






GRAVITY WAVES AND CLOUD STRUCTURES: AIRS OBSERVATIONS

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Question: Are gravity waves important in the troposphere?

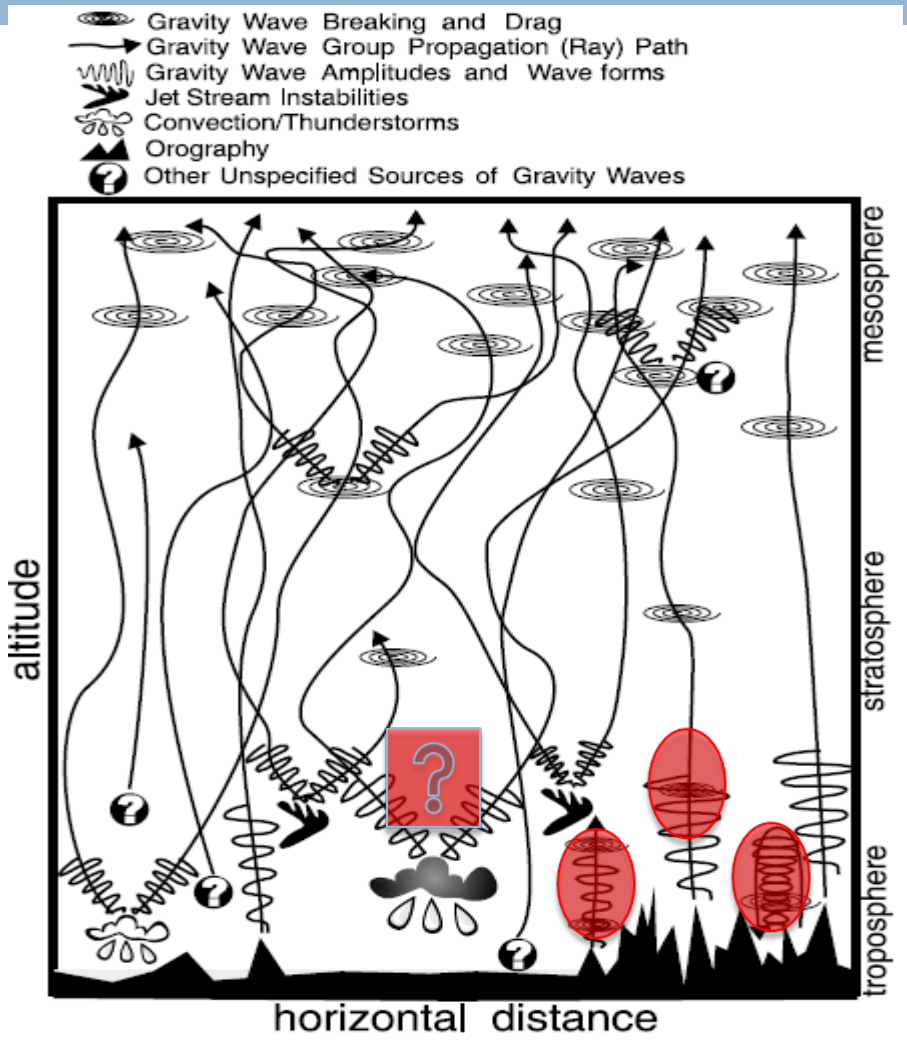
- If not associated with weather phenomena, NO!
- Otherwise, YES!
  - Induce turbulence – important for mixing of chemical species and water vapor (e.g., clear air turbulence, stratospheric cloud formation)
  - Modulate or initiate synoptic weather (e.g., gravity wave front)

If it's gravity wave only, ~ 0.1 – 1K temp. perturbation

If it's associated with latent heat release (i.e., cloud), temperature perturbations can be up to 10 K.

Are gravity waves important in the troposphere (con'd)?

- Gravity waves (GWs) are traditionally believed not important in the troposphere due to their small amplitudes compared with other waves and clouds
- Convections work one-way to generate GWs. No interactions at the GW-generation level.



(Kim et al., 2003, Atm-Ocn.)

Methodology

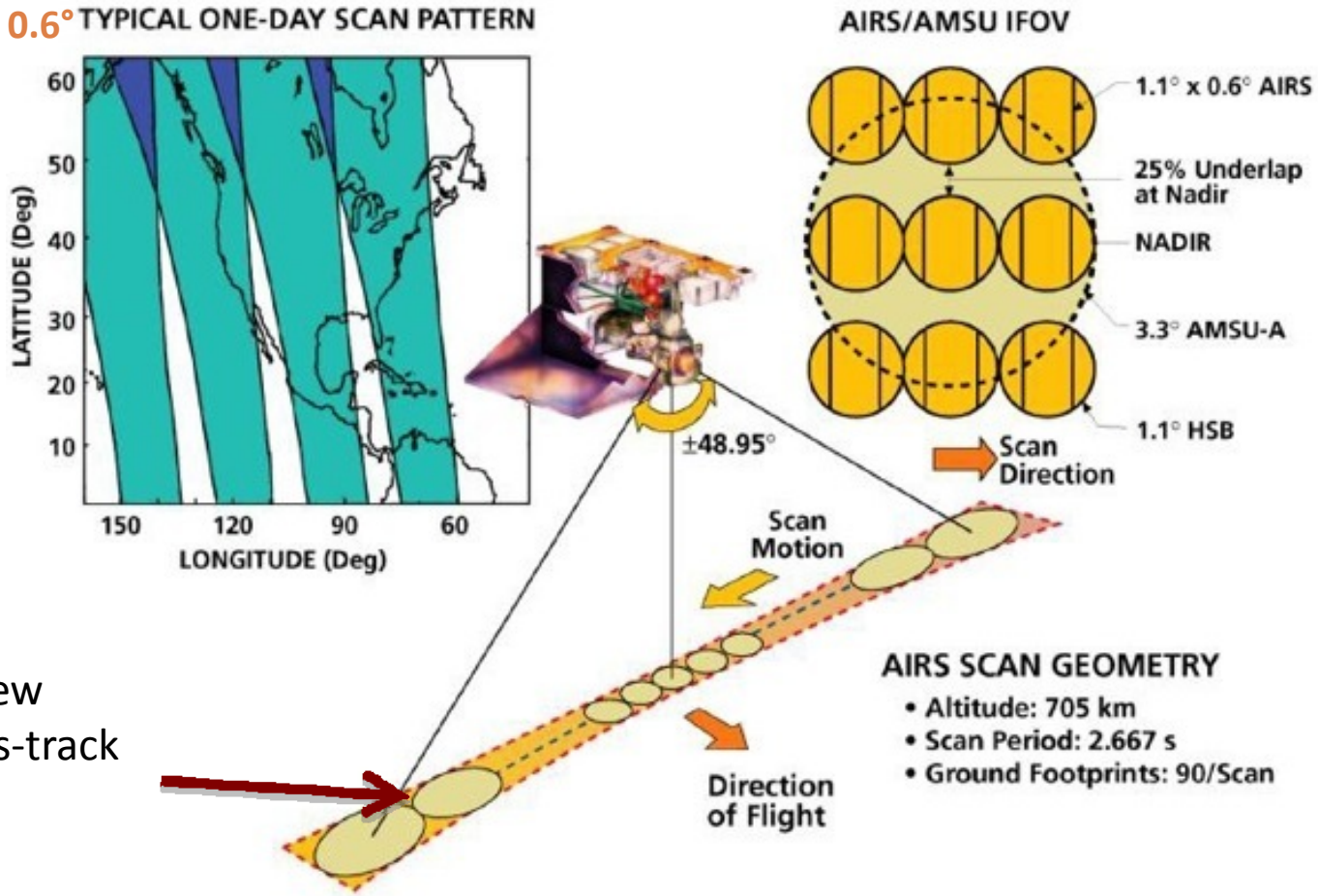
AIRS (Atmospheric Infrared Sounder) on NASA Aqua

Nadir Footprint: 1.1° x 0.6° (13.5 km x 7.4 km)

Scan range: ±48.95°

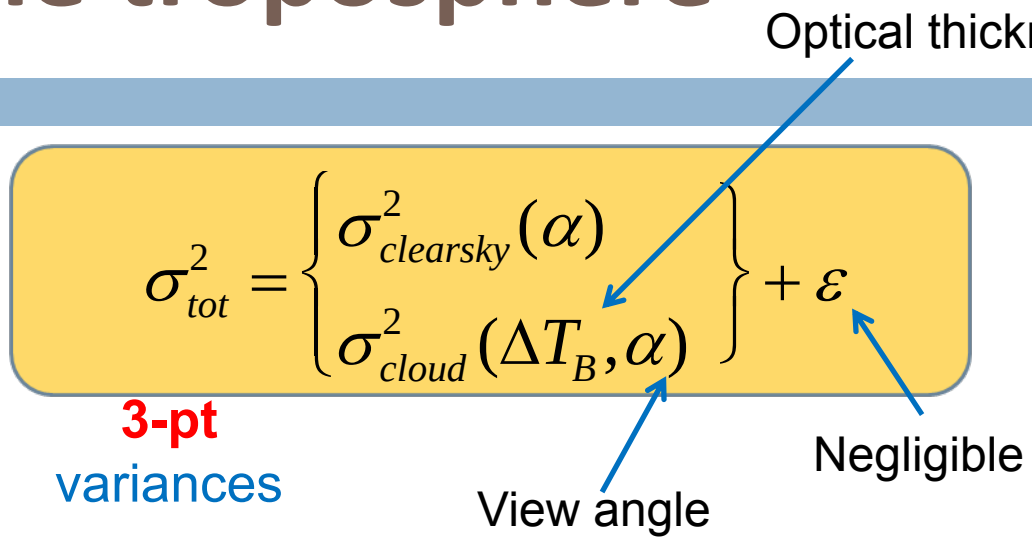
Across the EQ at:
1:30pm LST (Ascending)
1: 30am LST (Descending)

90 AIRS field-of-view (FOV) in each cross-track scan



http://airs.jpl.nasa.gov/instrument/how_AIRS_works/

In the troposphere



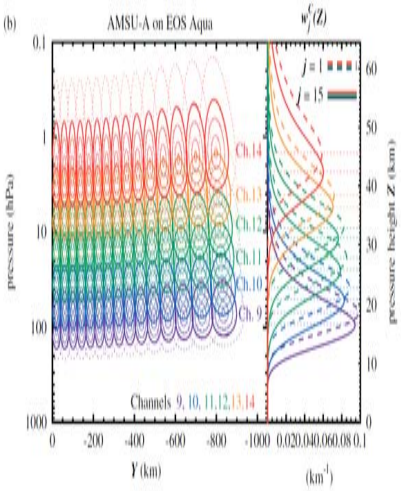
- Define PDF peaks of a month of brightness temperature (T_B) as the "clear-sky reference", and treat T_{ref} -3δ and below as "cloudy-sky", whereδis the standard deviation of the distribution function.
- Further categorize clouds into 8 bins according to the optical thickness (ΔT_B).
- Calculate $\sigma^2_{clearsky}$ and σ^2_{cloud} separately.

$$\sigma^2_{cloud} = f(\Delta T_B, \alpha)$$

T_{ref} -3δ
Below it is defined as cloud.

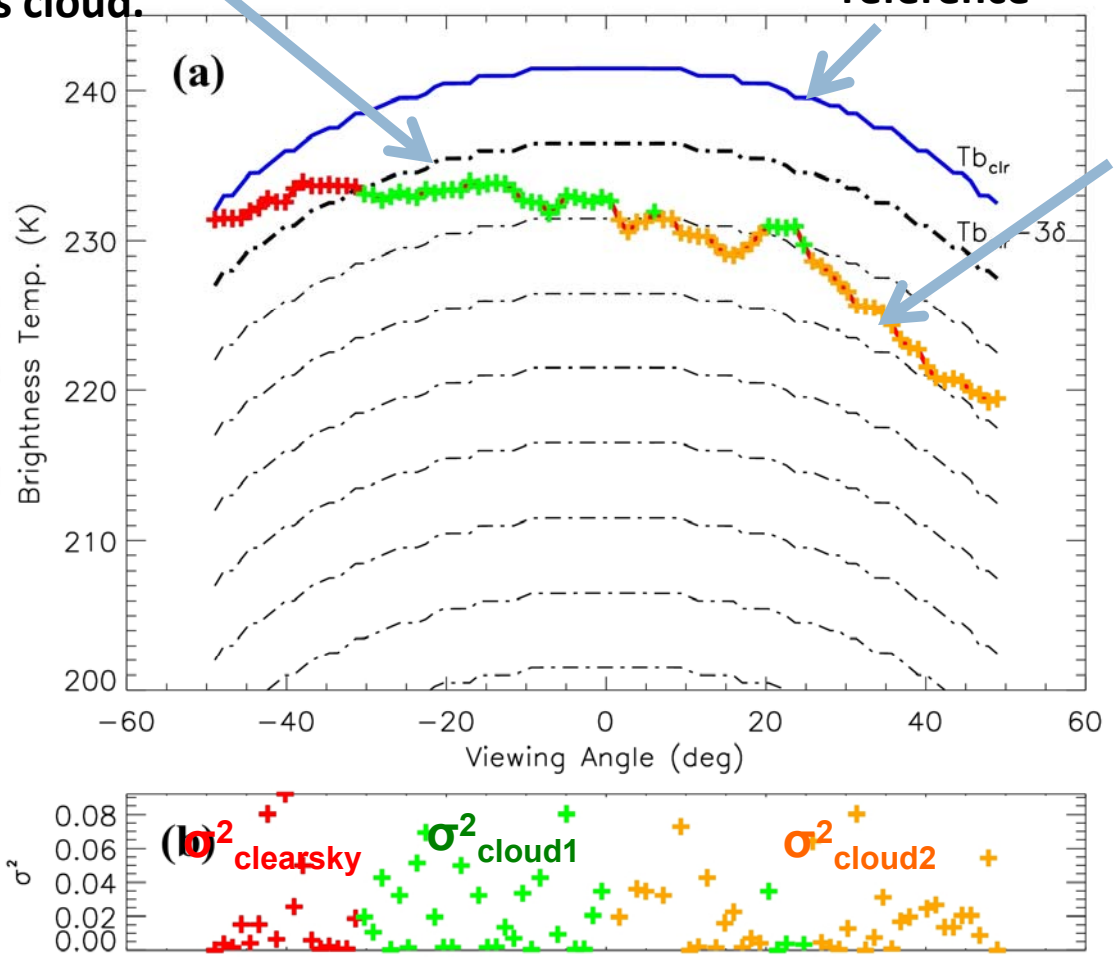
Clear-sky reference

A real profile



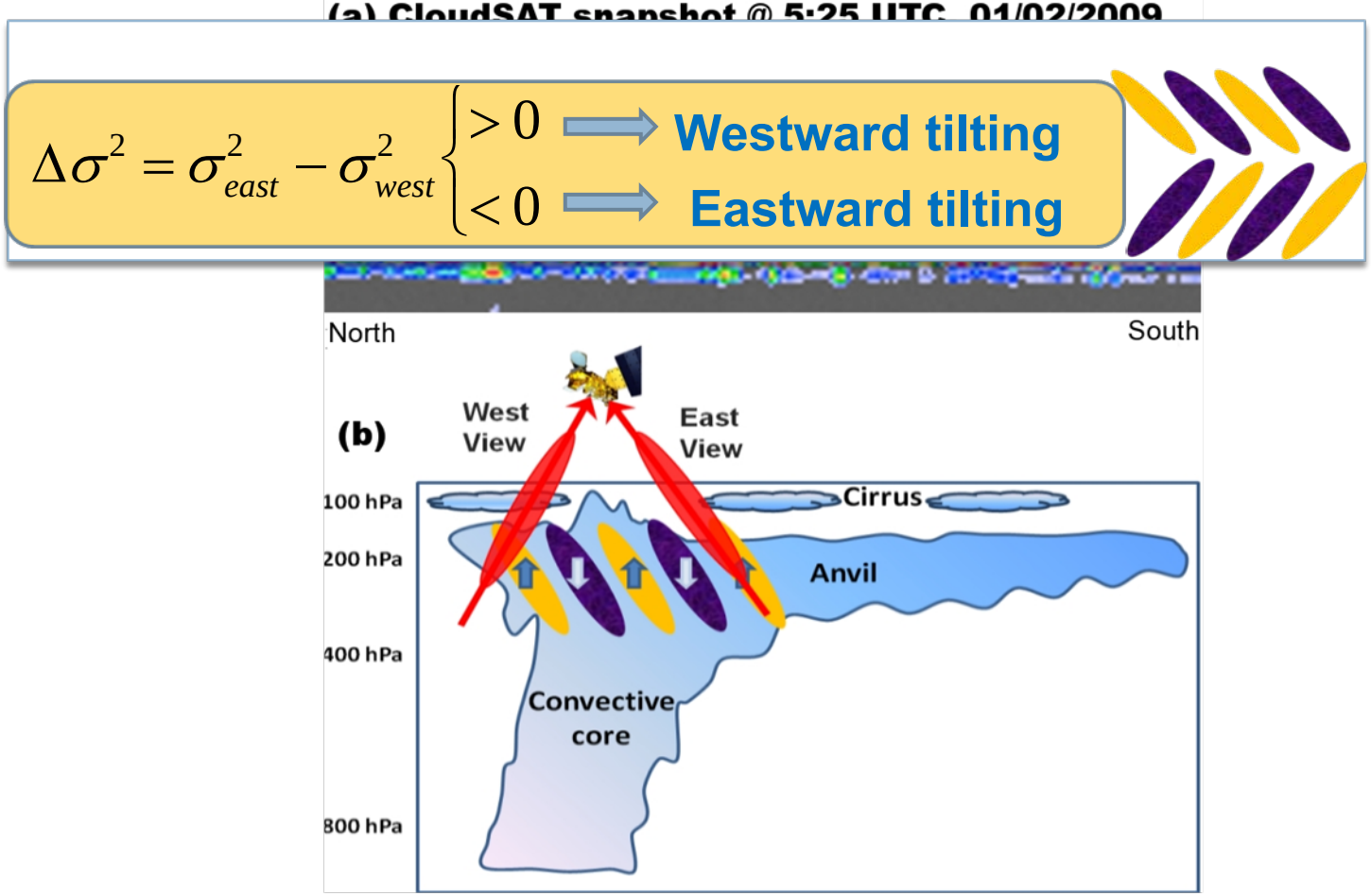
AMSU-A Weighting function

(Eckermann et al., 2007)



Wave smearing effect can be applied to cloud too

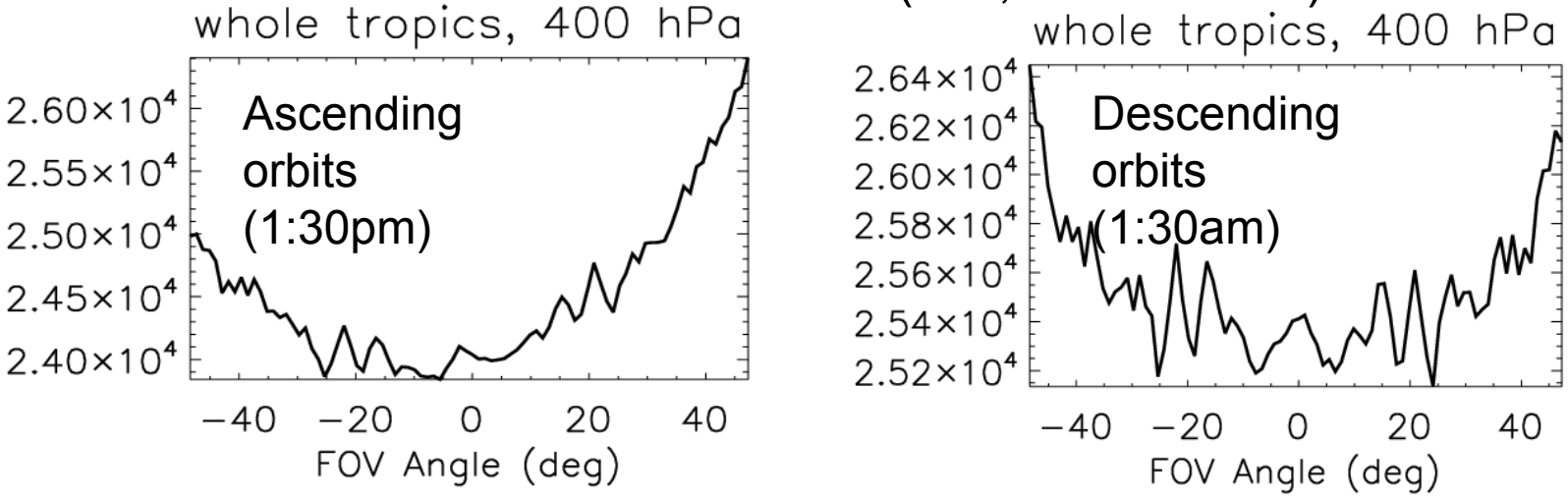
$$\Delta\sigma^2 = \sigma^2_{east} - \sigma^2_{west} \begin{cases} > 0 \Rightarrow \text{Westward tilting} \\ < 0 \Rightarrow \text{Eastward tilting} \end{cases}$$



Results

East-view preference of observing more clouds

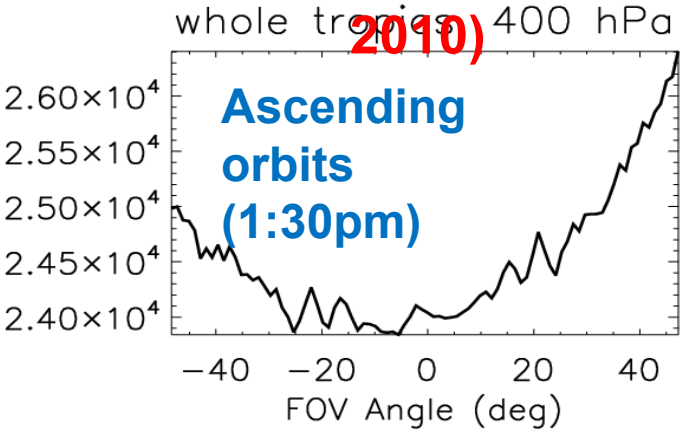
Total cloud counts (Jan, 2003 - 2010)

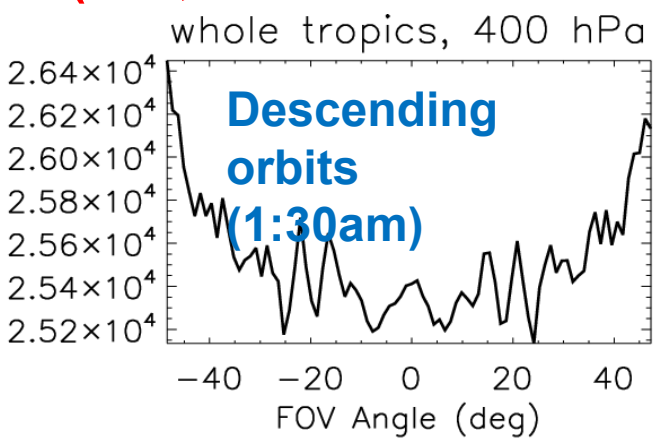


- At local noon (1:30pm), east-view sees **300 counts/month** more clouds than the nadir-view during each January, **200 counts/month** more than the west-view.
- At local midnight (1:30am), the largest difference is about **100 counts/month**.

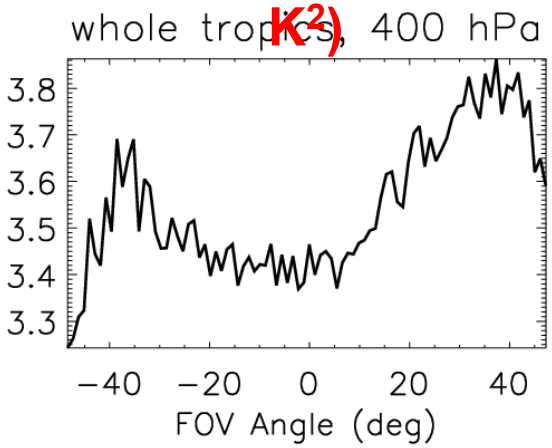
We can explain the curve from variance asymmetry

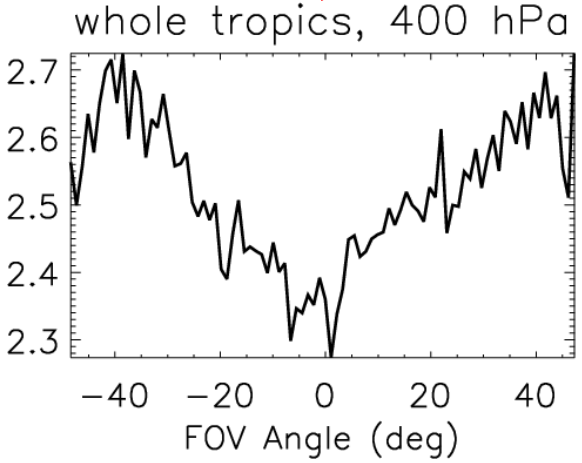
Total cloud counts (Jan, 2003 - 2010)



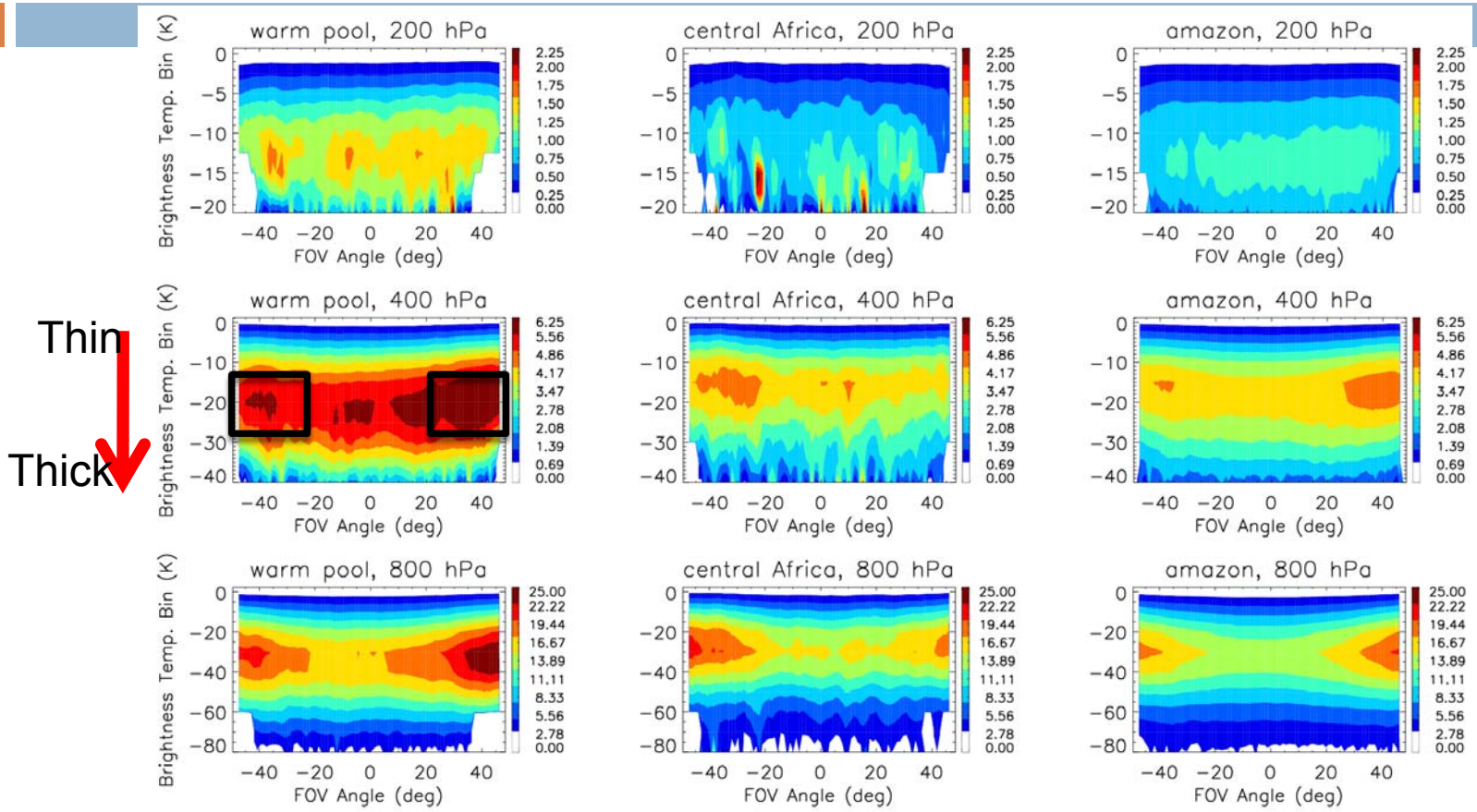


Total variance (Jan, 2003 – 2010, K^2)



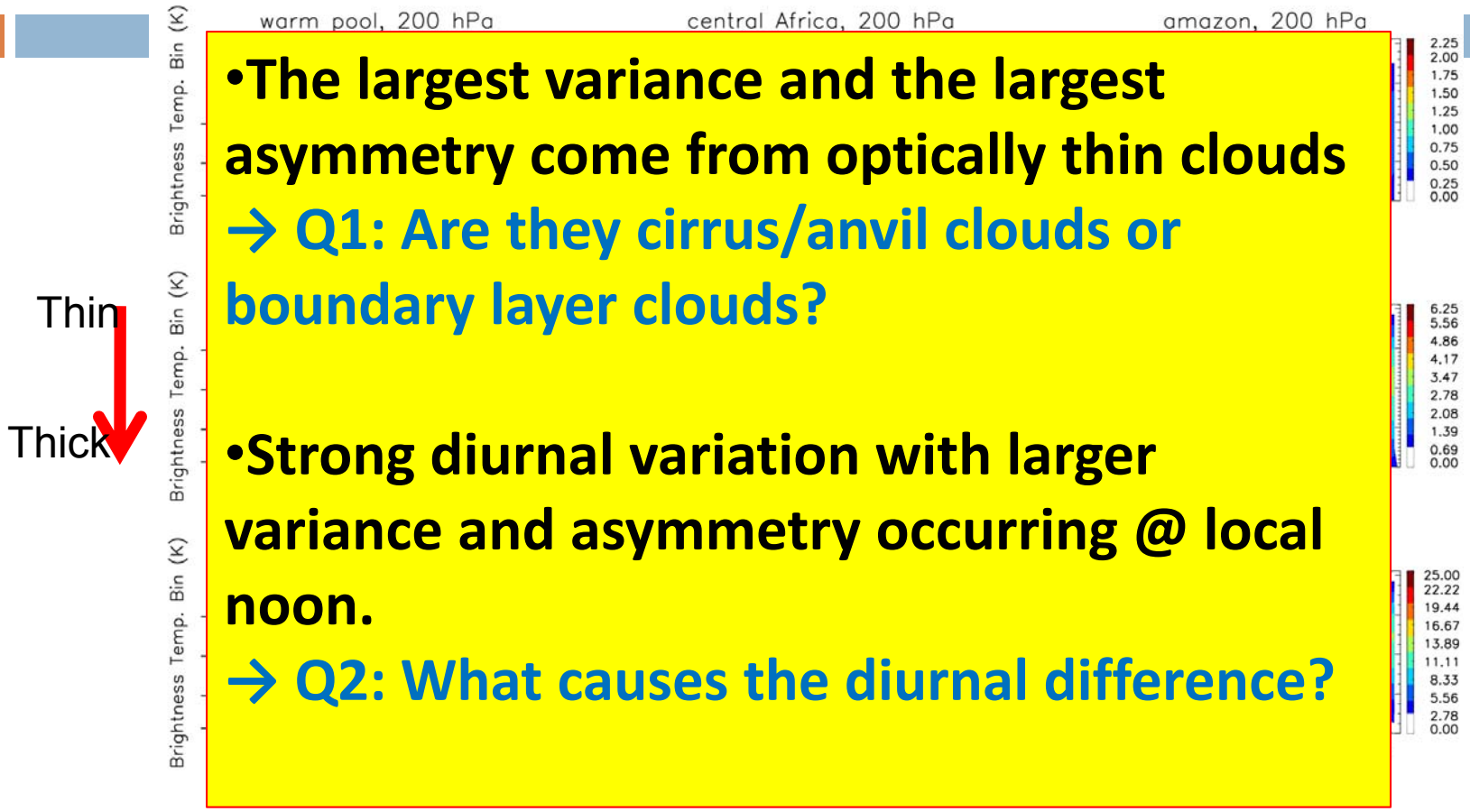


If we separate the cloud types, the largest variance and variance asymmetry come from medium thick clouds



- Variance as functions of cloud thickness and viewing angle for Jan, 2003 – 2010. Ascending orbits only.

At midnight, it's much more symmetric.



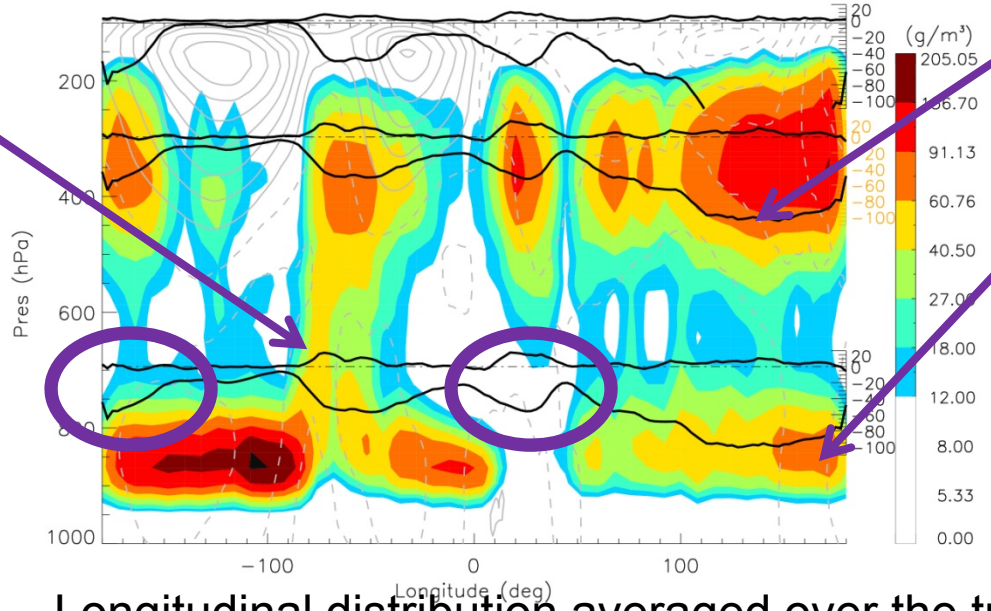
- **The largest variance and the largest asymmetry come from optically thin clouds**
  - **→ Q1: Are they cirrus/anvil clouds or boundary layer clouds?**
- **Strong diurnal variation with larger variance and asymmetry occurring @ local noon.**
  - **→ Q2: What causes the diurnal difference?**

- Variance as functions of cloud thickness and viewing angle for Jan, 2003 – 2010. Descending orbits only.

Q1: Are they cirrus/anvil clouds or boundary layer clouds?

- As an IR sounder, AIRS cannot see through optically thick clouds, e.g., convective cores.
- Therefore, if multi-layer or optically thick clouds present, AIRS only see the top portion.

Variance difference



AIRS cloud coldness

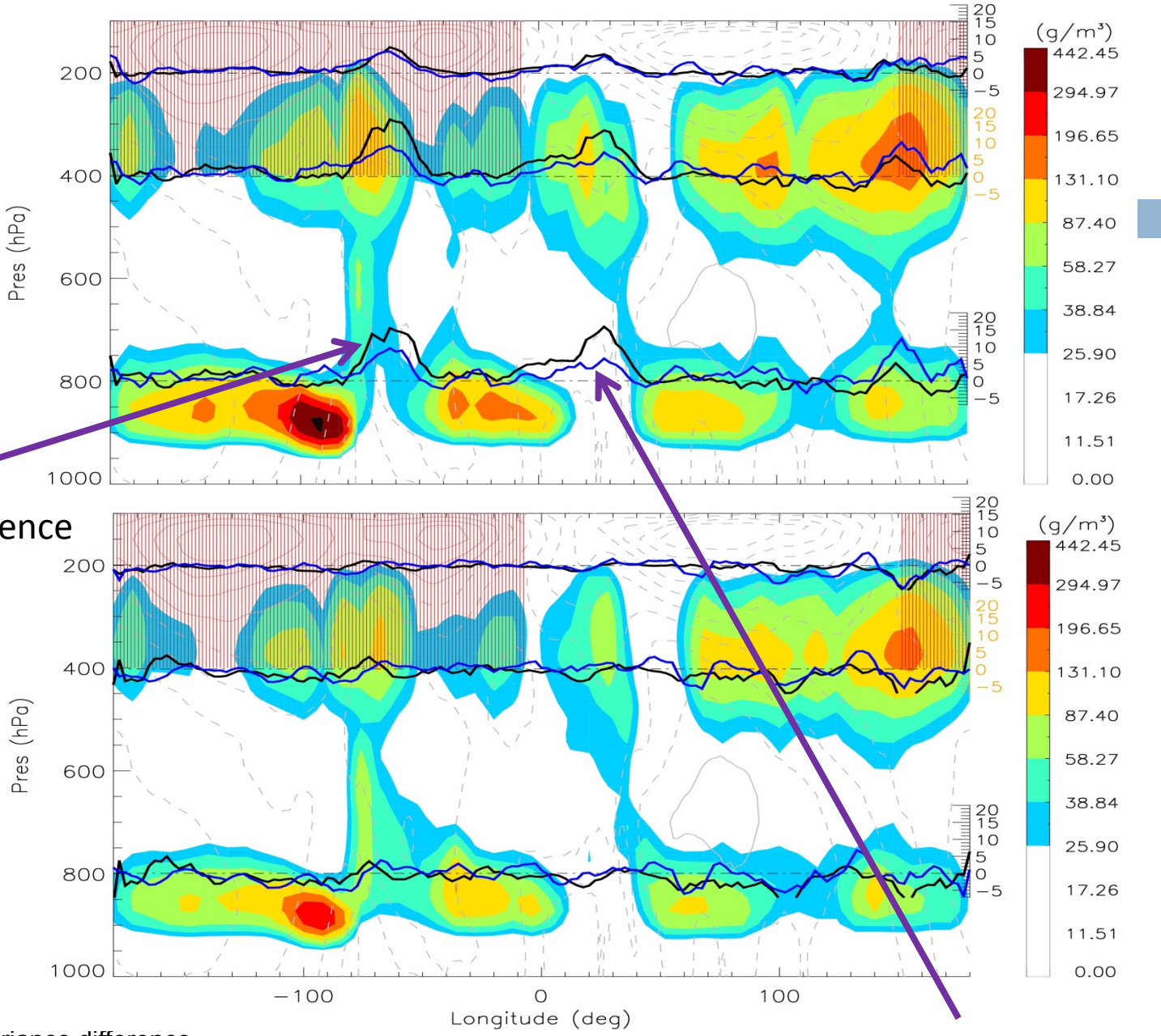
Color contours: CLOUDSAT cloud water content

Longitudinal distribution averaged over the tropics (10S – 10N) during January, 2003 – 2010, ascending orbits only.

Ascending, July.

Black line:
Variance difference

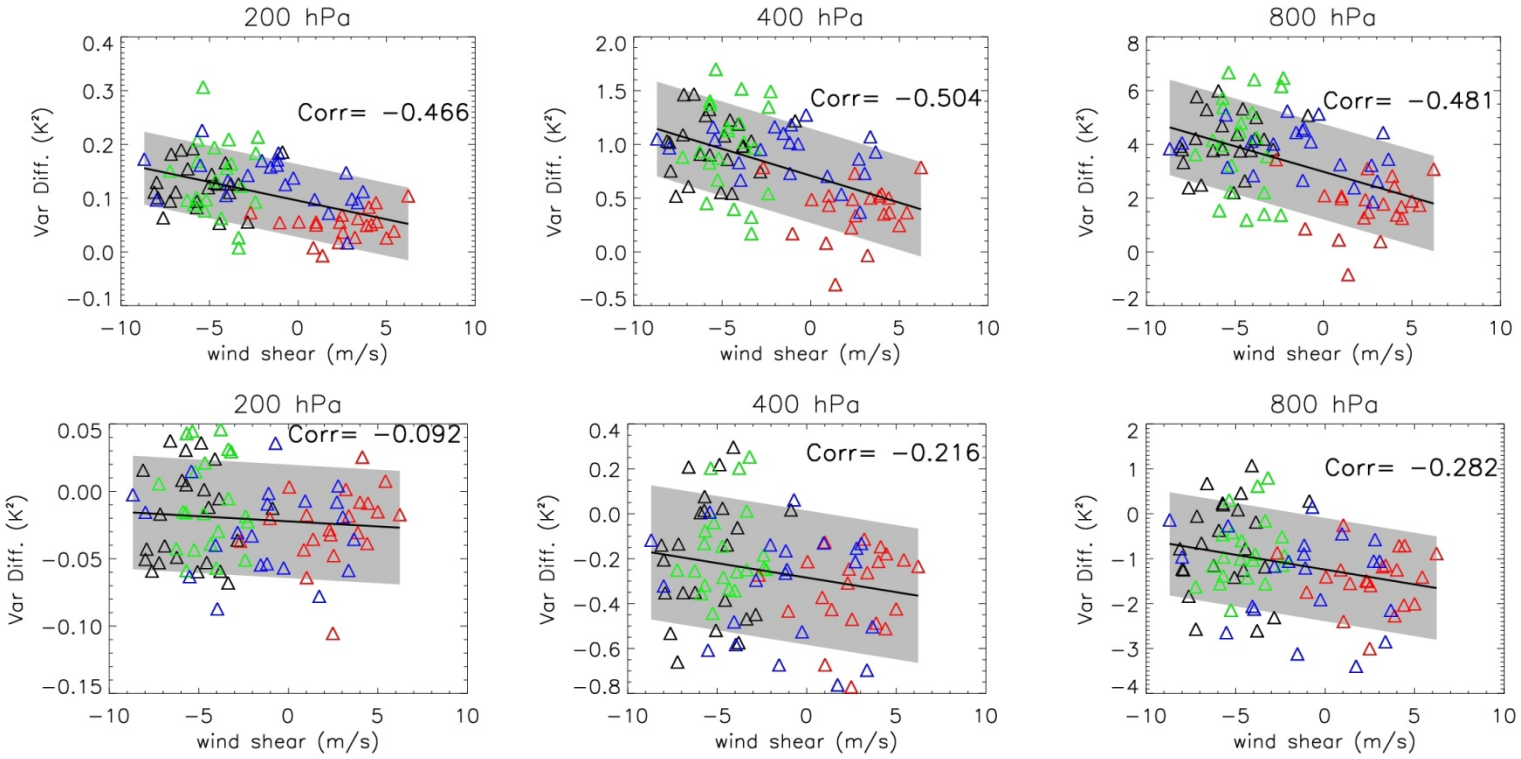
Descending July.



Black line: Variance difference
Blue line: Total counts difference

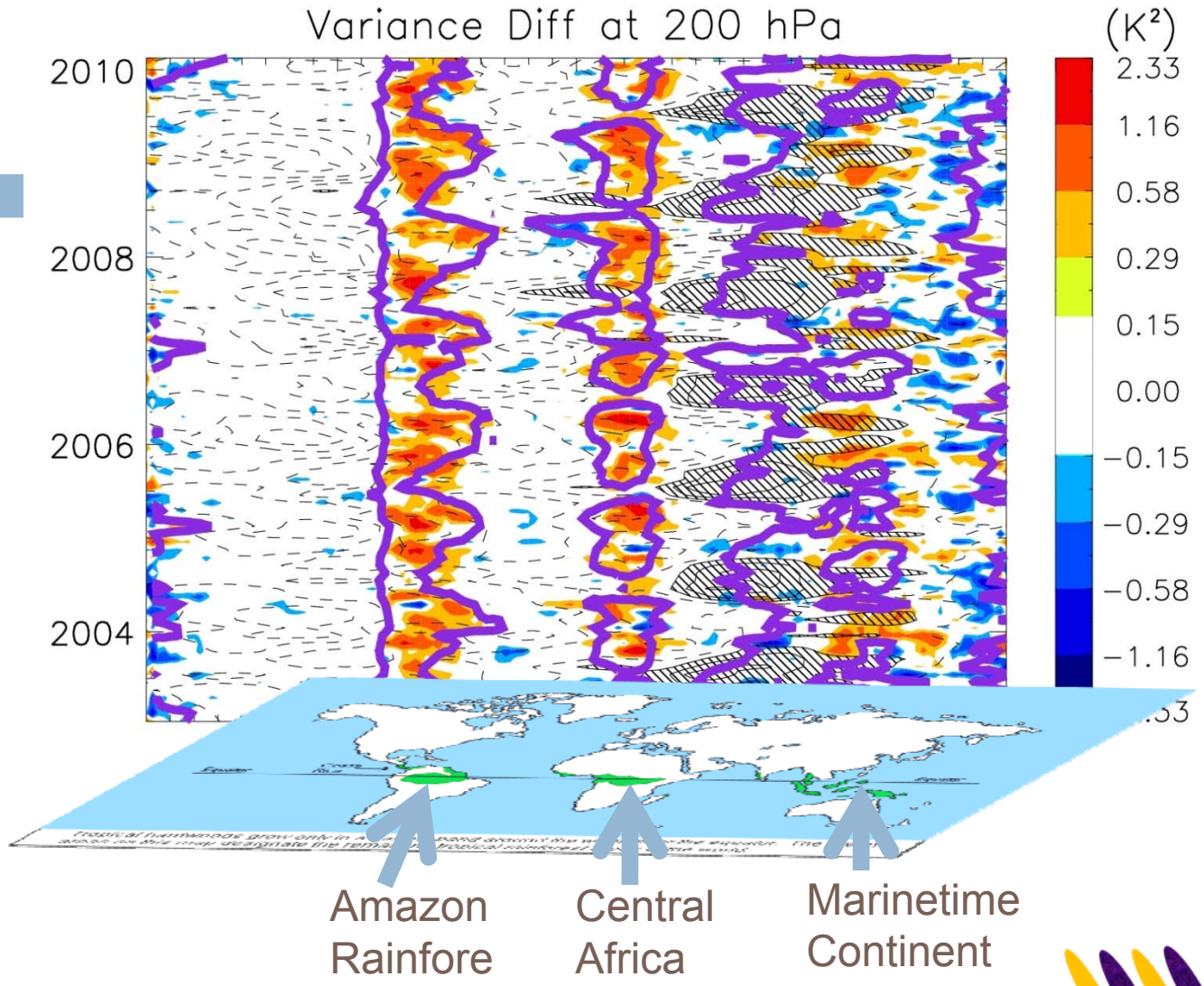
Blue line: Total counts difference

If we integrate over the entire tropical belt (10S – 10N) …



Variance differences for optically thin clouds anti-correlated with wind shear between 800 and 200 hPa ($U_{800} - U_{200}$).
→ Banded structures tilt **upgradient** of wind shear

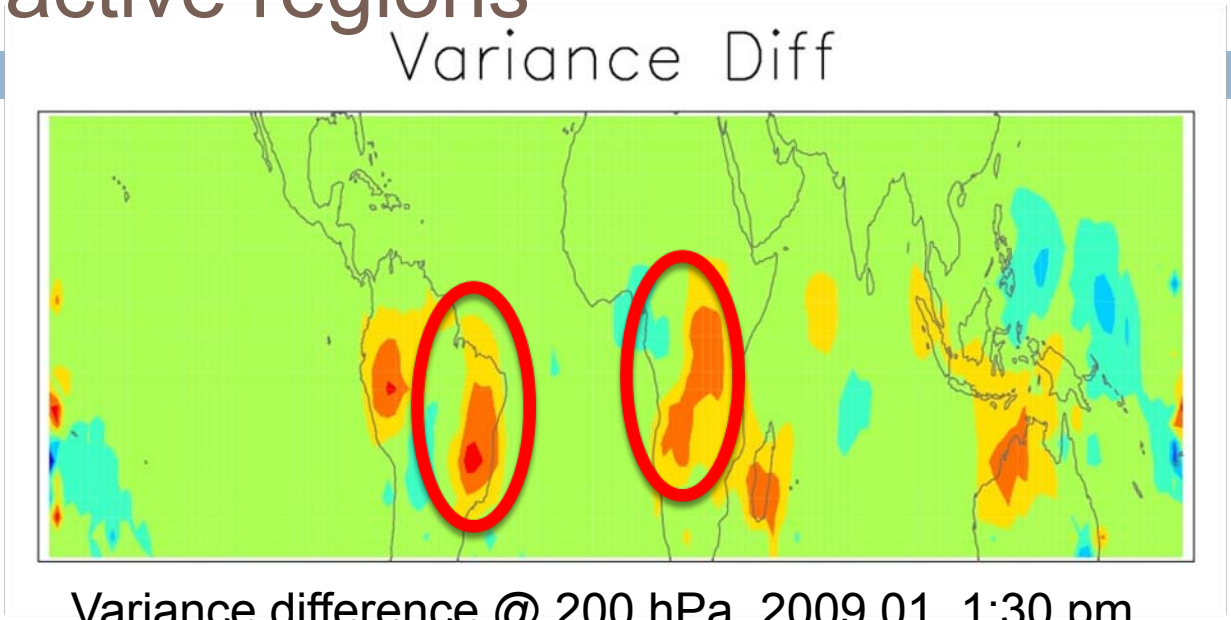
Black: DJF Green: MAM Red: JJA Blue: SON



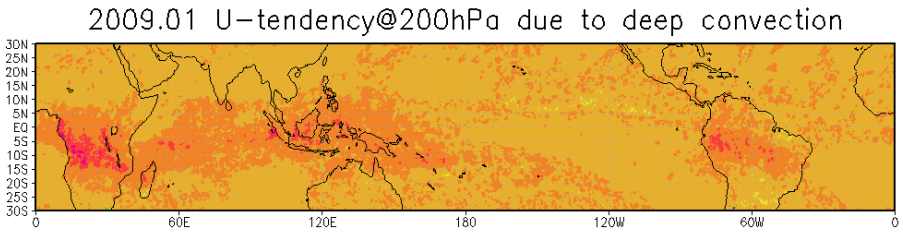
- **Positive asymmetry of anvils in warm colors (westward tilting)**
- **Negative wind shears ($U_{400} - U_{200}$) in dash contours (eastward shear)**
- **Convection active regions enclosed by purple lines**



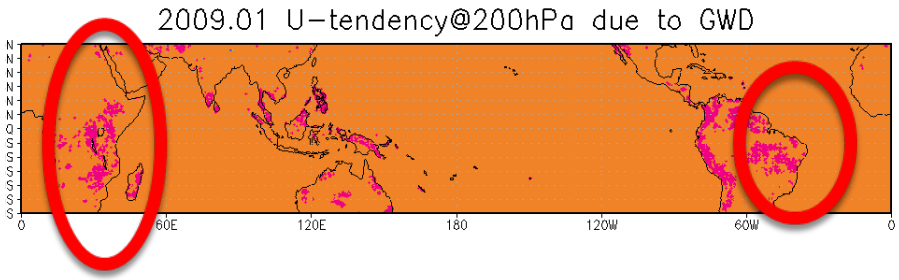
Some hot spots NOT come from convection most active regions



Variance difference @ 200 hPa, 2009.01, 1:30 pm



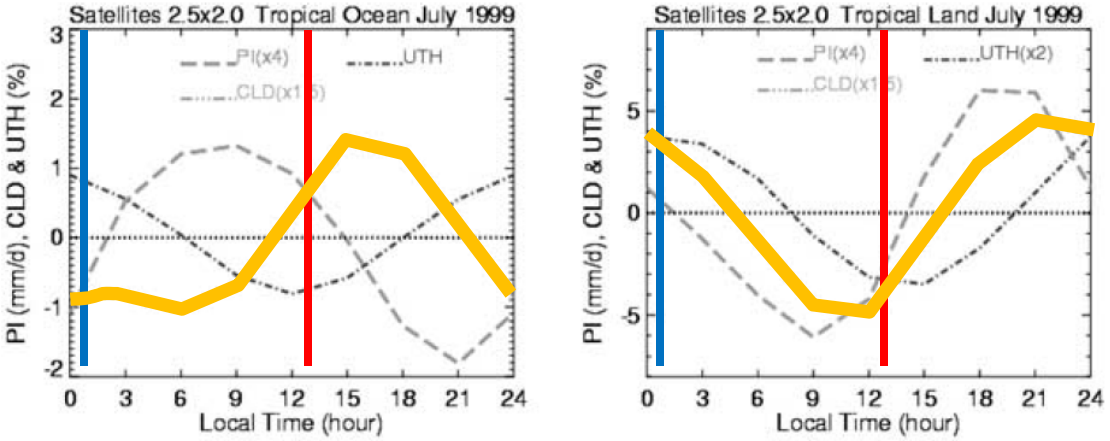
YOTC, U-tendency due to deep convection @ 200hPa



YOTC, U-tendency due to gravity waves @ 200hPa

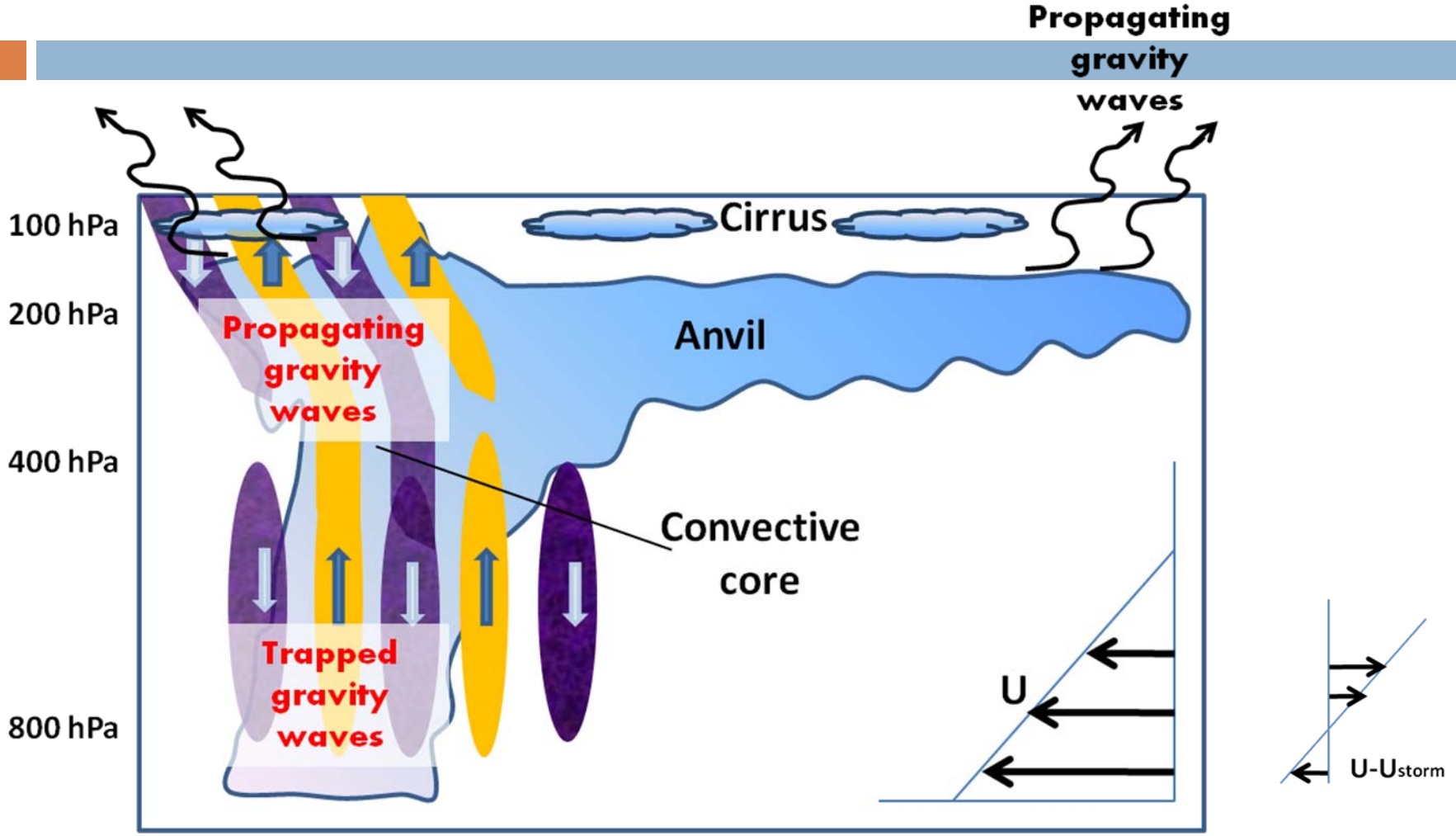
Q2: What causes the diurnal difference?

- Gravity wave can only propagate in stable layers
- Starting from local noon, convections begin to develop over lands. At local midnight, convections over lands reach the mature/decaying stages.
- Hence, gravity wave modulations on anvils tend to be large when convection is weak, vice versa.

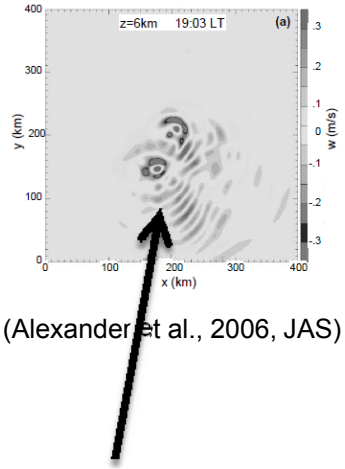


(Tian et al., 2004, JGR)

So, the picture should look like this:



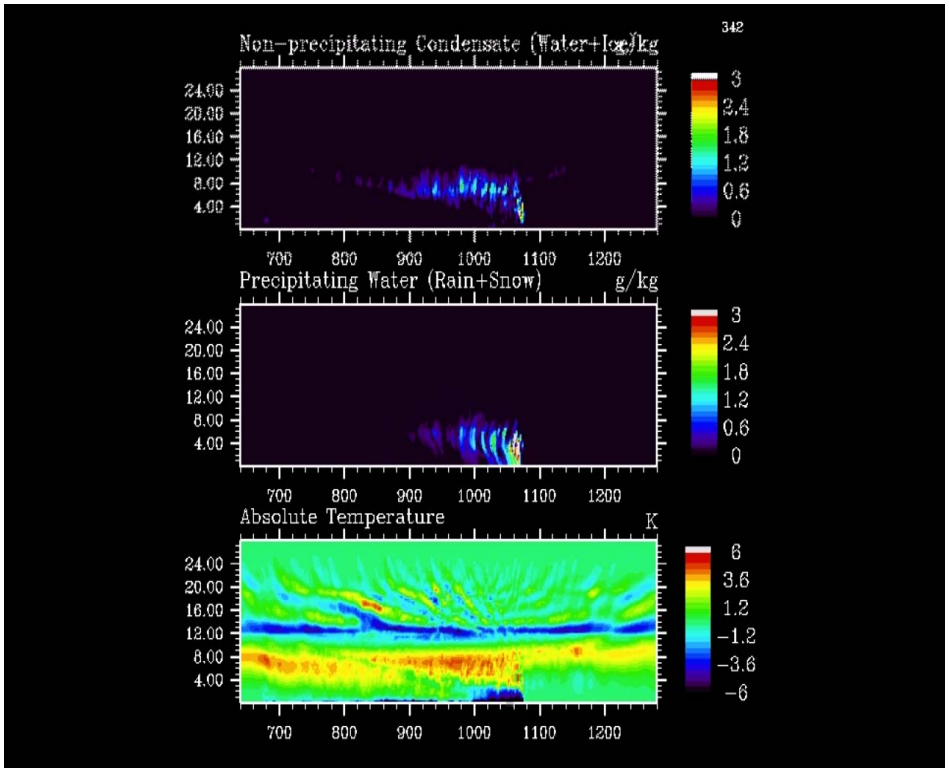
Implications



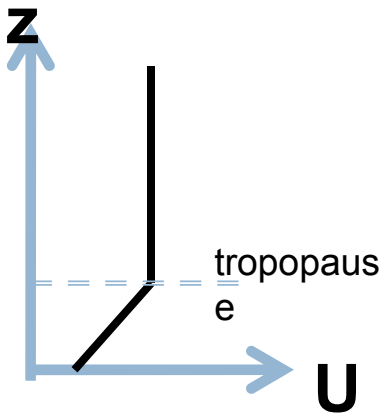
(Alexander et al., 2006, JAS)

Half ring structure due to stratosphere wind filtering

- **Wind (shears) in the troposphere also matters in determining GW generation spectrum**

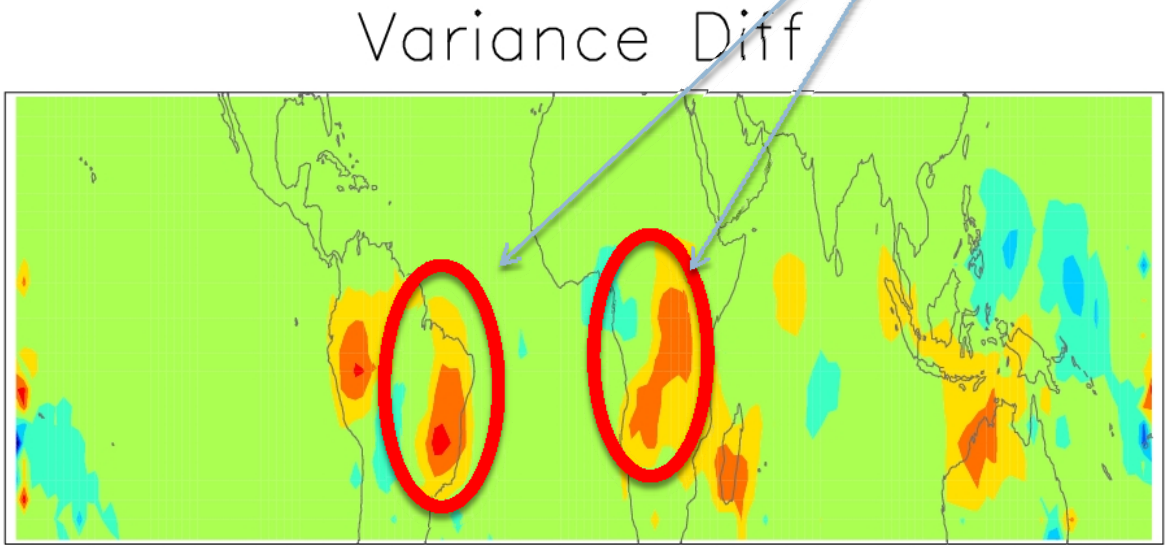


(Courtesy to Marat Khairoutdinov)

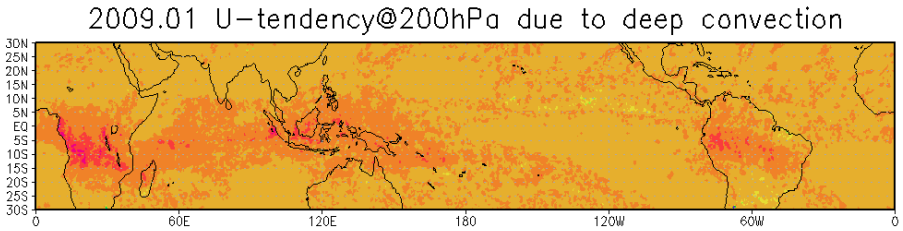


Implications II

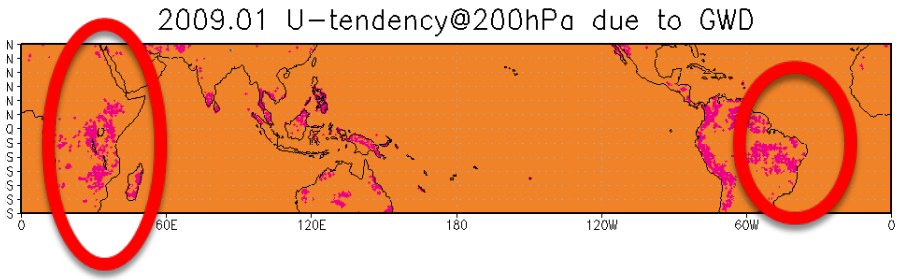
Not considered so far in GCMs



Variance difference @ 200 hPa, 2009.01, 1:30 pm



YOTC, U-tendency due to deep convection @ 200hPa



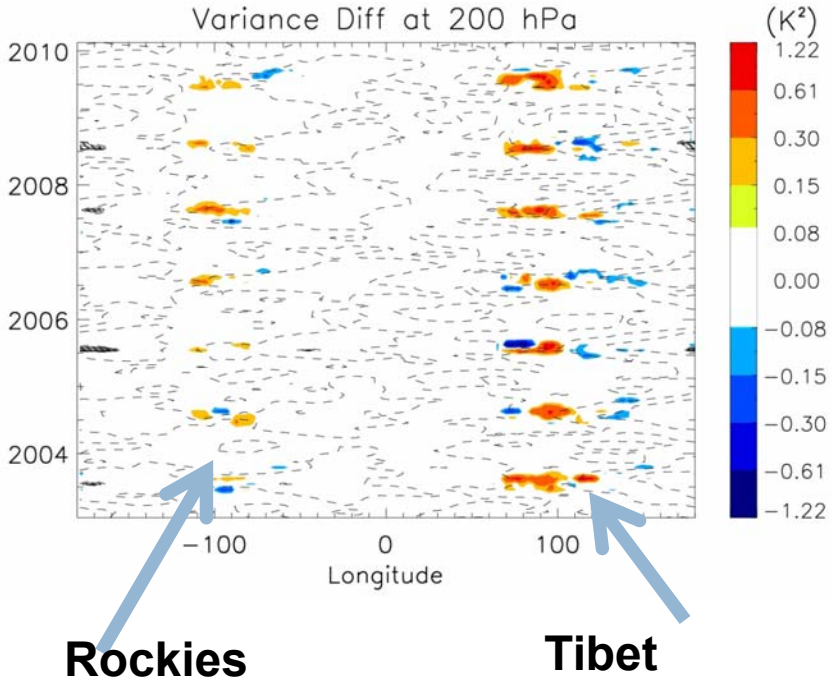
YOTC, U-tendency due to gravity waves @ 200hPa

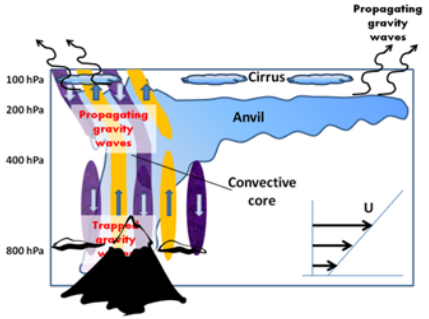
Summary and future works

- **We are able to tell banded cloud structures of upper-level clouds (mainly anvils/cirrus) from AIRS radiance variances.**
- **In the tropics, these banded structures are most prominent over lands, and prevailingly tilt upgradient of the upper-level wind shear when convection initiates, and disappear when convection enters the mature/decaying stage.**
- **The skewness of the banded structures can be explained by propagating gravity waves.**
- **These structures have profound impacts on gravity wave generation spectrum, cloud momentum transport and cloud heating structures; may also influence the global momentum and energy budgets.**

Future works

- Extend to the extra-tropics





- Parameterizations in GCMs

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- Youtube
- Wikipedia


Thank
you!