Water vapour : stratospheric variability - II

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Cargèse International School
Water Vapour in the Climate System (WAVACS)
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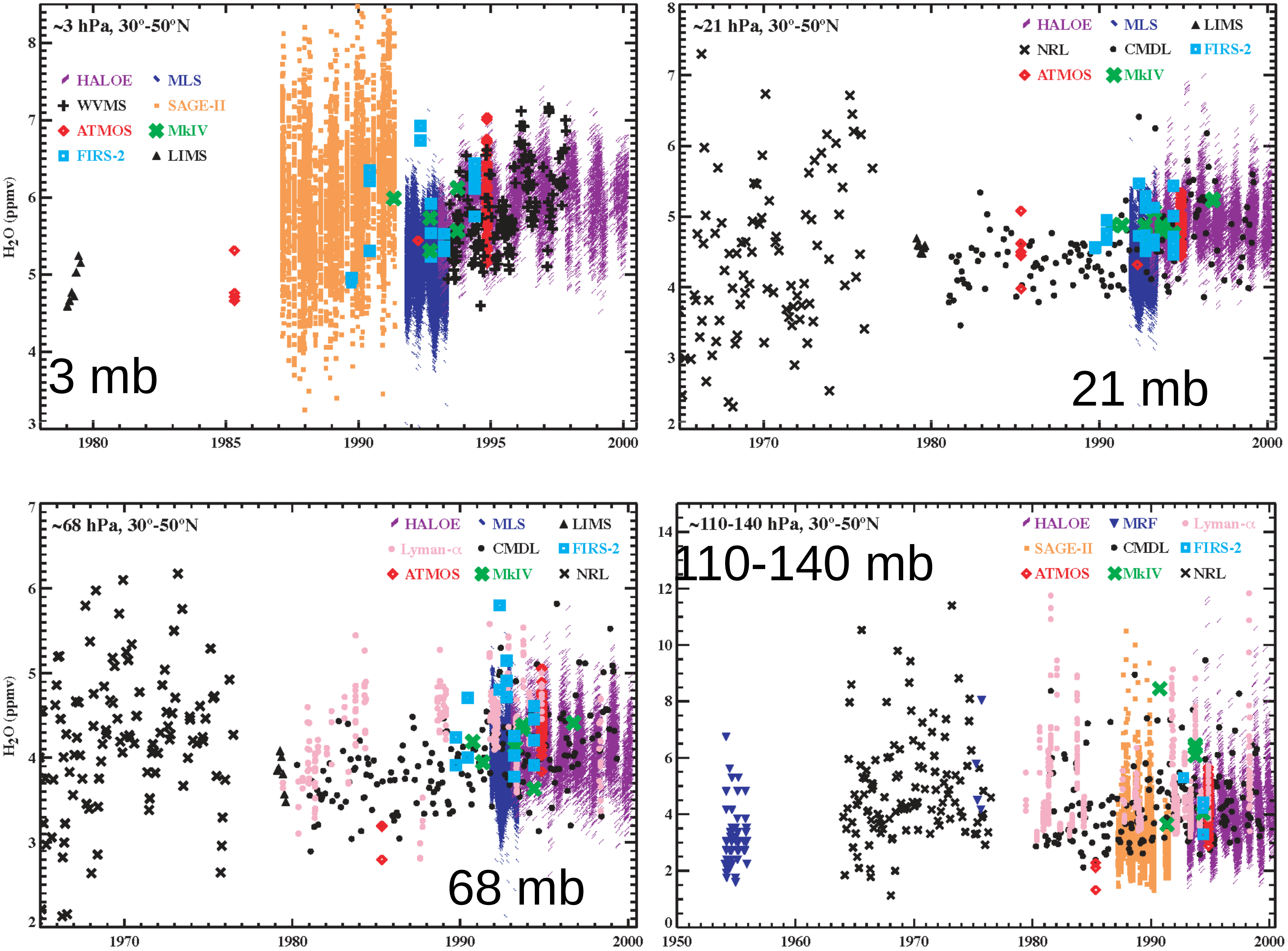
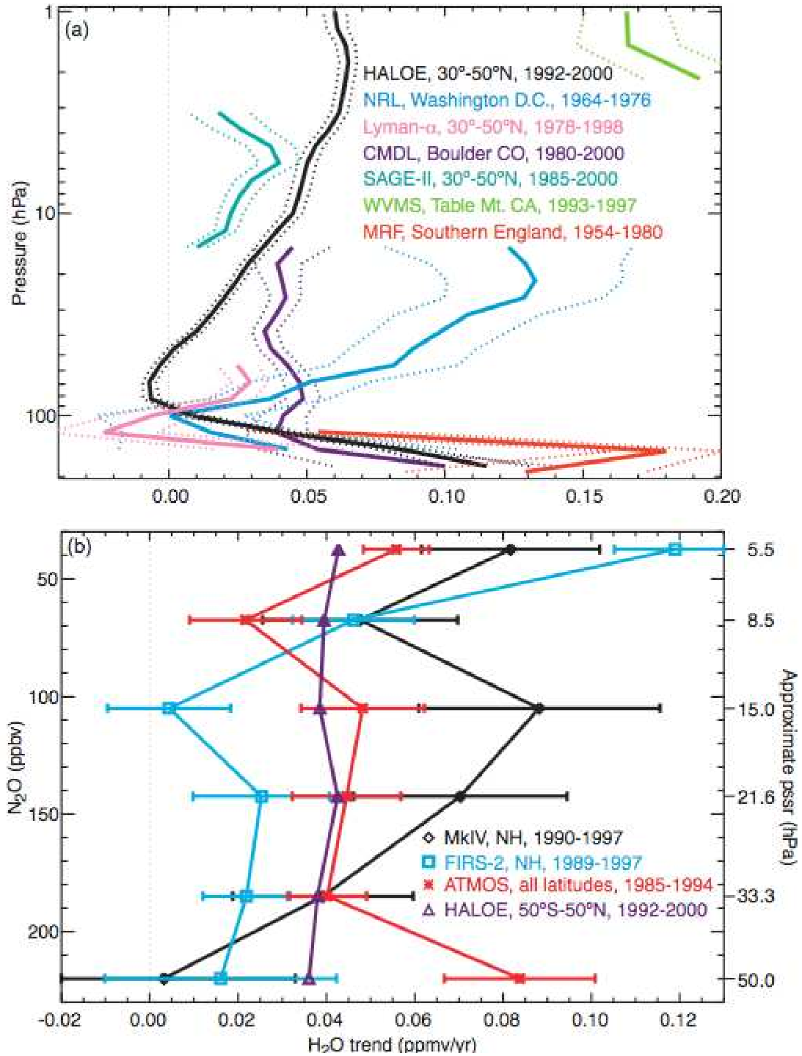
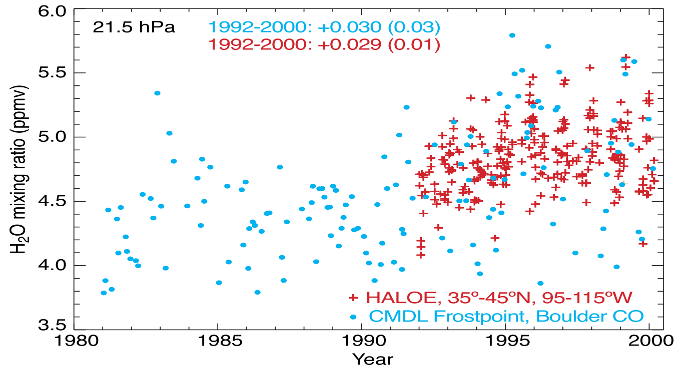
Lecture 3 of 4

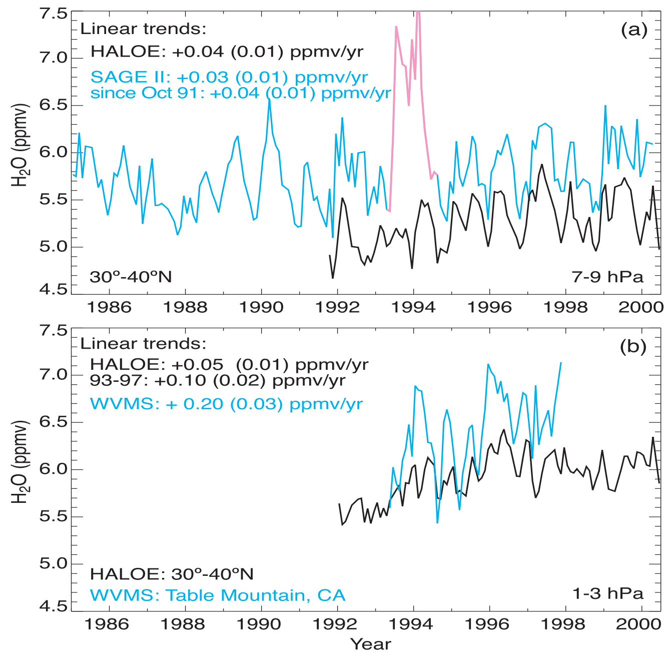
Long-term changes in stratospheric water vapor

SPARC WAVAS, 2000, 20-50ºN historical measurements









1) Linear terms largely positive: average = 0.045 ppmv/yr

2) Vertical structure in trends: minimum at 100-60 mb

3) When time periods overlap, trend calculations are similar for different data sets.

4) Over all conclusion: there was a trend over the time period considered, exact mechanism not fully understood.

(from Rosenlof et al, 2001, GRL)

Boulder FP data was recently quality controlled, and bias corrections in the early period were applied

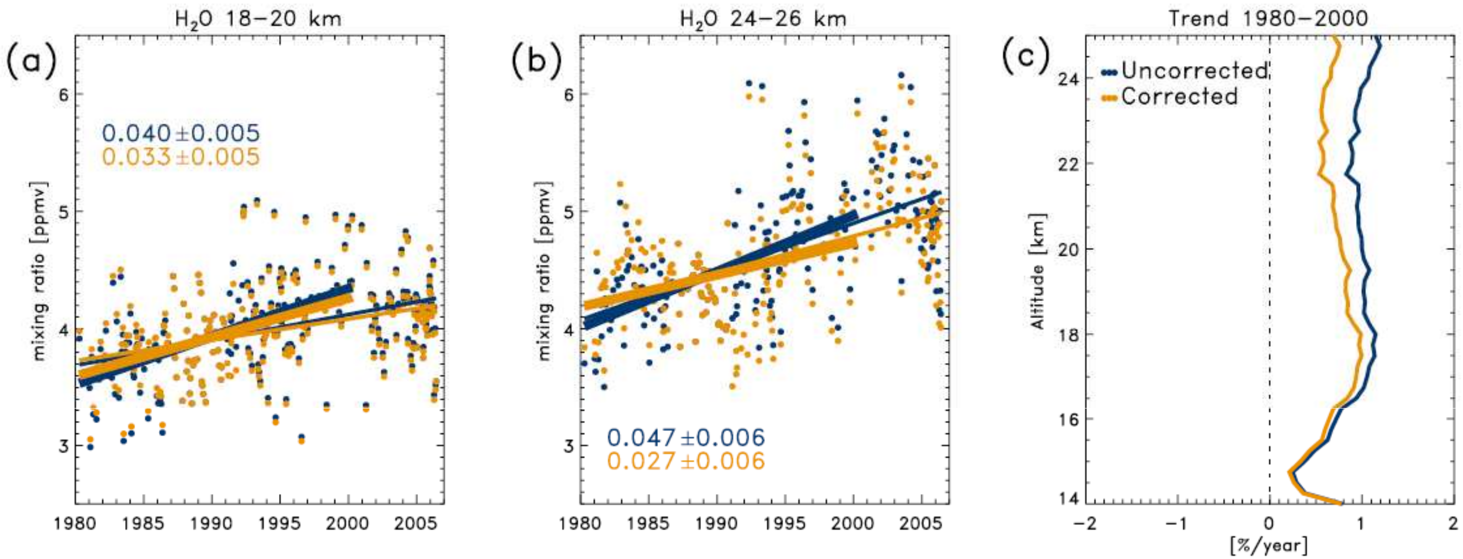
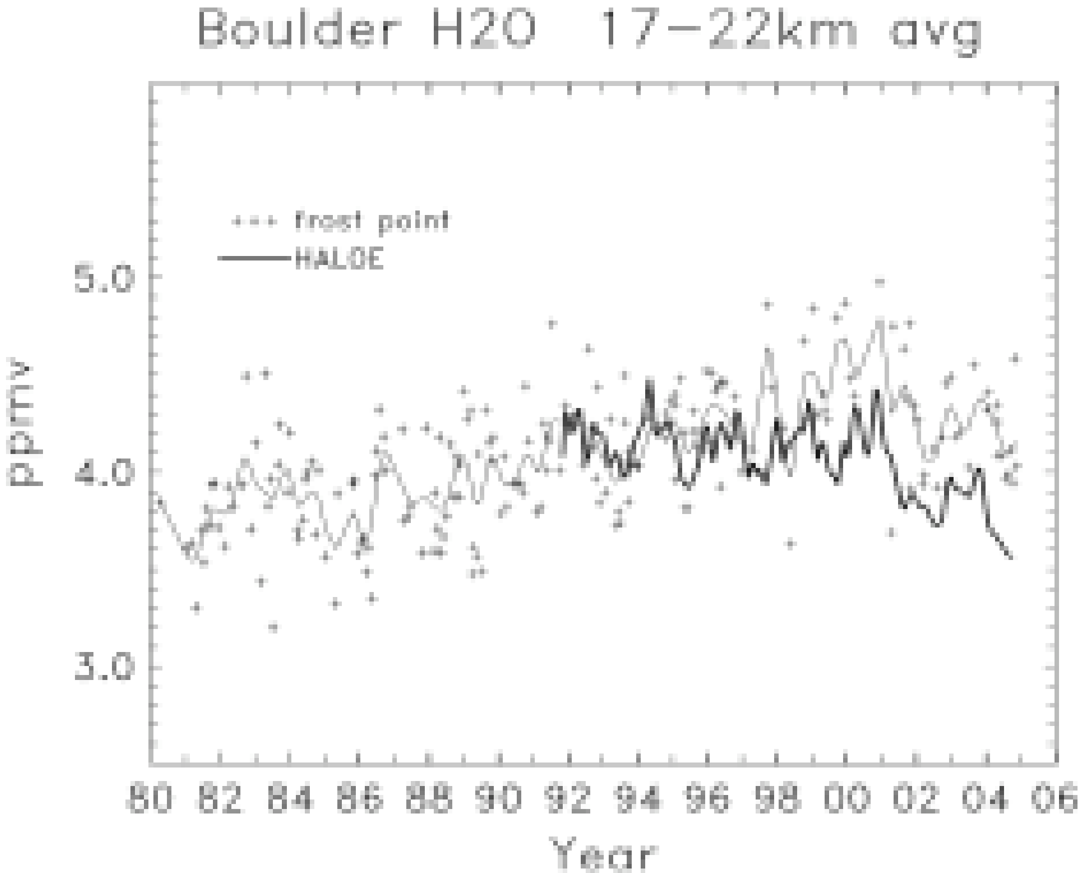


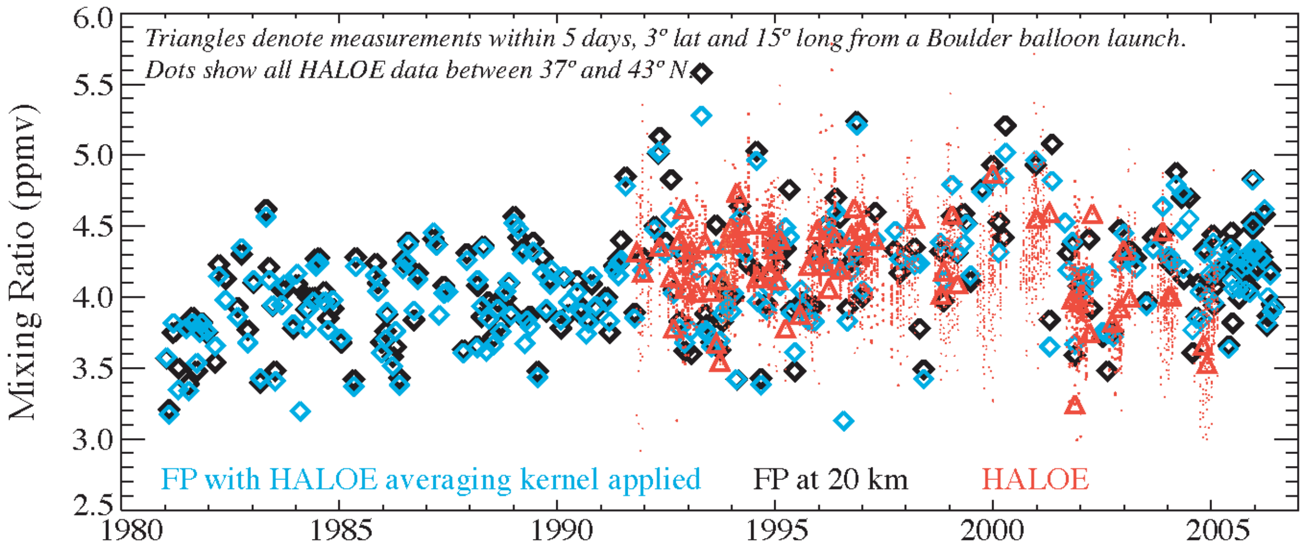
Fig. 1. Linear trend estimates of stratospheric water vapour from NOAA FP measurements. **(a)** For 18–20 km; **(b)** for 24–26 km; **(c)** trend profiles (in percent per year, confidence intervals omitted for clarity). Blue/yellow show uncorrected/corrected data, no correction applied for period 1987–1991. Trends for period 1980–2000 (slope and 2-σ uncertainty printed in panels a/b) for comparison with Oltmans et al. (2000). Note trend reduction of up to 40% due to data correction.

There are some disagreements between the Boulder frost-point and coincident satellite record in regards to long-term changes.

These differences are detailed in Randel et al., 2004 (Interannual Changes of Stratospheric Water Vapor and Correlations with Tropical Tropopause Temperatures , JAS)



NOAA CMDL/GMD frostpoint balloon and HALOE at 20 km

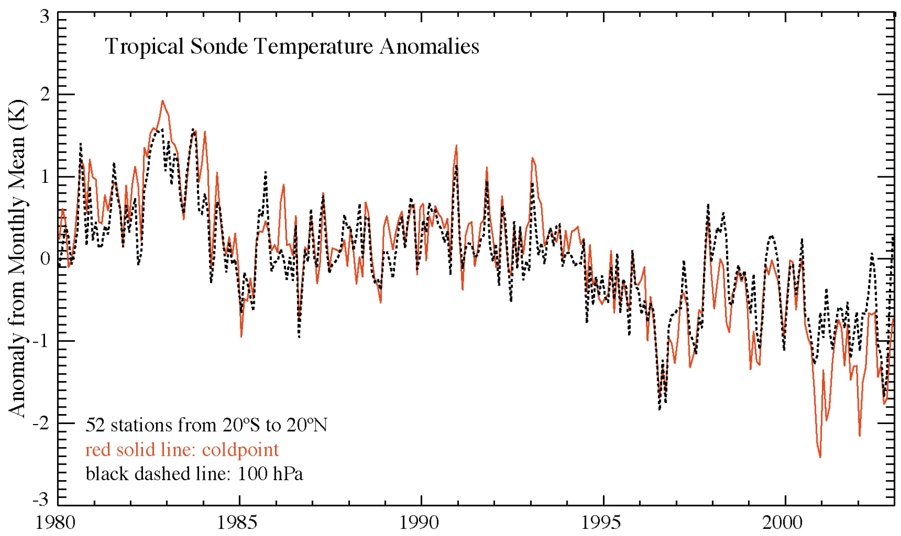


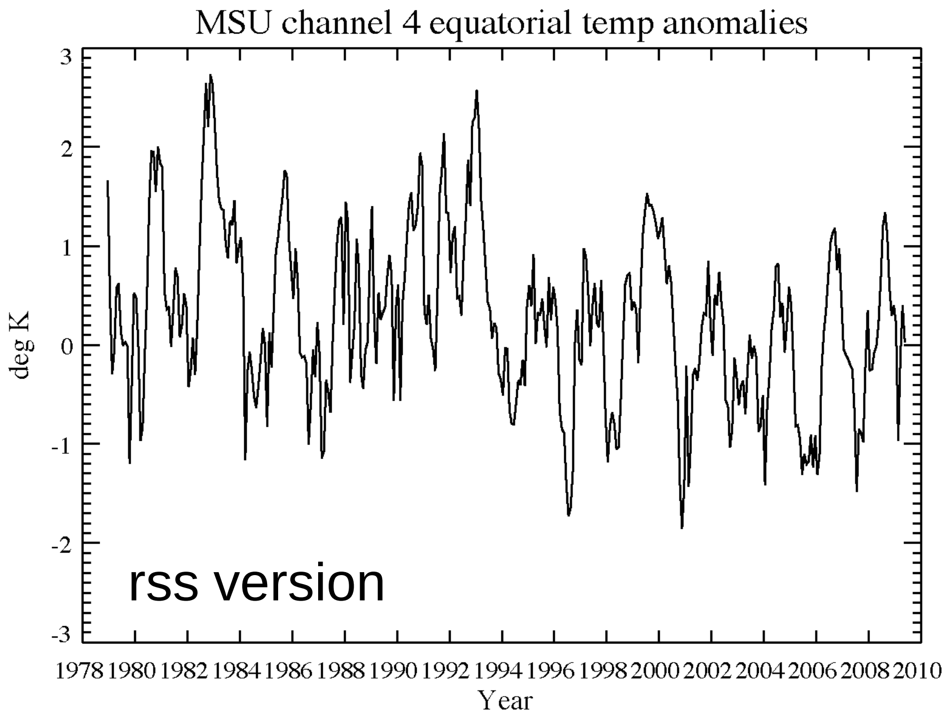
Boulder/HALOE comparison using updated frostpoint data set from Scherer et al, 2008

Trend in the corrected Boulder data set is is now .6% per year (~.03 ppmv/year). Rohs et al. (2006) show that methane can account for ~30% of a 1%/year increase (or ~.0132 ppmv/year). This is approximately half the observed increased...reasons for the remainder are unknown.

(as a comparison, annual cycle peak to peak amplitude in stratospheric entry levels values is ~1.5 ppmv, this is 0.3 ppmv over a decade.

An important unknown is why there is an increasing trend in middle latitude stratospheric water vapor from the suite of historical data in the presence of an apparent decreasing trend in tropical near tropopause temperatures (or at least a not increasing trend). (Zhou et al., 2001; Seidel et al., 2001, there are also significant uncertainties associated with estimating tropopause and lower stratospheric temperatures... also see Randel et al., 2009, JGR, An update of observed stratospheric temperature trends,doi:10.1029/2008JD010421





One possible explanation that has been discussed in the literature is that the increase could be due to changes in aerosol loading impacting microphysical processes near the tropical tropopause (Sherwood, 2002, Science).

> *More aerosols from biomass burning in the tropics could lead to smaller ice crystals in towering cumulus, and thereby more water vapor entering the stratosphere.*

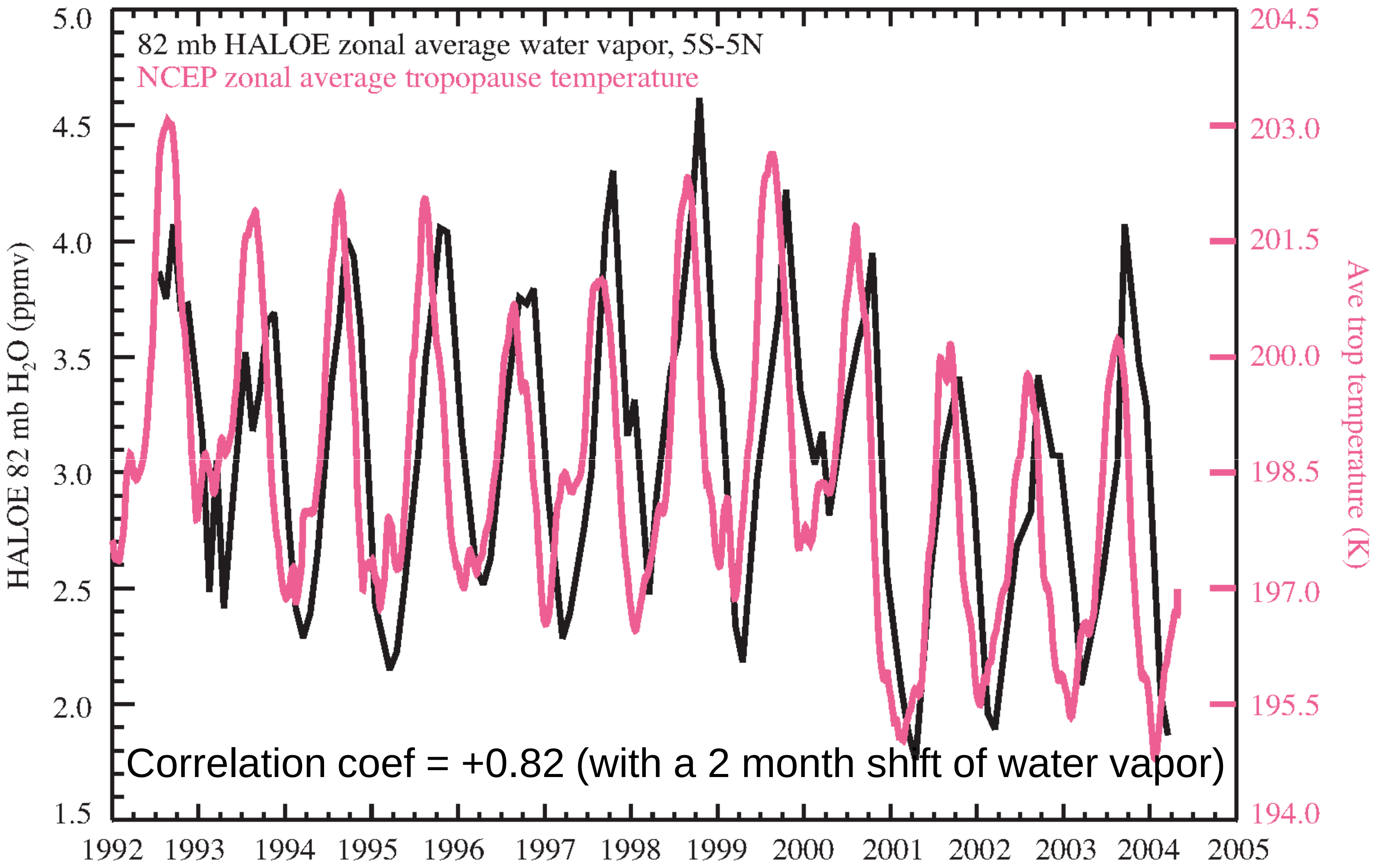
Another possibility: changes in the residual circulation, in particular associated with the width of the upwelling region; Increased in the latitudinal extent of the tropics could increase water in the stratosphere (Zhao, Geller and Zhang, 2001, JGR, Rosenlof, JMSJ, 2002), by bringing up a greater fraction of air at warmer temperatures.

Abrupt change in stratospheric water vapor

(discussed in Randel et al., 2006 and Rosenlof and Reid, 2008, both are JGR papers)

The stratospheric water/near tropopause temperature relationship is robust in the seasonal sense, but is unclear in the long term sense. However, a correlated change in near tropopause or cold point temperature and water vapor is clear at the end of 2000.

Tropical temp & water relationship



5ºN-5ºS water vapor mixing ratio from HALOE at altitude of average profile minimum & NCEP/NCAR reanalysis zonal average tropopause temperature

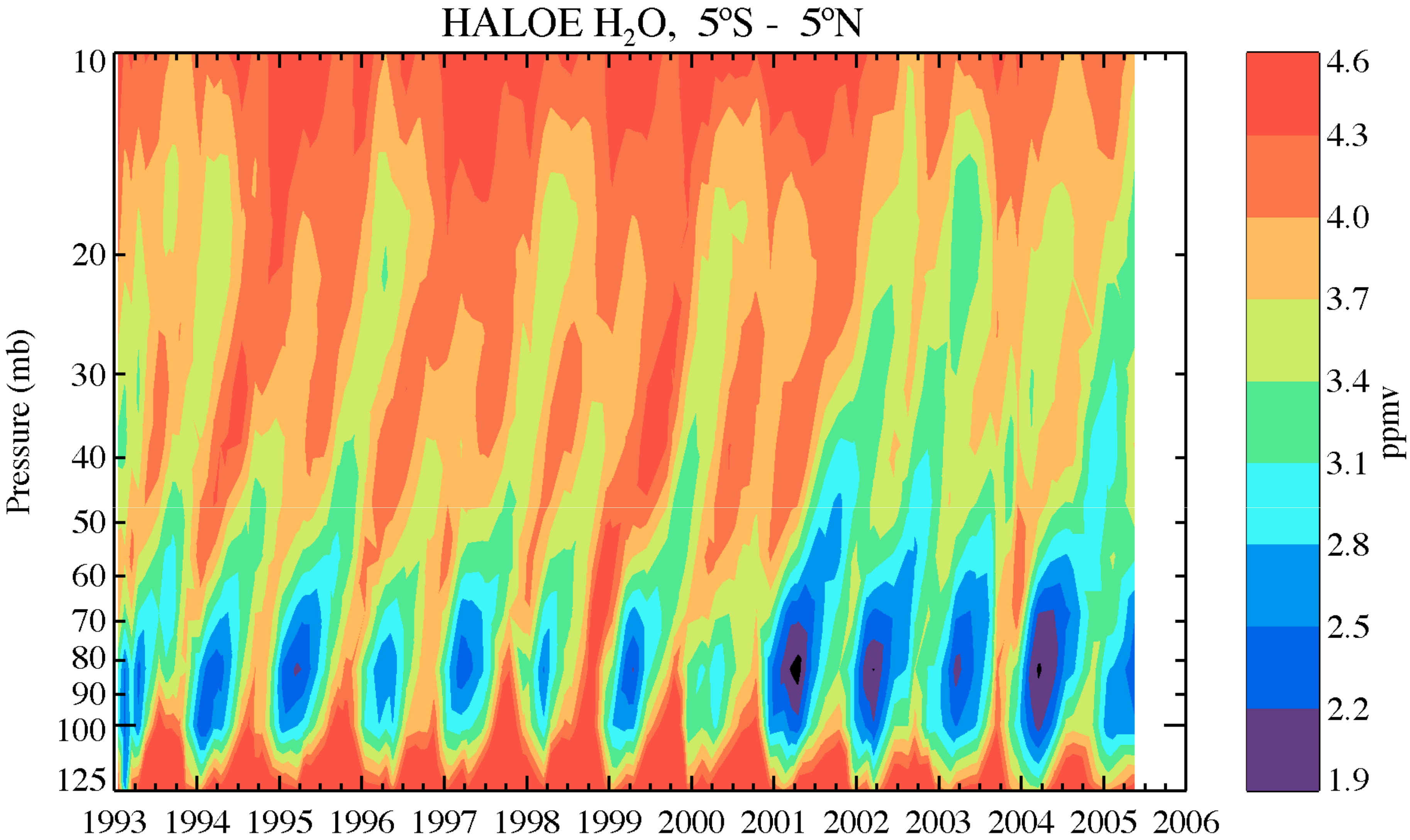
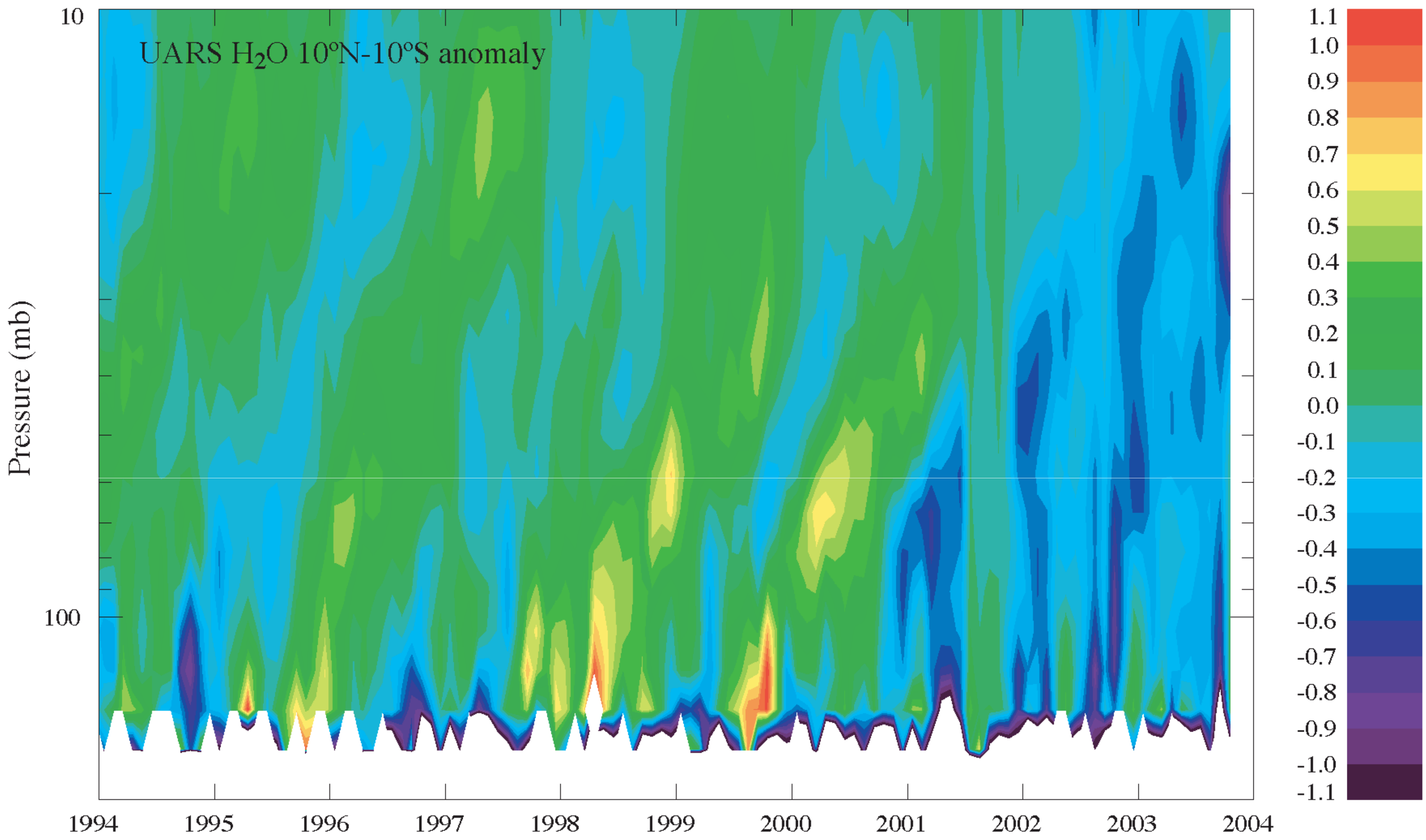
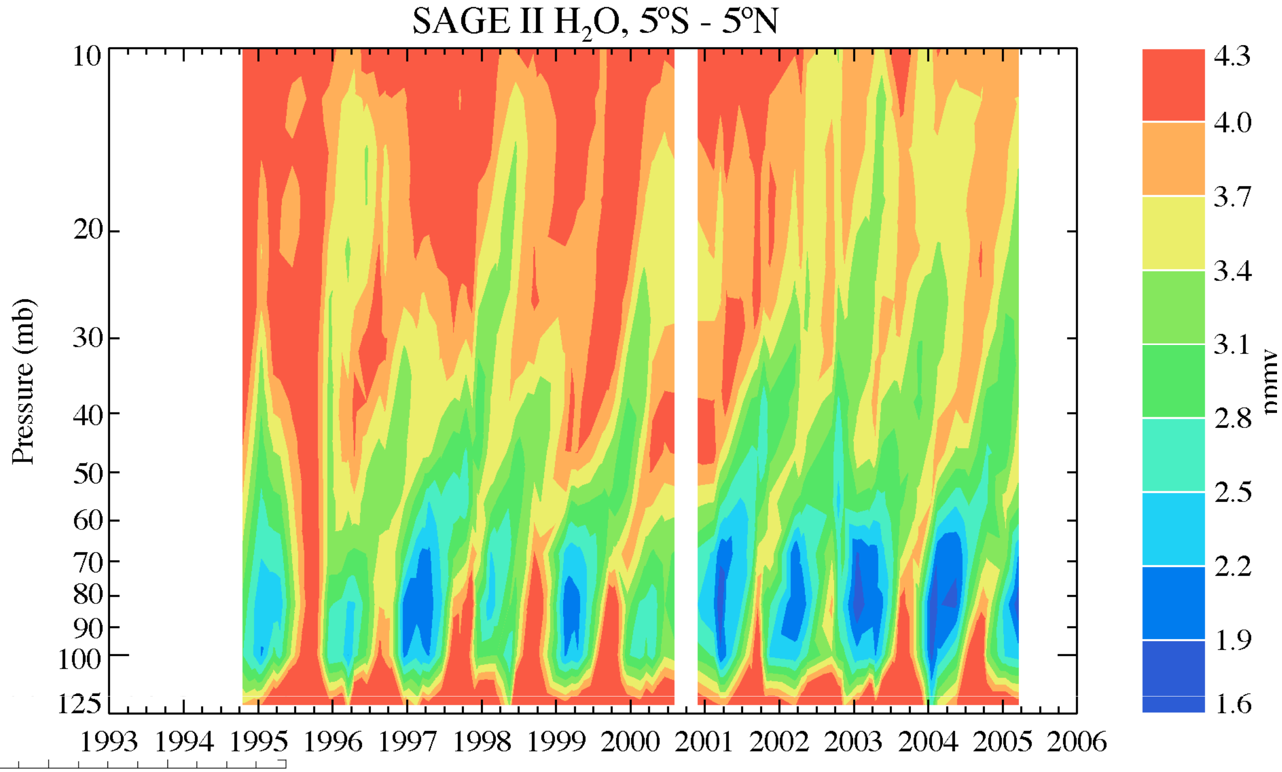


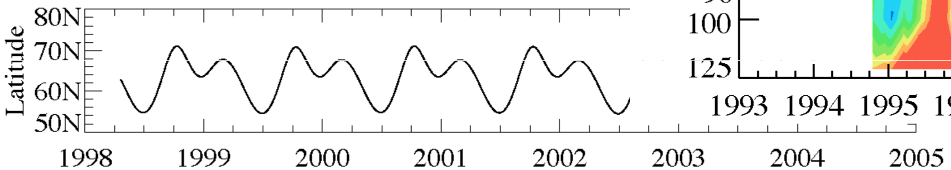
Figure 10. Tropical HALOE water vapor (tape recorder), 5ºS-5ºN, plotted versus time. Note the change to lower values of the hygropause at the end of 2000, and the upward propagation of those lower values in subsequent years.

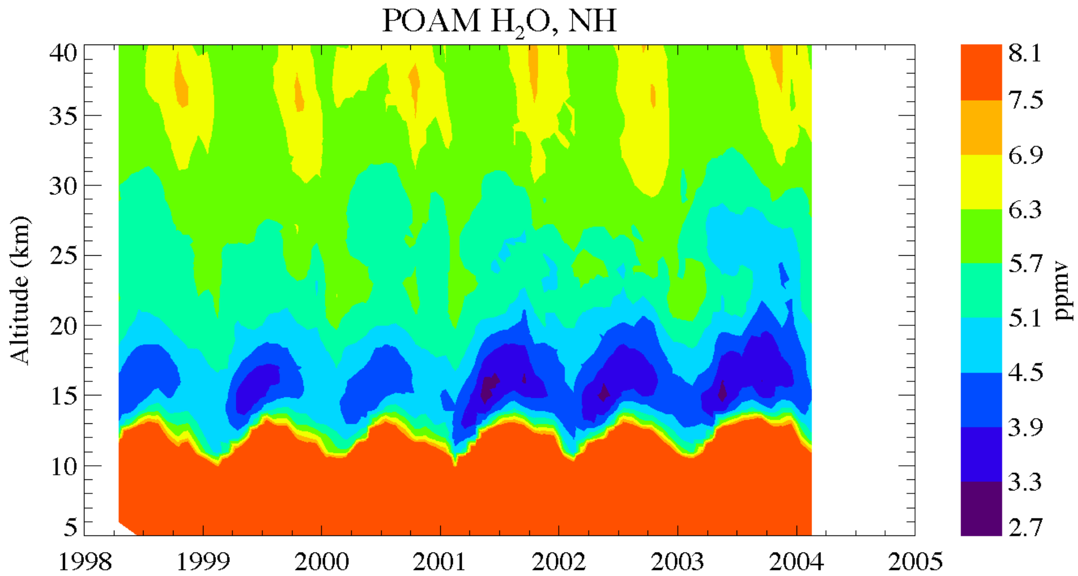


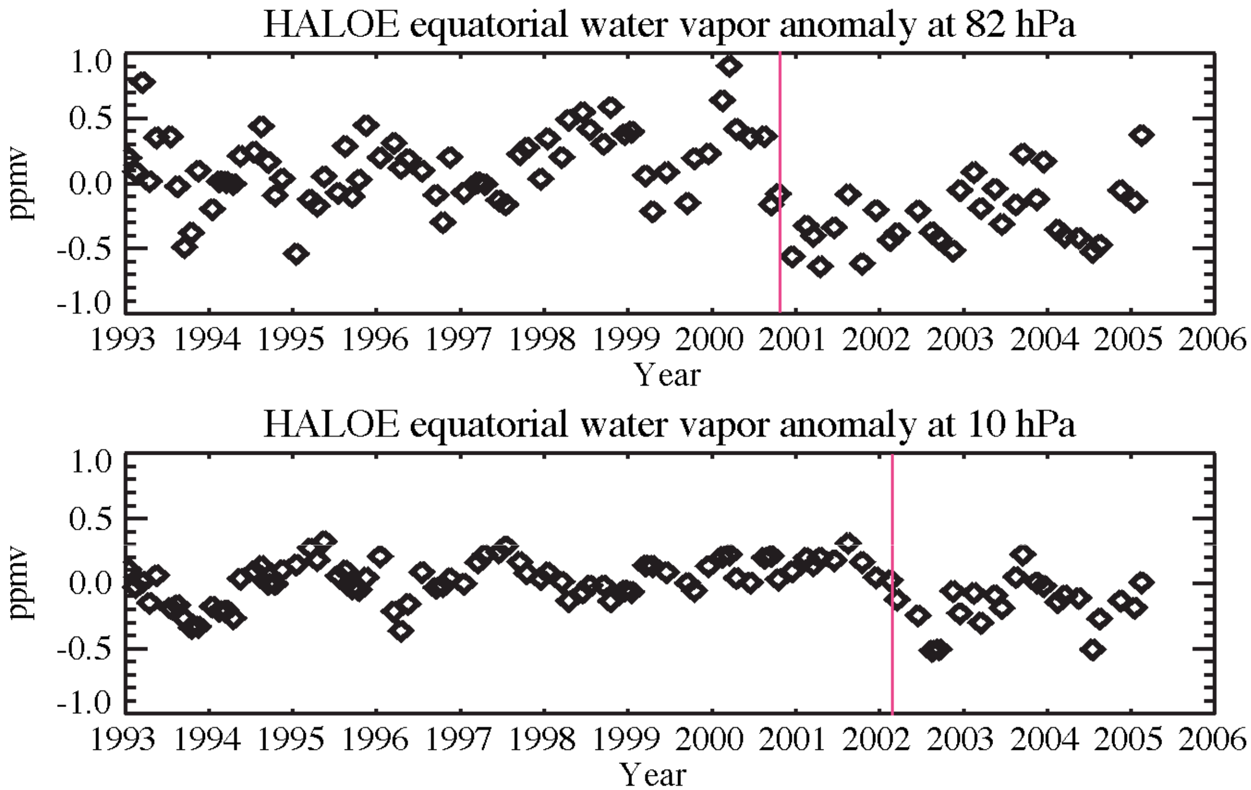
Tropical water vapor anomalies, HALOE

Stratospheric water vapor decrease at the end of 2000 not limited to HALOE data.

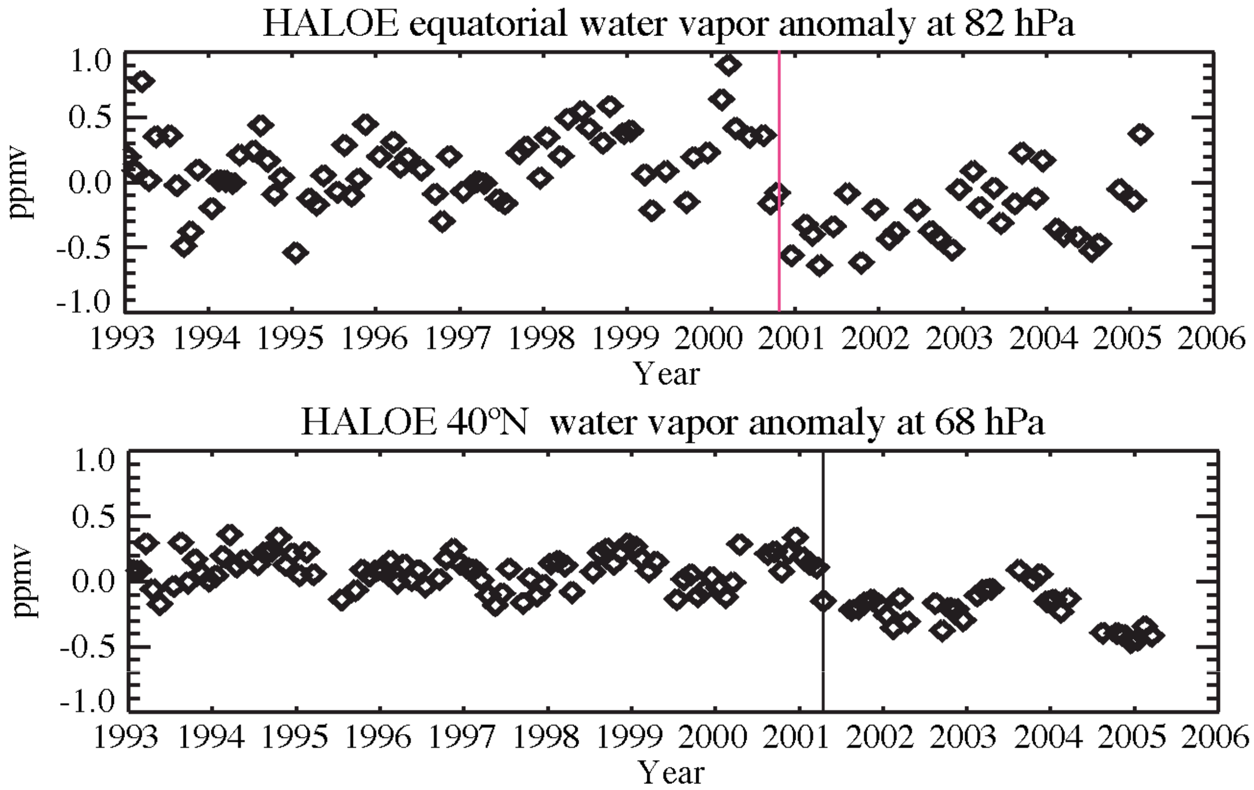








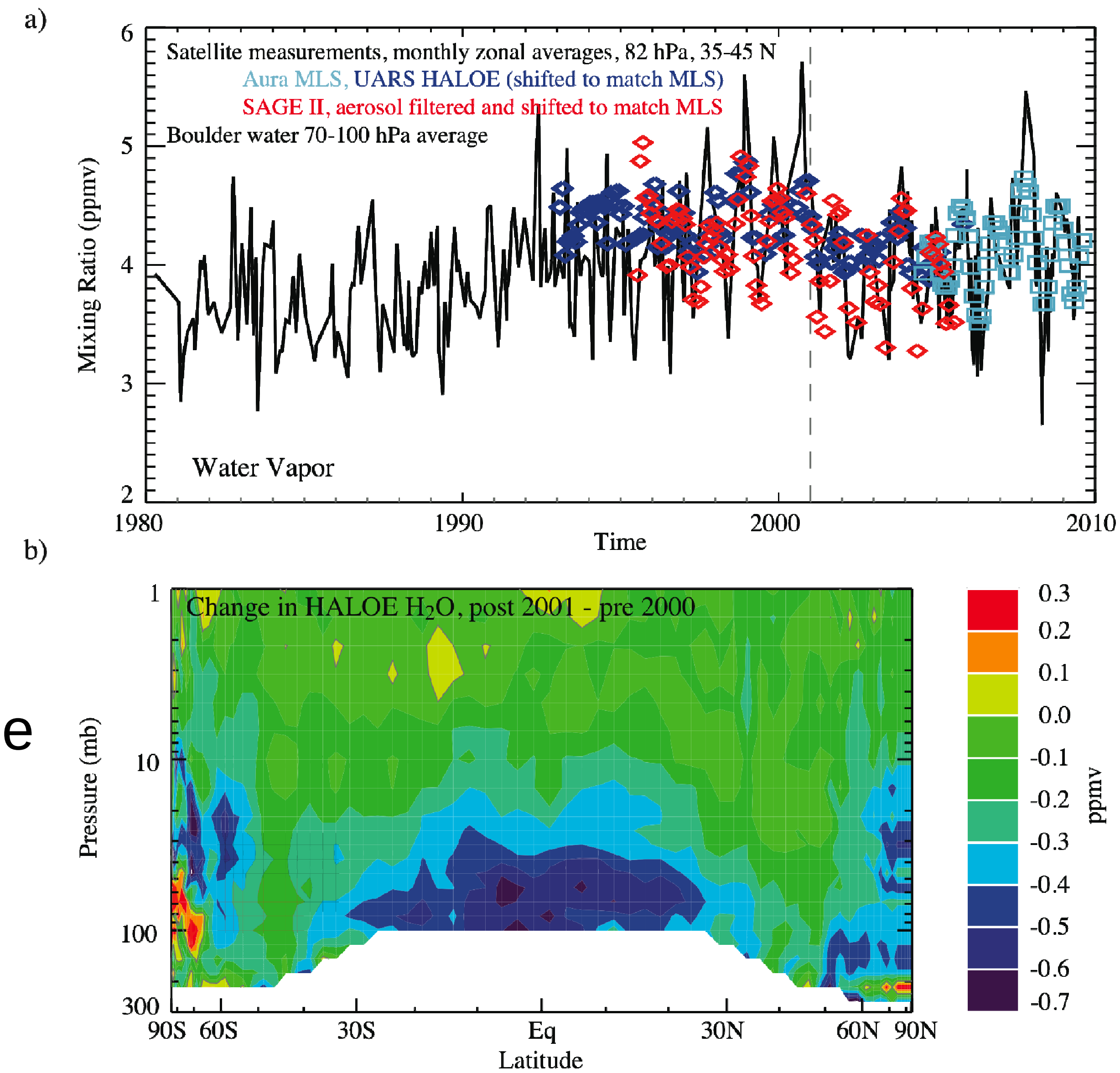
Signal propogates upward in HALOE measurements

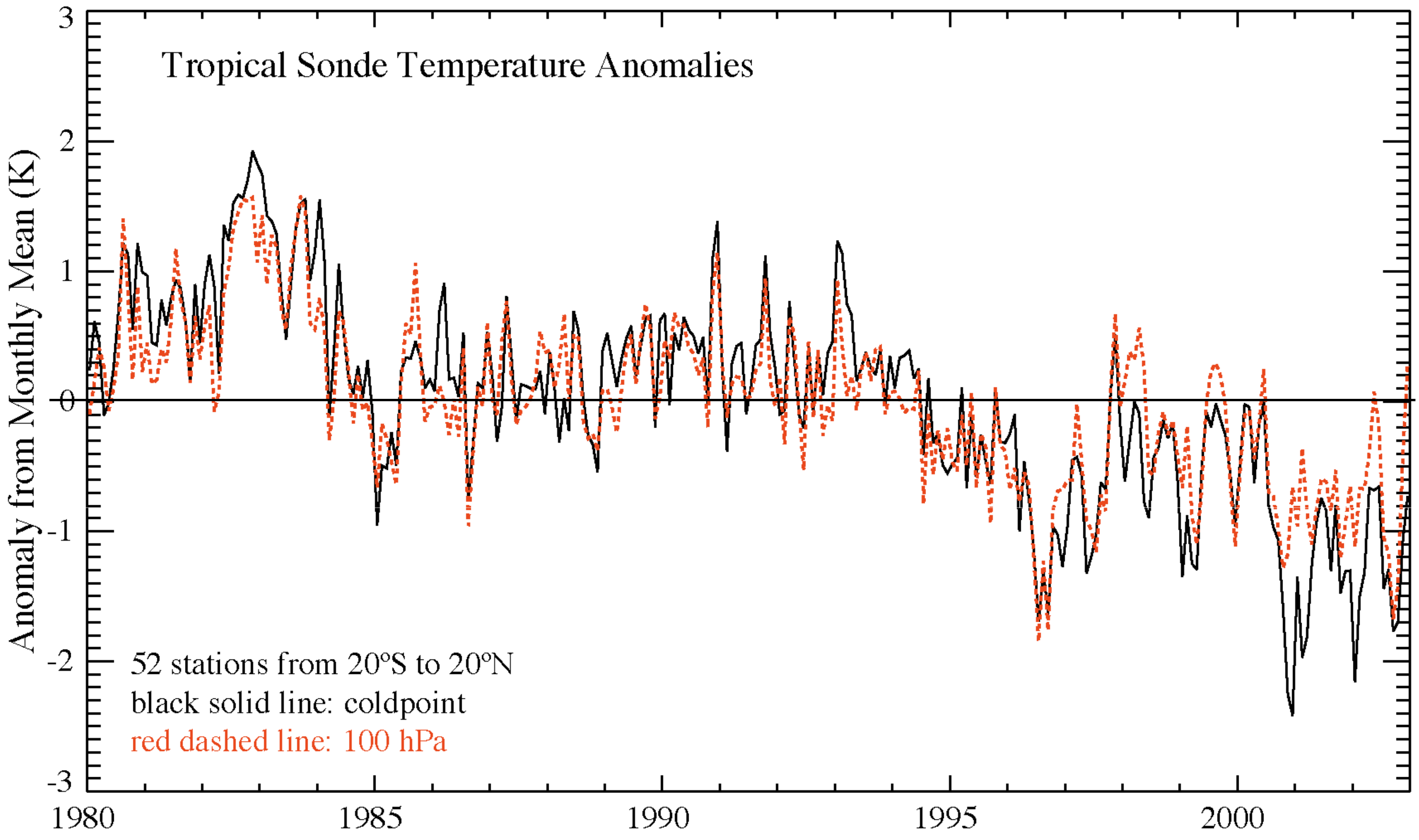


signal also propogates poleward (shown here, into the NH)

Signal appears in frostpoint balloon data at Boulder

There is spatial structure in latitude altitude space





In an average of tropical sonde data anomalies, we see a temperature decrease in the cold point temperatures (not as obvious in the 100 mb temperatures).

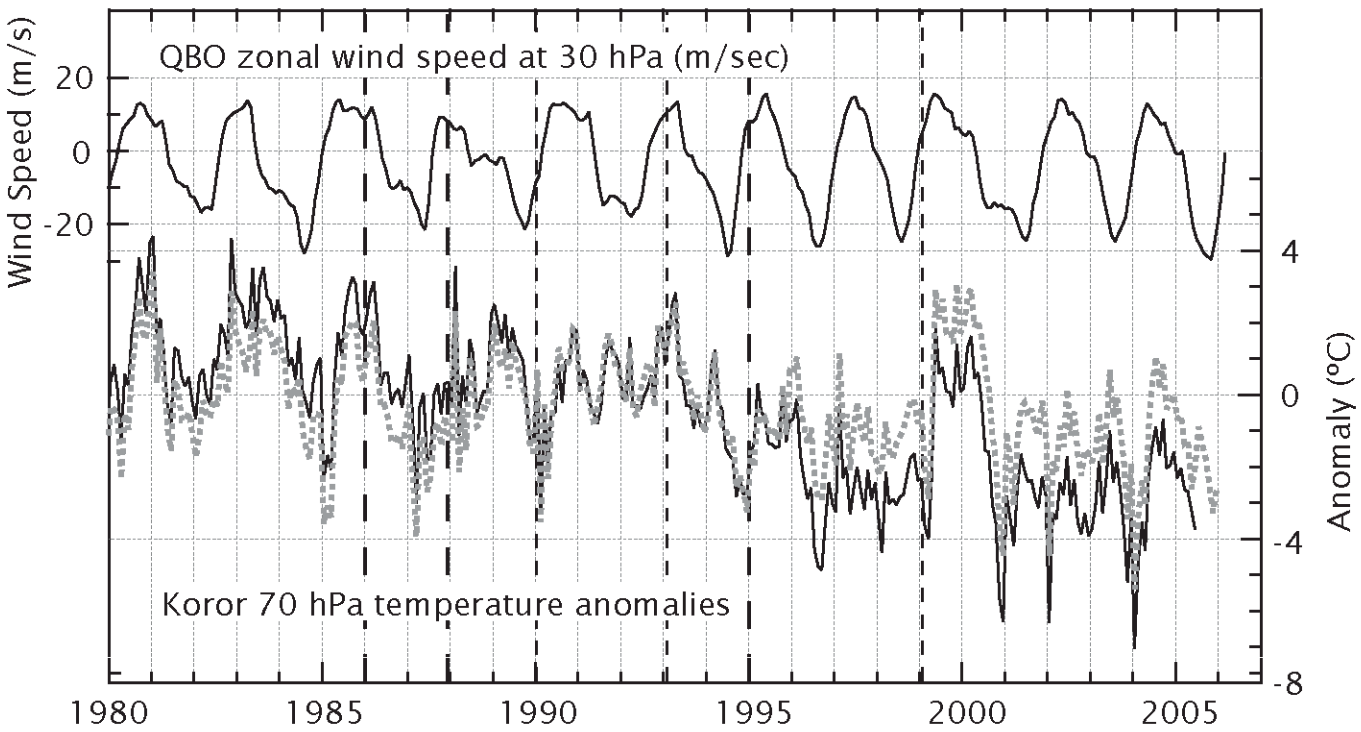


Figure 1: Monthly-mean temperature anomalies at Koror, together with locations of changes in instruments or data handling. Lines with short dashes show radiosonde instrument changes and lines with long dashes show other changes as indicated in Table 1. Grey dotted line shows the anomalies calculated using the homogenized temperatures described in Sherwood et al. (2008). QBO winds are also shown at the top of the figure. Key features to note are the disappearance of the QBO signal in temperatures in the early and late 1990s in both time series, and the occurrence of extremely low values after 2001.

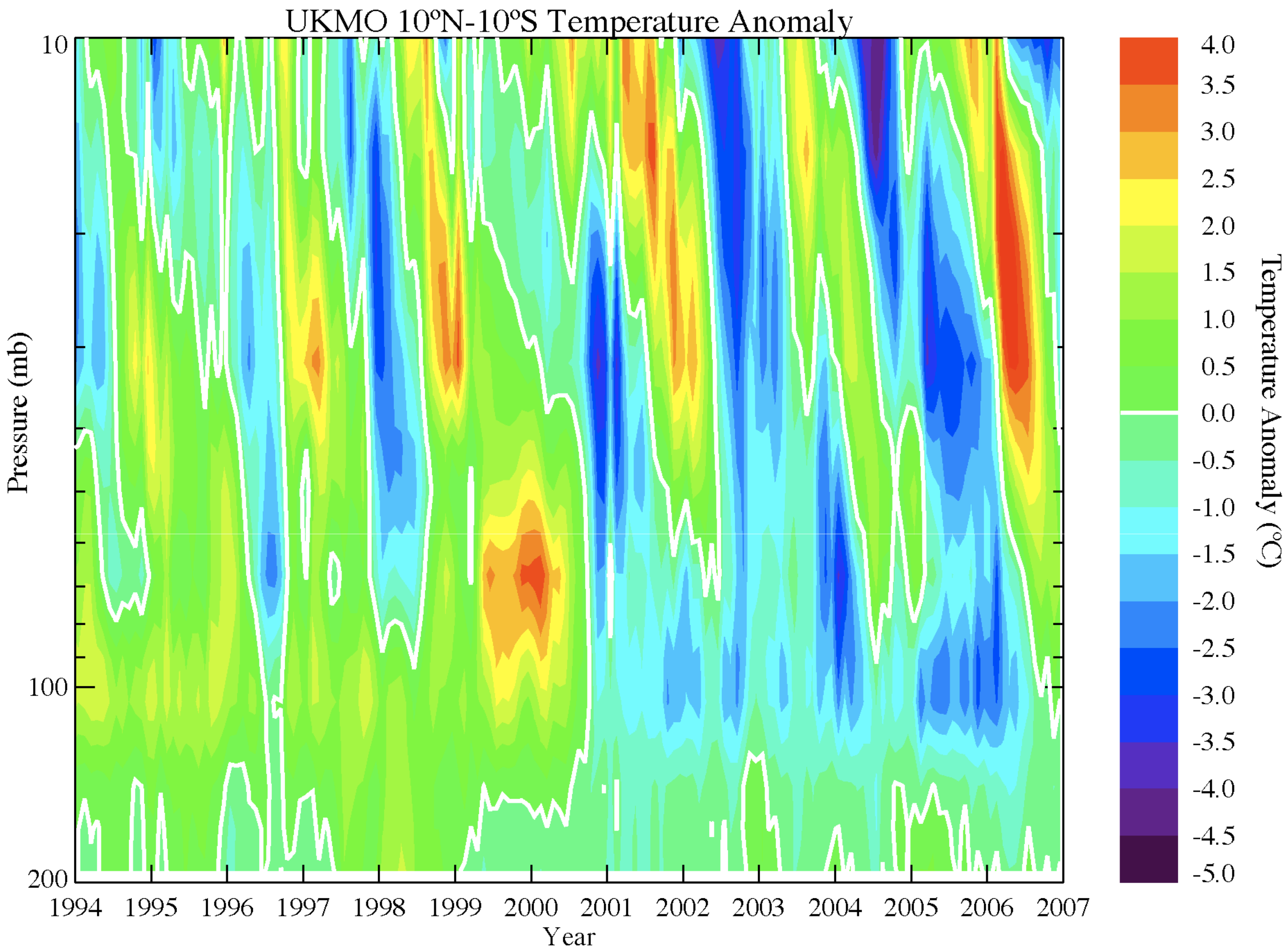


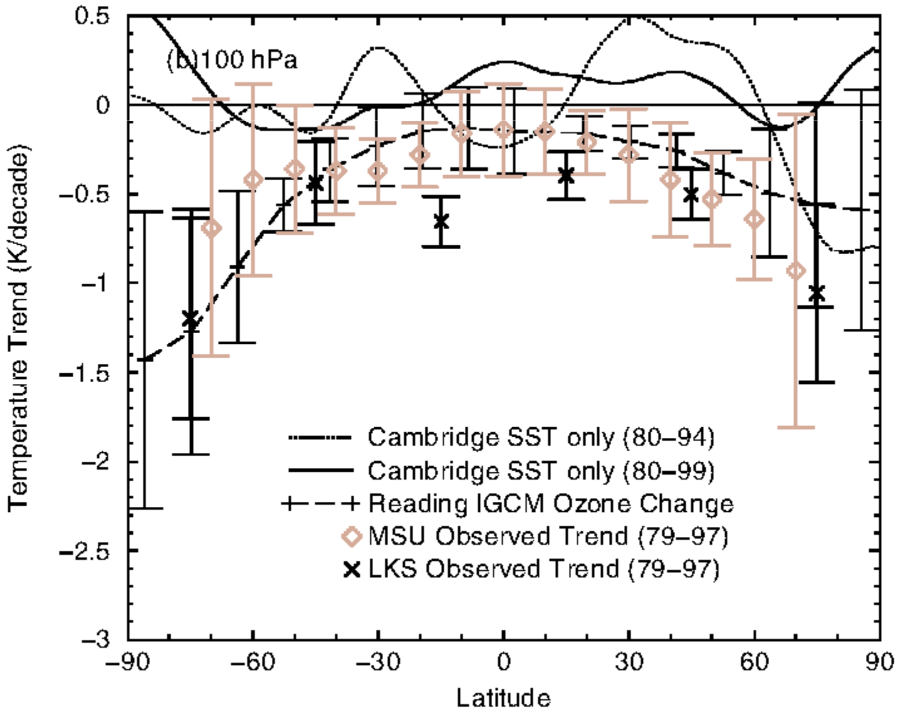
Figure 4. Zonally averaged temperature anomalies in the equatorial belt (10˚N to 10˚S) derived from the UARS/UKMO assimilation, 1994-2006.

The apparent change in the entry value of stratospheric water vapor over the period 2000-2001 is ~.3-.5 ppmv. Looking at cold point changes from sondes, the temperature change is ~1º-2º.

Delta Qsat = from 0.5 -0.7 ppmv for a 1K drop in the range from 189-192K, which is in the range of the coldest tropical temperatures observed from sondes (giving Qsat from 3-4.5)

In a zonally averaged sense it is clear that

1) Temperatures dropped at the tropical cold point at the end of 2000. The drop is on the order of 1-2ºC zonally averaged. As comparison, the annual cycle has a peak to peak amplitude at the tropopause of 5-6ºC.



from Shine et al (2003), shows temperature trends per decade at 100 mb (larger trends at higher levels in the stratosphere)...changes modeled here are due to ozone and greenhouse gas changes

LKS = Lanzante,Klein and Seidel, J. Climate, 2003

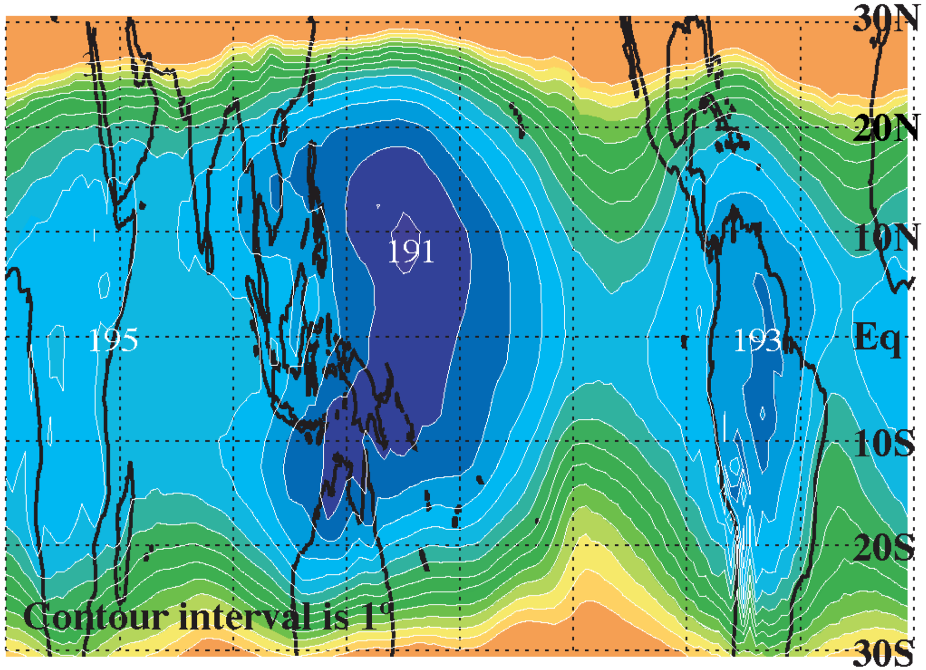
It seems apparent that the change in temperature changed the input of water vapor into the stratosphere....but, why did temperature change? And where did temperature change?

We wanted to determine:

Spatial pattern of the ~tropical tropopause temperature change

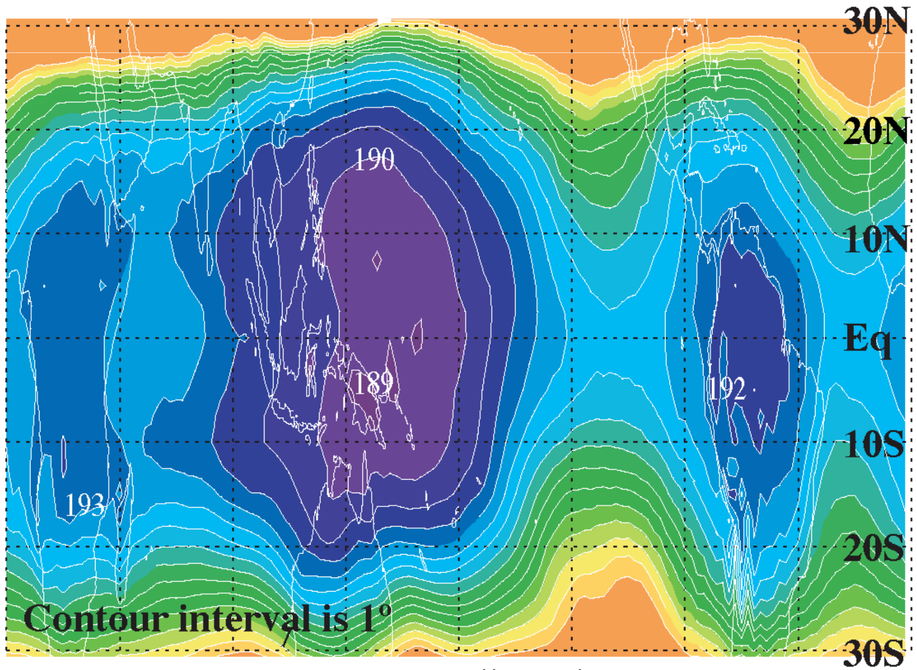
and check that features appear in radiosonde as well as assimilated temperatures

Consider possible drivers of the change at the end of 2000



NCEP Tropopause Temps (adjusted), Jan 1995-1997
includes a warm, cold and neutral ENSO year

NCEP tropopause temperatures (corrected for a bias estimated from comparisons with radiosondes)



NCEP Tropopause Temps (adjusted), Jan 2001-2003
includes a warm, cold and neutral ENSO year

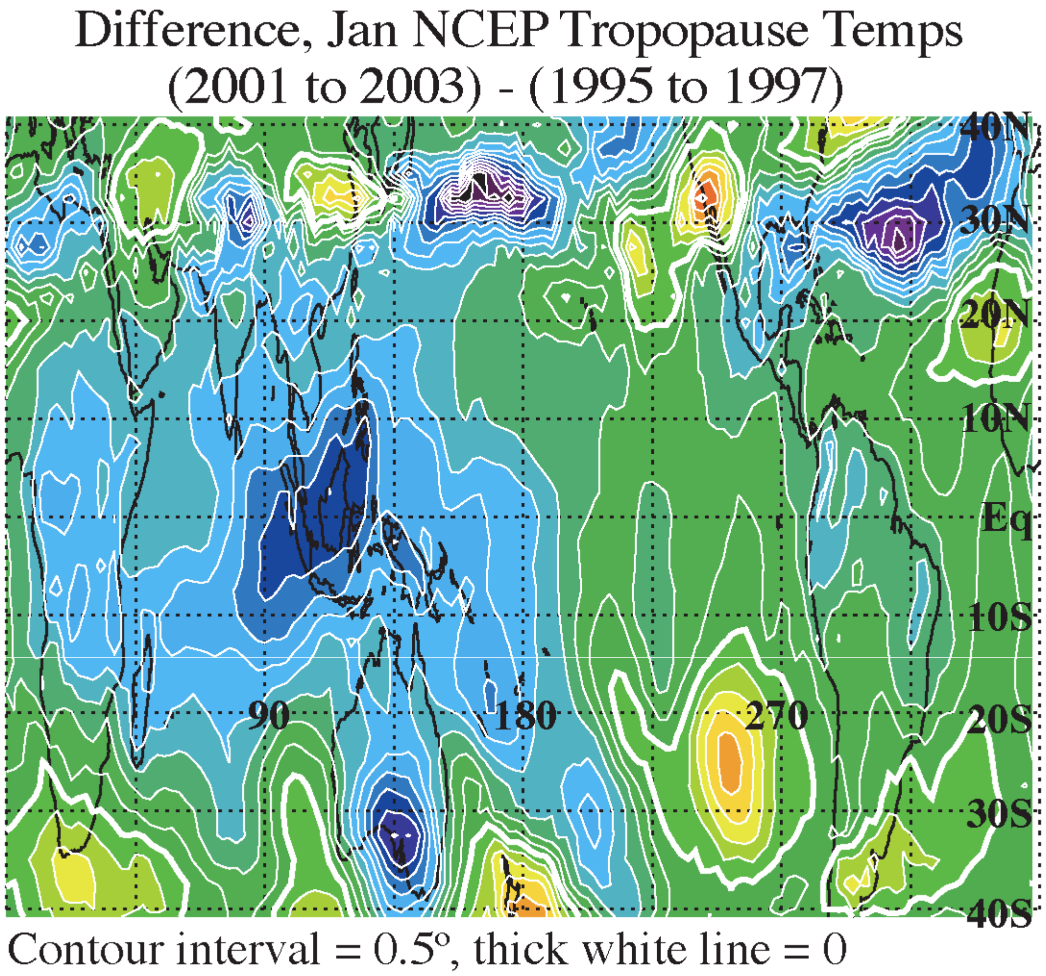


Figure 7. Geographical distribution of NCEP tropopause temperature differences between the 1995-97 period and the 2001-03 period. Most of the area between the 40° latitude meridians experienced cooling; only the small areas within the thick white lines experienced warming. The most extensive area of cooling lies over the western tropical Pacific/Indonesia region.

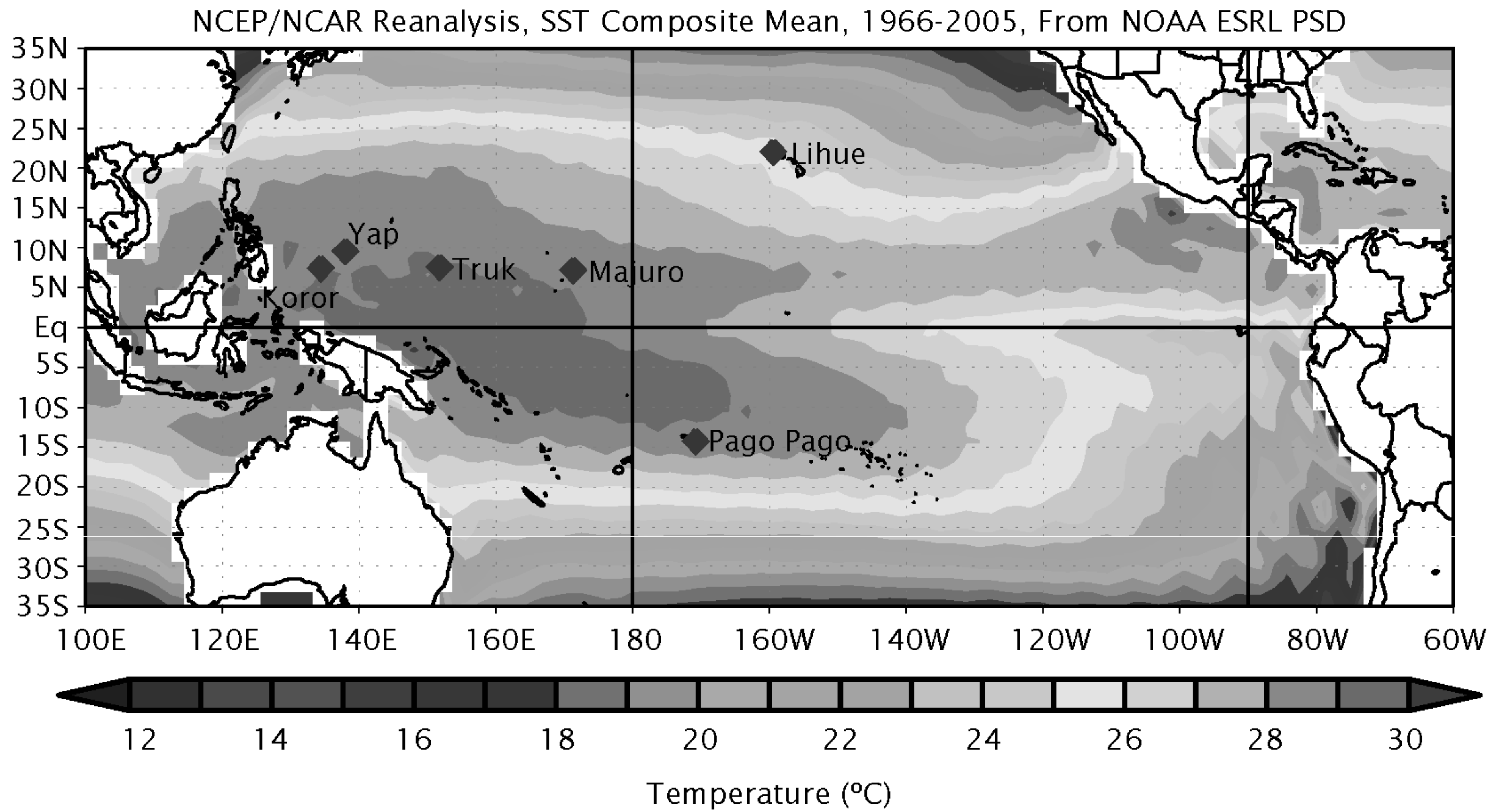


Figure 1. Location of the principal radiosonde stations used in this study, in relation to the climatological mean sea-surface temperatures (1966-2005) in the tropical western Pacific Ocean.

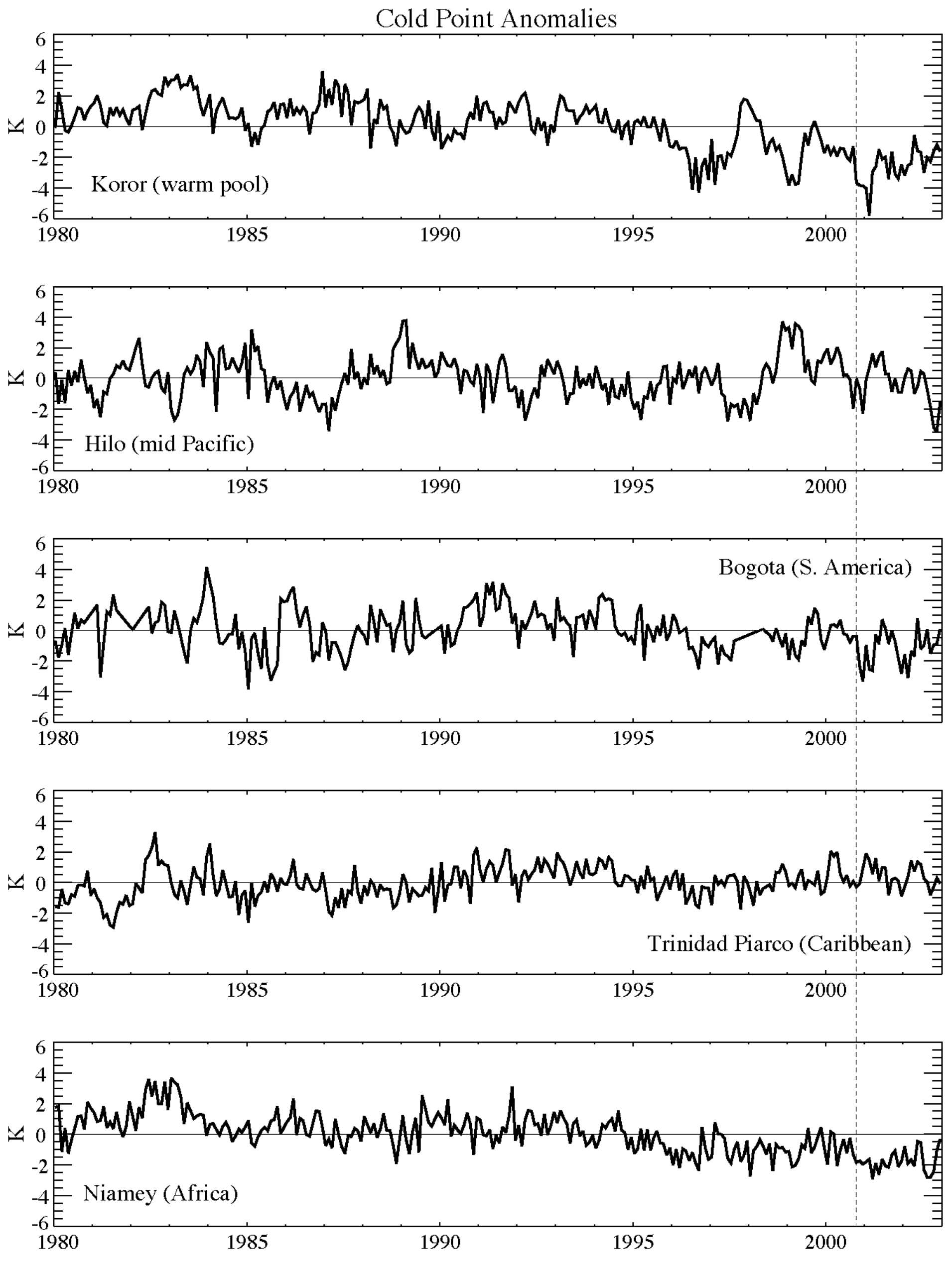


Figure 8. Cold point temperature anomalies for 5 radiosonde stations in the tropics positioned around the globe. Station names are noted on the individual panels.

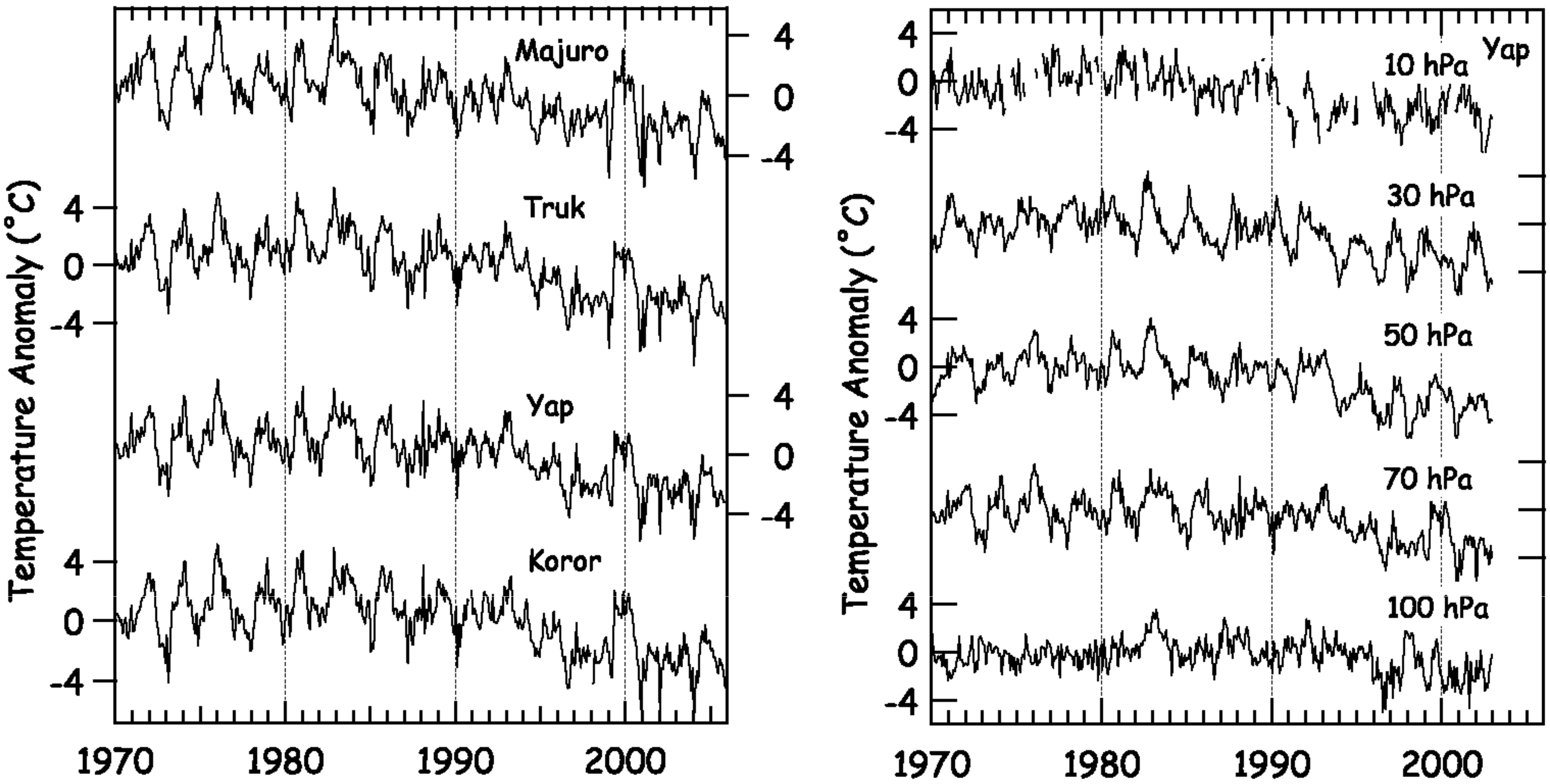


Figure 2. Monthly-mean temperature anomalies (departures from the long-term average) at the 70 hPa pressure level for the longitudinal chain of radiosonde stations, 1970-2006 (left panel) and the time series at all the available pressure levels at Yap (right panel). Stations and pressure levels are noted above the data curves. Correlations between the 4 stations pictures are all greater than 0.9, hence any of the 4 can be considered representative of the warm pool region.

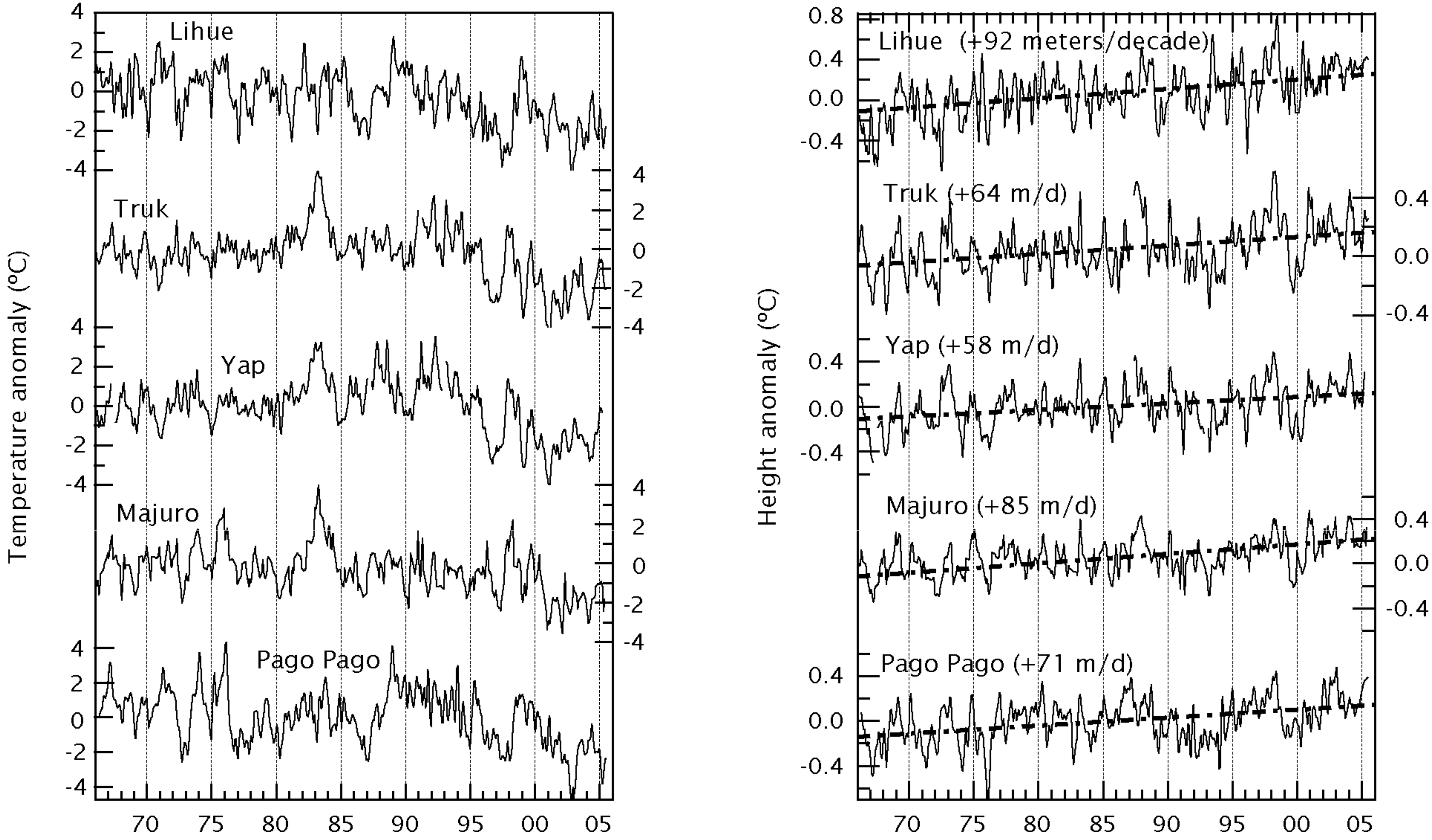


Figure 9. Monthly mean cold-point temperature (left panel) and height anomalies (right panel) for five radiosonde stations. Station names and linear trends are noted above each curve.

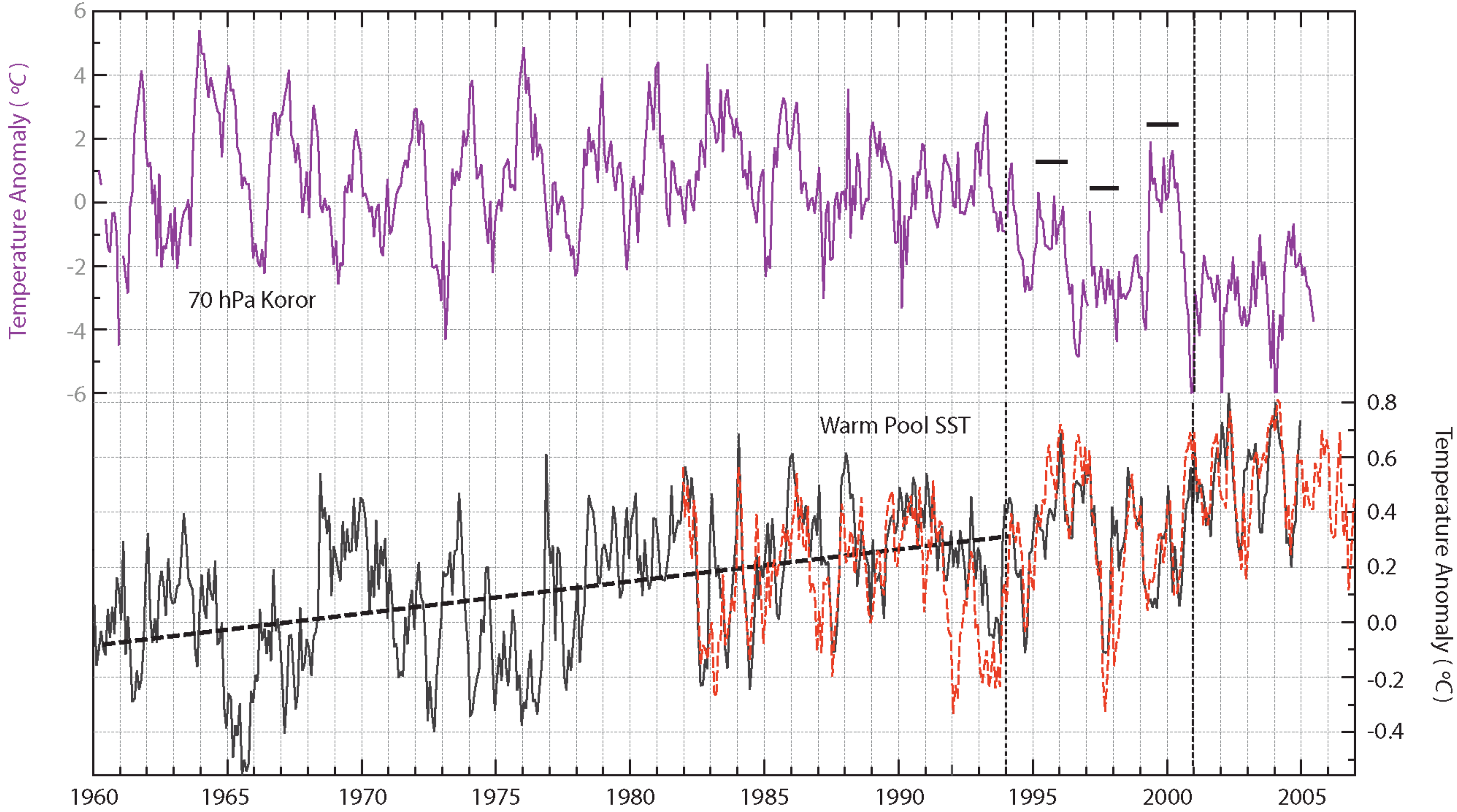
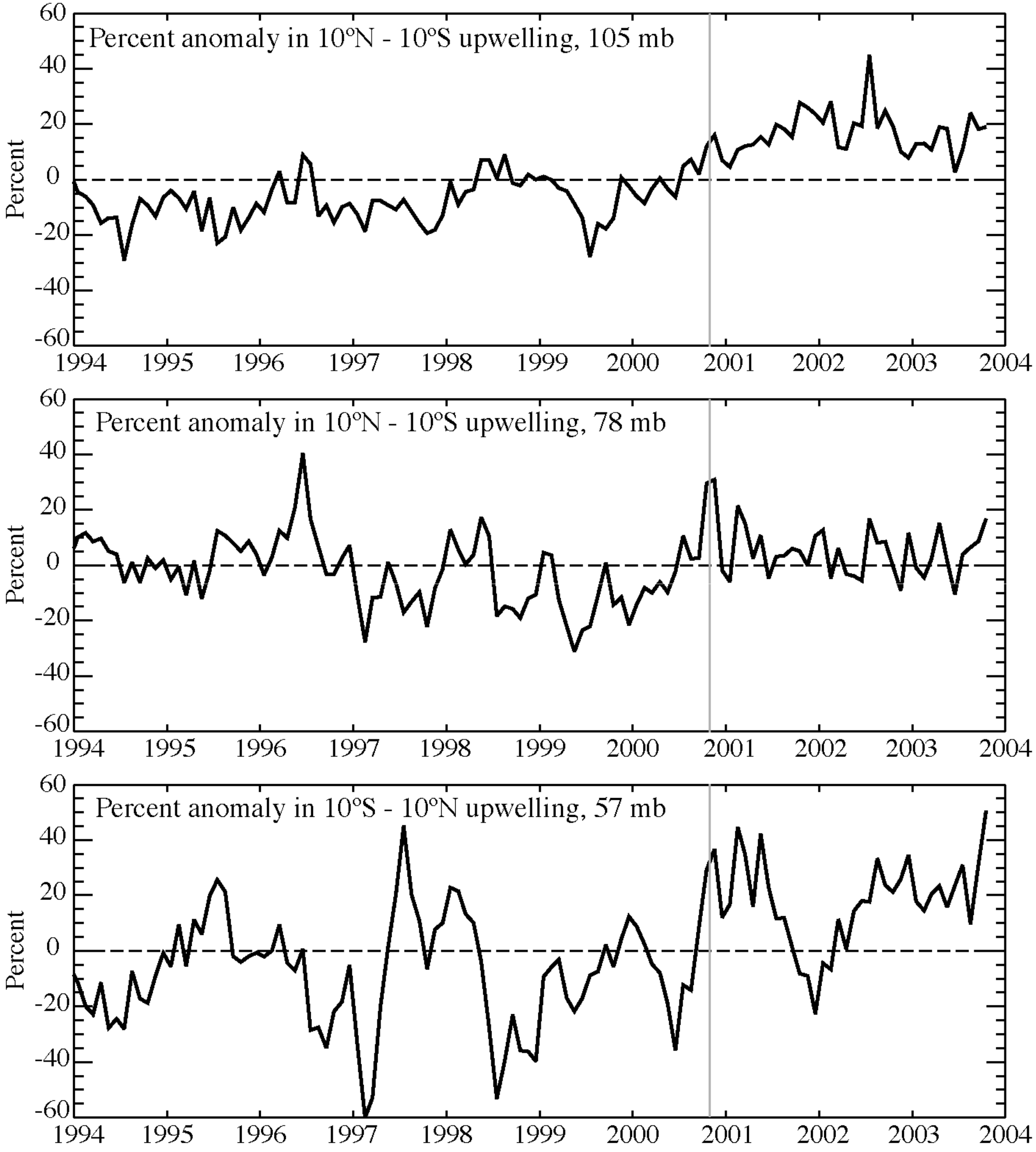
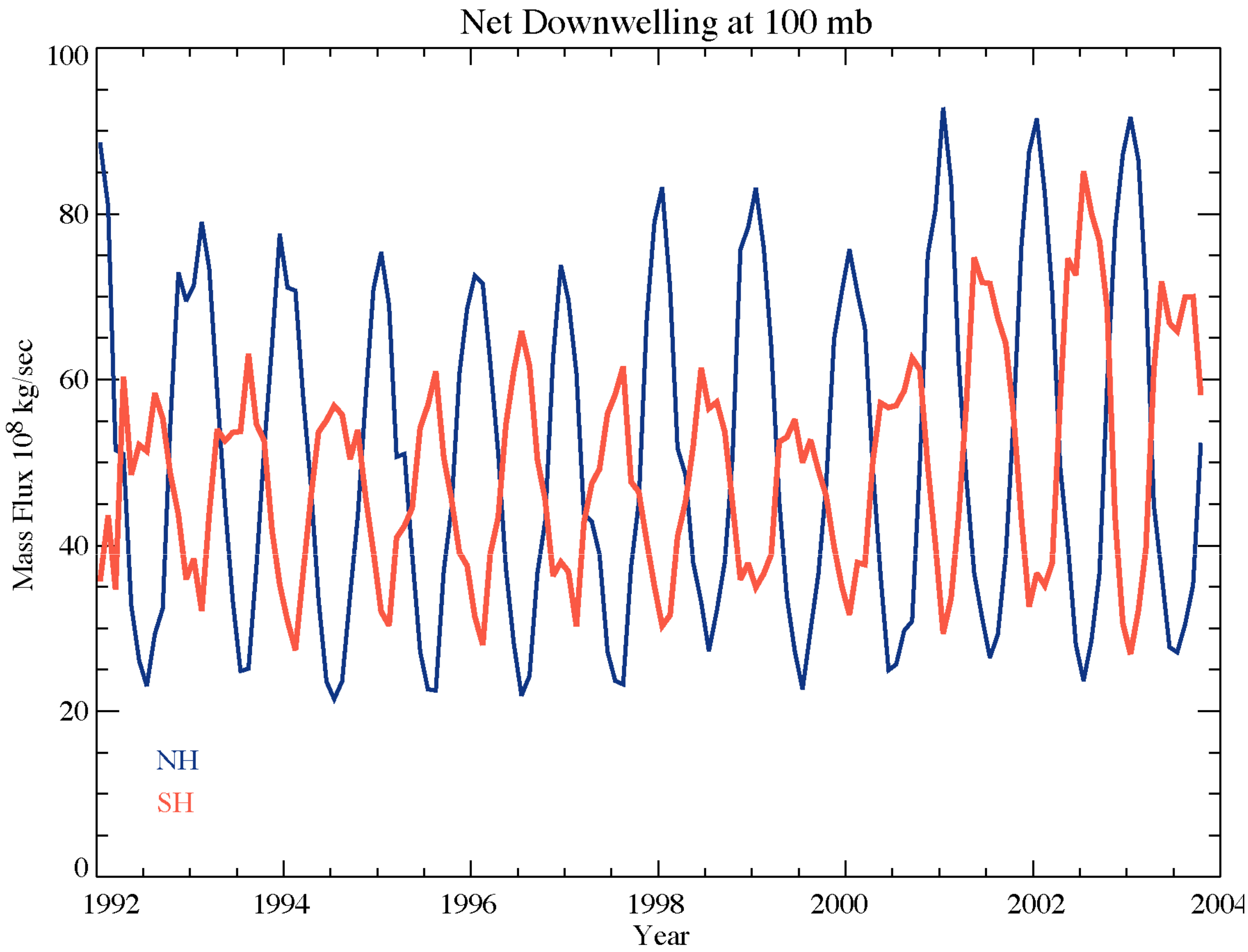


Figure 5. Monthly mean temperature anomalies at the 70 hPa pressure level over Koror (upper curve), and SST anomalies averaged over the area of the western tropical Pacific between 7.5˚S and 4.5˚N latitude and between 120˚E and 180˚ longitude (lower curves; solid curve is the Kaplan SST anomalies, and dashed red curve is the Optimal Interpolation Version 2; data was obtained from the NOAA/CIRES Climate Diagnostics Center). The dashed straight line is a least-squares linear fit to the Kaplan data from 1960-1994. The short horizontal bars denote the positive phases of the QBO signal in 1995-6, 1997-8, and 1999-2000. The vertical bars denote start of features discussed in the text.

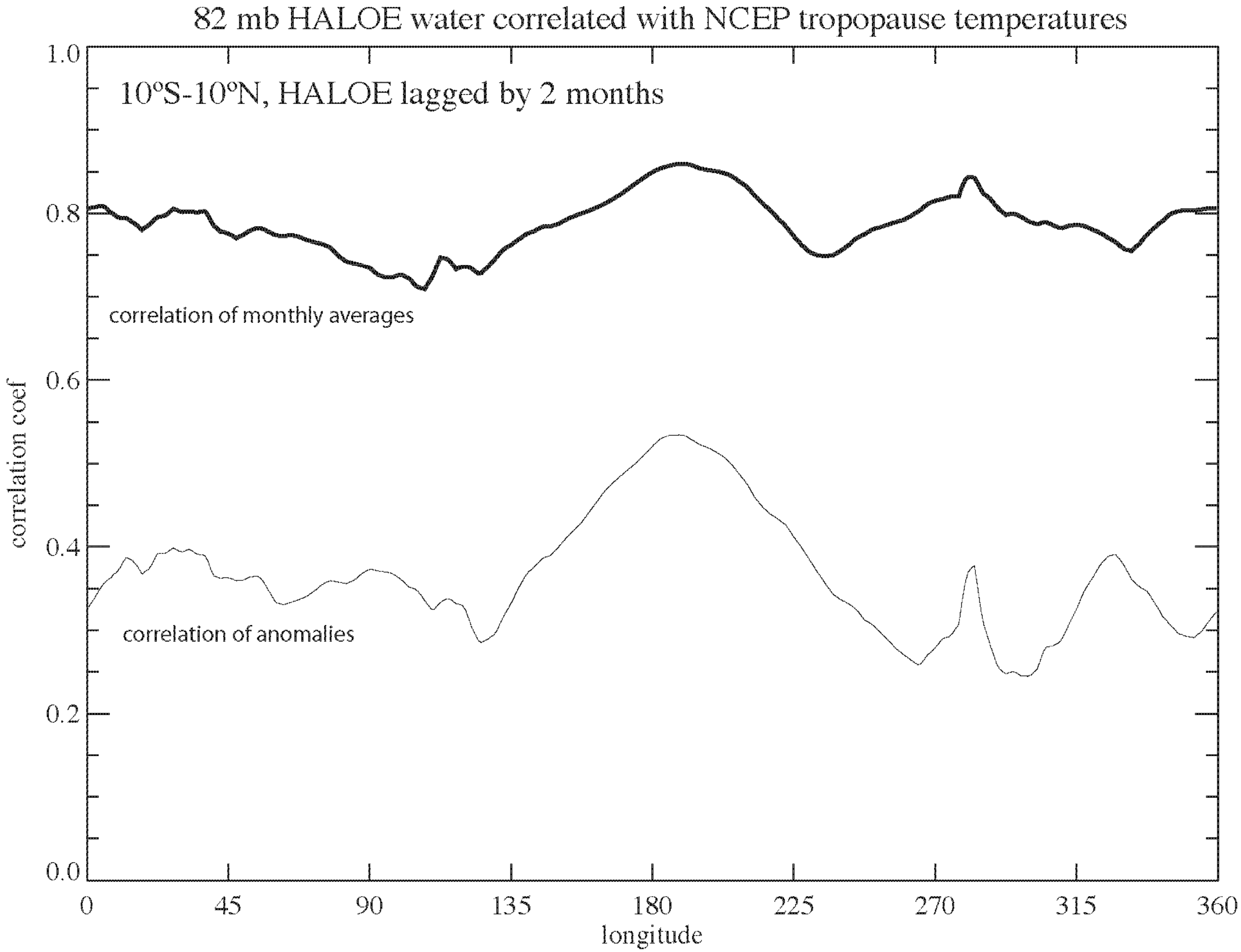


Dynamically, what changed?

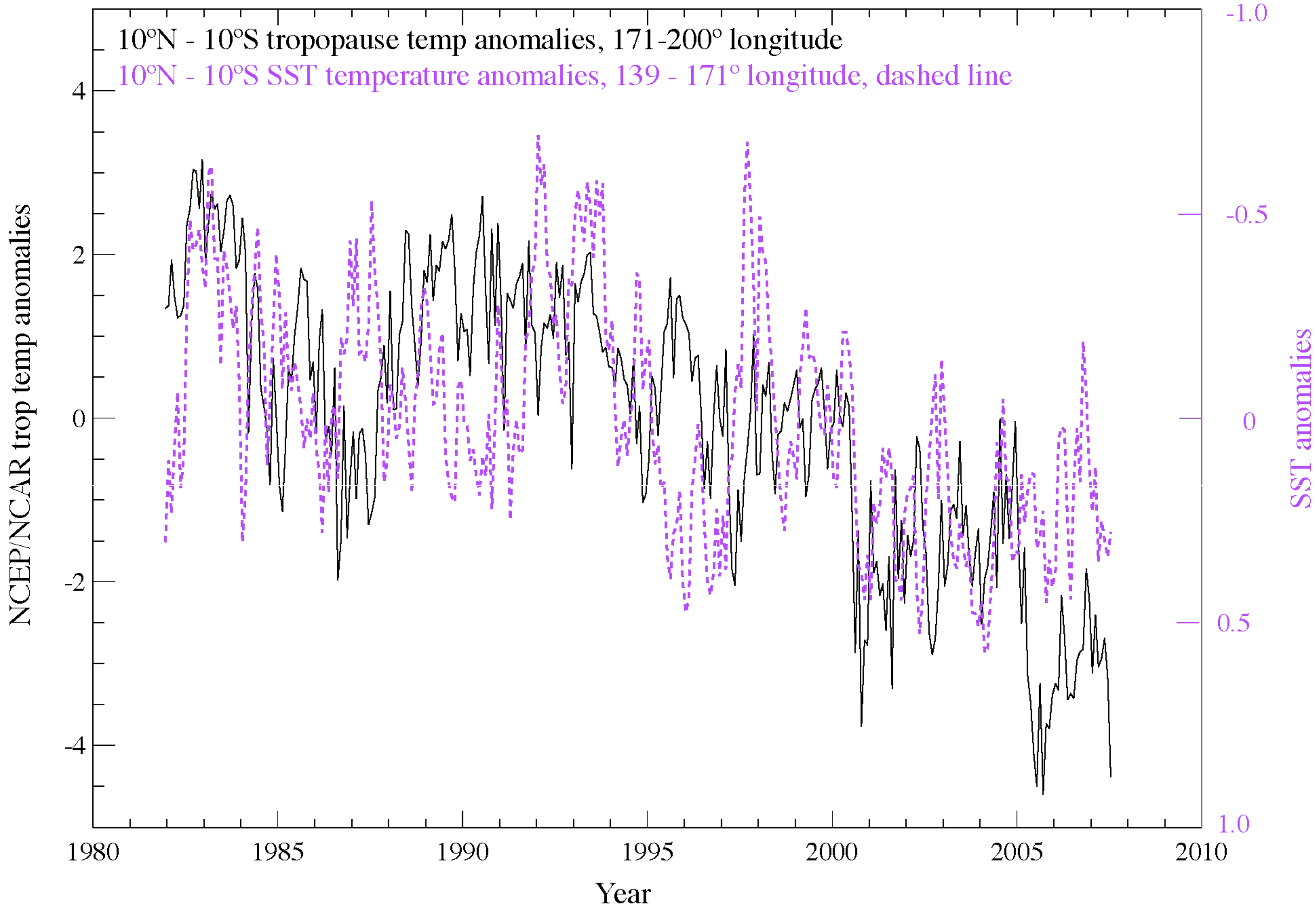
Radiatively determined upwelling anomalies in the tropics at 105 hPa (top panel), 78 hPa (middle panel) and 57 hPa (bottom panel). (this is a zonally averaged calculation).



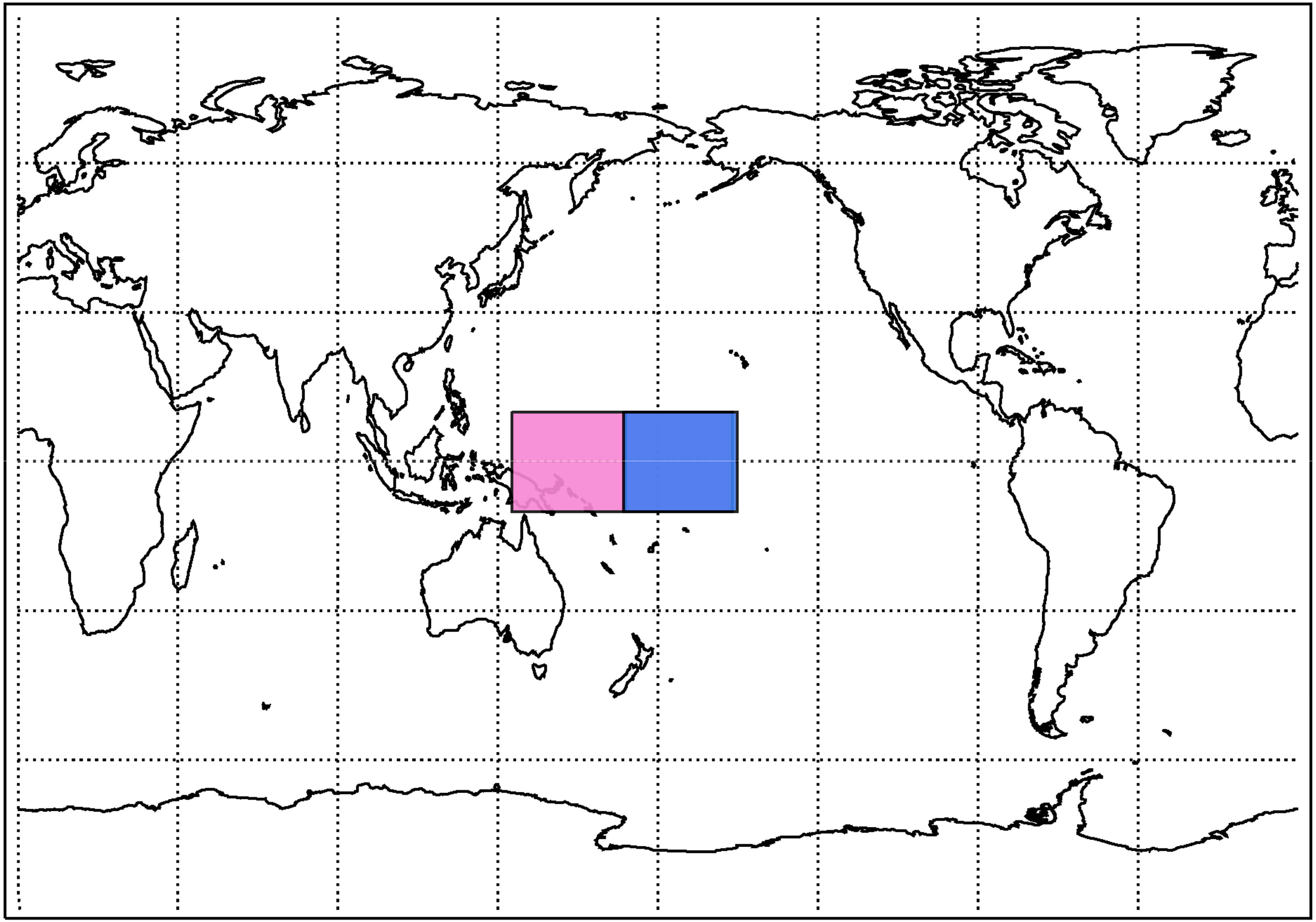
Downwelling changes are mainly in the winter hemisphere.



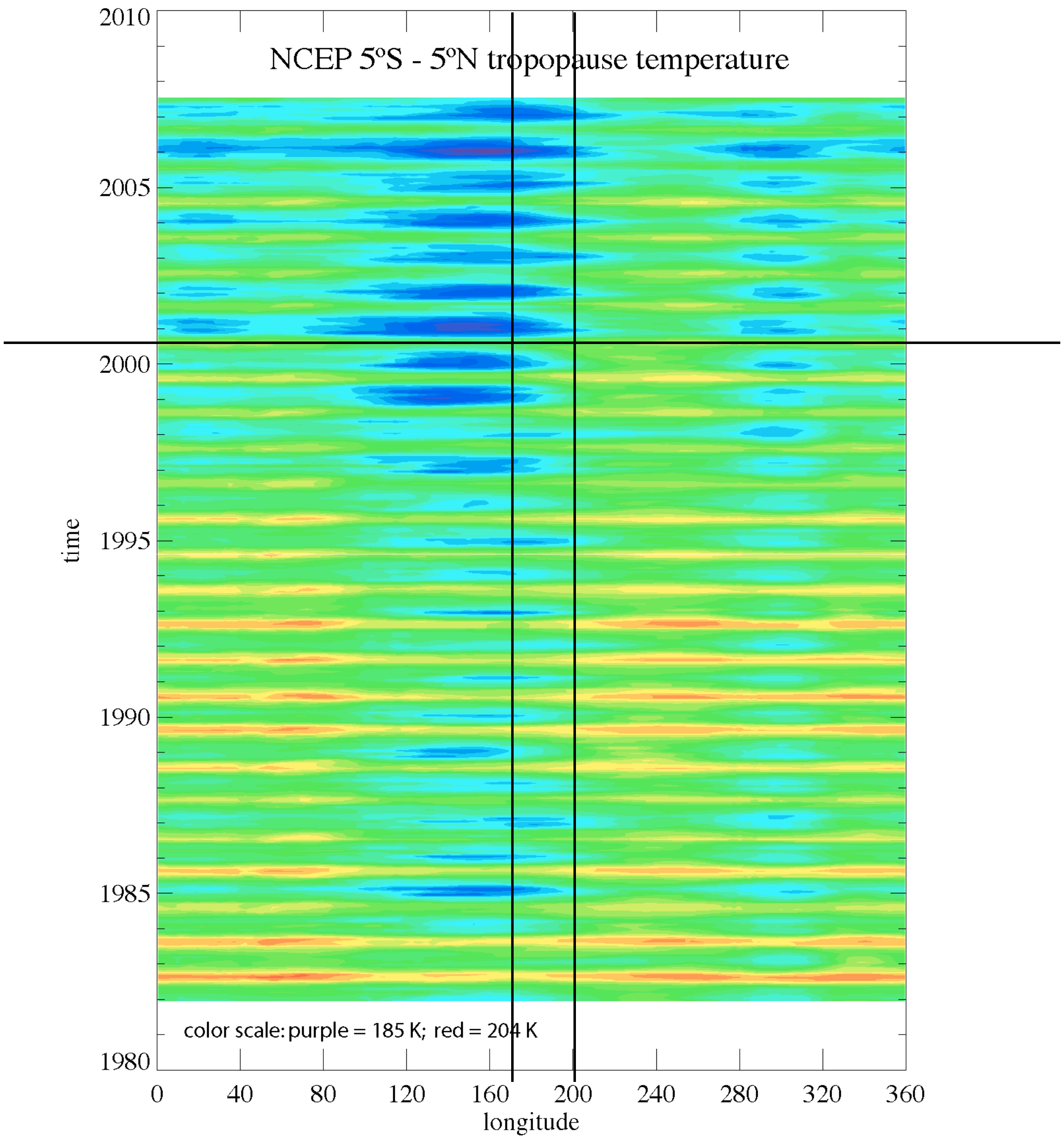
Looking at spatial correlations, the annual cycle (and tape recorder) is a zonally averaged phenomenon, but the change at the end of 2000 is best correlated with a limited longitude region.

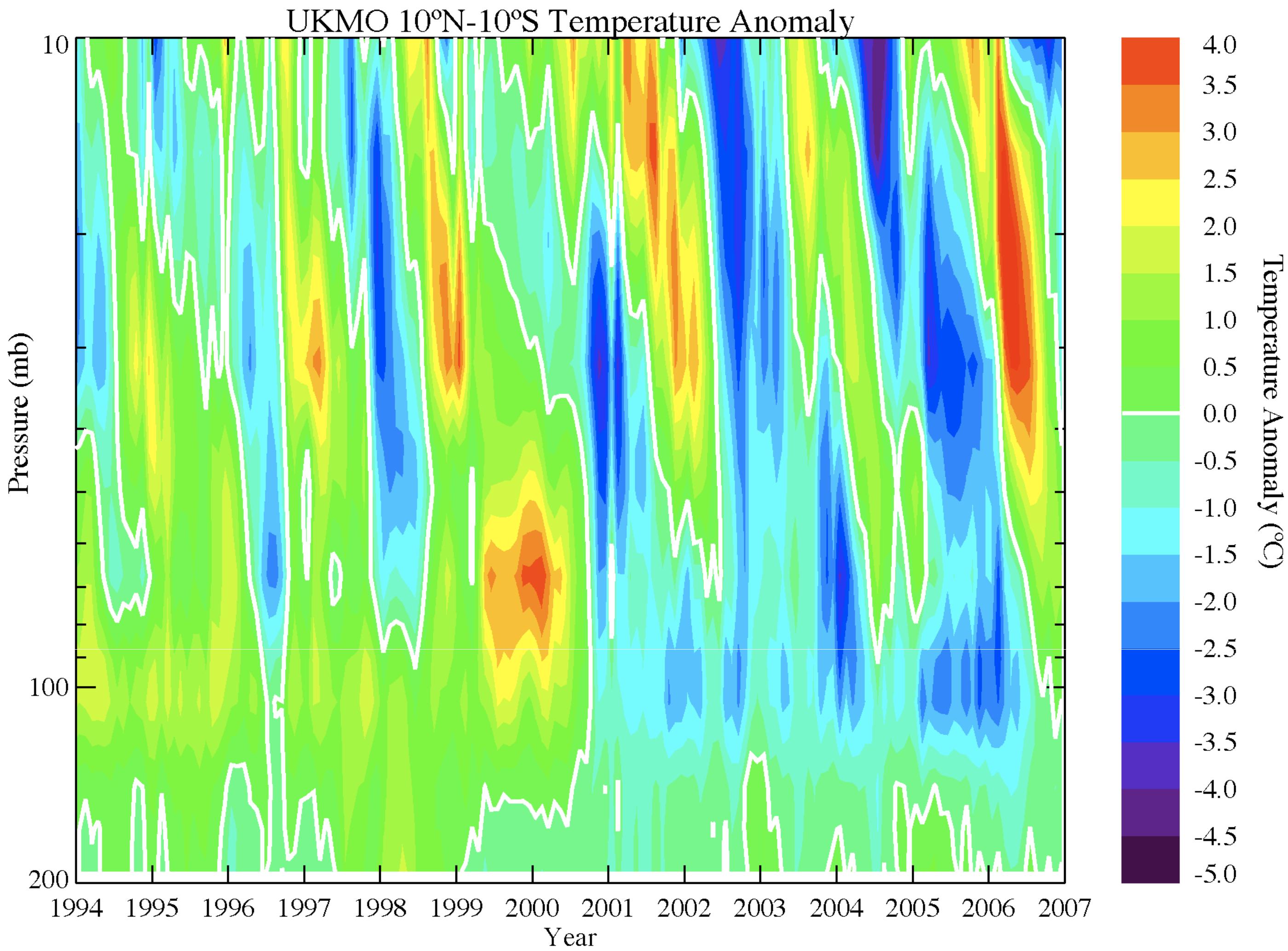


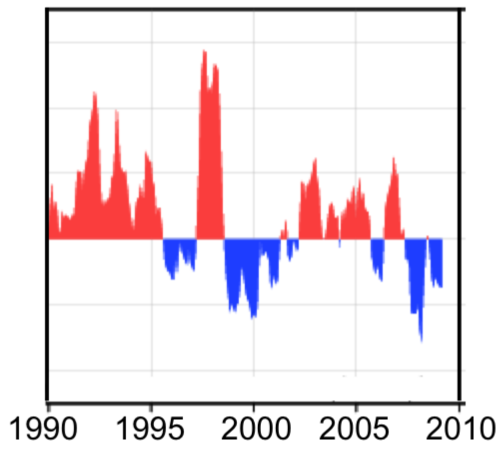
Then, when looking at the relationship with SSTs, the best correlation occurs to the east of the region with the the highest water/tropopause temp correlation.



There appears to be an expansion of the cold tropopause region to the east of the warm pool, and also in recent years, more cooling centered at 300º longitude.







multivariate ENSO index (NOAA/ESRL/PSD/CIRES/CDC)

The cause for the decreased water vapor is a drop in near tropical tropopause temperatures. The biggest change is in the very lower part of the tropical stratosphere, and immediately follows a large warm anomaly that appears to be associated with the 2000 La Nina.

Coincident with the temperature and water vapor changes, is an ozone decrease that would correspond to an increase in upwelling as well. Randel et al, 1996 also found consistency with a downward control mass flux calculation based on changes in subtropical momentum balance. There may also be some radiative reinforcement of the cold LS anomaly due to ozone decreases.

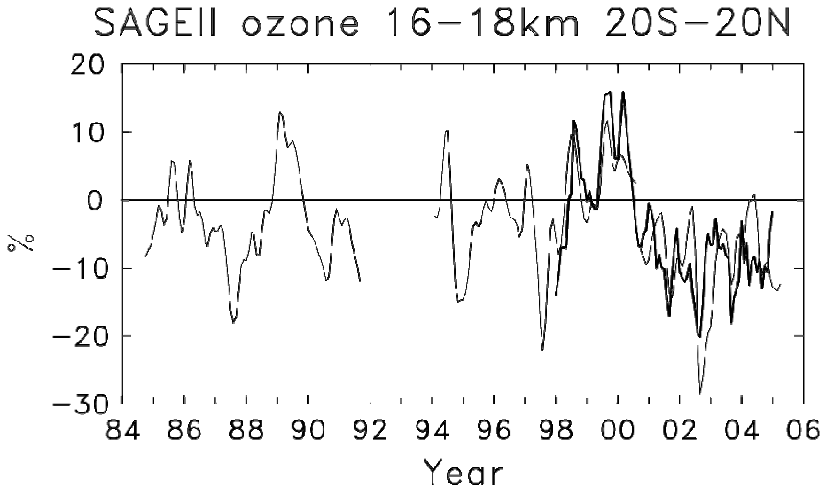
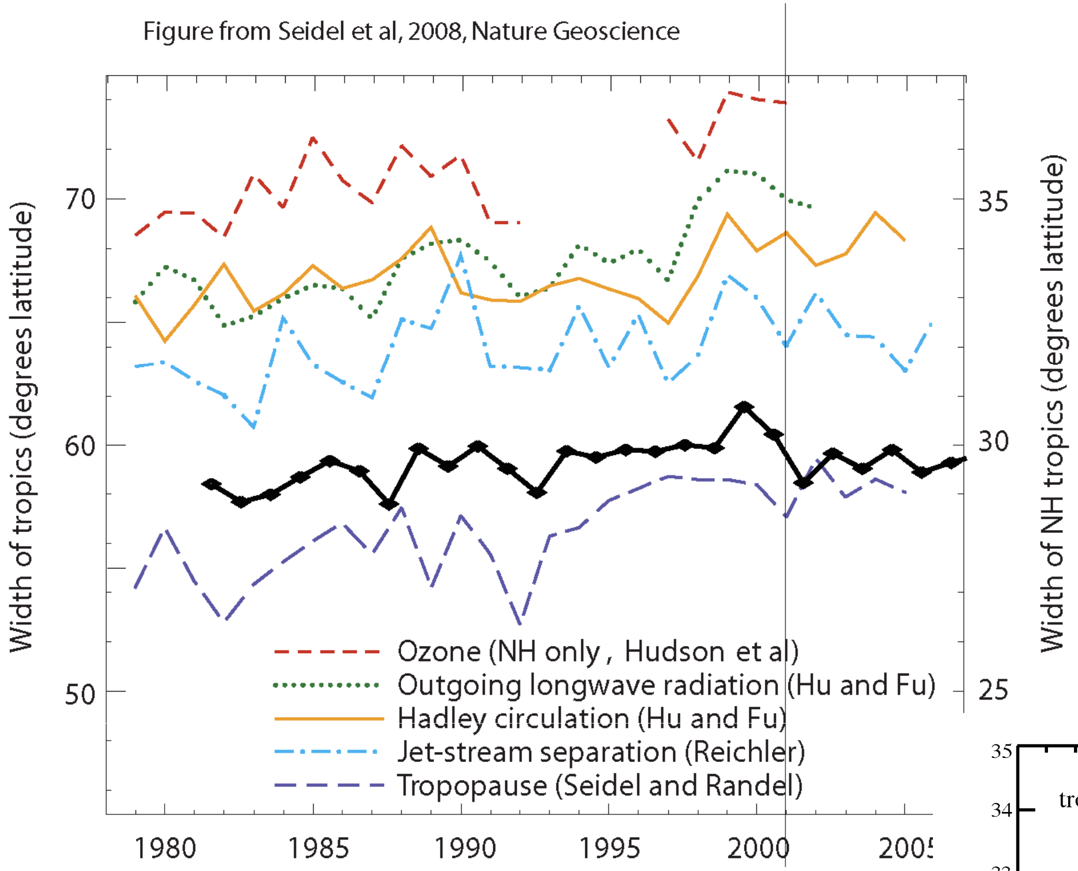
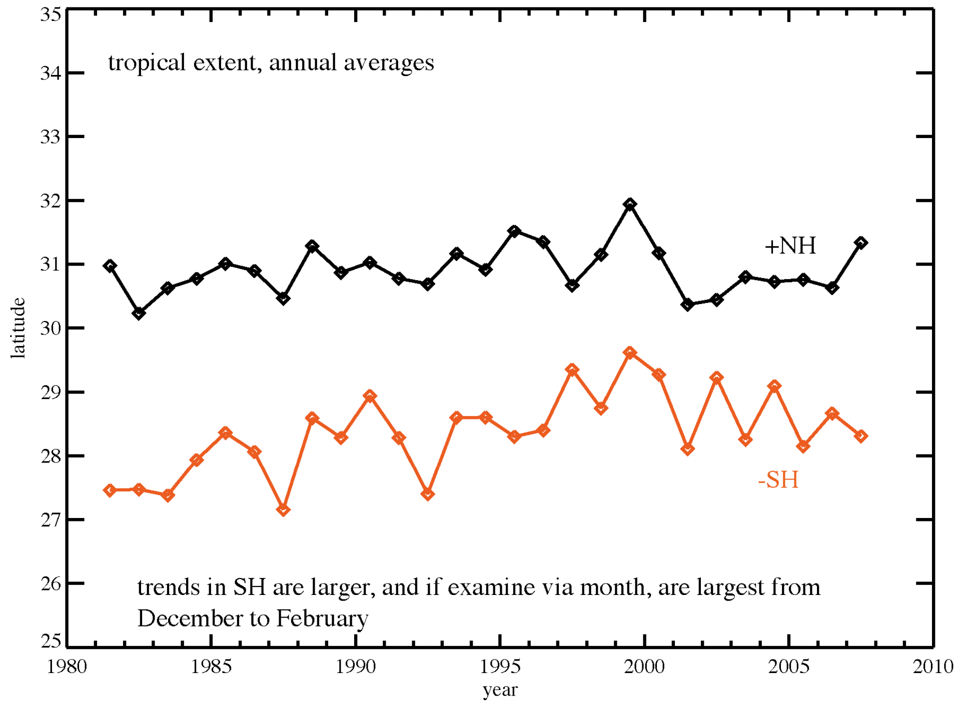


Figure 7. Dcscasonalizcd zonal mcan ozonc anomalics over 16 18 km and 20 N 20 S (thin lines), derived from SAGE II zonal mean data. Corresponding anomalies calculated from an average of 7 tropical ozonesonde stations from SIIADOZ (thick line), covering just 1998–2004.



What other changes occurred near the tropical temperature change?

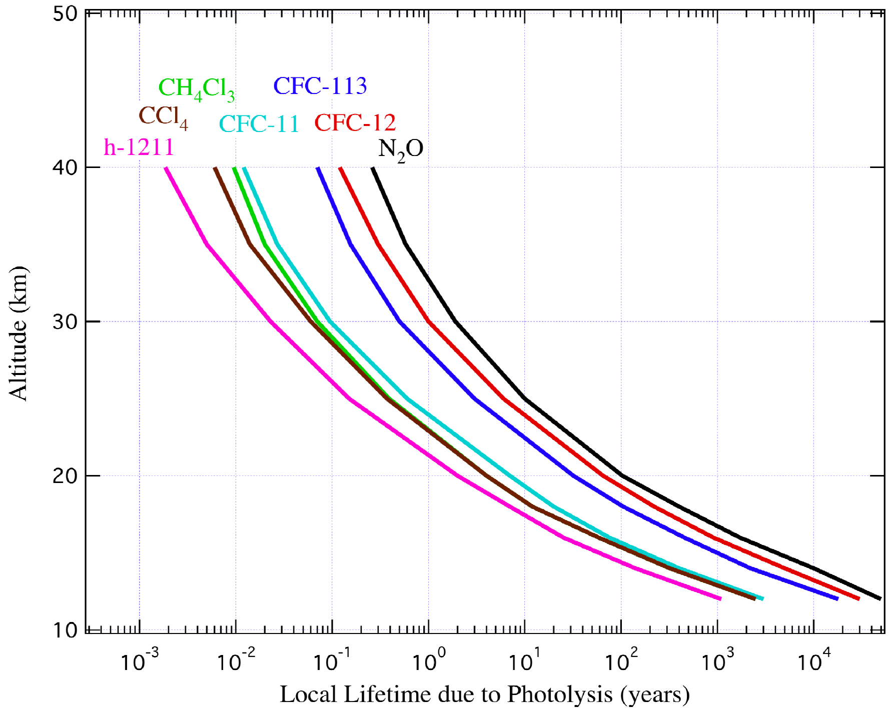
Trends in the SH are larger than the NH, and if partitioned by season, are largest from December to February.

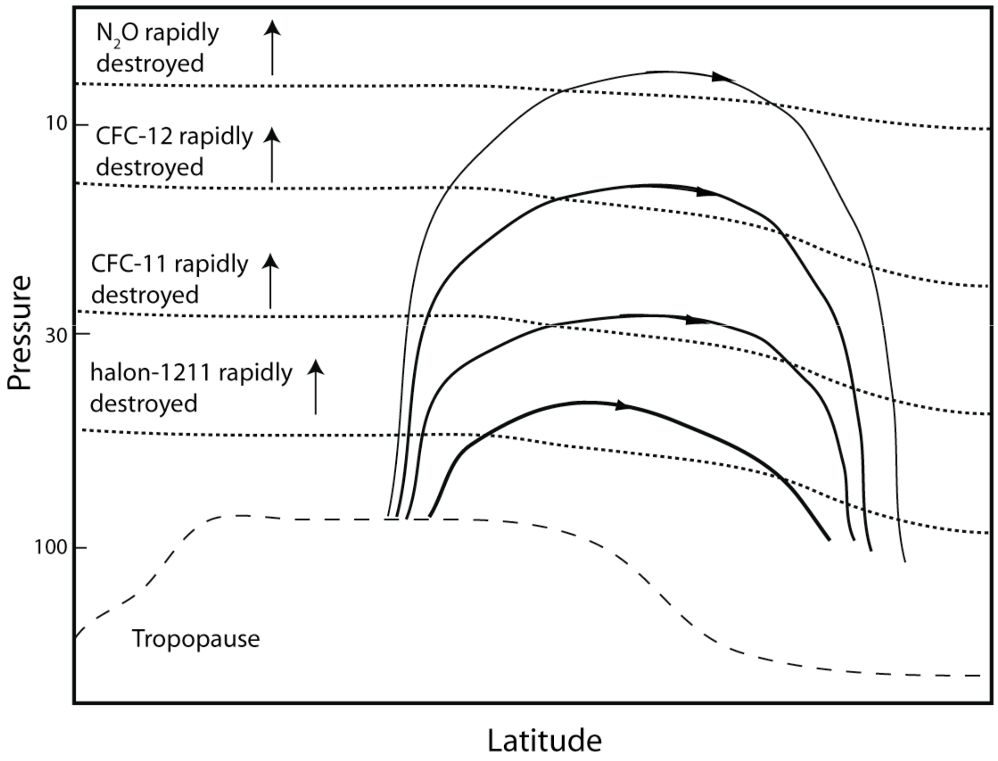


There appears to be a stagnation of the tropical width increase summarized in Seidel et al, 2008 (and other papers cited within.)

added line to the Seidel plot is based on horizontal gradients in NCEP tropause pressures.

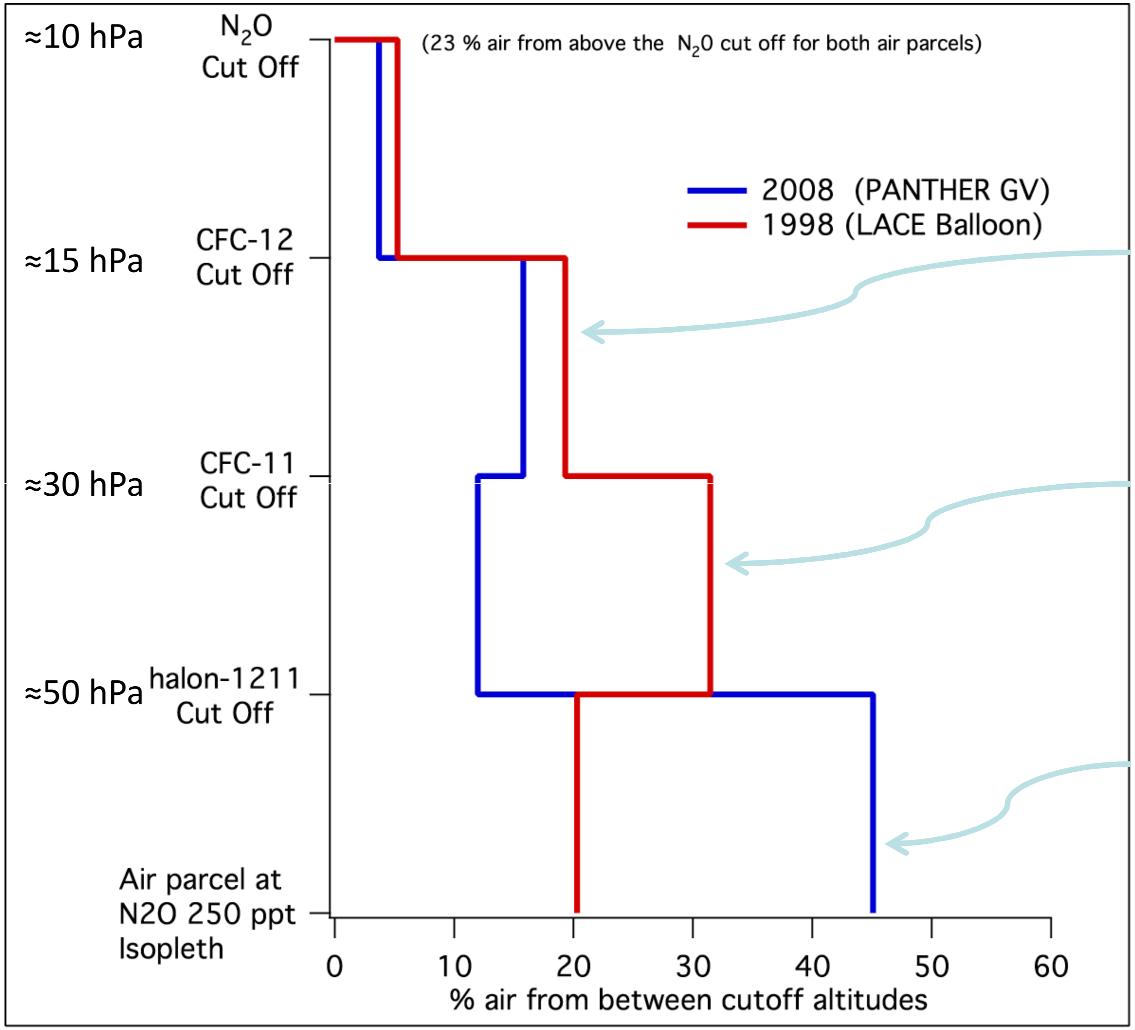
Other change noted is in photolytic tracer correlations (Eric Ray and Fred Moore, manuscript in preparation).





The photolytic tracers are sensitive to changes in the maximum path height of an air parcel and each tracer is sensitive to a different height.

Profile of Circulation Changes Implied by Photolytic Tracer Correlation Changes



slow down

speed up

Small changes above 30 hPa consistent with observed small mean age changes at this level.

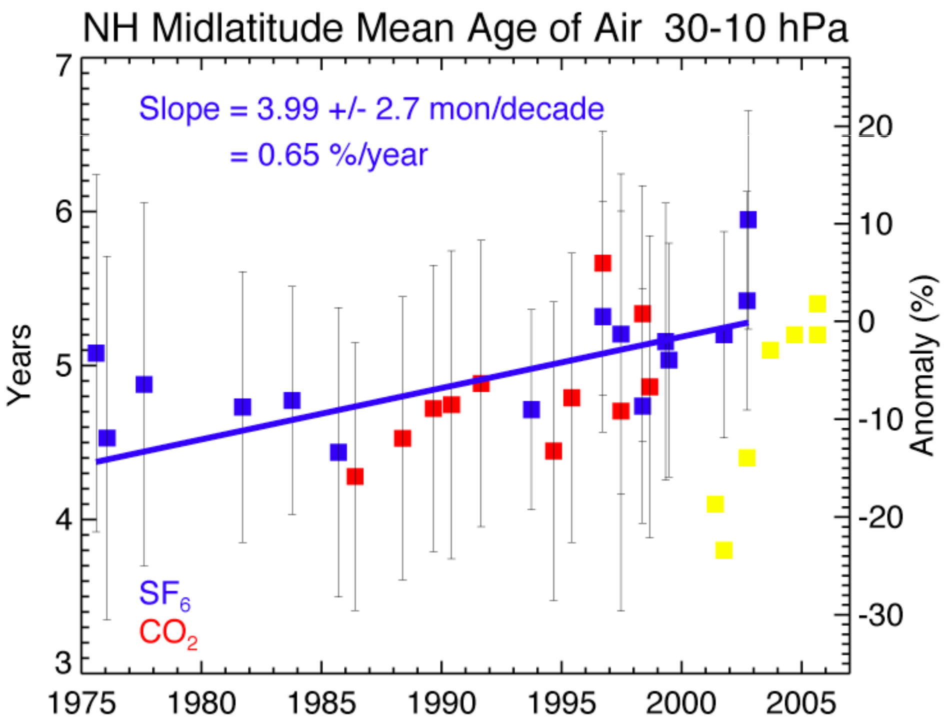
20% less air from between the halon-1211 and CFC-11 cut off altitudes in 2008.

25% more air from below the halon-1211 cut off altitude in 2008.

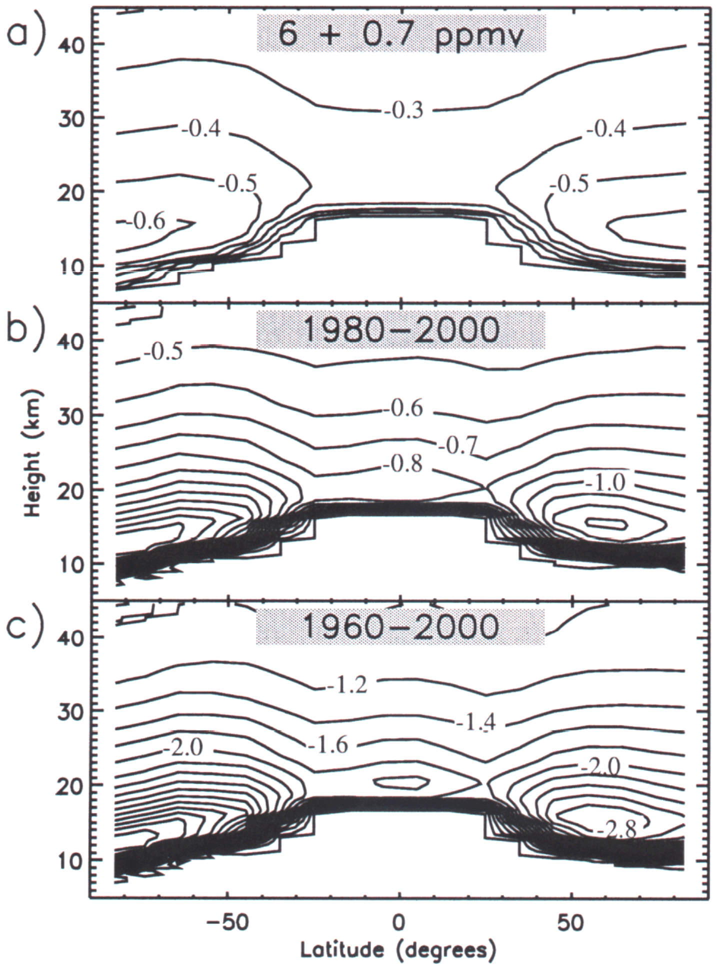
compared GC data from before and after 2001 at NH mid latitudes.

See possibly different trends in the BD circulation depending on the level in the stratosphere:

This may help explain results in Engel et al. 2008 age of air paper.



- There is likely a radiative significance to this change, which has an average value in the stratosphere of ~.32 ppmv (or half the magnitude that Forster and shine [2002] used in the top panel shown below (but of the opposite sign). Instead of a cooling in the stratosphere, the water vapor drop should produce a stratospheric warming.



Summary

- Variations in tropical temperatures near the tropopause control large variations in the entry value of stratospheric water.
- The change near the end of 2000 is correlated to tropopause temperature changes in the vicinity of the warm pool.
- Changes in warm pool SSTs are correlated with impacting those key near tropical tropopause temperatures.
- The widening of the tropical region appears to have stopped at the same time the tropical tropopause temperatures dropped...perhaps even contracted in the NH.
- The speed up of the circulation starting at the end of 2000 seems to be greater in the very lowest part of the stratosphere.
- Is this a climate shift...or a return to conditions from the late 1980s?
- Establishing mechanisms requires further study (and modeling). Is thre something to do with the QBO and La Nina of 1999/2000 being in phase at that time?
- Current work involves assessing the radiative significance of this change...look in the near future for a paper by S. Solomon et al.