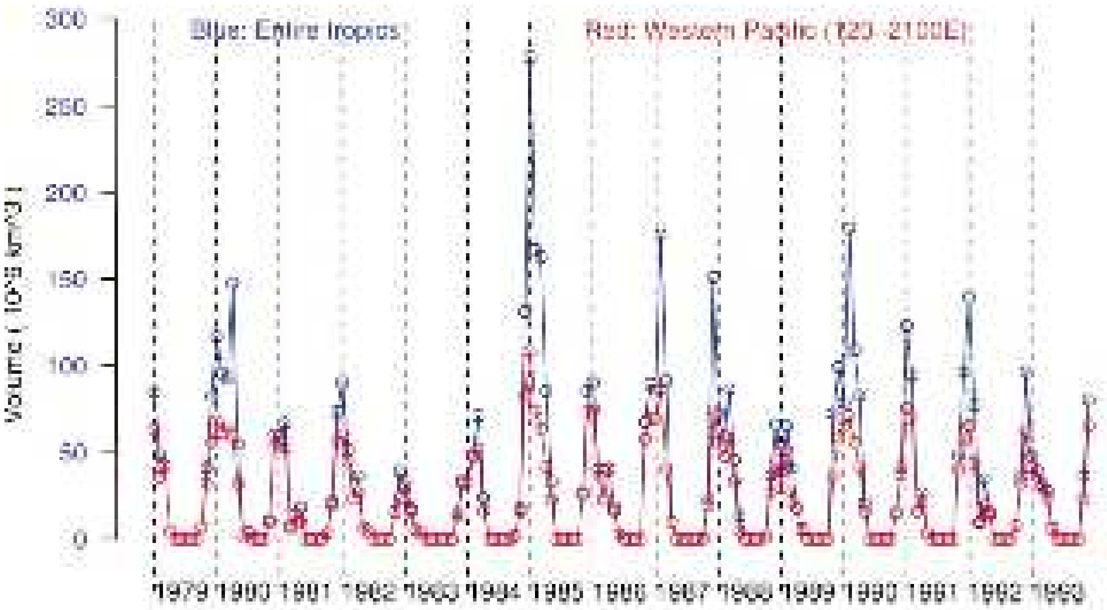
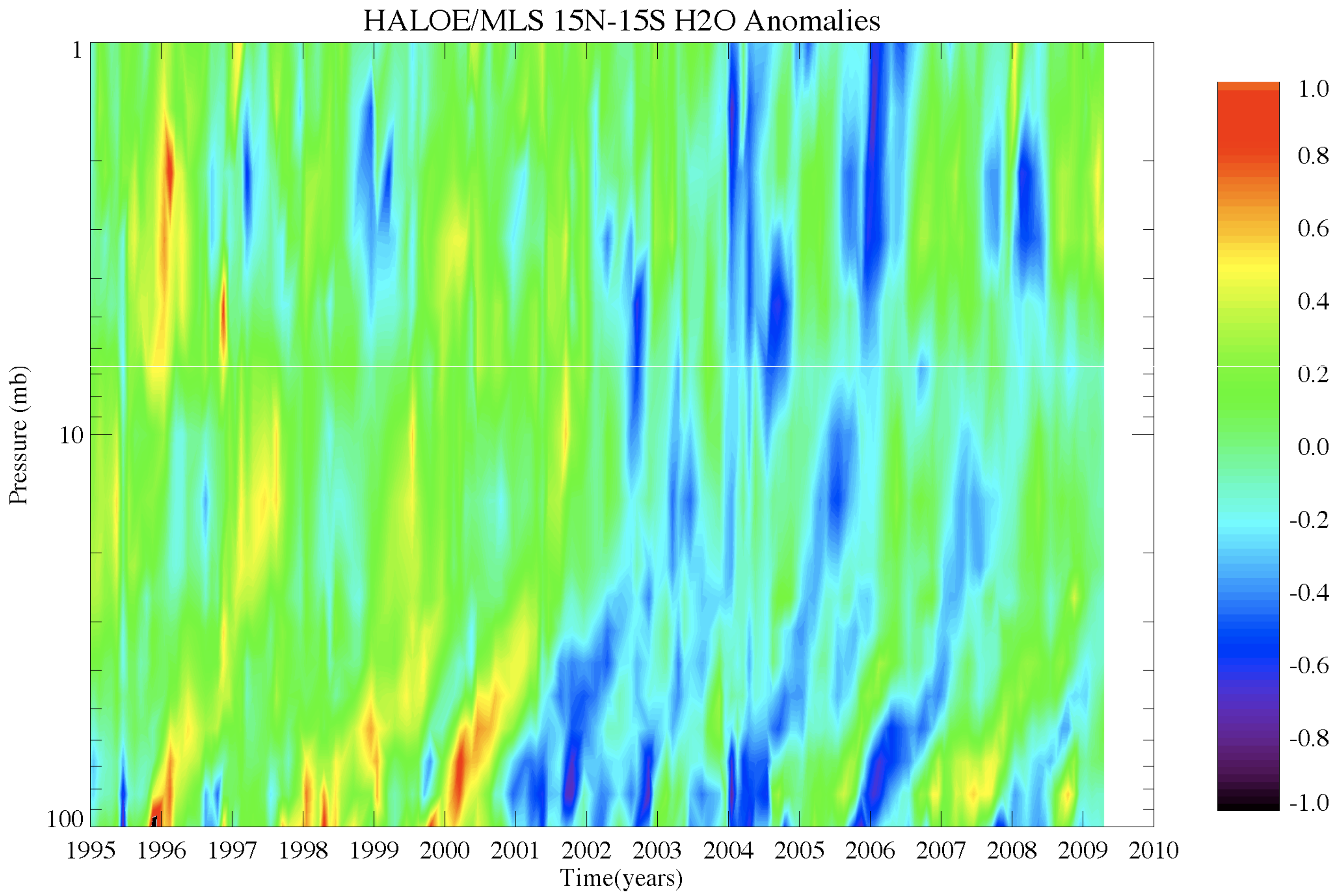


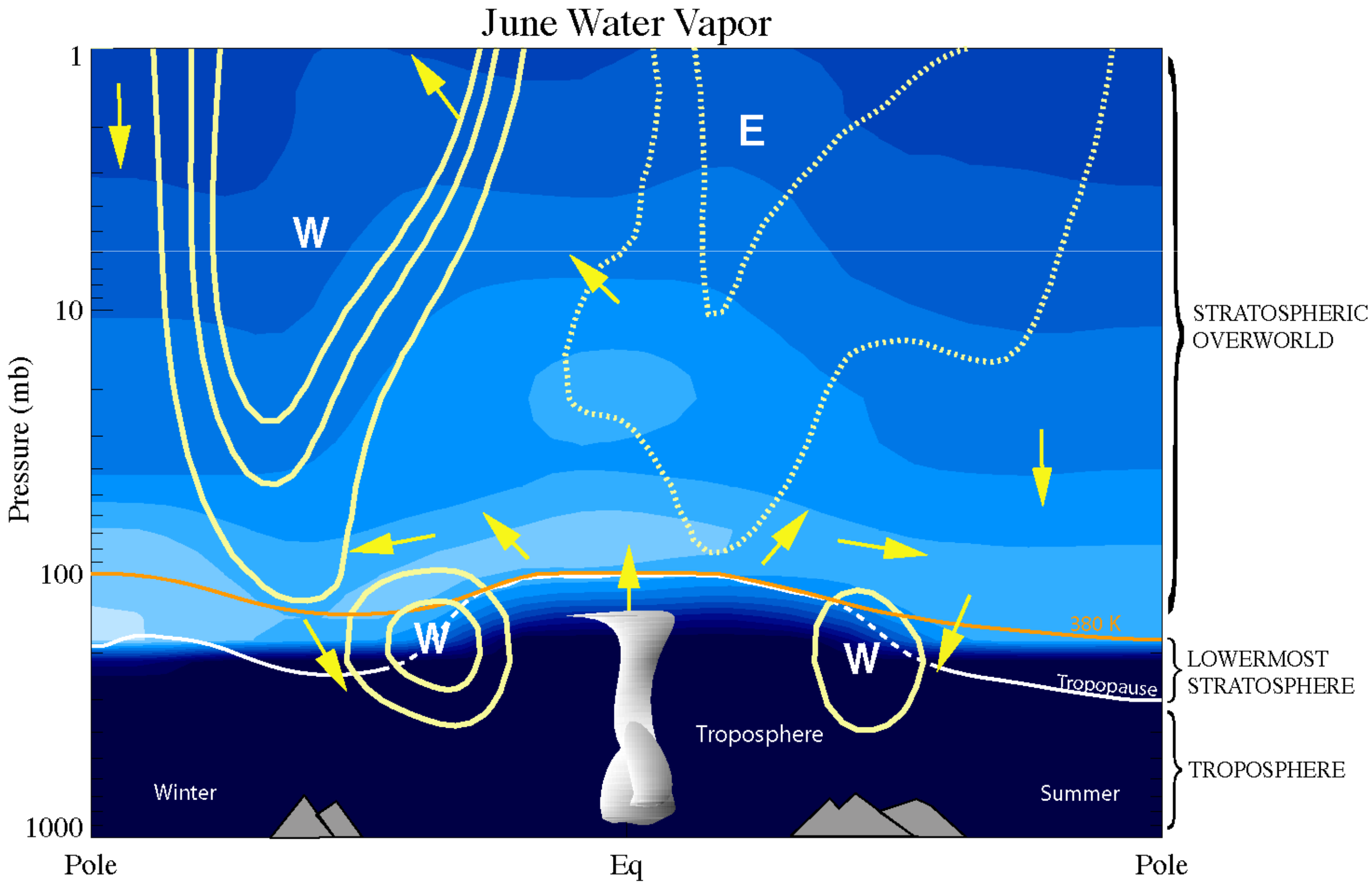
FIG. 3. Dehydration volume based on ERA-15 monthly mean temperatures. The blue curve is DV for the entire Tropics and the red curve is for the western Pacific (120°–210°E).

tropical anomalies, shows QBO entry values moving upwards in the tropical pipie region

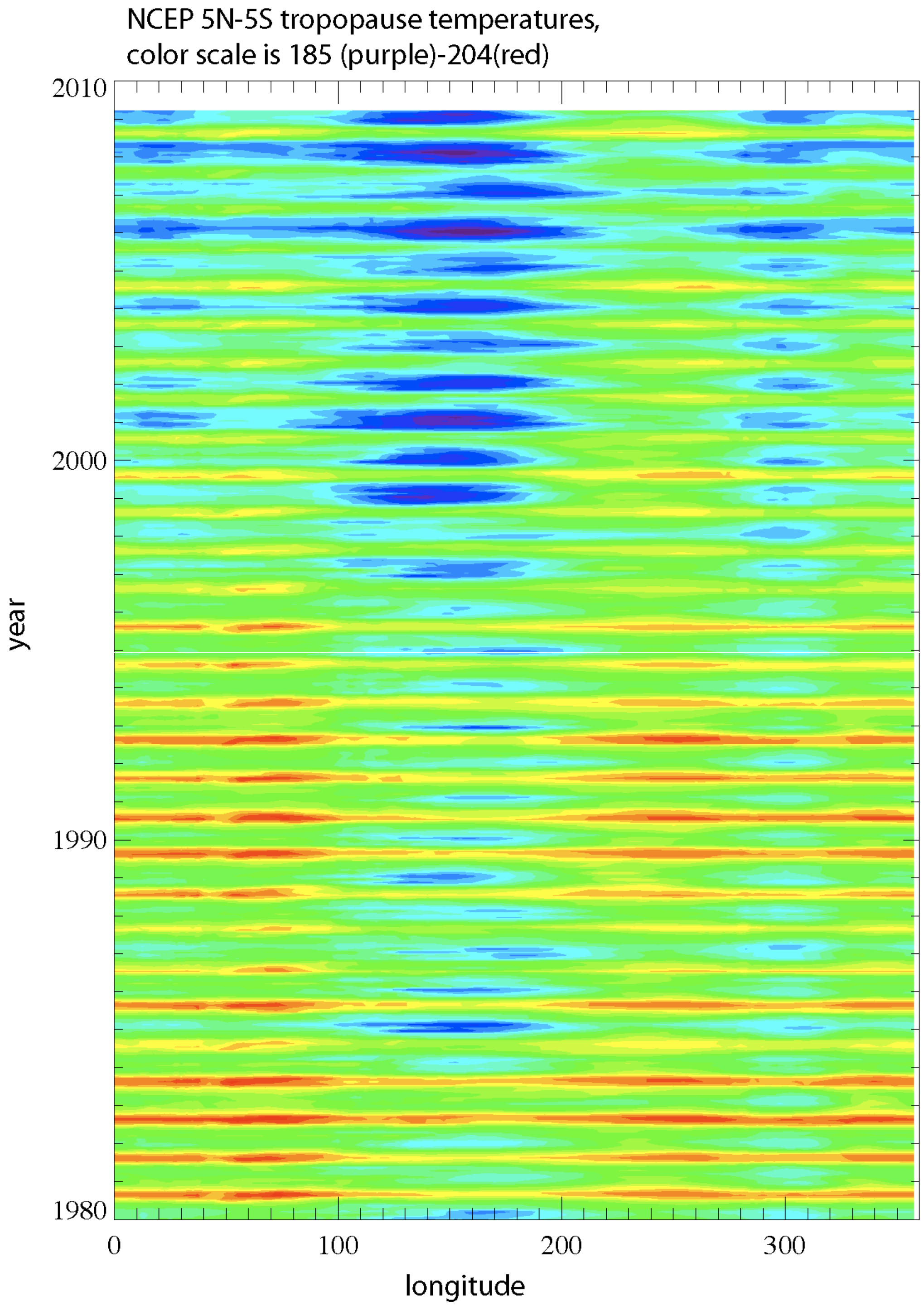


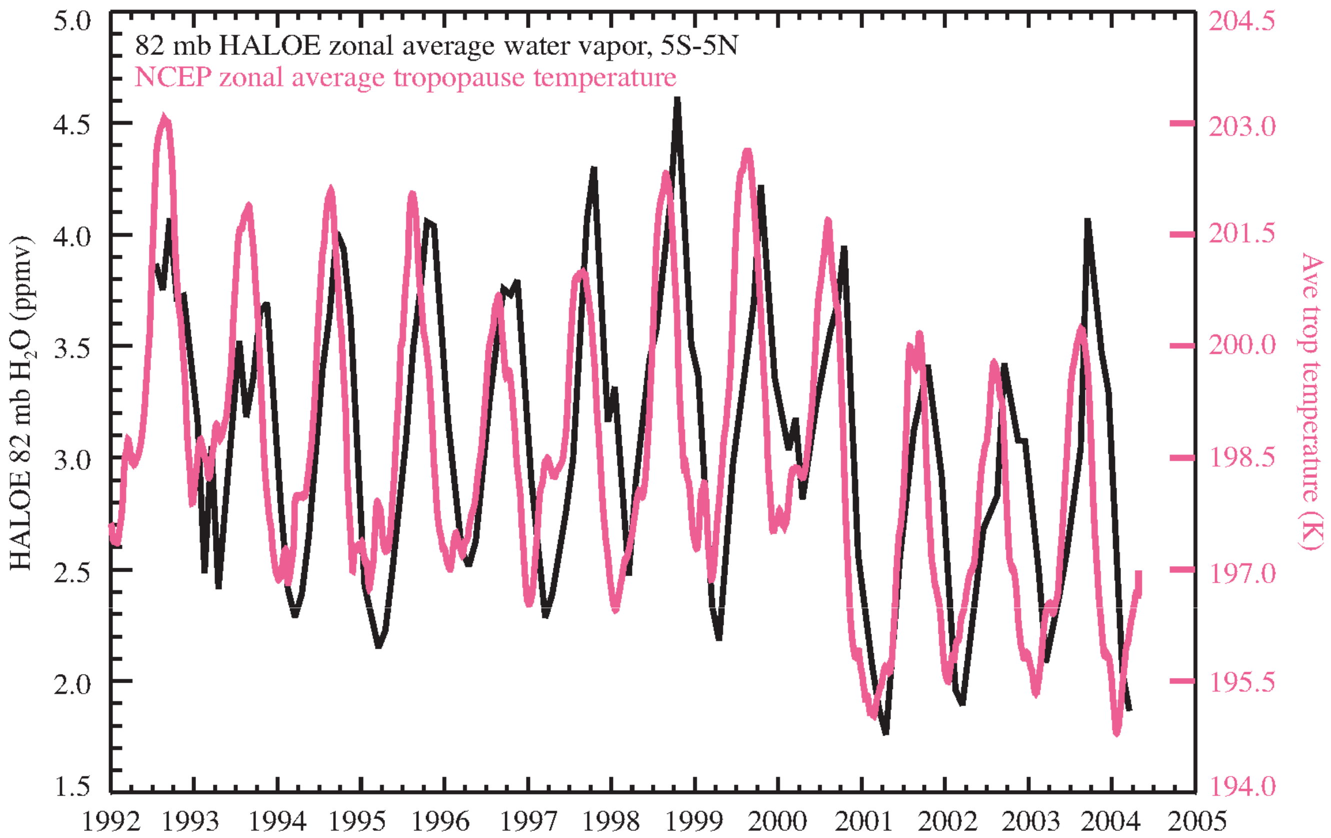
Annual cycle

Water vapor is impacted on the annual cycle both via cycles in tropical cold point temperature and via variations in the global Lagrangian mean circulation (Brewer-Dobson circulation)

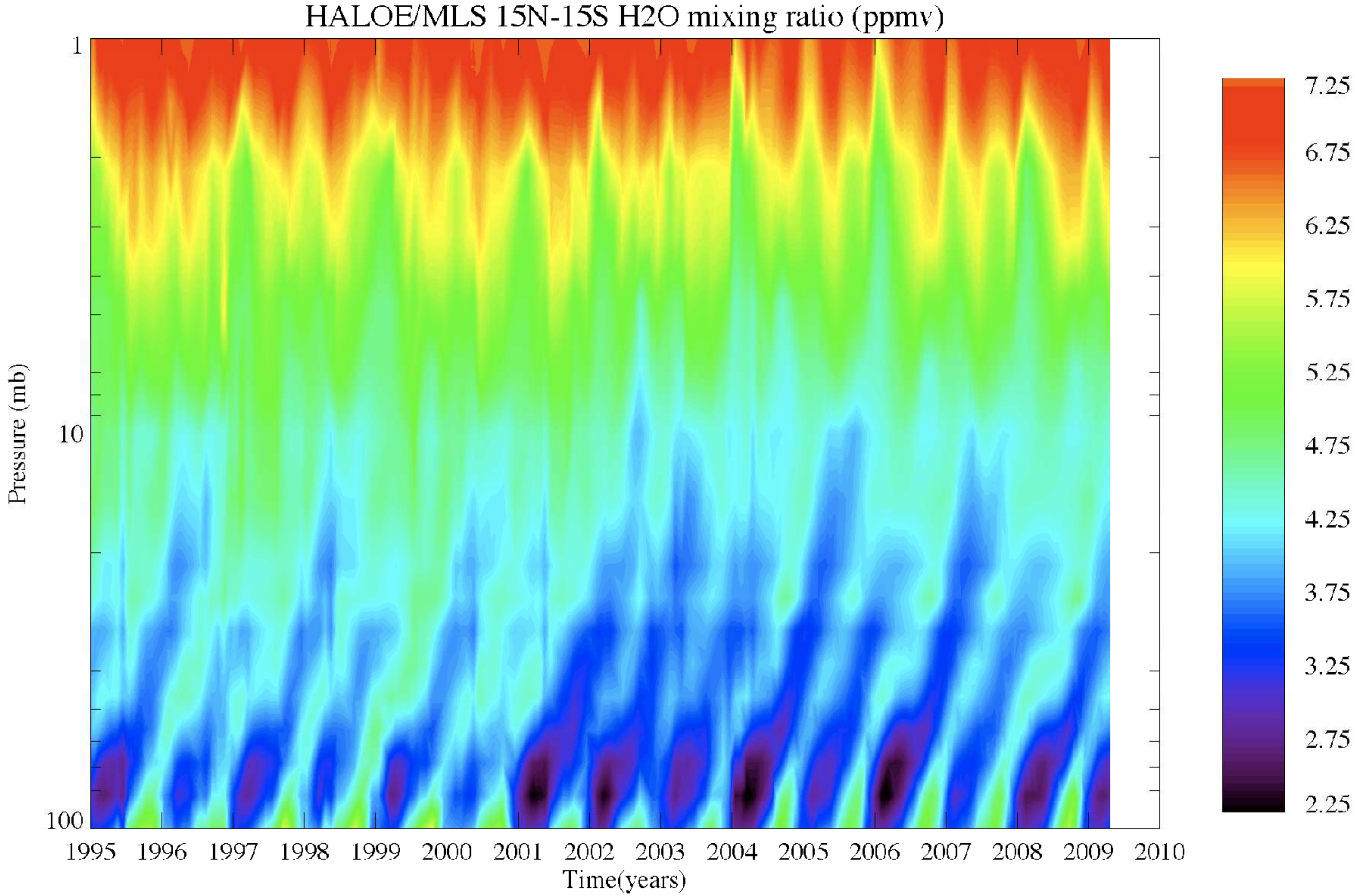


Shows annual cycle in tropical near tropopause temperatures as function of longitude



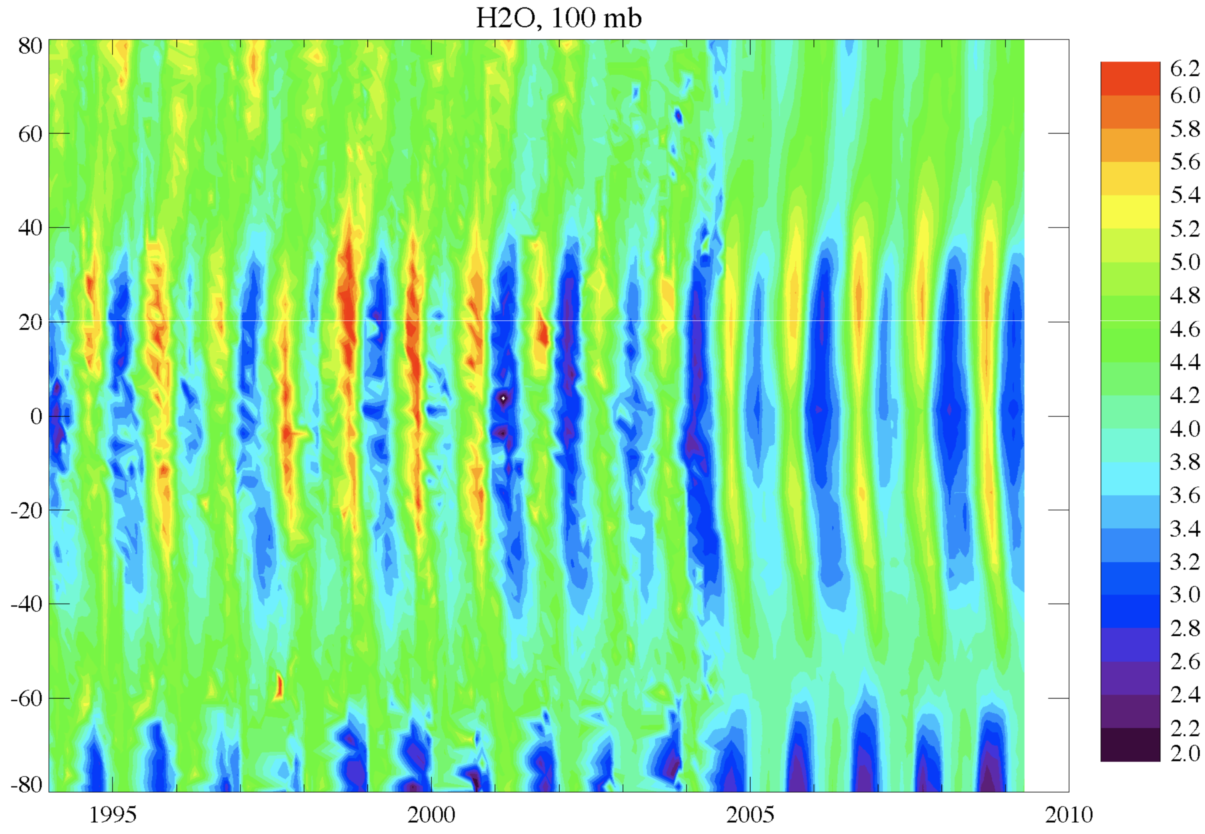


Shows annual cycle temperature water relationship in the tropics. Magnitude of the annual cycle in entry value is


HALOE/MLS 15N-15S H2O mixing ratio (ppmv)
Pressure (mb)
1
10
100
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Time(years)
7.25
6.75
6.25
5.75
5.25
4.75
4.25
3.75
3.25
2.75
2.25

Annual cycle temperature amplitude, ~5K peak to peak

Annual cycle H_2O amplitude, ~1.5-2 ppmv (~40% of the mean)



climo developed in Randel et al, 1998.

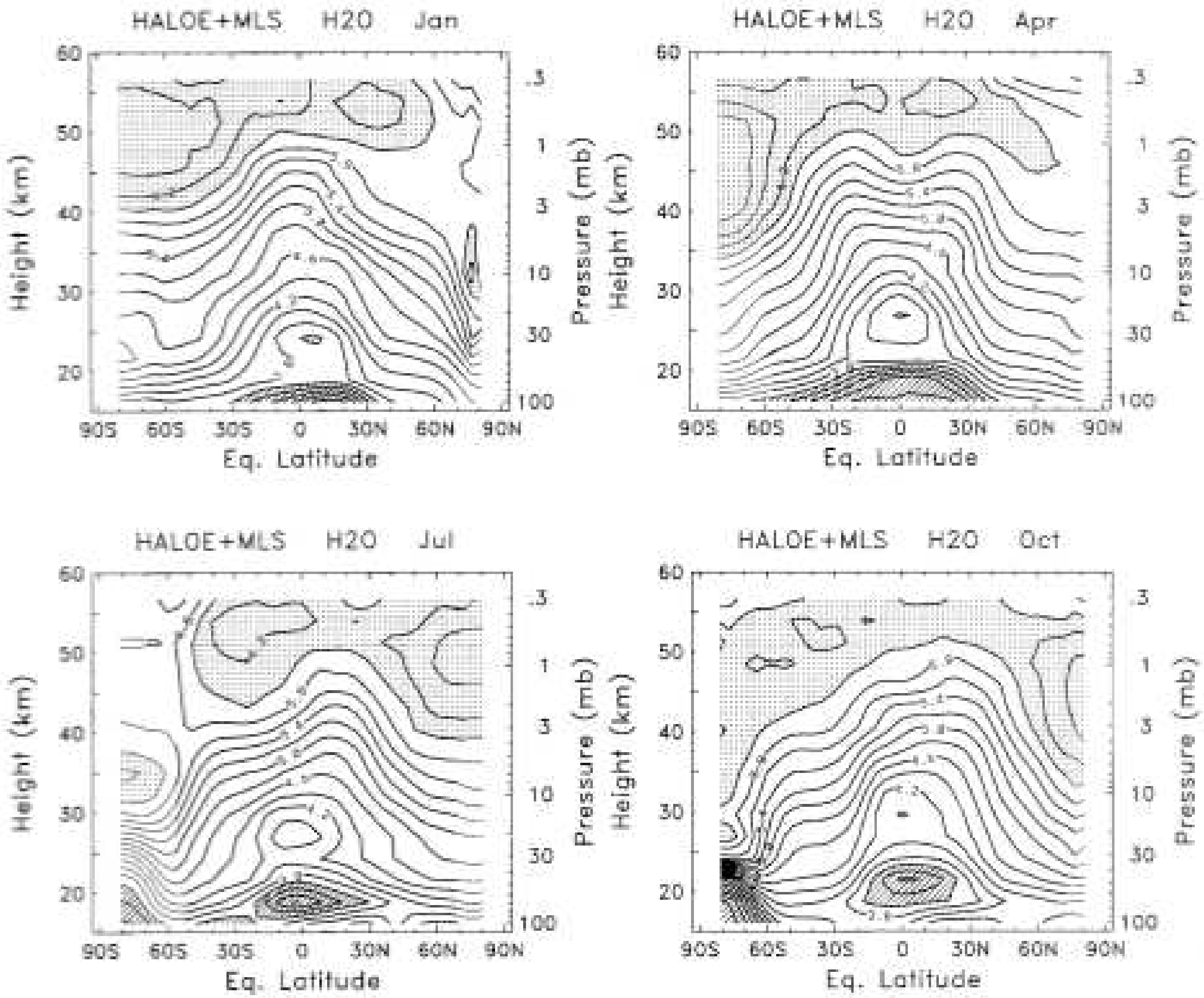
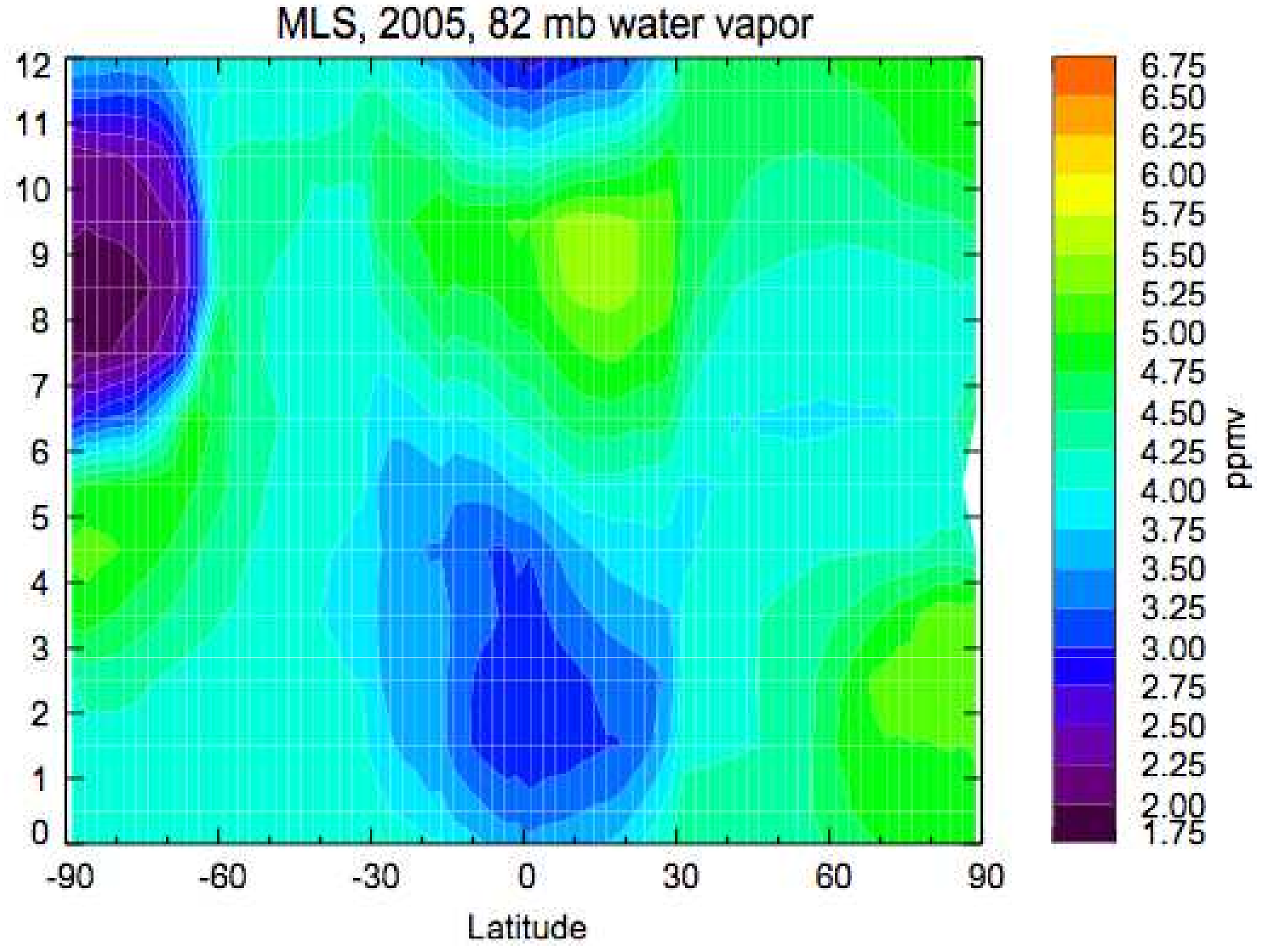


Fig. 7. Seasonal cycle estimates of H_2O in January, April, July, and October. Contour interval is 0.2 ppmv. Values below 3.6 ppmv are hatched, and values above 6.0 ppmv are stippled.



high latitude SH cycle due to Antarctic dehydration, high latitude NH cycle due to annual variations in downwelling.

Annual cycle in tropical cold point temperatures:

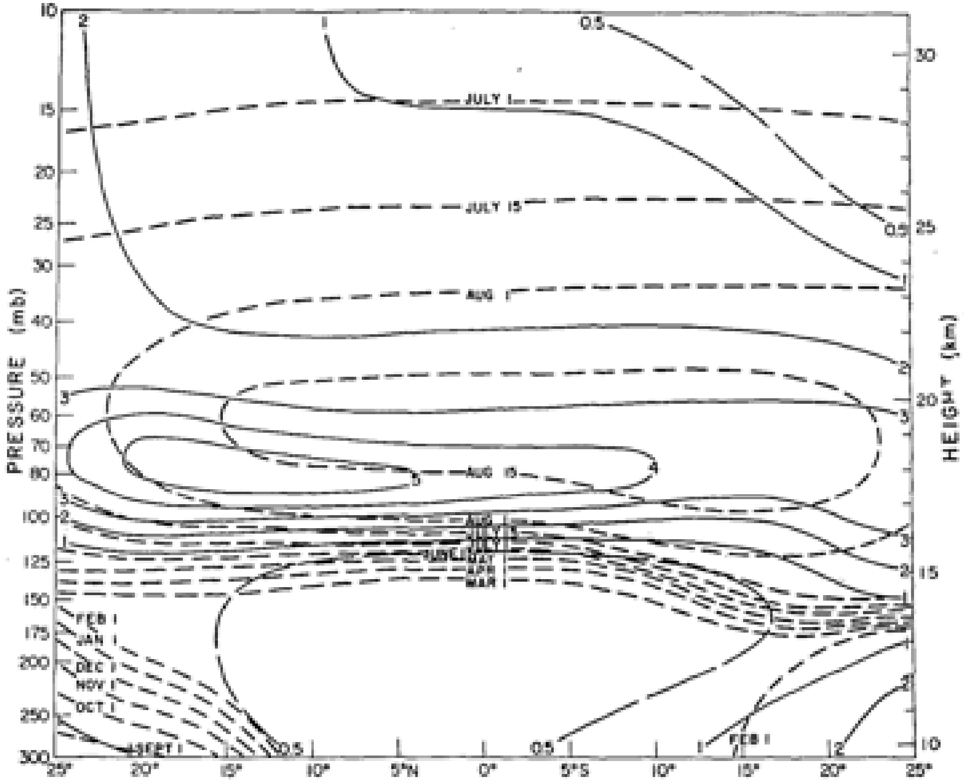
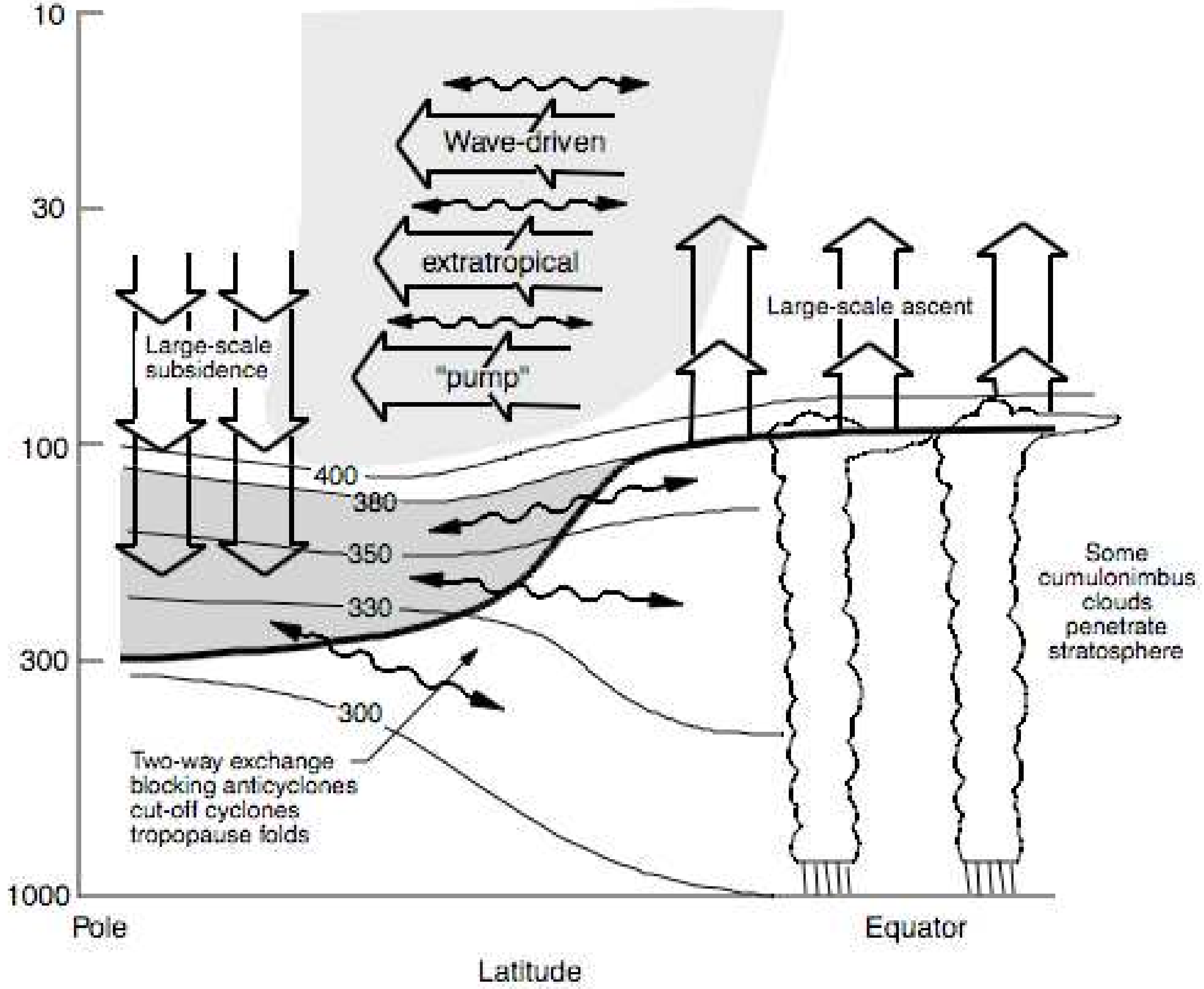


FIG. 1. Amplitude and timing of the peak of the annual temperature cycle as a function of latitude and height, based on harmonic analysis of extended records of radiosonde data. After Reed and Vlcek (1969).

related to the annual variation in strength in the Brewer-Dobson circulation

Holton et al. 1995 (Geophysical review paper)



Variations in the strength of the circulation are related to variations in wave driving at latitudes poleward of the tropics, and above the cold point level. (Downward control, Haynes et al., 1991)

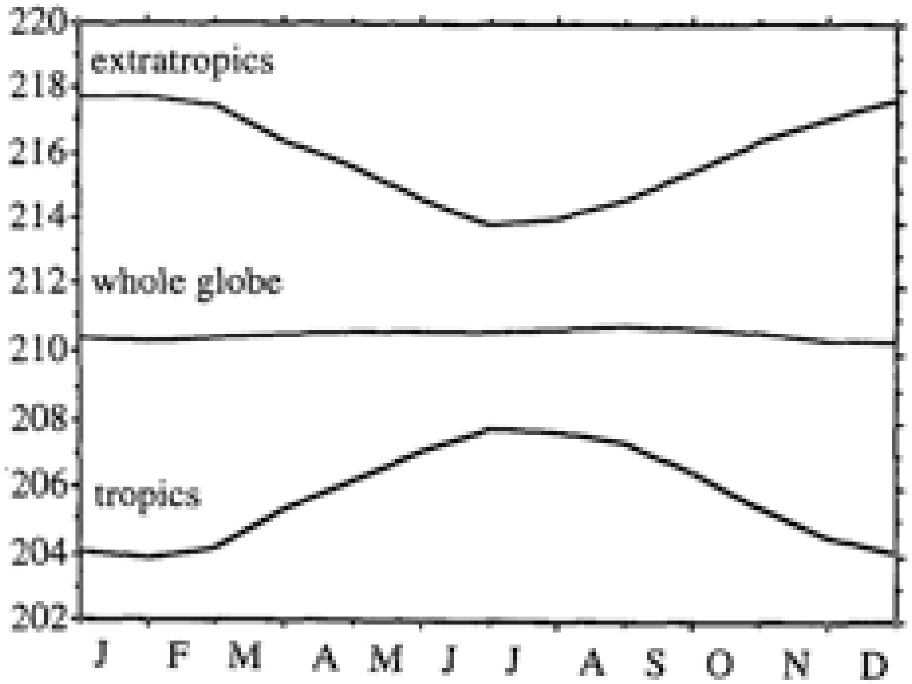


FIG. 2. Climatological mean annual march of lower-stratospheric temperature based on MSU-4 data for the period 1979–91, averaged over the tropics (30°S–30°N), the extratropics (poleward of 30°S and 30°N), and the entire globe.

from yulaeva et al, 1994

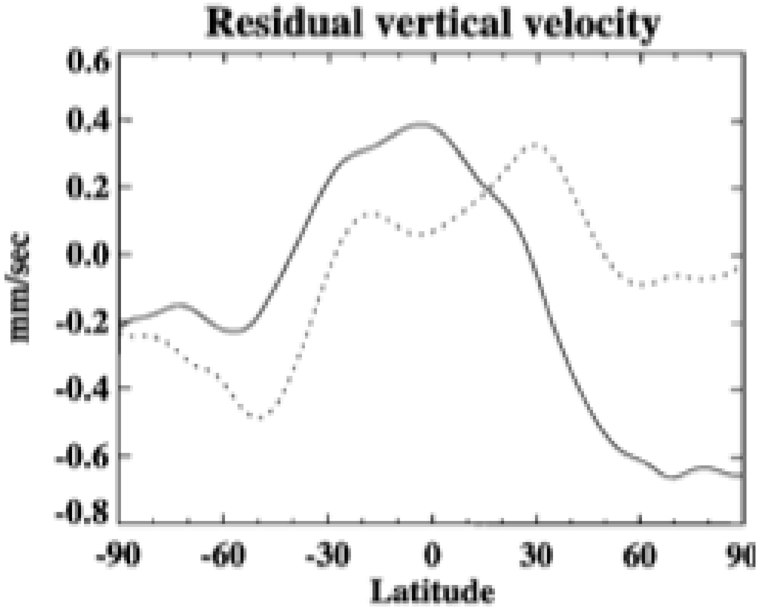


Figure 13. Latitudinal cross section of radiatively derived residual vertical velocity at 70 hPa for January (solid curve) and July 1993 (dashed curve).

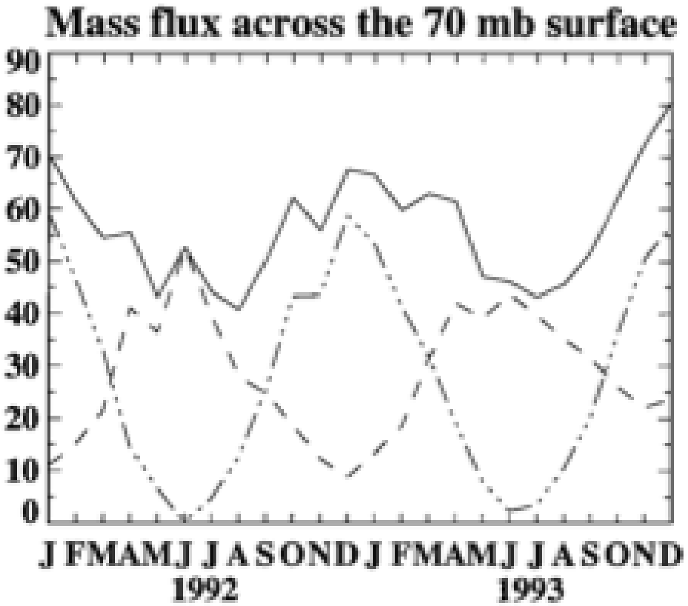


Figure 14. Time series of mass flux across the 70-hPa surface in units of 10^8 kg/s computed from the radiatively derived stream function. Solid curve is the net upward tropical flux; dotted-dashed curve is downward flux into the northern

Conclusions...annual cycle in stratospheric wave driving related to hemispheric assymetries in waves forced, likely due to topography and variations in land sea distributions between NH and SH.

El Nino/Southern Oscillation

Variations in water vapor related to ENSO are again a consequence of ENSO impacted tropical cold point temperatures. These variations are going to be seen primarily in the lower part of the stratosphere.

There is a new paper by Randel et al. (2009) that discusses the relations between ENSO and tropical near tropopause temperatures.

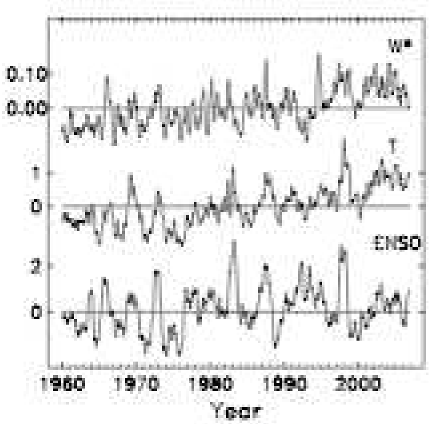


Figure 1. (bottom) Time series of the Multivariate ENSO Index (MEI) used to identify ENSO variability in the statistical regression analysis. (middle) WACCM zonal mean temperature anomalies (K) at 300 hPa, averaged over 30 N–30 S. (top) WACCM residual mean vertical velocity anomalies (mm/sec) at 100 hPa, averaged over 20 N–20 S.

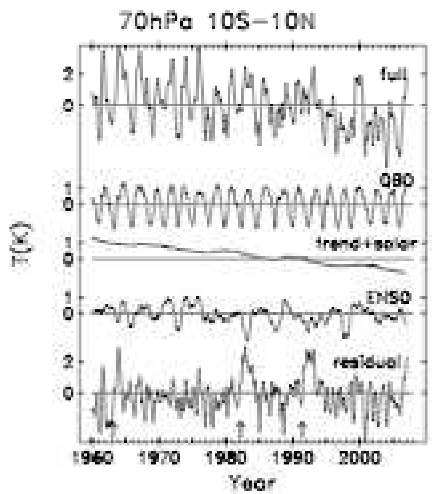
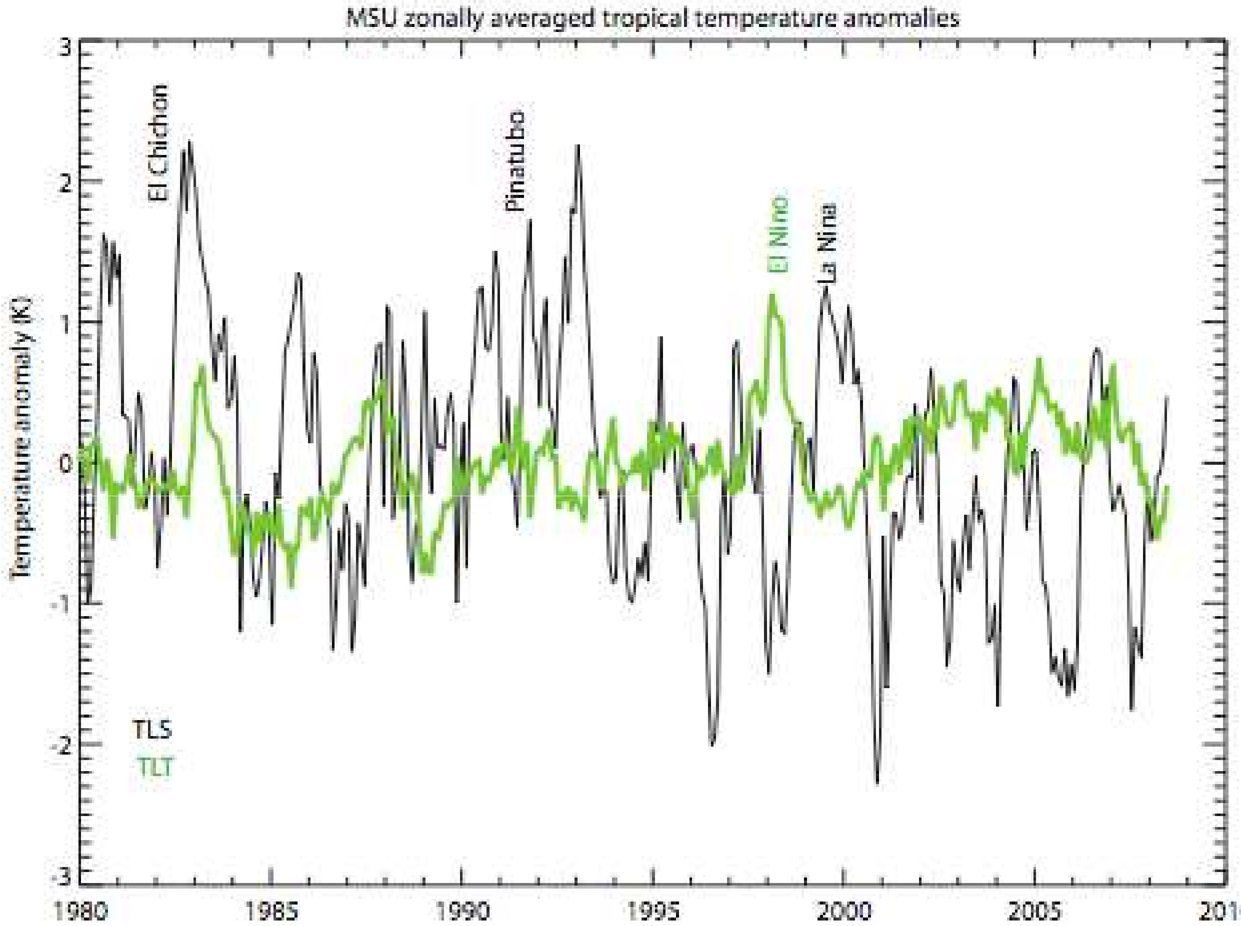
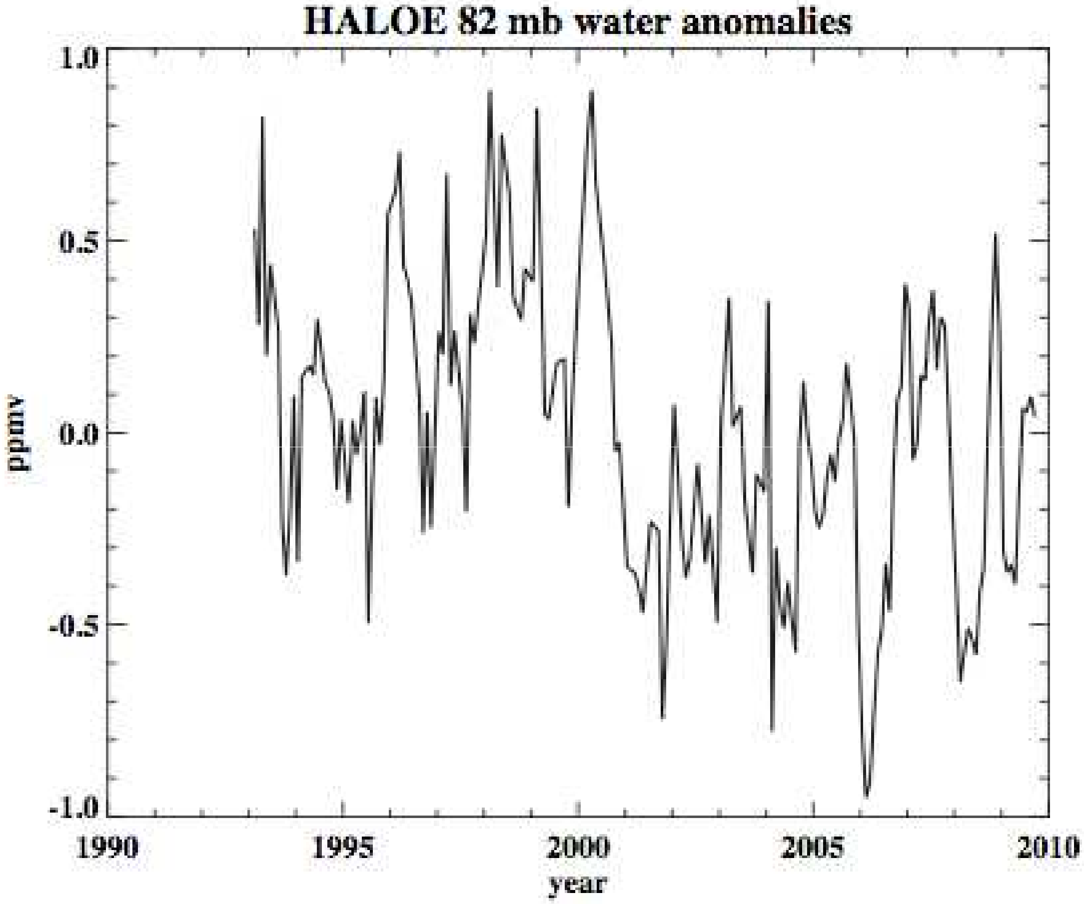


Figure 3. Top curve shows time series of zonal mean temperature at 70 hPa averaged over 10 N–10 S from the RICH radiosonde data set. The lower curves show components of variability derived from the multivariate regression fit, together with the residual. Note that the volcanic warming signals of Agung (1963), El Chichon (1982) and Pinatubo (1991) (noted by the arrows) are clearly seen in the residual time series, although not evident amid the other variability in the full time series.


MSU zonally averaged tropical temperature anomalies
Temperature anomaly (K)
El Chichon
Pinatubo
El Nino
La Nina
TLS
TLT
3
2
1
0
-1
-2
-3
1980
1985
1990
1995
2000
2005
2010

If ENSO impacts the cold point temperatures, one would also expect to see a response in water vapor entry. Geller et al. 2001 suggested this would occur in a modeling study. Observations tend to show a hint of this (in particular a response to the extended La Nina in around 2000), but there may not be a long enough period with good water vapor data in the absence of aerosol effects to say definitively.


HALOE 82 mb water anomalies
1.0
0.5
0.0
-0.5
-1.0
ppmv
1990
1995
2000
2005
2010
year

Summary:

Water vapor variations due to annual, semiannual and QBO periods appear to be the largest source of variability in stratsopheric water vapor.

ENSO variations may be acting as well, but it is harder to assess.

Variability in stratospheric water vapor in the mid to upper stratosphere is largely a function of variability in the Brewer Dobson circulation strength (and will be accompanied by similar variations in methane of the oppposite sign).

Variability in the lower stratosphere is largely a function of variability in tropical cold point temperatures.

Trends and an example of an abrupt change will be addressed tomorrow, and trends and monsoon impacts will also be addressed by Bill Randel next week.