Comparison of TTL waves and precipitation variability in satellite observations and a reanalysis

Ji-Eun Kim
ATOC, University of Colorado-Boulder

M. Joan Alexander
NorthWest Research Associates-Boulder

David Ortland
NorthWest Research Associates-Seattle

Outline

- Tropical Tropopause Layer (TTL) waves
  - HIRDLS satellite temperature
  - MERRA temperature sampled at HIRDLS measurement points
- Precipitation variability
  - TRMM satellite
  - MERRA reanalysis

Motivation

- TTL cirrus clouds preferentially form in the cold phases of tropical waves.
- Wave motions affect cloud occurrence frequency and particle size distribution.
- Also, tropical waves are partially responsible for the Brewer-Dobson circulation.

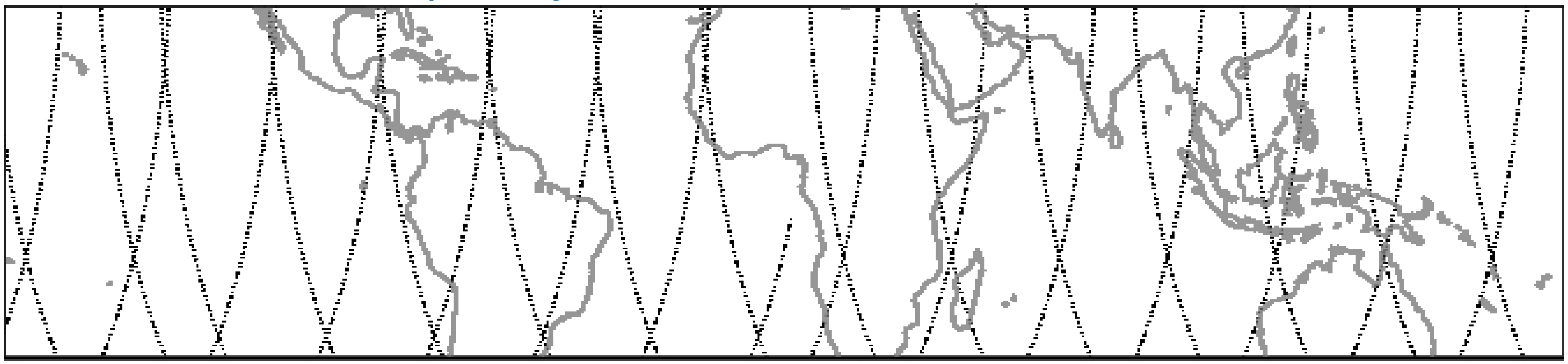
- We examine the representation of tropical waves and convection–a main source of tropical waves–in MERRA reanalysis against satellite observations.

Waves in the Tropical Tropopause Layer

HIgh Resolution Dynamics Limb Sounder (HIRDLS)

An Infrared Limb Scanning Instrument on the Aura Satellite

Example day of HIRDLS data: Profile locations



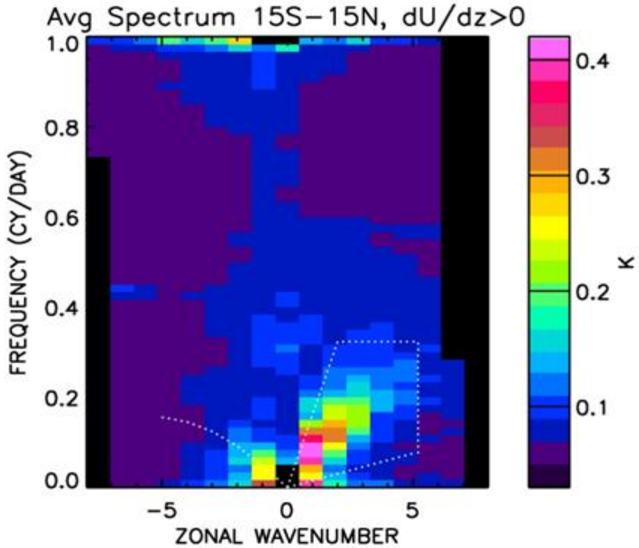
	HIRDLS	SABER	GPS
Vertical Resolution	.67-1.2 km	~2-2.5km	~1 km
Zonal resolution	wn ~ 7	wn ~ 7	wn<8?
10S-10N profiles/day	~650	~200	~200*

* Champ + COSMIC

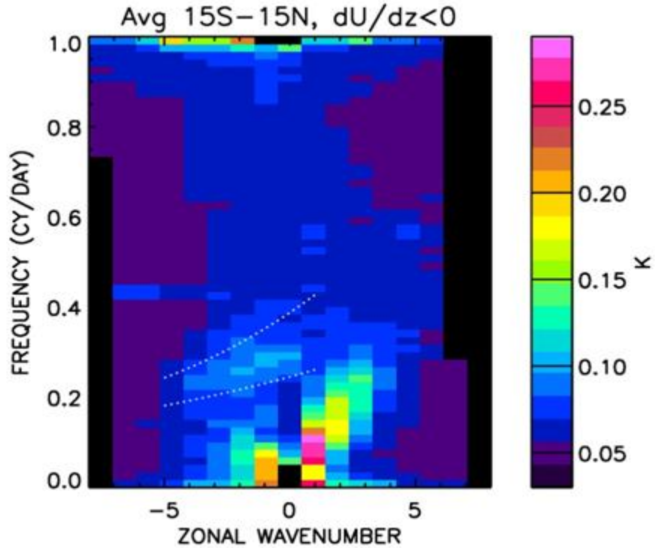
- HIRDLS has similar vertical resolution to GPS, but has very high latitudinal resolution ~1^{o}. giving excellent sampling for the study of equatorial wave modes at tropical latitudes.
- HIRDLS measures IR.

Asynoptic Fourier Transform of HIRDLS Temperatures

spectrum at z=15-32 km, 15ºS-15ºN over Jan 2005 - Jan 2008



Eastward wind shear



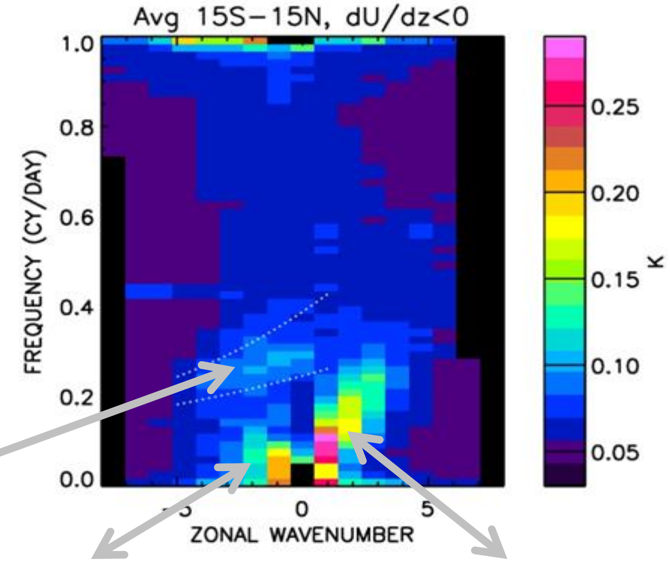
Westward wind shear

- Use Salby [1982] method to derive the equatorial wave spectrum from HIRDLS temperatures.
- Dotted curves show equatorial wave dispersion curves.

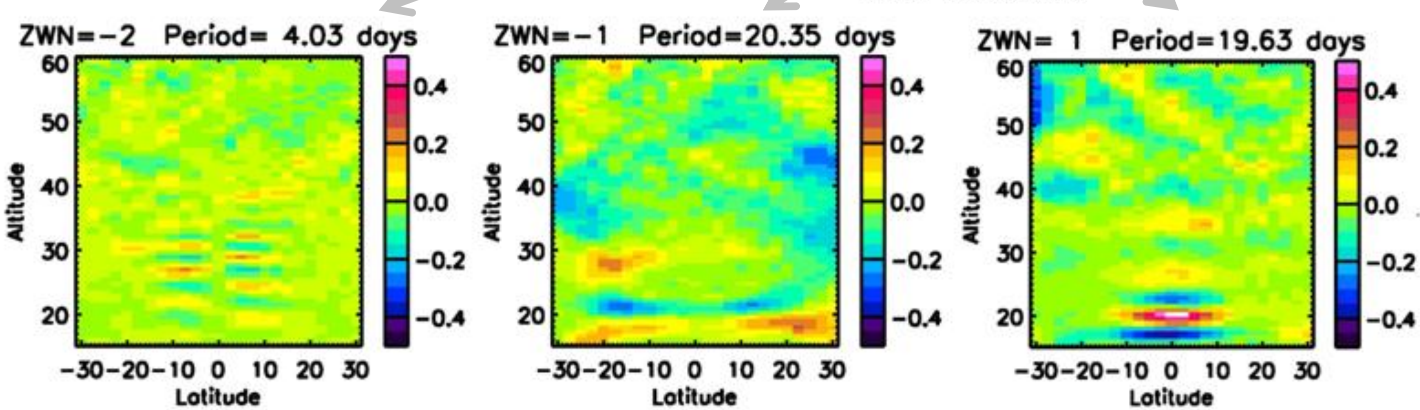
Asynoptic Fourier Transform of HIRDLS Temperatures

- The equatorially-trapped symmetric or anti-symmetric structure with oscillating phase with height is a clear confirmation of the interpretation of these signals.

- Wavelengths as short as 4 km are clearly observed.



Examples:



Mixed Rossby-Gravity | Equatorial Rossby | Kelvin

EP Flux $F^{(z)}$ from Satellite Temperature Measurements

EP Flux vector:

$$F^{(z)} = \rho a \cos\phi \left[\frac{\bar{Z}}{N^2} \overline{v'\Phi'_z} - \overline{w'u'} \right]$$

$$F^{(y)} = \rho a \cos\phi \left[\frac{\bar{u}_z}{N^2} \overline{v'\Phi'_z} - \overline{v'u'} \right]$$

For small perturbations
Single mode $\propto e^{imz}$

Can show

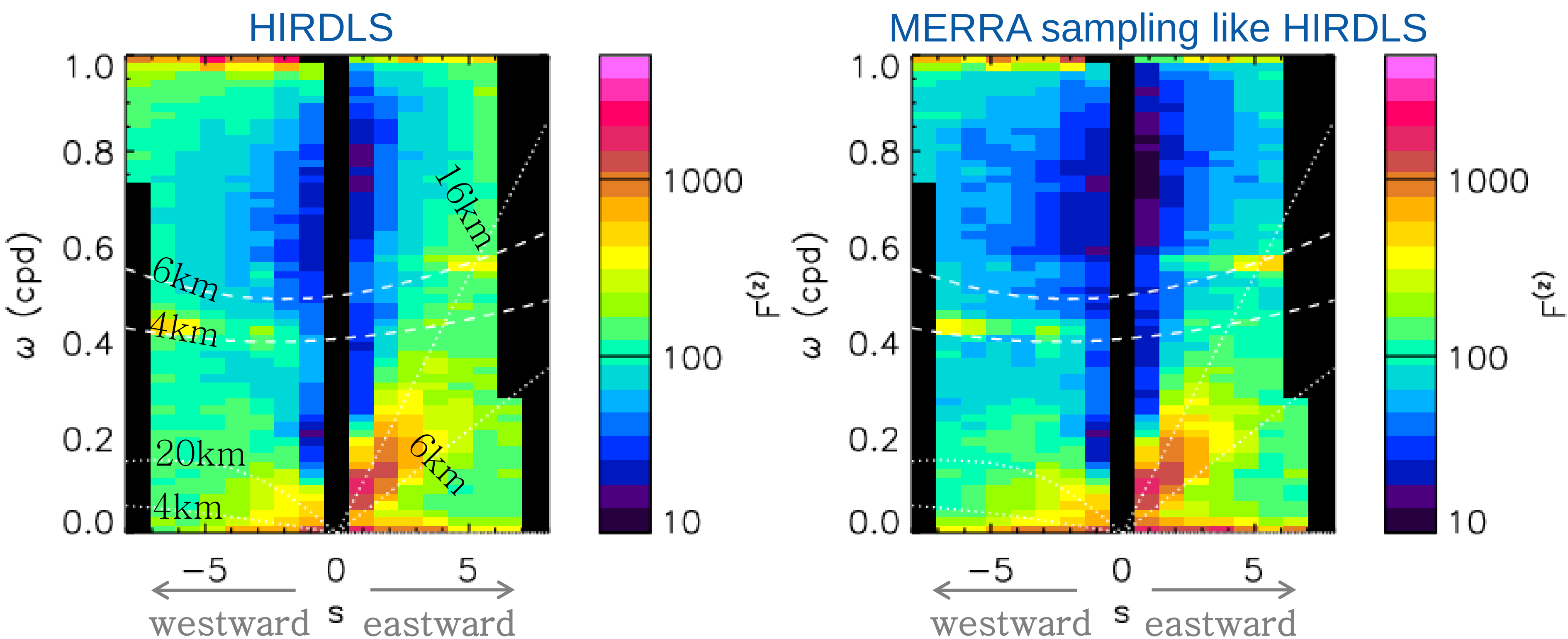
$$F^{(z)} = \frac{\rho s}{2m} \frac{g^2}{N^2} \frac{|\hat{T}|^2}{\bar{T}^2}$$

Same for all waves.
Assumes zonal propagation,
neglect $\bar{u}_z$, and $m^2 >> 1/(2H)^2$.

All quantities directly observed by HIRDLS

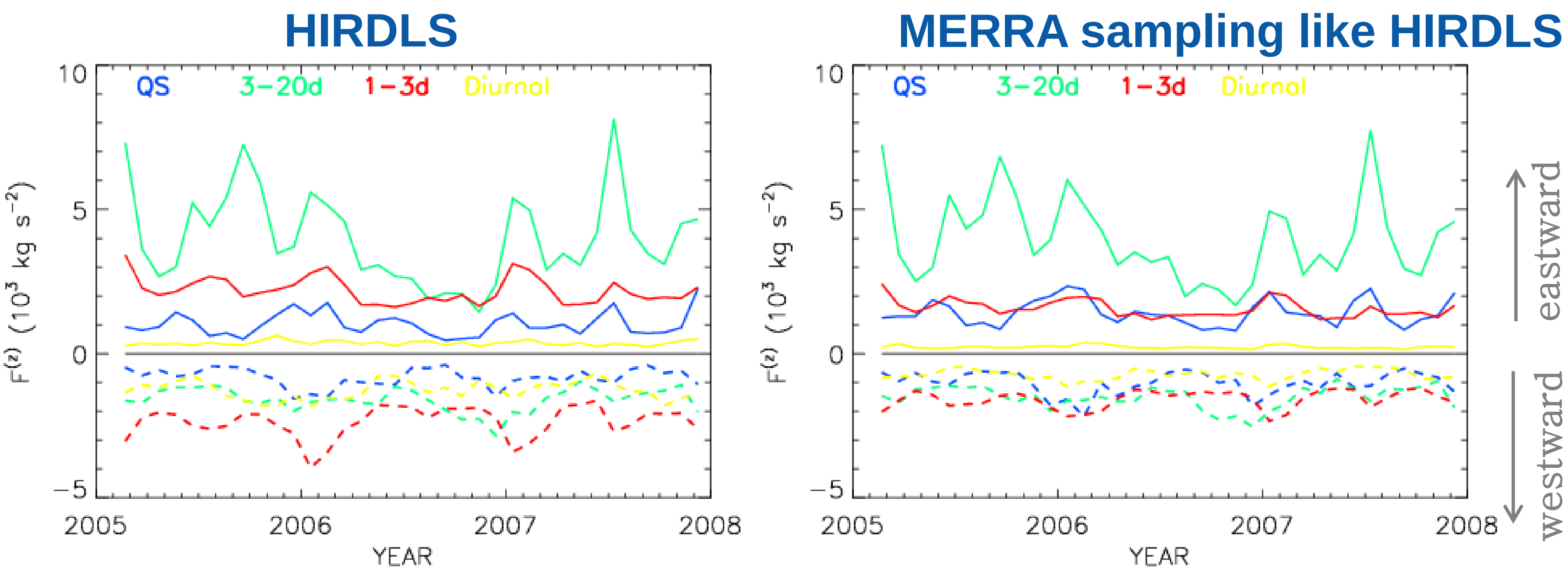
(u', v', w') = wind, Φ' = geopotential anomalies
$\bar{Z}$ = Zonal mean vorticity; $\bar{f}$ = Modified Coriolis frequency
a = Earth radius; ϕ = latitude; $y = a\phi$
s = zonal wavenumber; m = vertical wavenumber
ρ = density; g = gravity; N = buoyancy frequency

EP Flux Spectra (2005-2007) in the TTL (20ºS-20ºN)



- Wave fluxes are similar in low frequency ranges.
- Inertia-gravity wave fluxes are small in MERRA.

Time series of EP Flux in TTL



- Kelvin waves (green line) are well represented in MERRA.
- The inertia-gravity wave fluxes (red) are consistently ~50% larger in HIRDLS than in MERRA.
- The weak wave fluxes in MERRA is likely due to weak variability in MERRA precipitation.

Wave source – Tropical convection (precipitation)

precipitation Datasets:
3 years(2005-2007), 15S-15N, 3(6)-hourly

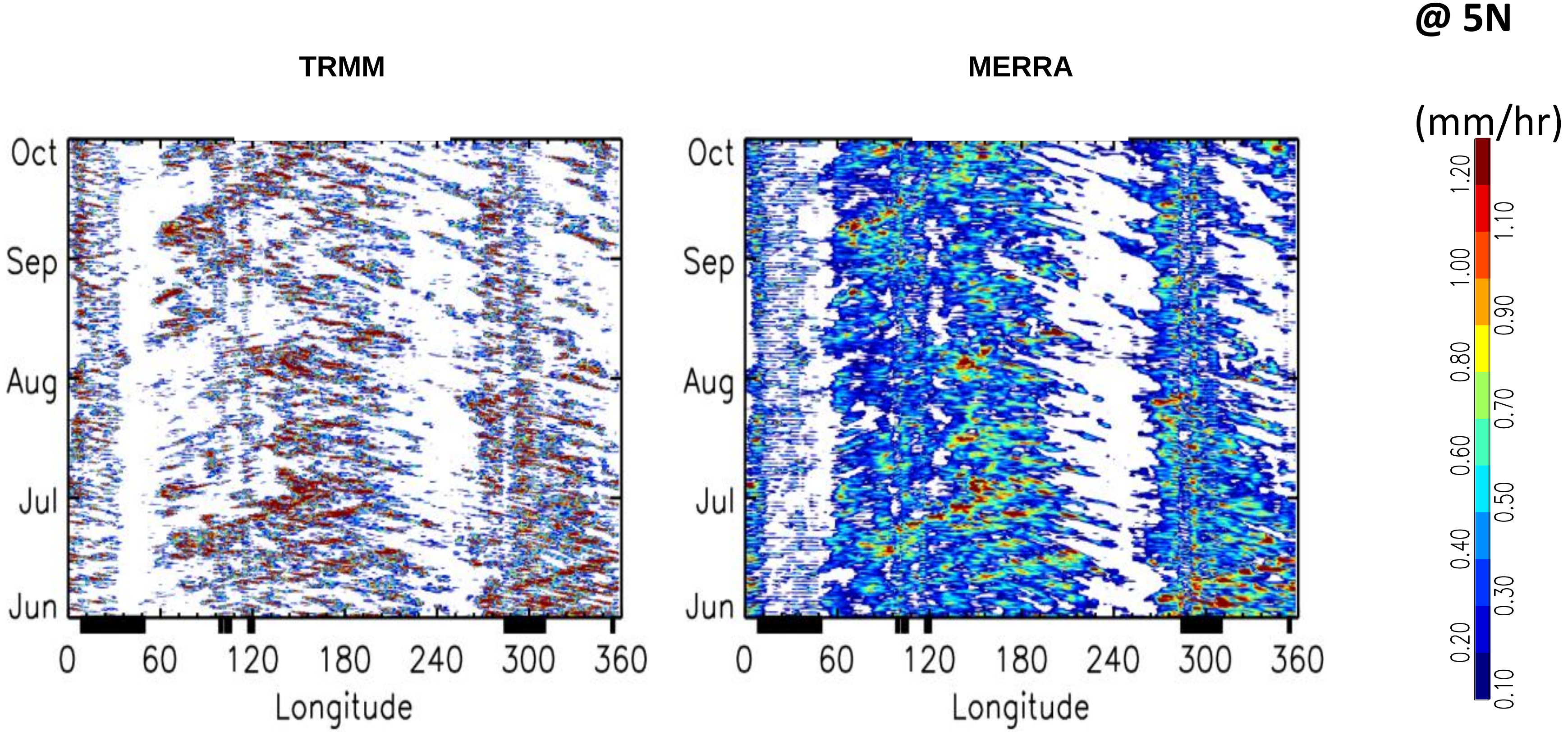
Reference

- Tropical Rainfall Measuring Mission **(TRMM)** **3B42**:
  - merged estimate from satellite (radar, microwave, IR) and rain gauge data

Reanalysis

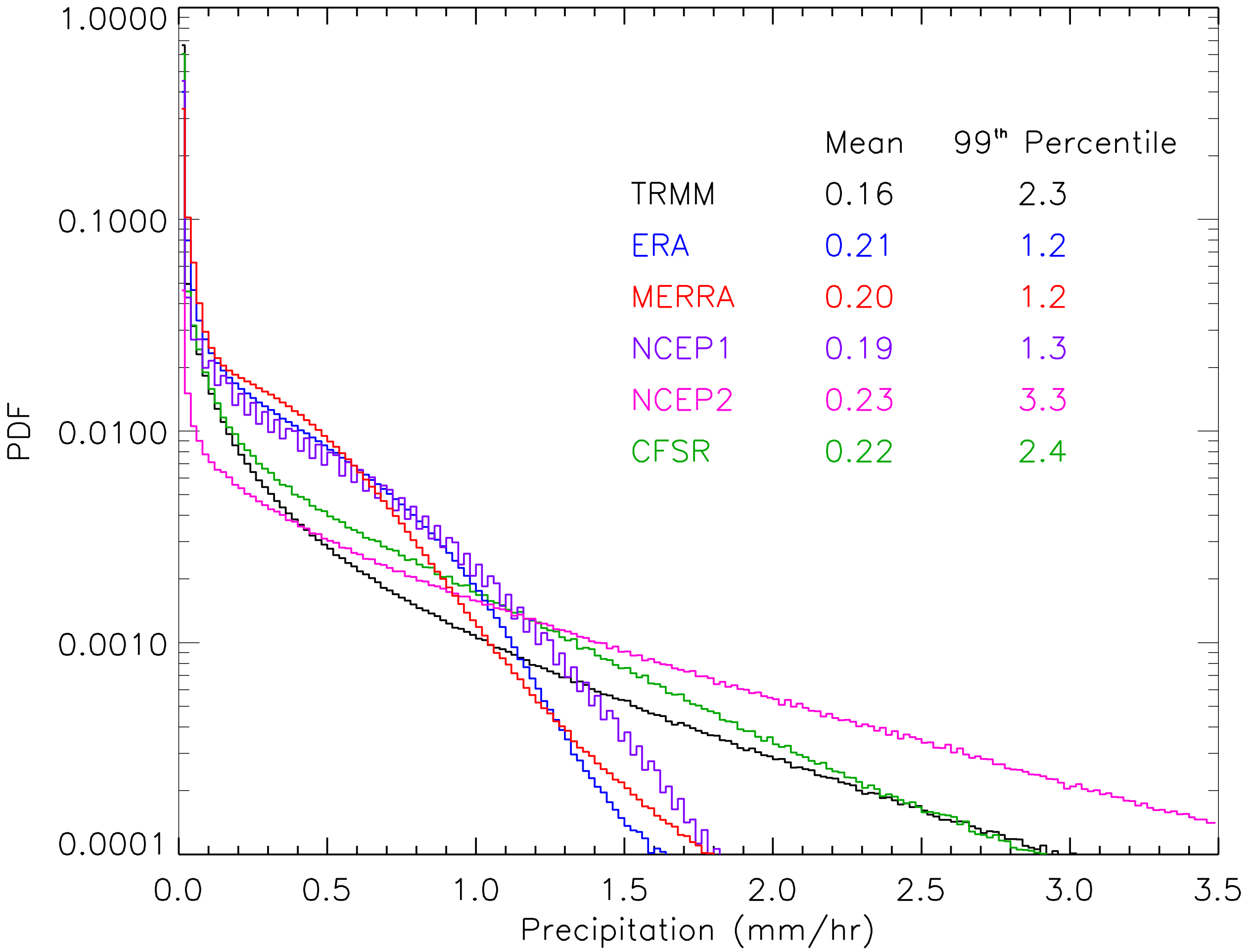
- MERRA:
  - NASA GEOS-5
  - $1/2^o$ X $2/3^o$ L72
  - Modified relaxed Arakawa-Schubert convective scheme

Hovmoller diagram of precipitation



- Eastward and westward propagations
- Weak and persistent precipitation in MERRA

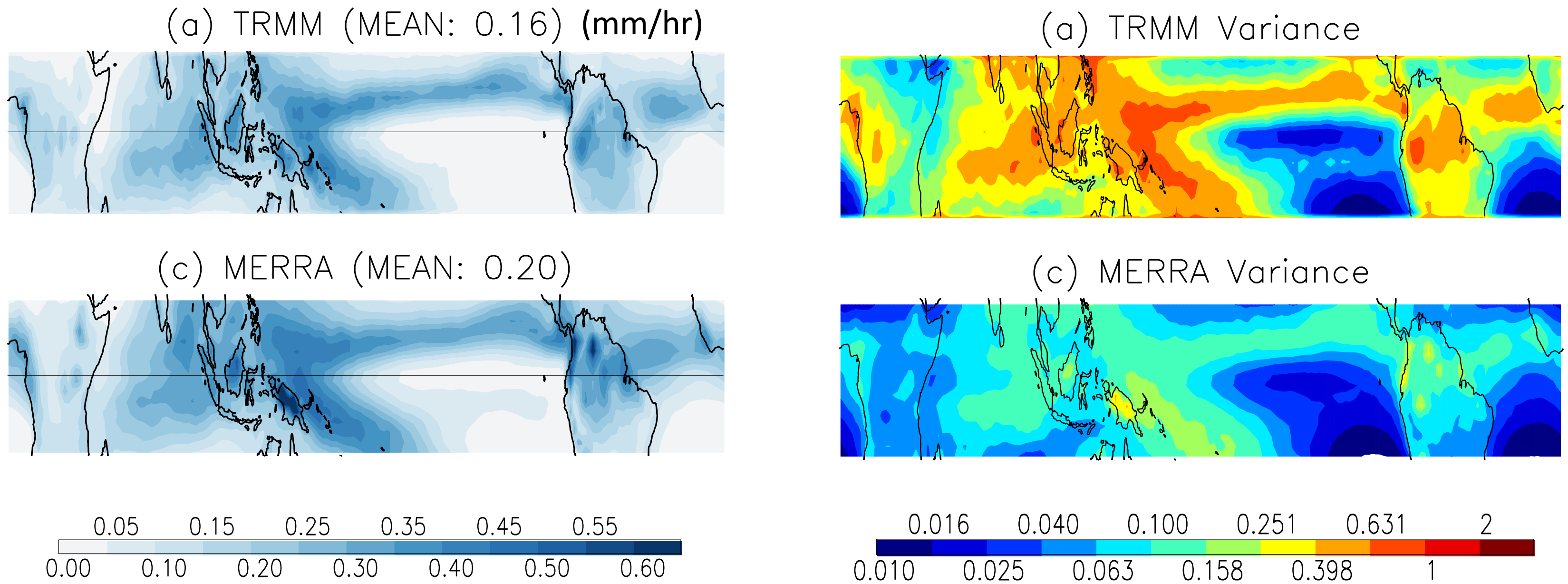
Statistics of tropical precipitation



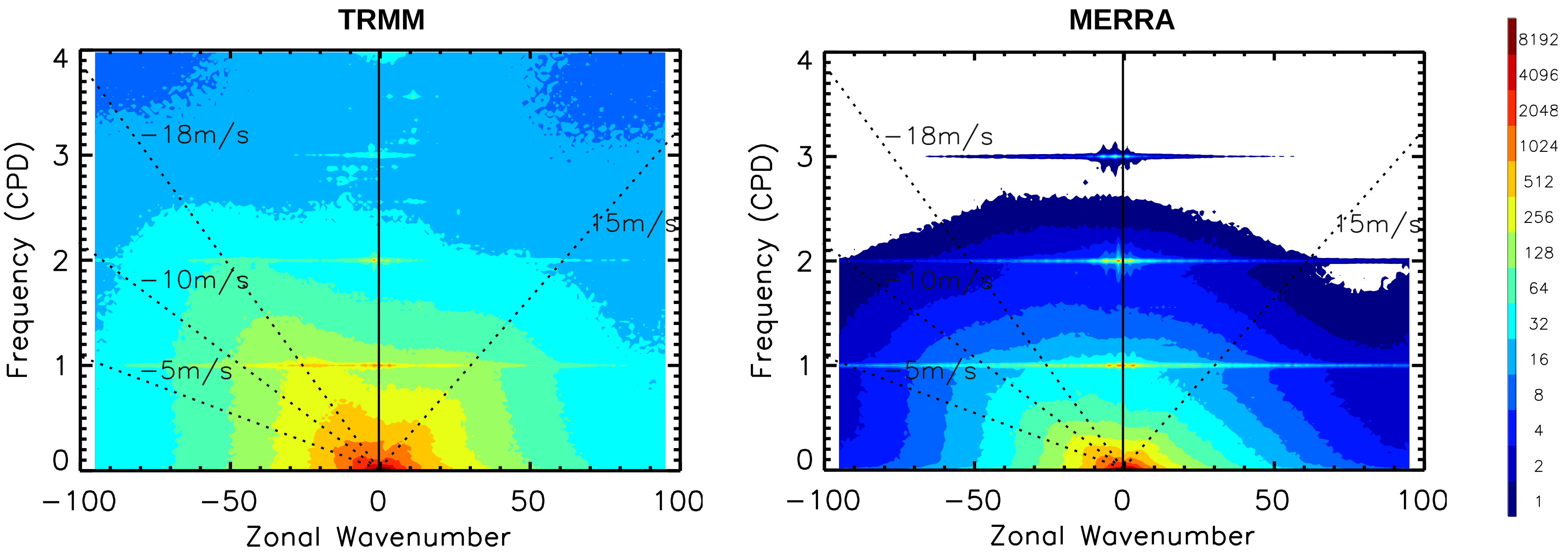
- PDF also shows MERRA generates persistent weak rainfall.

MERRA mean is overestimated, but variance is much smaller

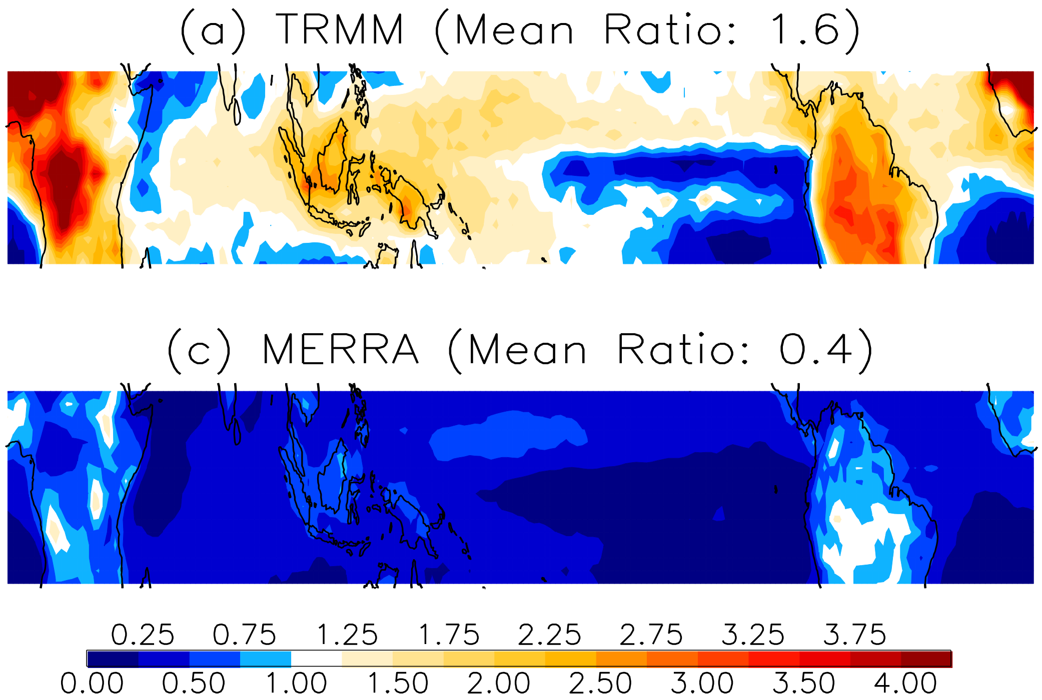
Mean vs. Variance



MERRA Spectrum shows is “over-reddened.”



High-frequency variability is not well represented



Variance Ratio (High-freq. / Low-freq.*)

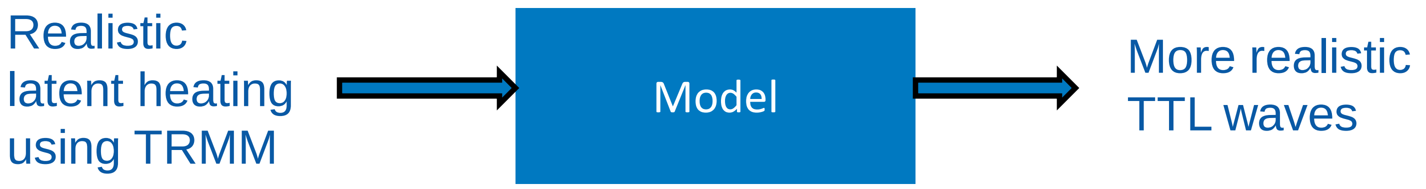
*frequency higher and lower than 1/3 cpd (3-day period)

Summary and Conclusion

- We derive the equatorial wave EP flux $F^{(z)}$ spectrum directly from HIRDLS temperature observations and compare to MERRA reanalysis.
  - Spectra include Kelvin, equatorial Rossby, mixed Rossby-gravity, and inertia-gravity waves.
  - Kelvin waves are similar in HIRDLS and MERRA.
  - Inertia-gravity wave fluxes from HIRDLS are 50% stronger than in MERRA reanalysis data; Likely due to weak variability in precipitation at these frequencies.
- We compare tropical precipitation variability in TRMM and MERRA.
  - MERRA generates very persistent weak rainfall and small variability.
  - Particularly, high-frequency variance is very small in MERRA.

Future work

• Transient waves are not well resolved in a reanalysis.



• A combined analysis of our model results and ATTREX measurements may give better understanding of inertia-gravity wave effects on cirrus.