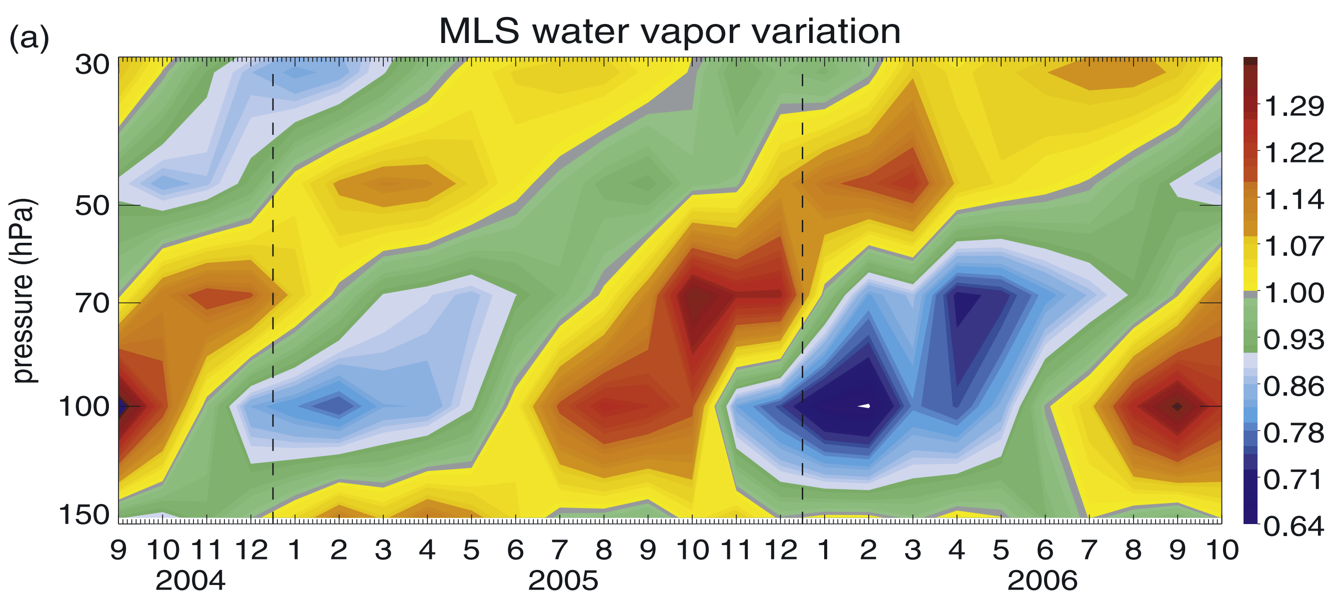
TTL Upwelling driven by Equatorial Waves

What drives the annual cycle in TTL upwelling?



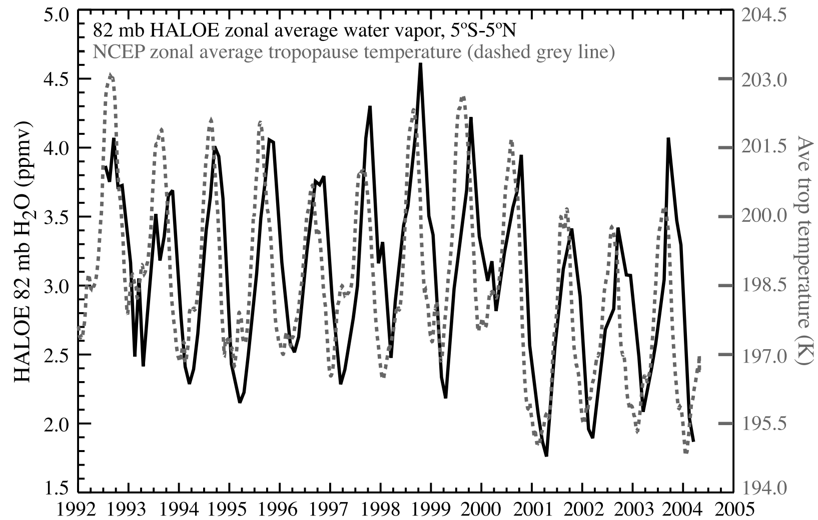
Liu et al. (2007)

Ortland, D. and M. J. Alexander, The residual mean circulation in the TTL driven by tropical waves, JAS, (in review), 2013.

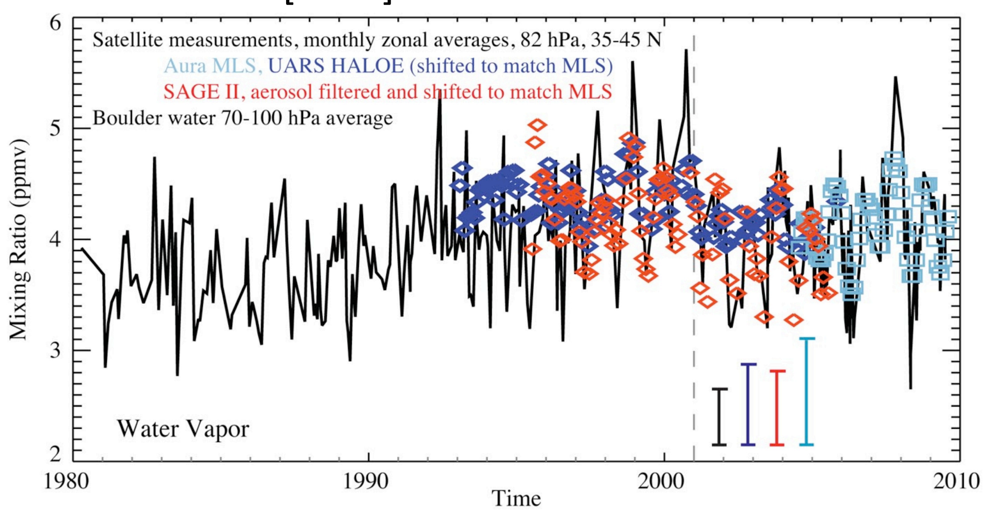
Water Vapor and Cold Point Temperatures

are causally related on many timescales

Rosenlof & Reid [2008]



Solomon et al. [2010]



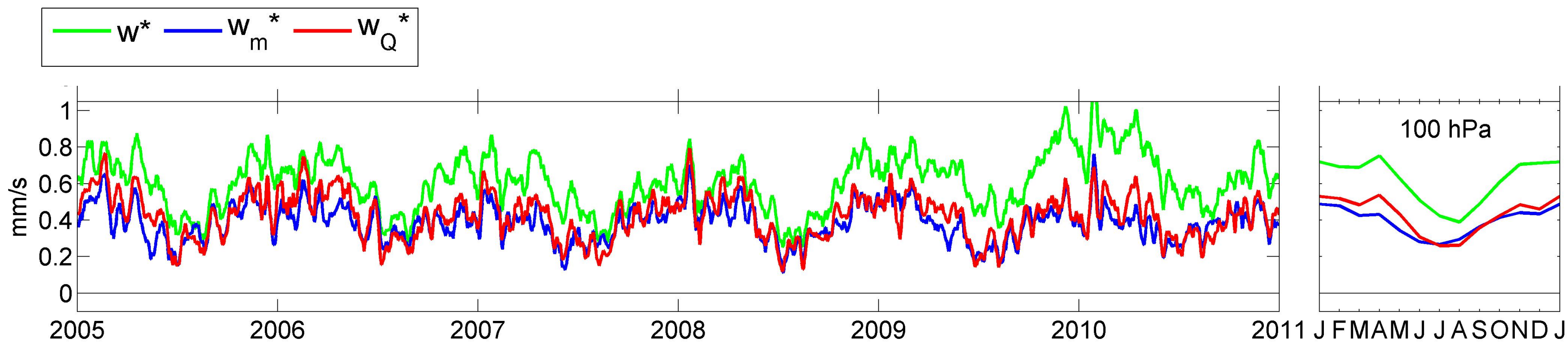
- Causes of the annual cycle in water vapor, temperature, and upwelling in the TTL "remain to be clarified" [Randel & Jensen, 2013].
- Causes of recent decadal-scale changes in stratospheric water vapor are poorly understood, yet these changes have resulted in significant decadal-scale changes in surface warming.
- Likely related to changes in TTL upwelling.

Upwelling rates at 100hPa

- Schoeberl et al. [2008]: Upwelling rates in TTL based on H_2O observations
  ~0.4-0.5 mm/s

- Dima and Wallace [2007] from ERA-40 ~ 0.55 mm/s

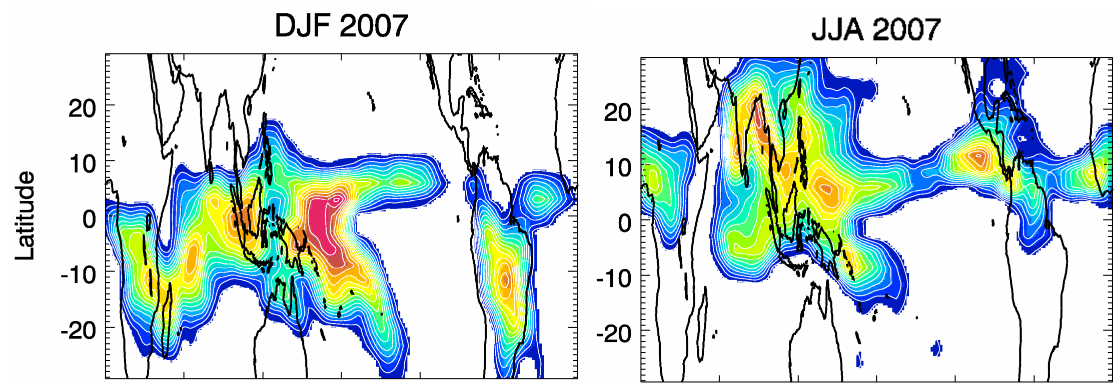
- Abalos et al [2012]: ERA-Interim; three different methods:

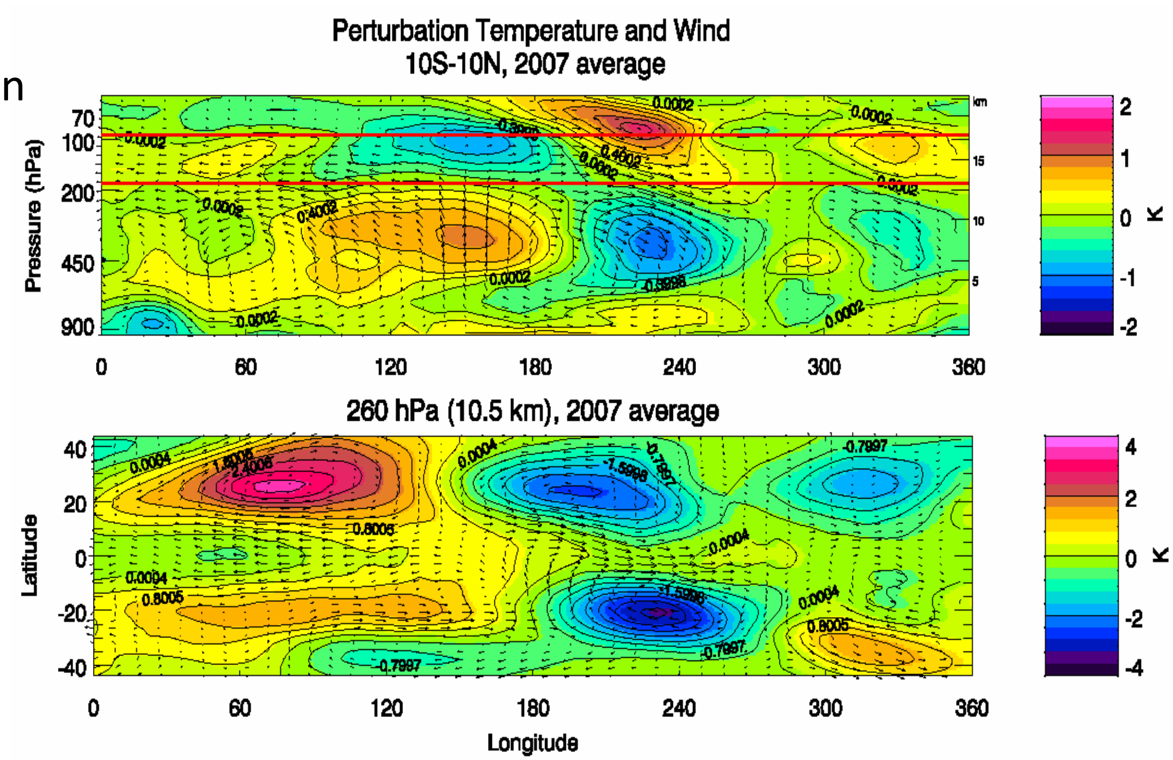


Annual Mean ~ 0.4-0.5 mm/s
Annual Cycle ~ a factor of two

Our Work: Model Study of Tropical Waves Effects in the TTL

- Idealized global primitive equation model
- Waves forced by latent heating Q(x,y,z,t) derived from observed precipitation
- TRMM Rain Rates gridded 0.25°x0.25° and 3-hrly
- Examine tropical waves, wave propagation and dissipation
- Zonal-mean U and T constrained to observations 30S-30N.
- Compute wave EP-Flux and EP-Flux divergence.
- Compute residual circulation and TTL upwelling driven by the EP-Flux divergence.

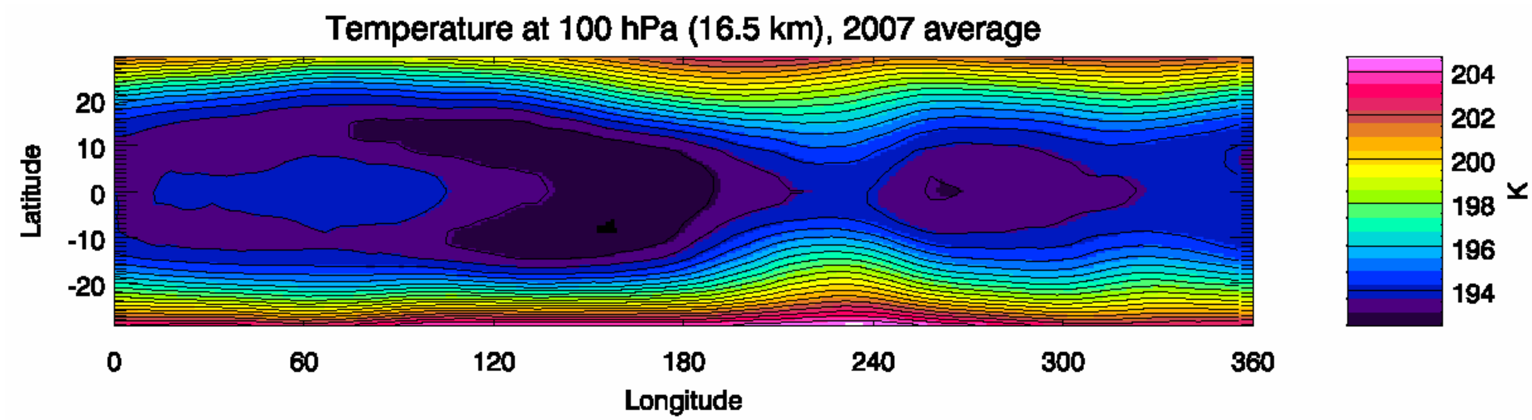




Model Annual Mean Compared to Reanalysis

Realistic tropopause temperatures and cold pool

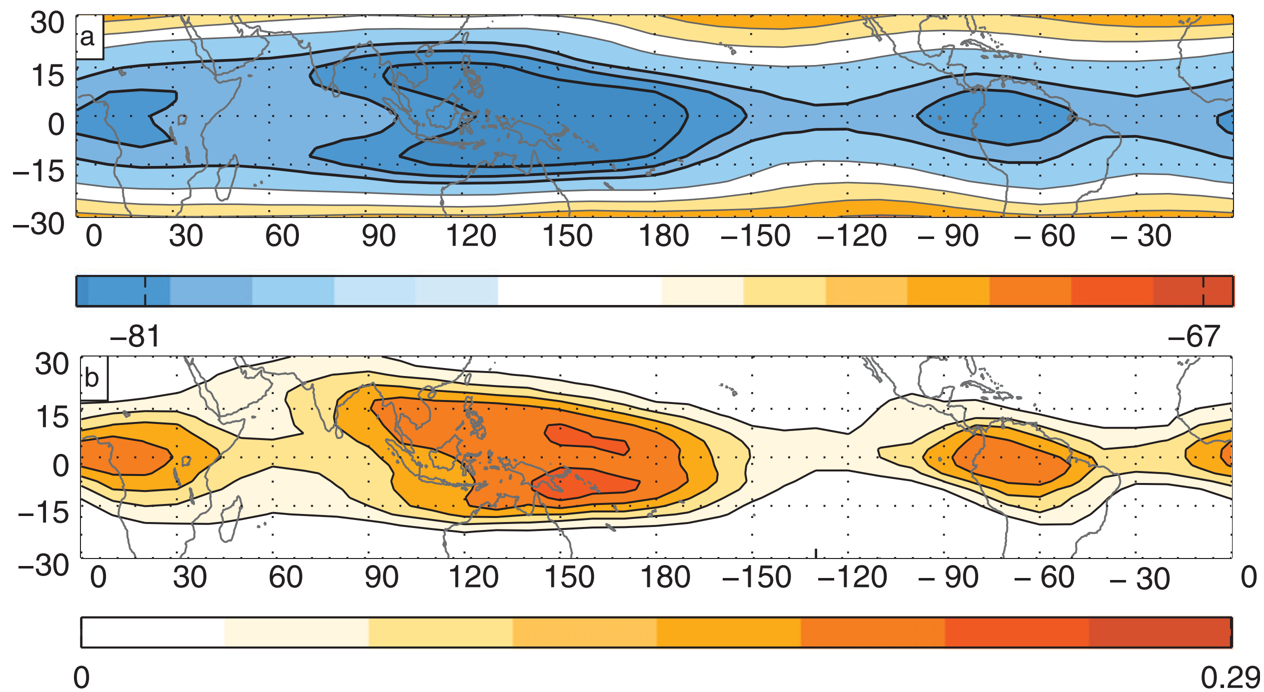
100 hPa
Temperature
lon/lat



Virts et al. [2010]
100 hPa ERA-40
Temperatures

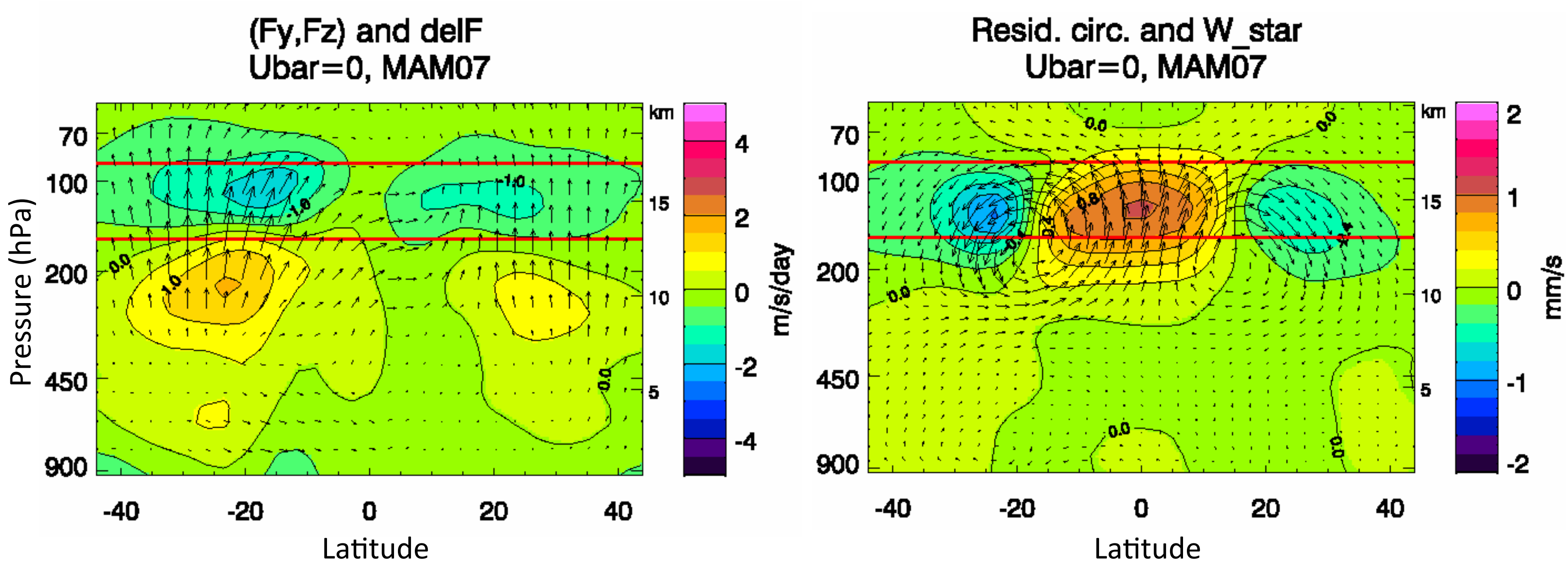
and

CALIPSO
Cirrus above 15km



Model Results: Tropical Waves Only with U=0

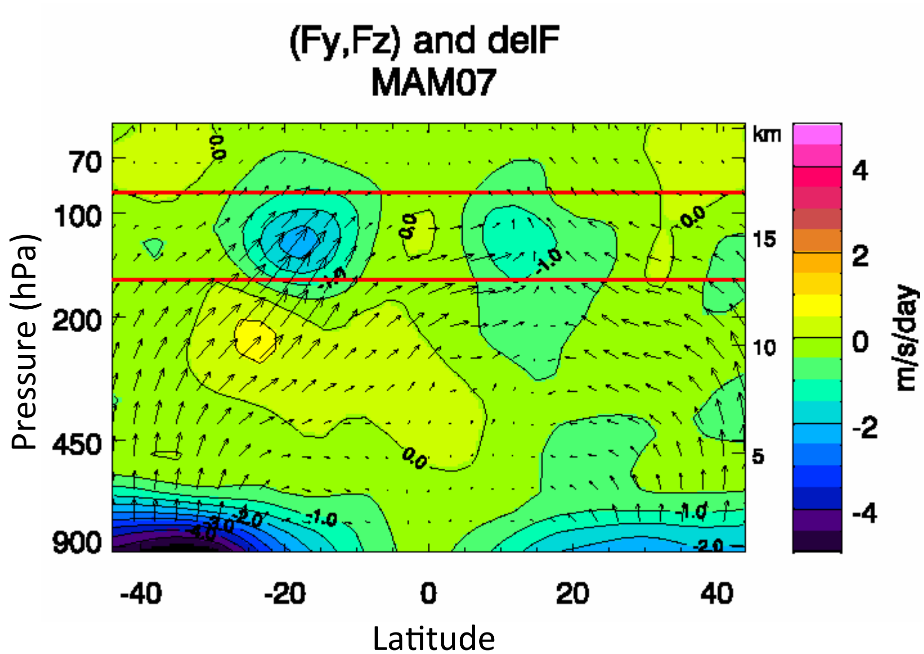
EP Flux and Flux Divergence (left) and Residual Circulation and Upwelling (right)

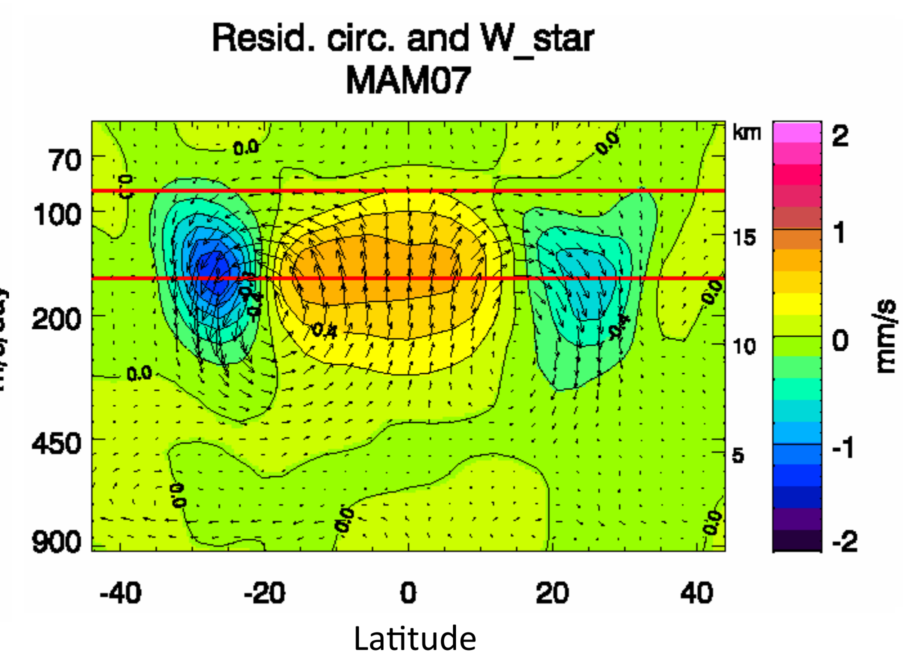


Tropical Waves Only with Observed Winds U ≠ 0

EP Flux and Flux Divergence (left) and Residual Circulation and Upwelling (right)

Winds shift the patterns downward with slightly weaker upwelling.





Two-year runs with observed Zonal-Mean Winds 2006-2007

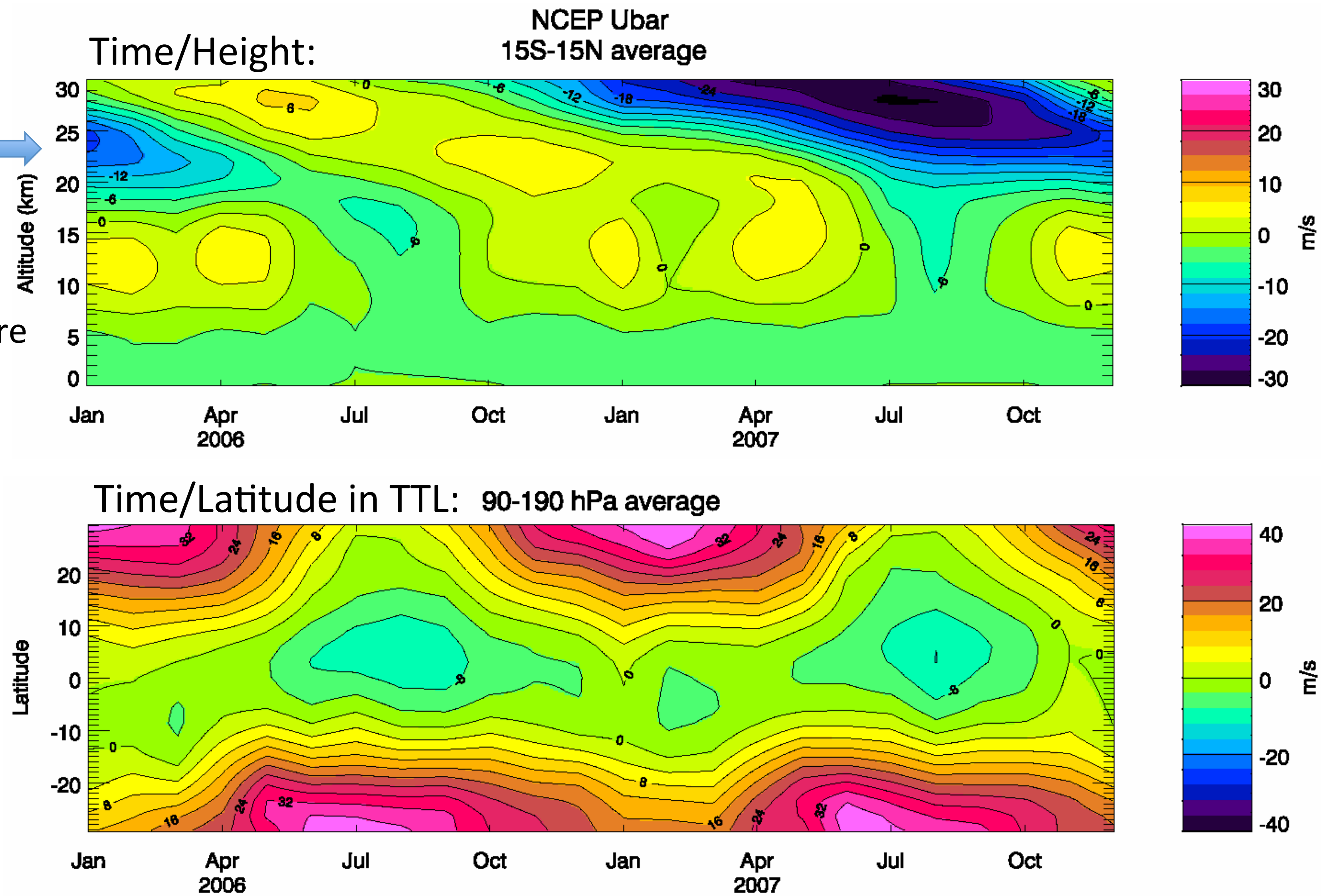
The important waves have low phase speeds: Influenced by changes O~5m/s

QBO

Variable upper troposphere

Variable Subtropics

Weak easterly near equator

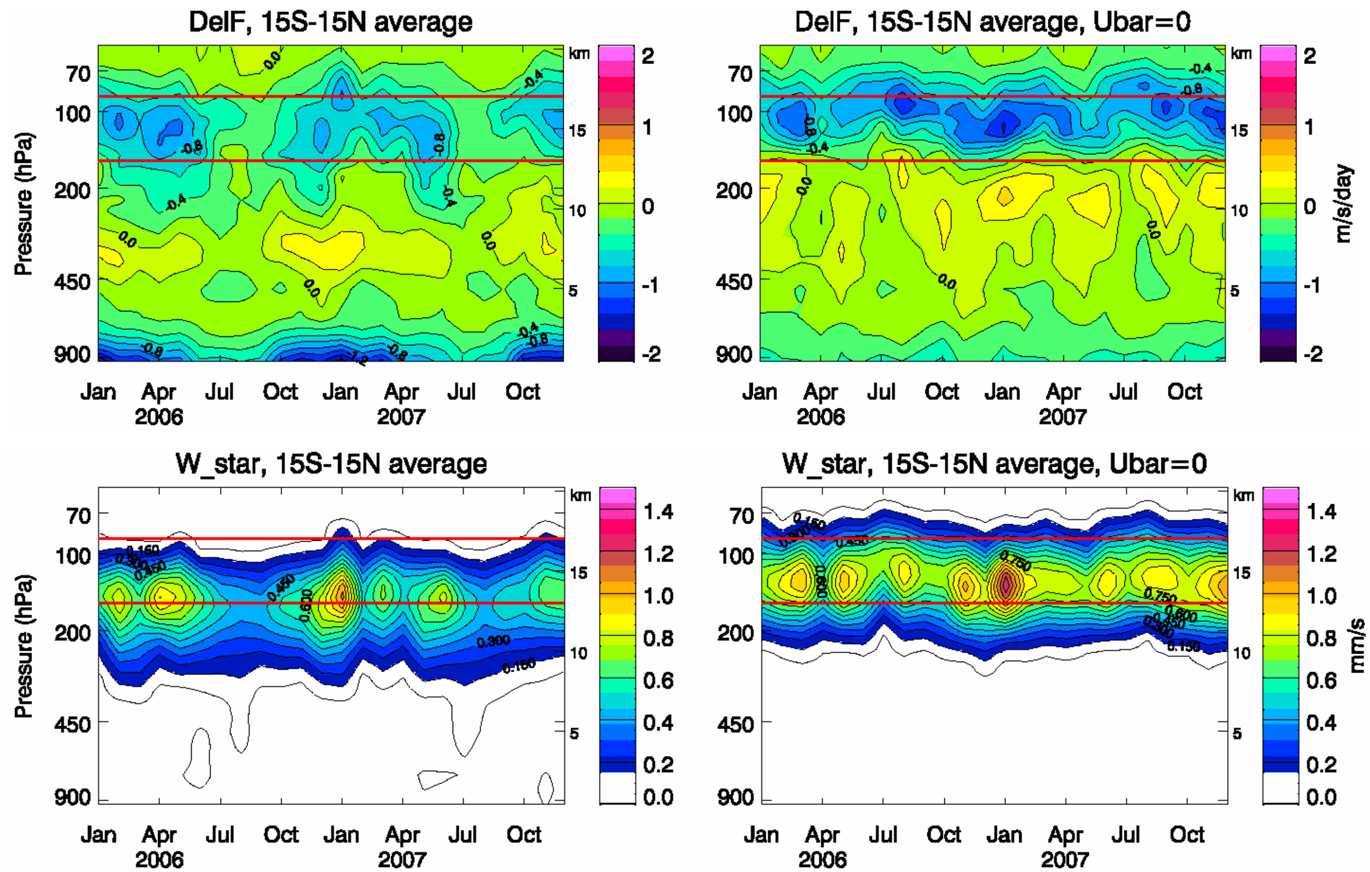


2006-2007 Tropical Mean: EP-flux divergence and Upwelling

Observed Winds

***U* ≠ 0**

***U* = 0**

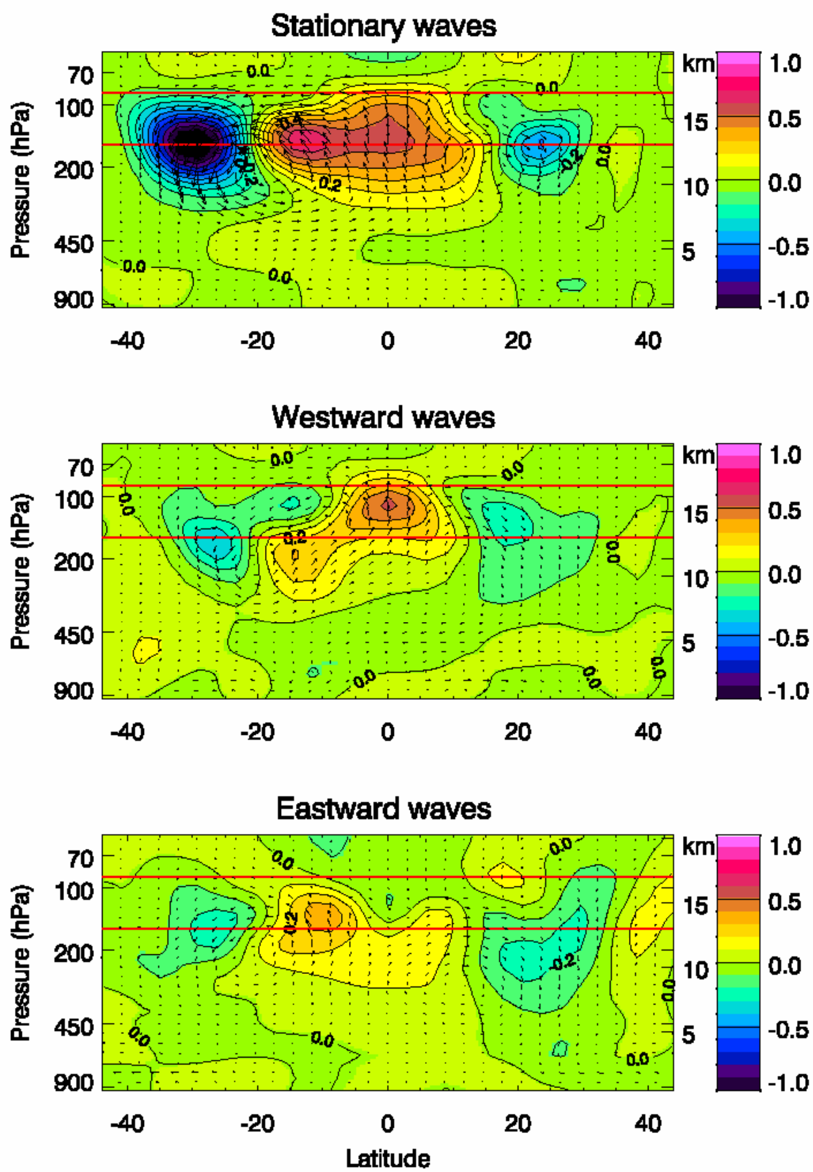


With U=0, there is variability, but no clear annual cycle.

Seasonal changes in the winds give clear seasonal variations in tropical wave driving and upwelling.

Spectral Decomposition: Which waves are most important?

w/Observed winds: **Residual circulation and W_star DJF07**



Stationary equatorial Rossby waves primarily drive the TTL upwelling.

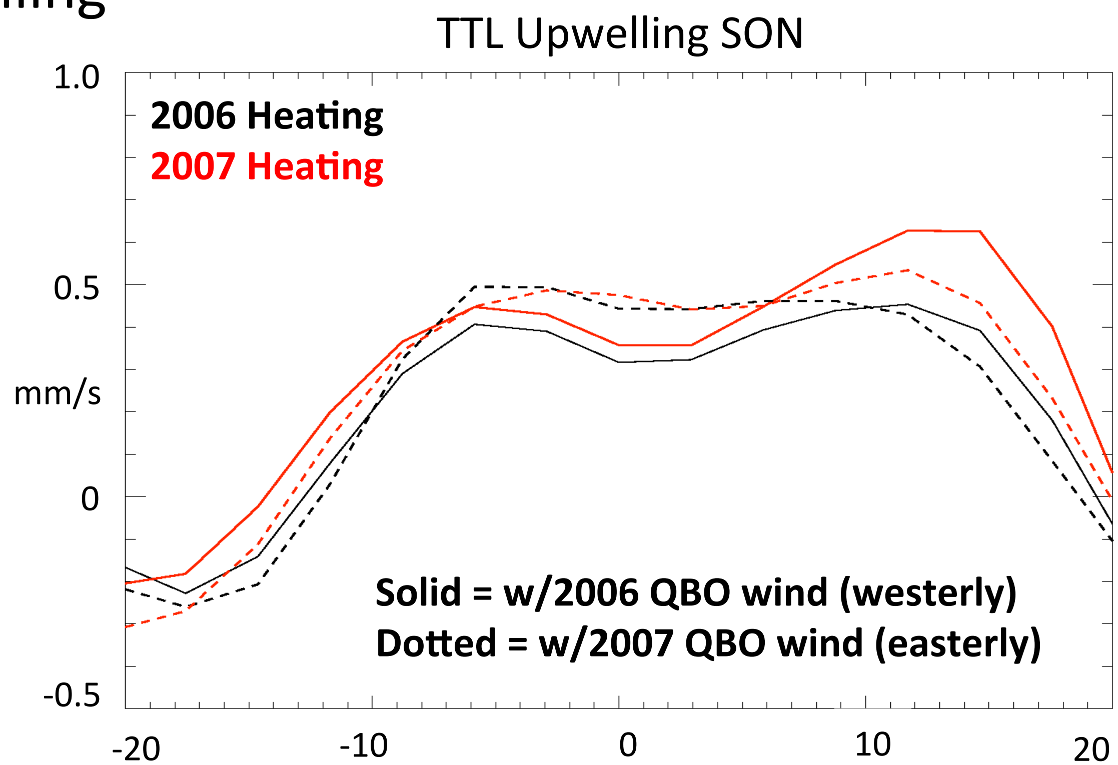
Transient westward waves much less.

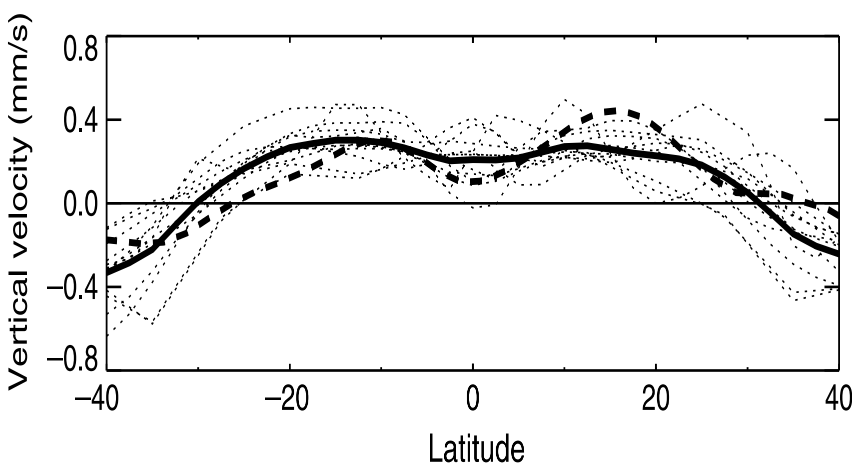
Kelvin waves contribute a small downwelling component close to the equator.

QBO Effects on TTL Upwelling

Local minimum at the equator is associated with enhanced Kelvin wave drag in the lower-most stratosphere in the QBO westerly wind case.

Differences in heating patterns (i.e. differences in wave forcing) in different years also create some differences.





Butchart et al. [2006] multi-model comparison

Multi-Model Mean

UKMO analysis (10-yr mean)

Differences in wave forcing and/or differences in QBO winds in the lowermost stratosphere could cause differences in tropical upwelling.

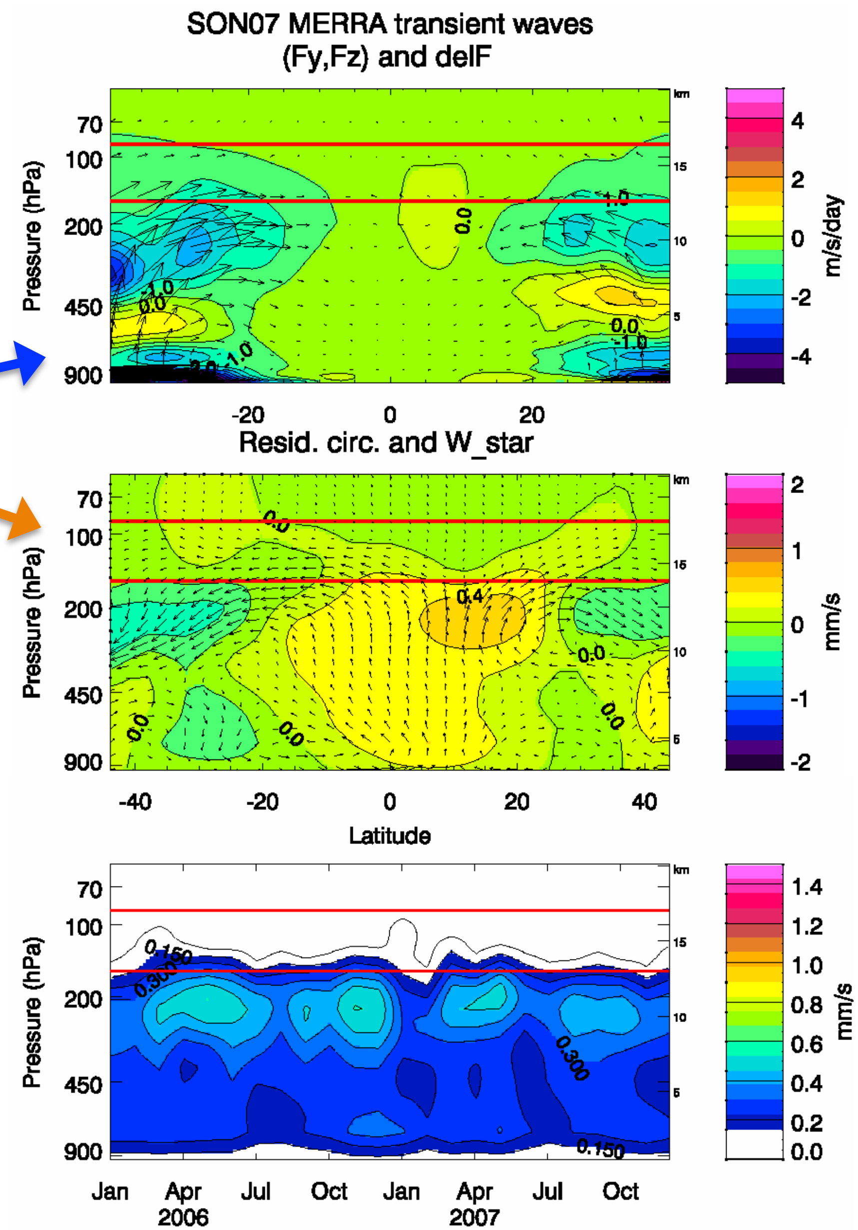
TTL Upwelling: What is the role of extratropical synoptic waves?

Results shown so far eliminated synoptic waves.

- *Stationary* equatorial waves drive the TTL upwelling, and
- Synoptic waves are *transient*
- Here we isolate *transient* waves in MERRA

EP FLUX and DIVERGENCE

RESIDUAL CIRCULATION and UPWELLING

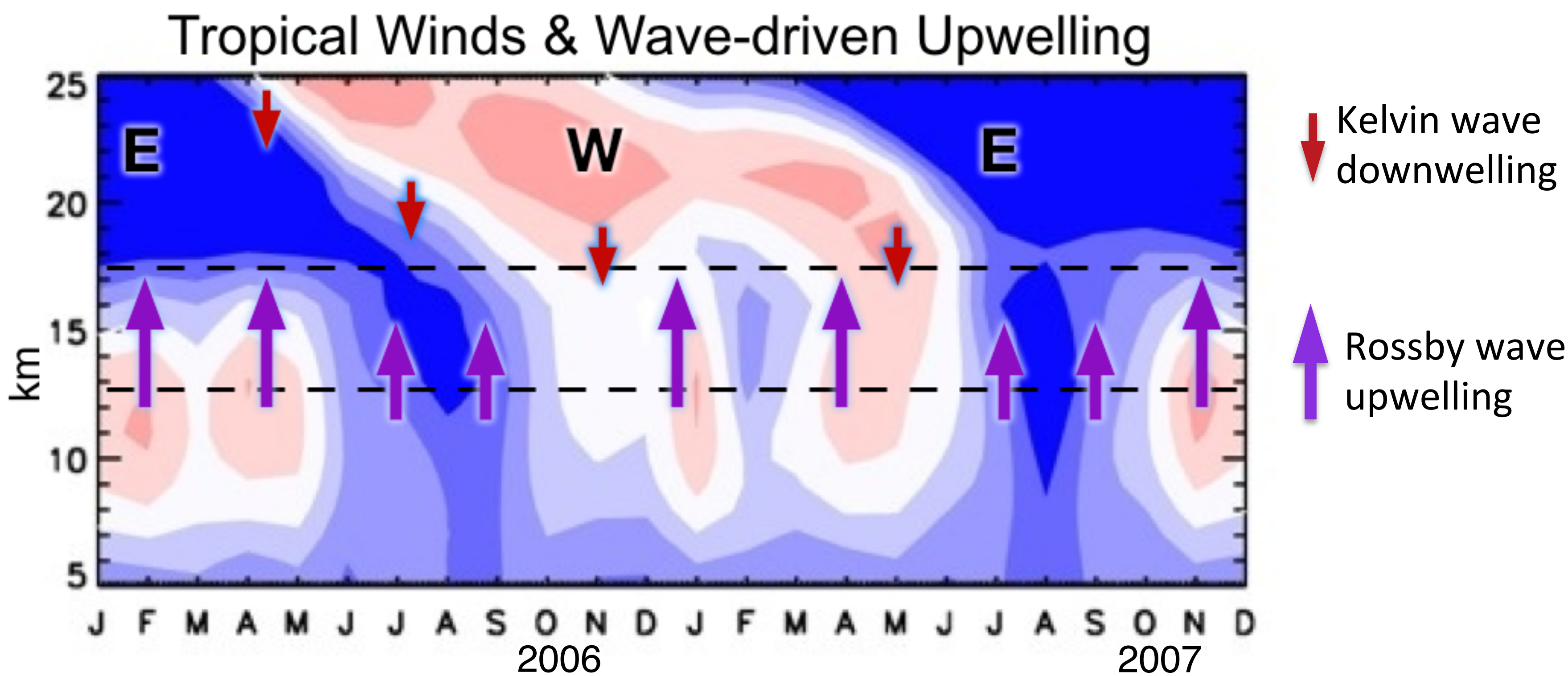


- Upwelling driven by synoptic waves in current climate lies below the TTL.
- The seasonal cycle of synoptic wave-driven upwelling is semi-annual.

Conclusion is synoptic waves are not an important driver of seasonal variations in TTL upwelling.

Conclusions:

- Annual cycle in TTL upwelling 15S-15N primarily driven by stationary equatorial Rossby-wave interactions with upper tropospheric winds.
- Kelvin waves contribute a smaller downwelling close to the equator that is modulated by QBO winds in the lowermost stratosphere.



Note: Small zonal wind biases in models O ~ 5 m/s could lead to differing conclusions.