

**ATTREX Science Team Meeting**  
NASA-Dryden  
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**Tropical Waves**  
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## ***ATTREX: “A Mission to Understand the Role of the Tropical Tropopause Layer (TTL) in Earth's Climate”***

Tropical waves have a climate influence through their effects on cirrus clouds and water vapor.

Key to these influences are tropical wave effects on:

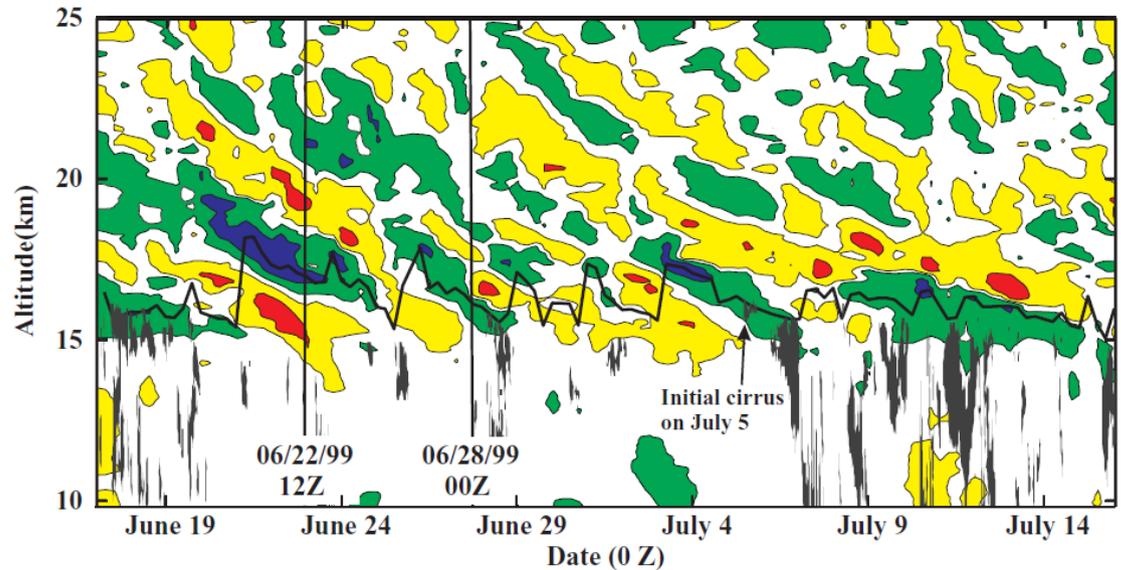
1. TTL temperature structure
2. Upwelling in the TTL

# Example of Tropical Wave Temperature Fluctuation Effects on Cirrus

## Cirrus preferentially forming in the cold phases of tropical waves

Radiosondes and lidar at Nauru  
Boehm & Verlinde (2001)

Temperature Anomalies,  
Cold-Point Tropopause,  
and Cirrus



Wave modification of the cold-point led to periodic modulation of tropical cirrus formation.

Holton et al. (2001) from analysis of soundings at this one site, could determine that these are global-scale Kelvin waves,  $wn=2$  and  $4$ , with periods of 9.5 and 5 days.

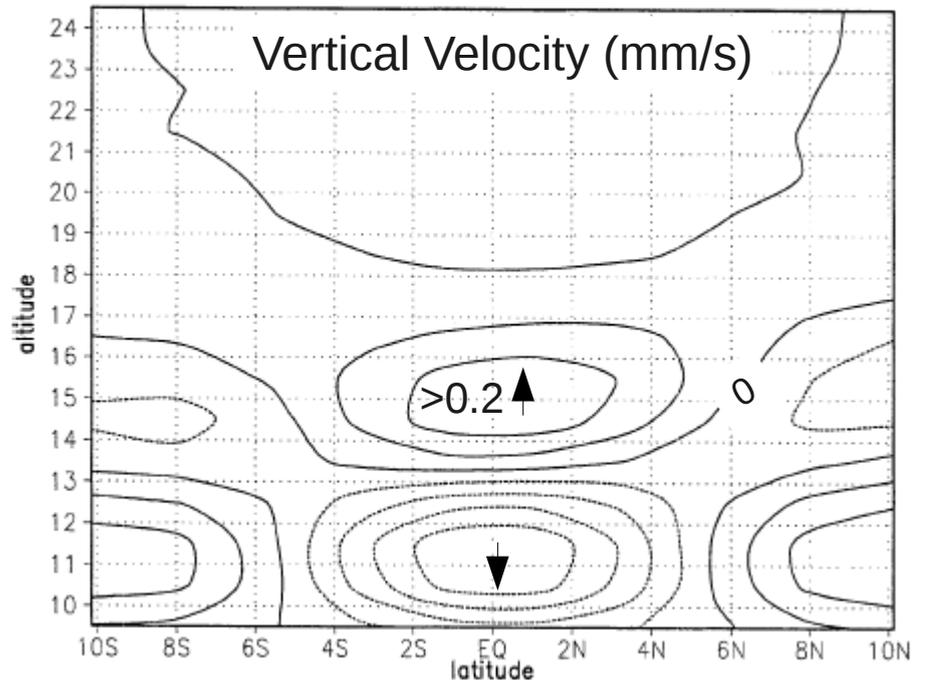
# Example of Tropical Wave Effects on TTL Upwelling

## Wave driving of TTL upwelling above convective outflow

Boehm & Lee (2003)

Vertical velocity driven by tropical EP-flux divergence derived from NCEP-NCAR reanalysis

(April mean 1958-1997)



**Tropical waves come in many different sizes and colors.**

**Stationary** vs **Transient**

Global-scale, Medium-scale, or Small-scale

**Low-frequency**, **Mid-frequency**, or **High-frequency**  
(equatorially trapped) (meridionally propagating)

Which should we try to observe with the ATTREX measurements?

Which are most important for TTL climate influences?

Which would be unique observation targets for ATTREX?

## ***Stationary*** versus ***Transient*** Waves

***Stationary waves*** with large horizontal scales are relatively well described by global reanalysis products produced by ECMWF and NCEP and therefore relatively well studied.

***Transient waves*** are relatively poorly described in ERA-40 and NCEP. Observational validation of transient waves in models is also lacking. Transient waves include global scale, equatorially trapped modes as well as gravity waves that can have small horizontal scales and short periods propagating in any direction.

ATTREX measurements may have their main impact by improving our understanding of the nature and effects of the transient waves.

# Wave Driving of Tropical Upwelling

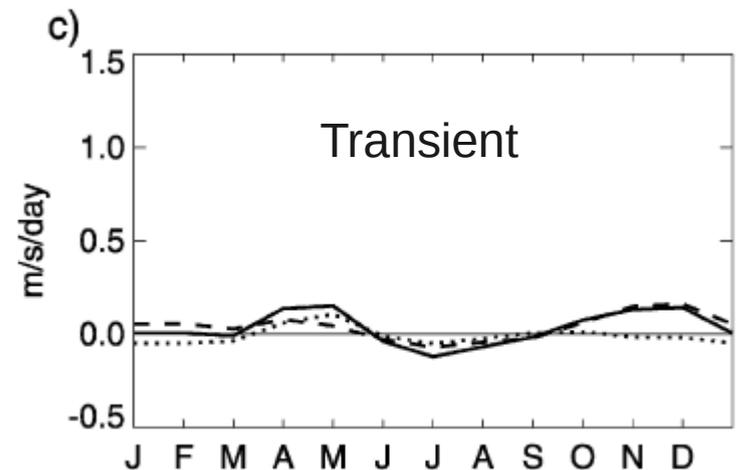
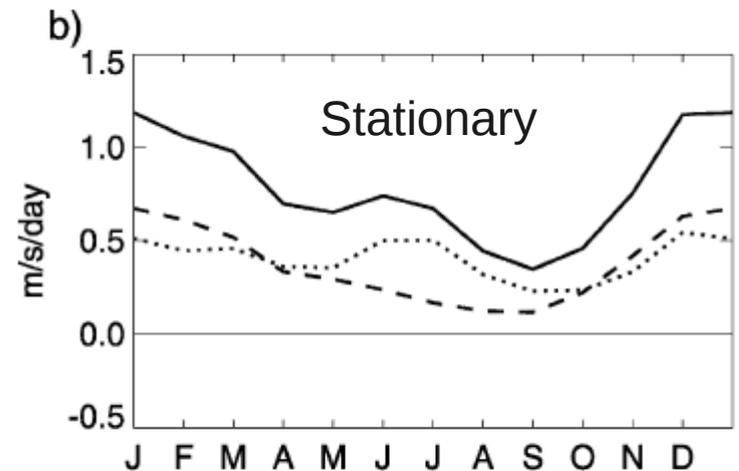
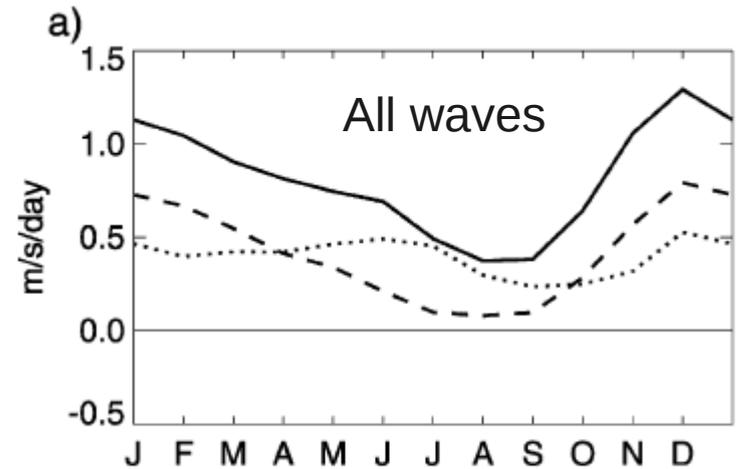
Kerr-Winslow and Norton (2006)

ECMWF analysis (ERA-15) at 90hPa

- EP-Flux Divergence
- ..... Horizontal Component
- - - Vertical Component

*Are the transient waves unimportant?  
Or do the analysis products do a poor job  
of describing them?*

*Our own preliminary work suggests that  
the spectrum of transients are important  
for enhancing wave-driven upwelling  
across tropopause.*



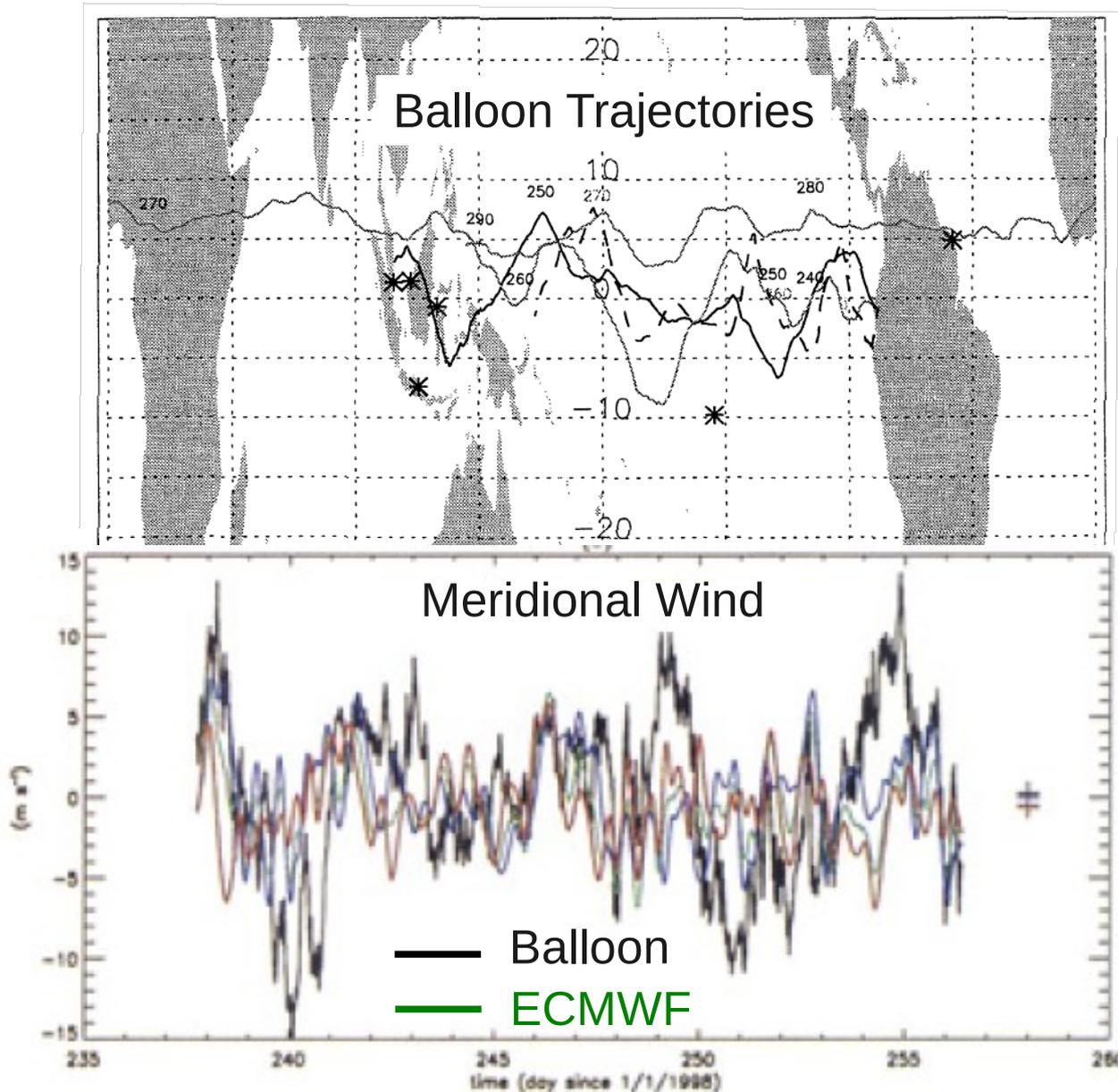
# Lagrangian Balloon Measurements and comparison to ECMWF

Vial et al. (2001)

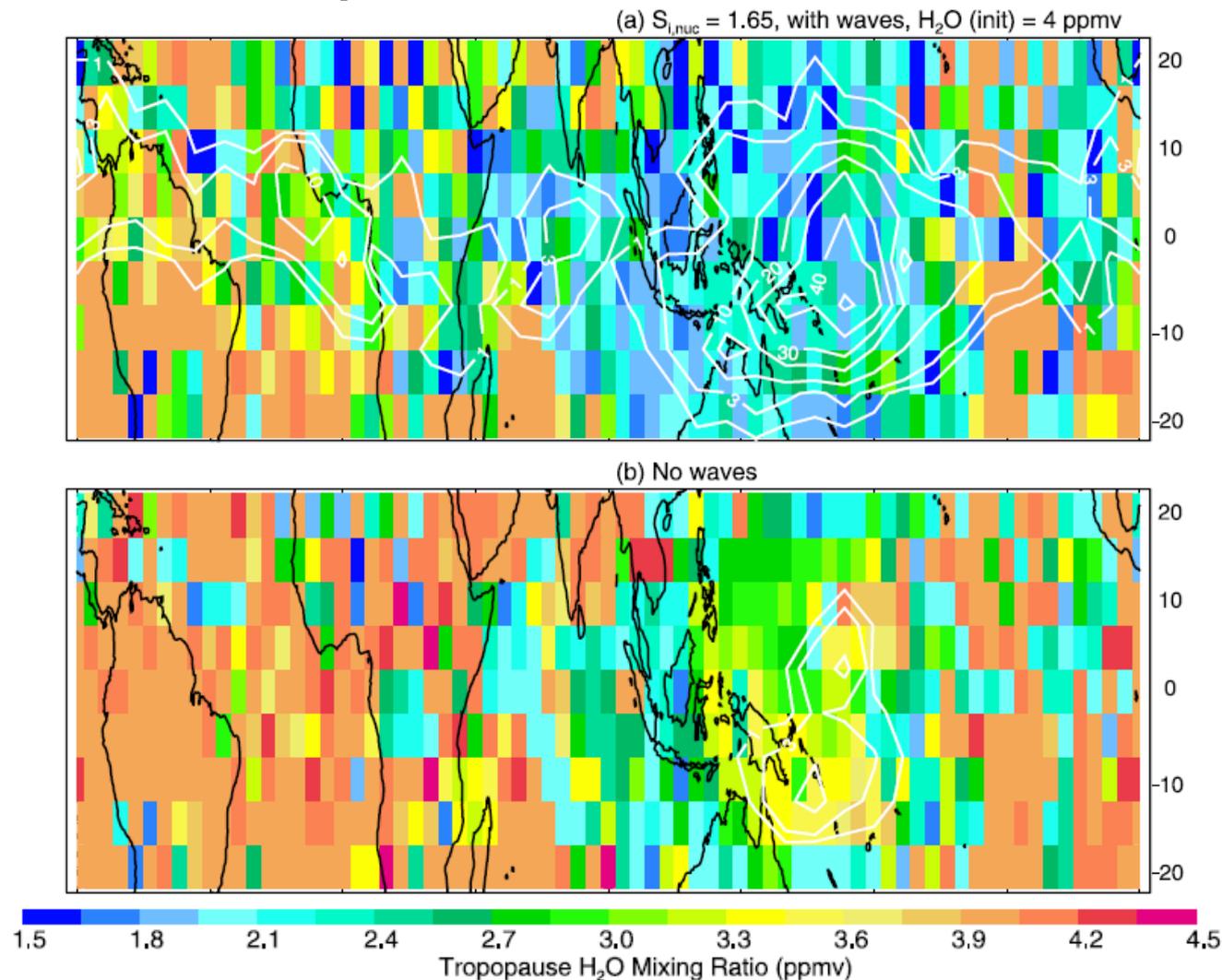
Equatorial balloon flights at 20km (~60hPa)

The balloons sampled a large amplitude Rossby-gravity wave with wavenumber=4.

The wave is virtually absent in the ECMWF analysis as seen in a comparison of meridional velocities sampled along the balloon trajectory.



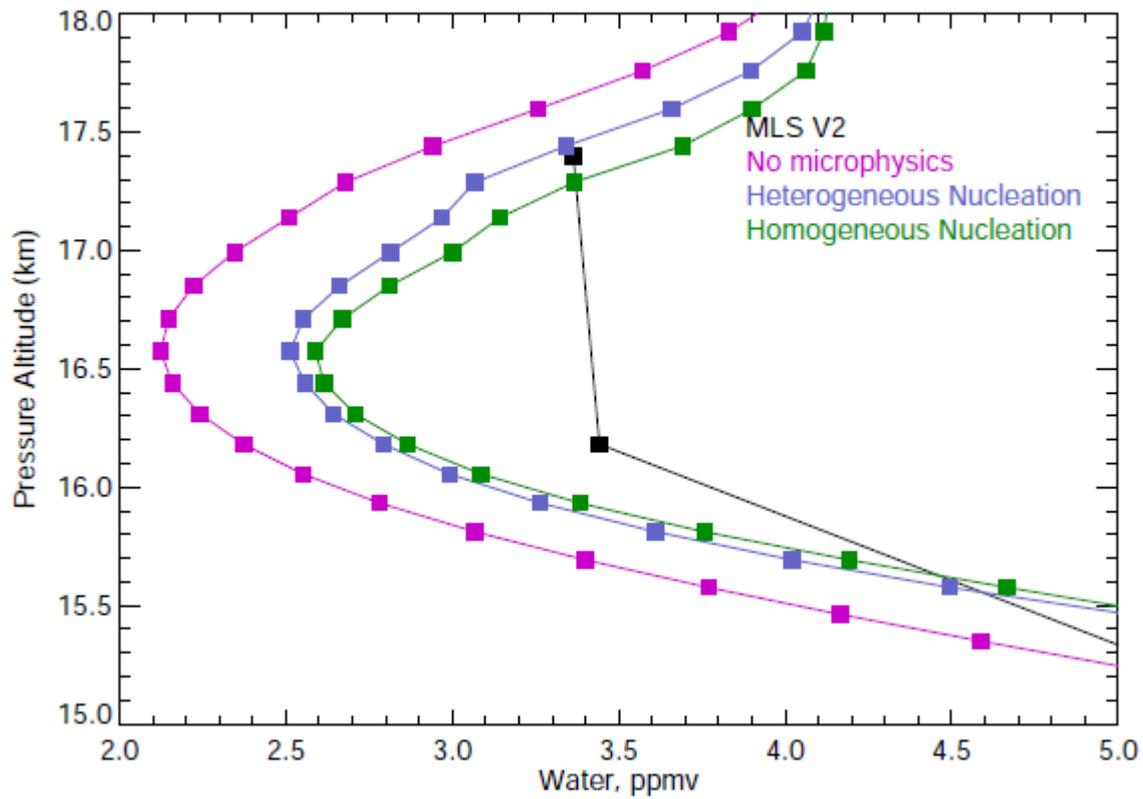
# Transient Wave Temperature Effects on Cirrus (Jensen & Pfister, 2004)



Addition of a spectrum of gravity wave temperature fluctuations to trajectory-following temperature curtains derived from the NCEP reanalysis has a major effect on cirrus occurrence frequencies (white contours).

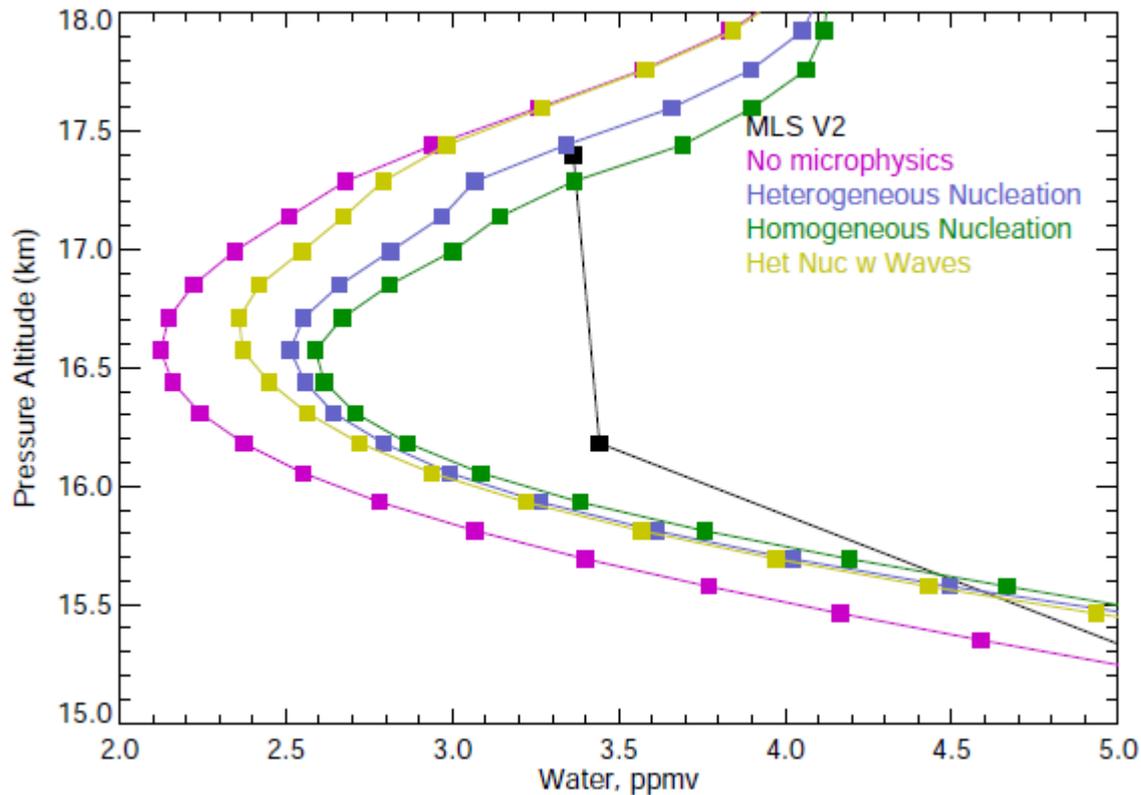
# Effects of a spectrum of transient waves on TTL water vapor

Tropical water vapor profiles under different assumptions



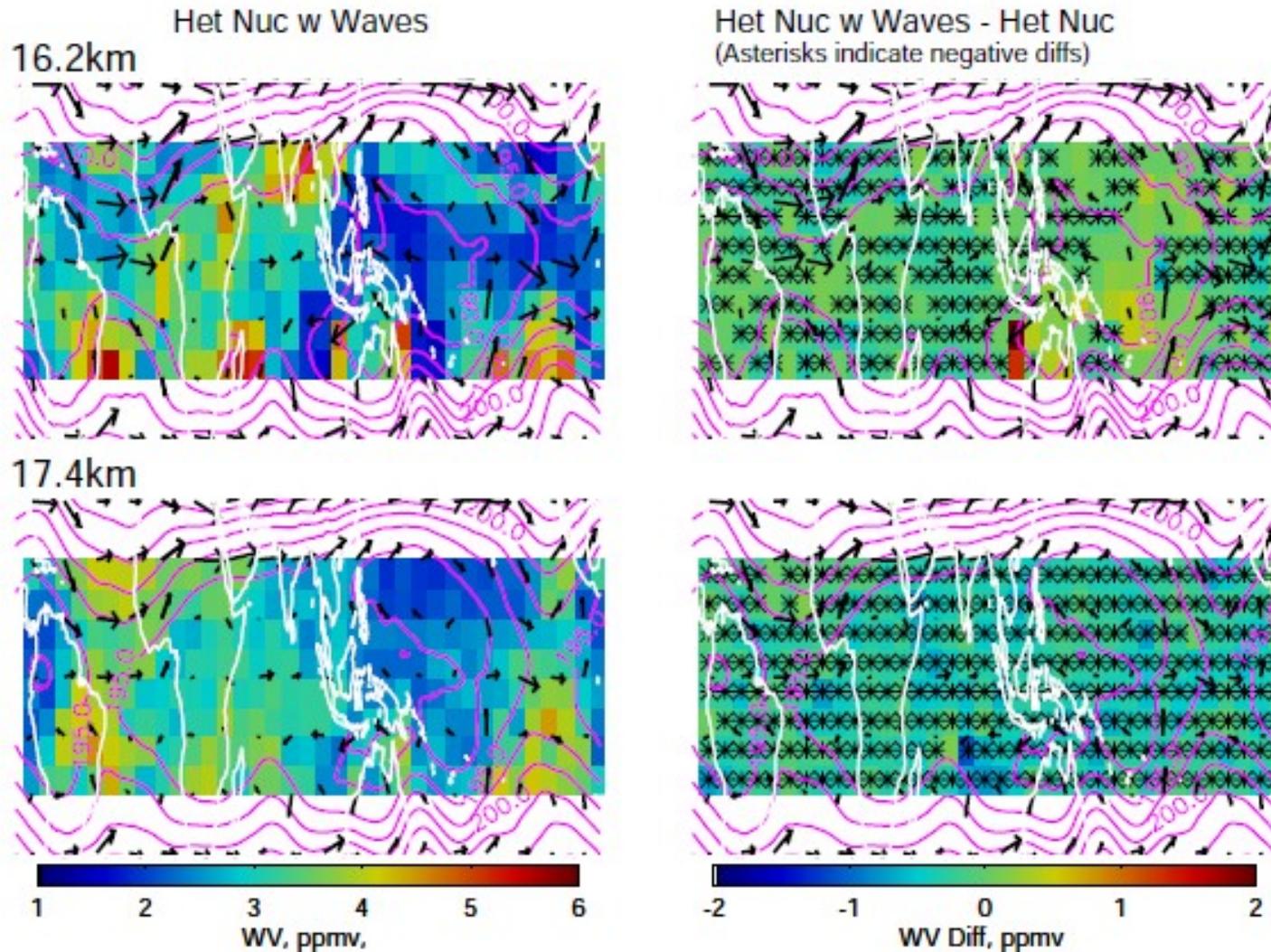
# Effects of a spectrum of transient waves on TTL water vapor

Tropical water vapor profiles under different assumptions



With the addition of wave temperature fluctuations, the ice particles grow large enough to enhance precipitation and removal from the TTL.

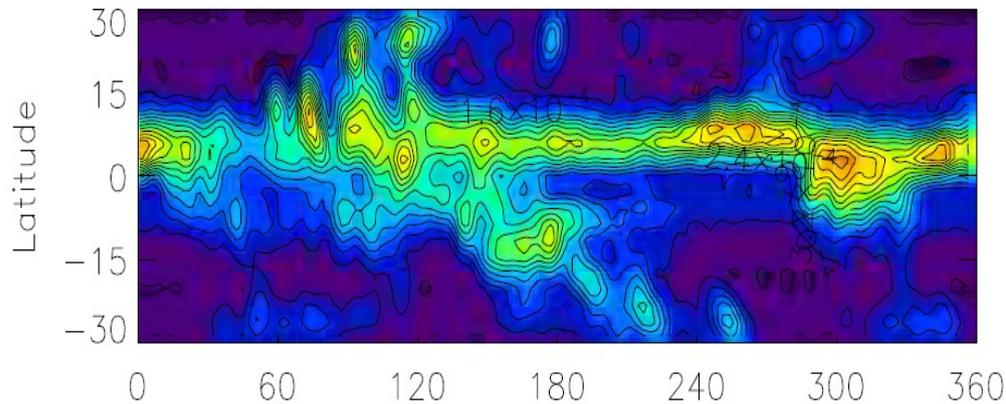
## Water Vapor and Differences



At the lower altitude, waves can sometimes increase water vapor, due to ice falling and evaporating at the lower level.

# Tropical Rainfall Measurement Mission (TRMM) Precipitation and Forcing of the Tropical Wave Spectrum

TRMM-based heating for May 2006

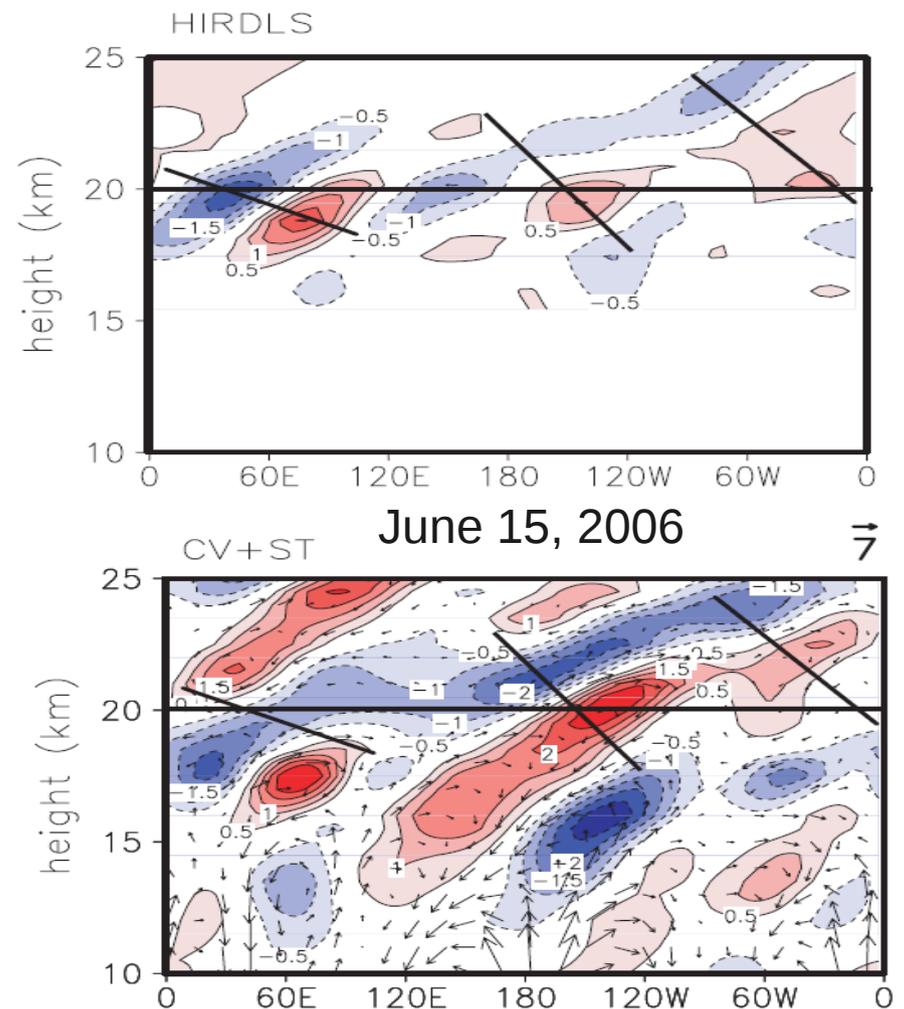


The TRMM data have  $0.25^\circ$  spatial and 3-hourly time resolution.

We use TRMM precipitation observations to force very realistic transient waves in a global model that can be directly validated against observations.

[Ryu et al., 2010; Alexander & Ortland, 2010]

Comparison of Kelvin waves in HIRDLS observations and model (color =  $T'$  (K))



## Key ATTREX Measurements for Tropical Waves:

- Temperature (MMS)
- Temperature profile (MTP)
- Horizontal Wind Vector (MMS)
- Vertical wind for higher-frequency gravity waves (MMS)
- **Synergistic Measurements:** Cirrus cloud properties, water vapor, convective cloud top heights and precipitation.

## ATTREX Flight Plans for Observing Tropical Waves:

- Straight, constant pressure, constant latitude flight legs desired.
- Length  $>$  wavelength of the wave.
  - Pacific basin scale is a desirable length for large-scale waves at constant latitude at  $\sim 2.5$ - $10$  degrees latitude.
  - Long legs at least  $\sim 5000$ km required to meet mission objectives.
  - Shorter legs close to deep convection may be useful for gravity waves.
- Location: Western Pacific is a key region for T' and upwelling effects. Observations at all longitudes in the tropics are useful.