Exploring the relationship between surface wind convergence and convective rainfall in the tropics

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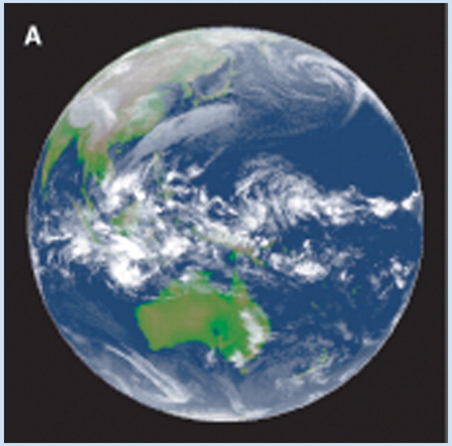

Miura et al. (2007)

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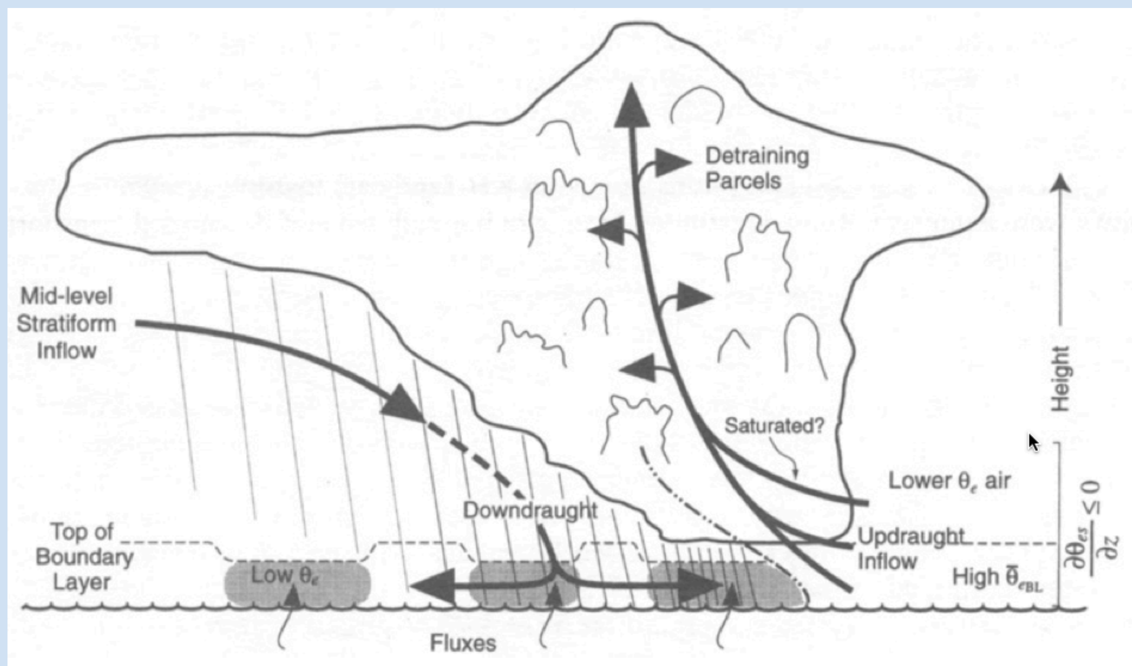
Introduction

- Equatorial waves (Kelvin, inertia-gravity, etc.) strongly influence tropical convection at the planetary and synoptic scales (e.g., Wheeler and Kiladis 1999).
- How closely are the inertia-gravity wave modes coupled to *mesoscale* convection? Can scatterometers detect divergent gust fronts (cold pools) associated with mesoscale convection?
- This new line of analysis into the relationship between surface wind convergence and tropical rainfall anticipates the next-generation scatterometer/radiometer.

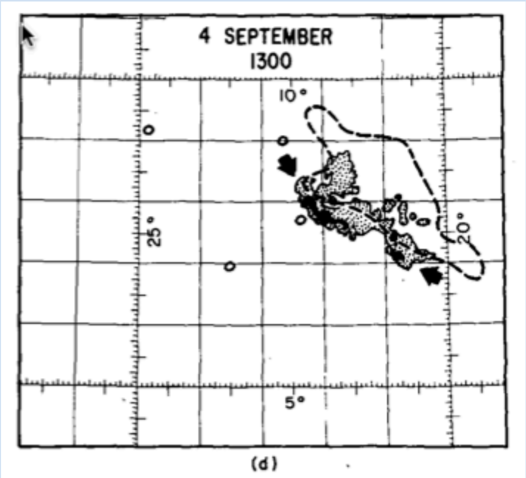


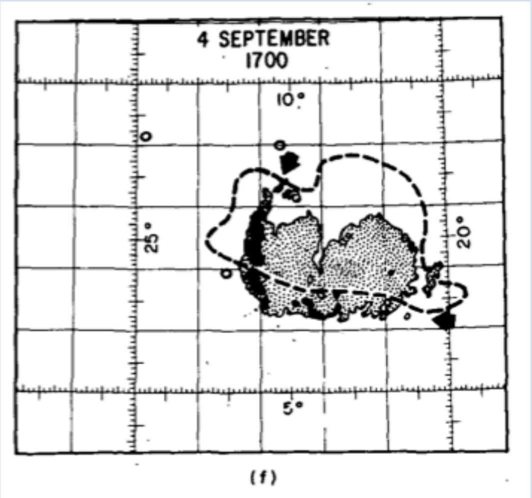
Idealized squall line
(*Kingsmill and Houze 1999)*

Mesoscale convective systems / squall lines

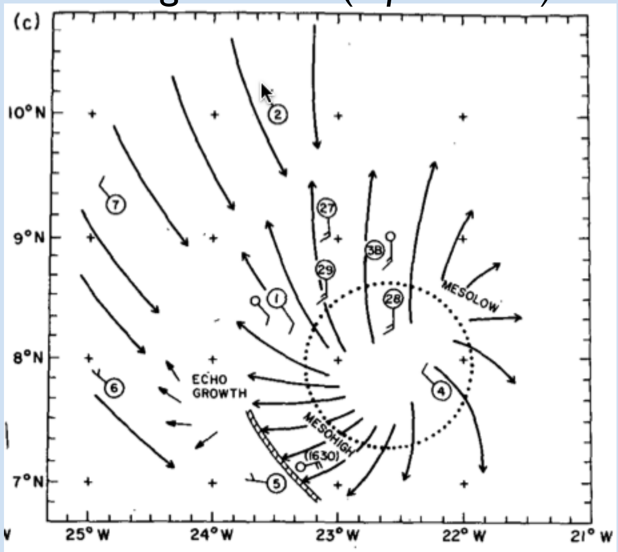
- Mesoscale convective systems are characterized by cool downdrafts due to evaporating rain drops (*Zipser 1969, 1977; Houze 1977*); surface "cold pools" propagate outward like a gravity current (divergent gust front).
- The big tropical convection observation programs (GATE, TOGA-COARE, DYNAMO) have not utilized scatterometer measurements of surface winds.
- The anvil/stratiform region in mature systems can reach 100-300 km size, so should be observable using scatterometer/radiometer combination. Caveats: rain contamination, sampling rate.

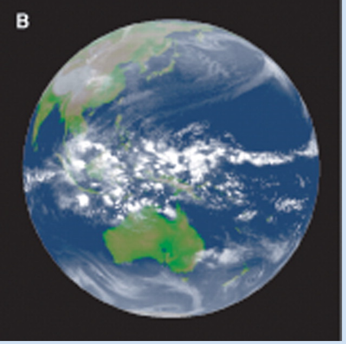
GATE squall line (*Houze 1977*)



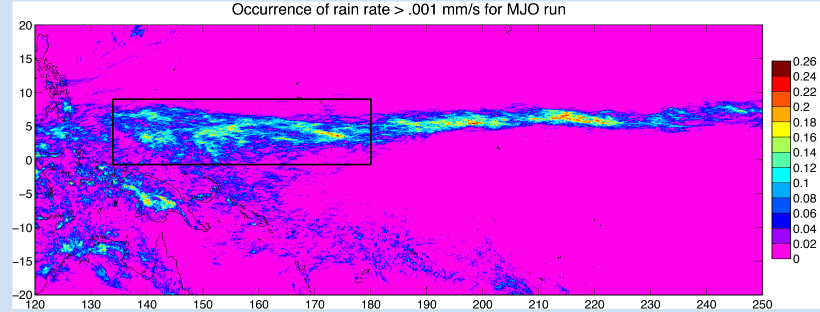


GATE gust front (*Zipser1977*)



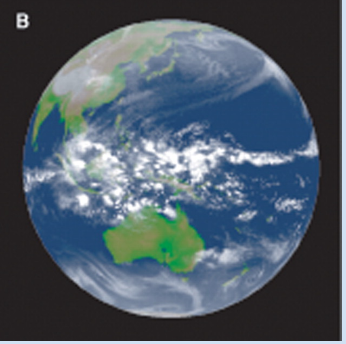


Model



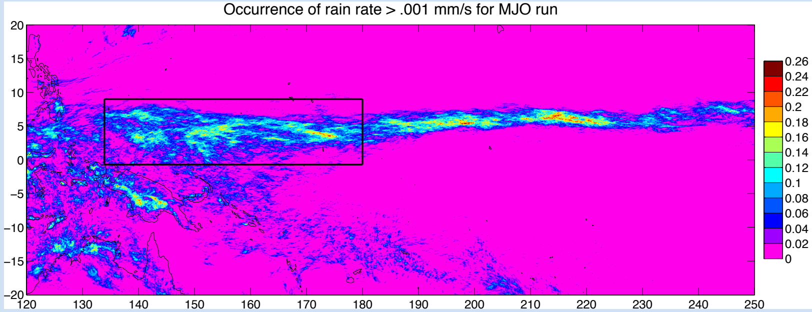
Miura et al. (2007)

- Global, cloud system-resolving, nonhydrostatic icosahedral atmospheric model (NICAM; Tomita and Satoh 2004; Nasuno et al. 2007).
- NICAM is unique in that it explicitly resolves both large-scale organized convection (e.g. ITCZ) and individual mesoscale convective systems (downdraft, cold pool, etc.).
- Global 3.5 km and 7 km mesh MJO runs (Miura et al. 2007) contain multi-scale convective systems.
- "Train" with model ➔ apply diagnostics to observations.



Miura et al. (2007)

Model



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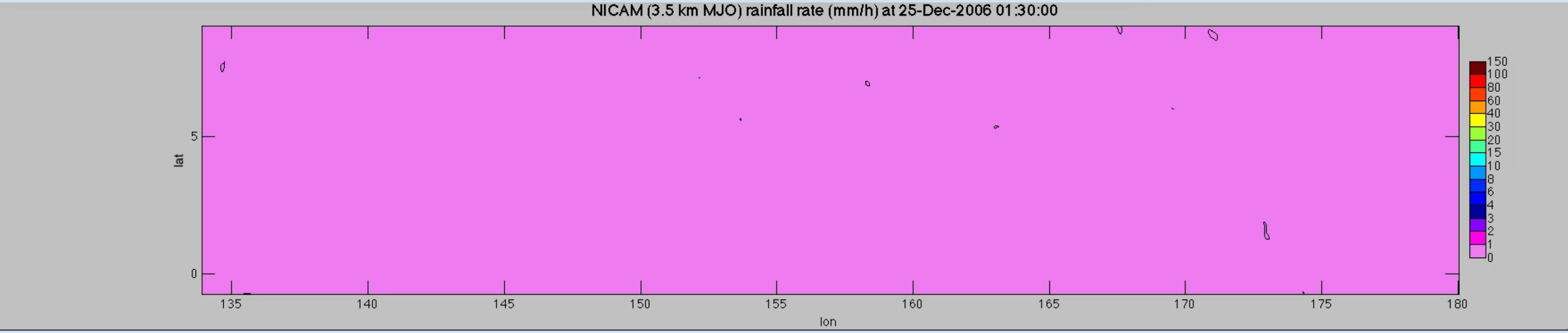
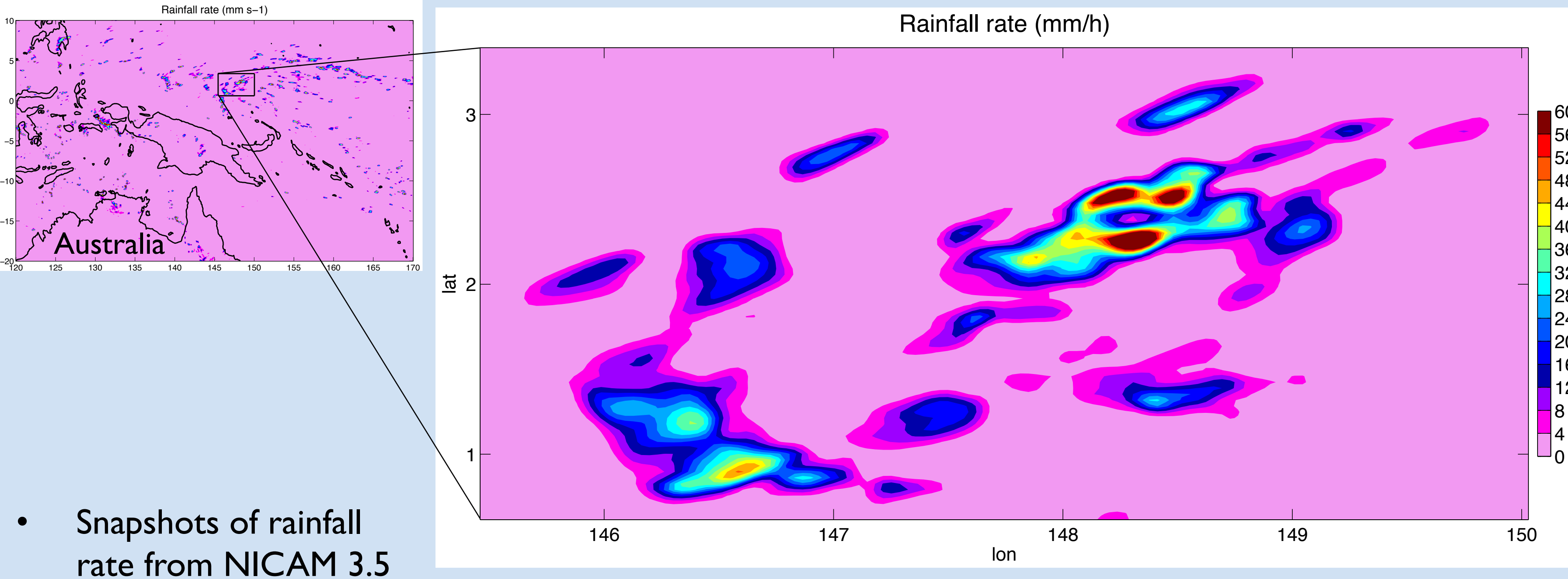
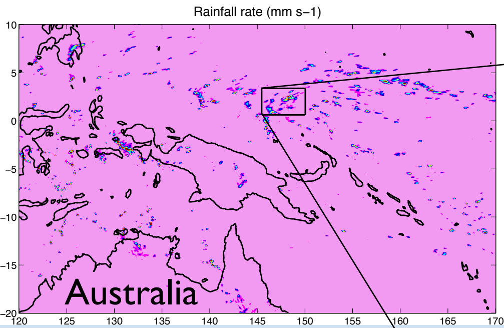
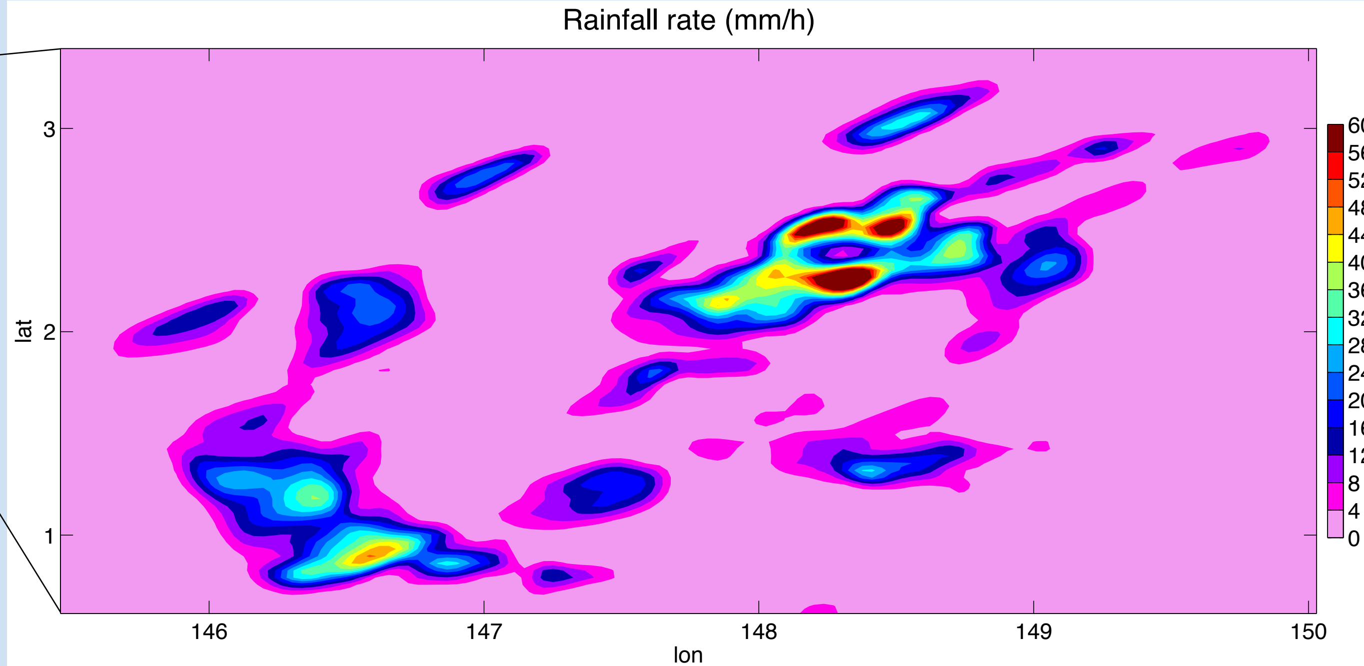
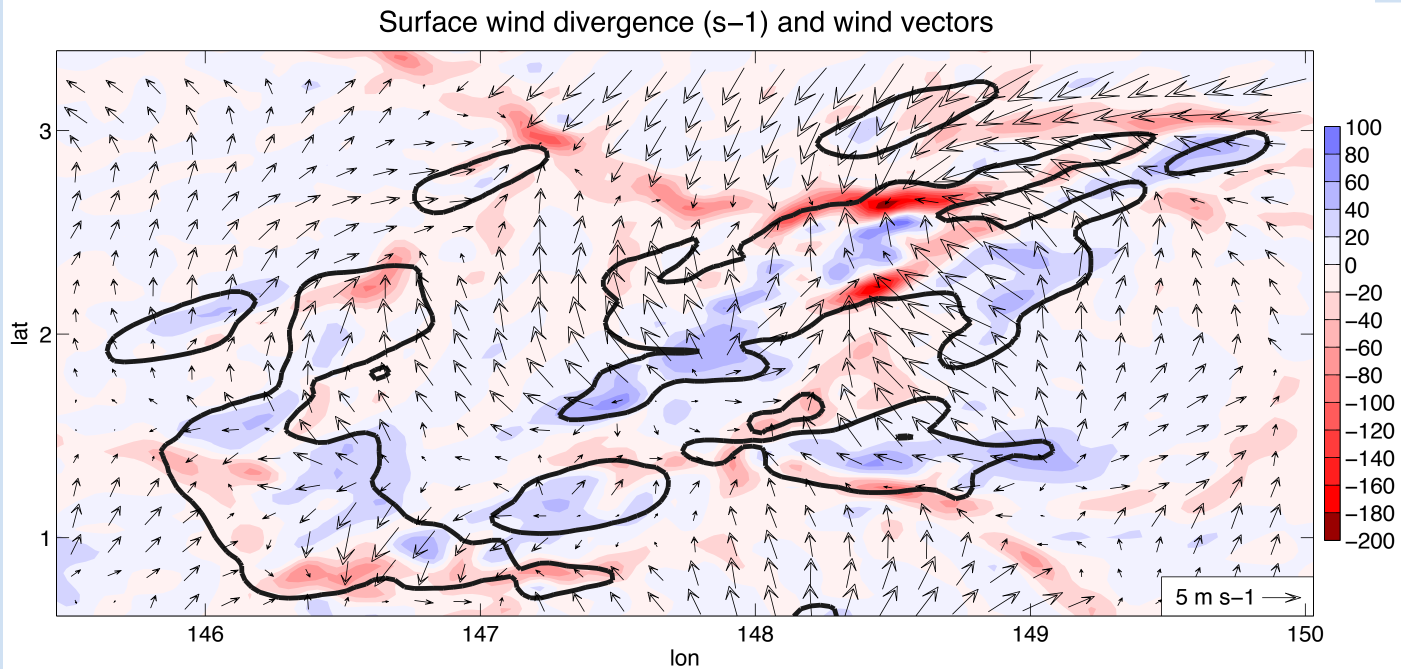




- Snapshots of rainfall rate from NICAM 3.5 km “MJO” run.
- Top: snapshot of rainfall rate indicates mesoscale convective systems.

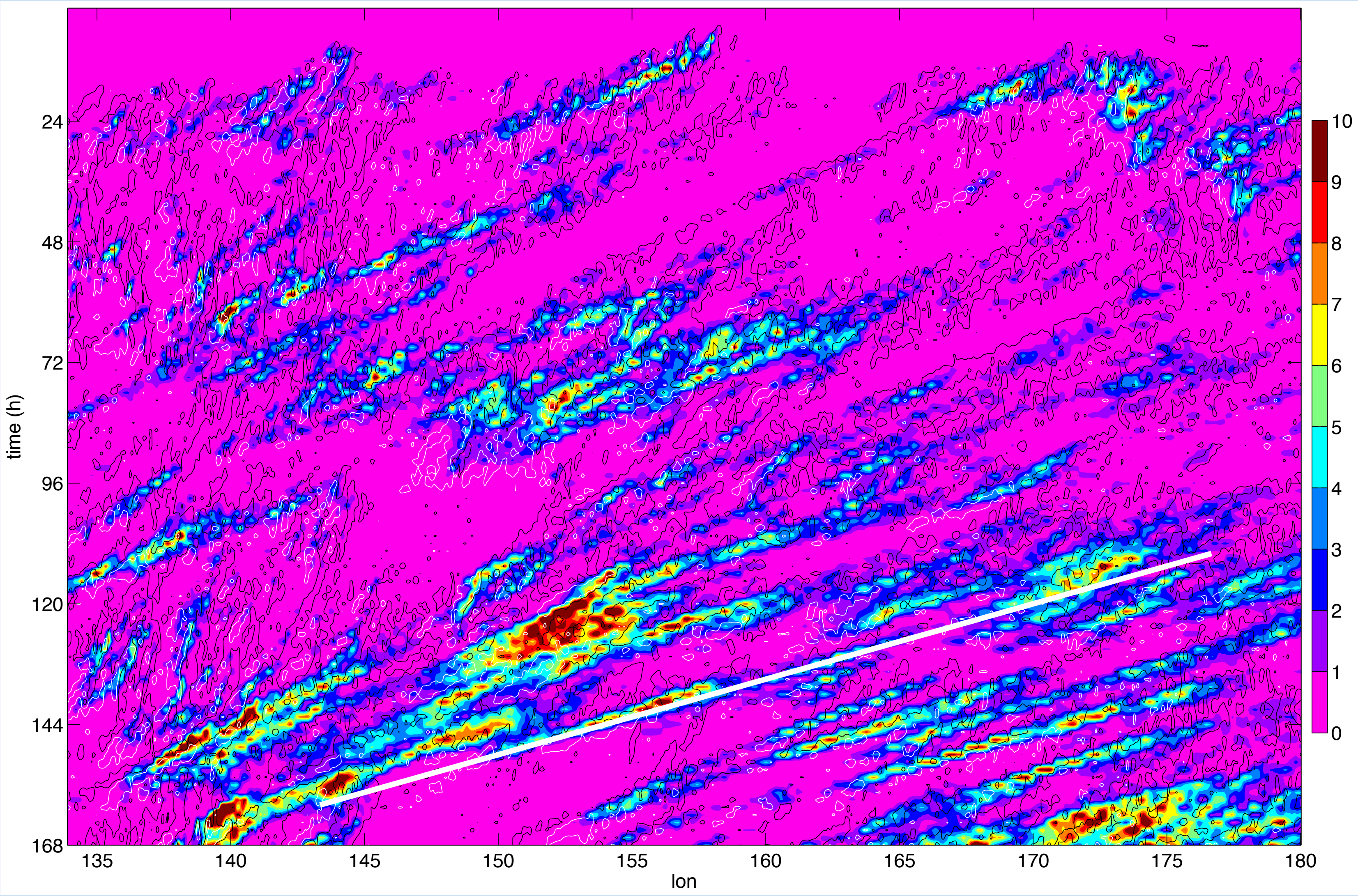






- Snapshots of rainfall rate from NICAM 3.5 km “MJO” run.
- Top: snapshot of rainfall rate indicates mesoscale convective systems.
- Bottom: Heavy rainfall (black contour) associated with surface wind *divergence* (blue), presumably related to cold pool dynamics.

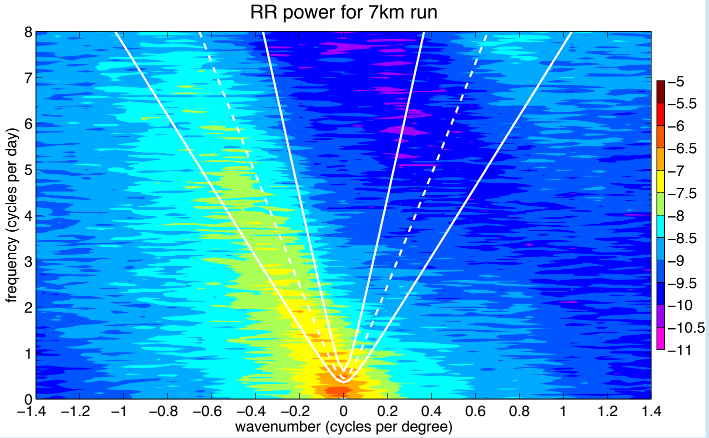
Hovmoller of rainfall rate

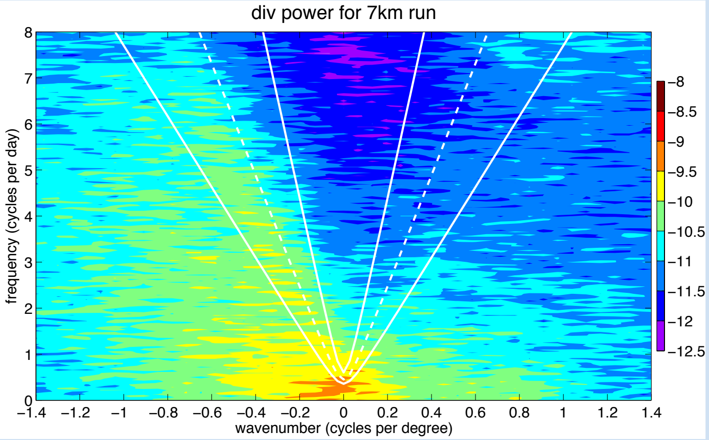


- White contour = $4\times10^{-5}\ s^{-1}$ (divergence), black = $-2\times10^{-5}\ s^{-1}$(conv.).
- Reminiscent of westward-propagating cloud clusters (Nakazawa 1988).

Cross-spectral analysis

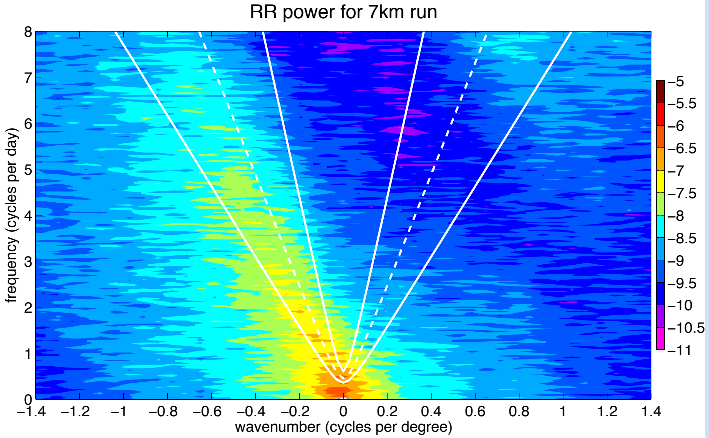
- Wavenumber-frequency coherence analysis of NICAM 7km shows relationship between surface wind divergence and rainfall rate.

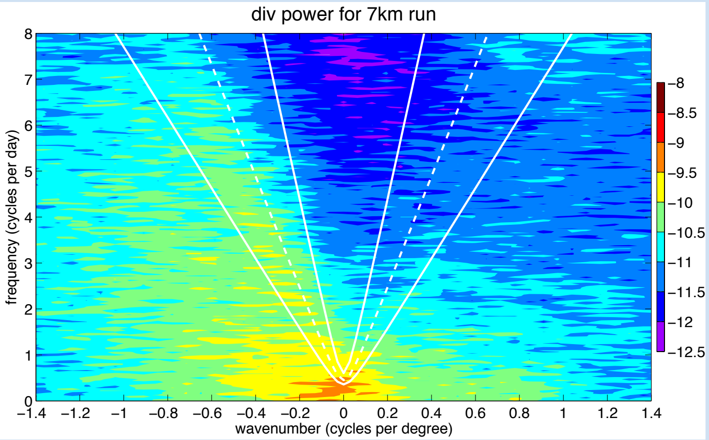


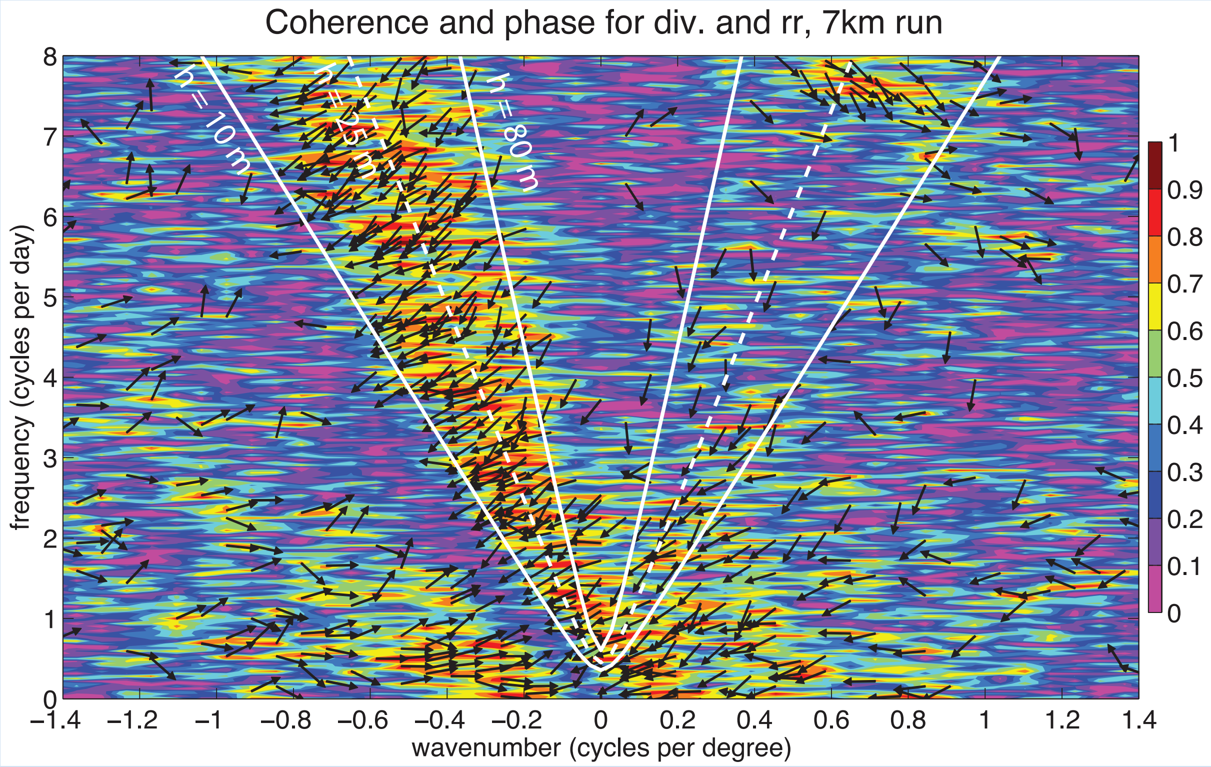


Cross-spectral analysis

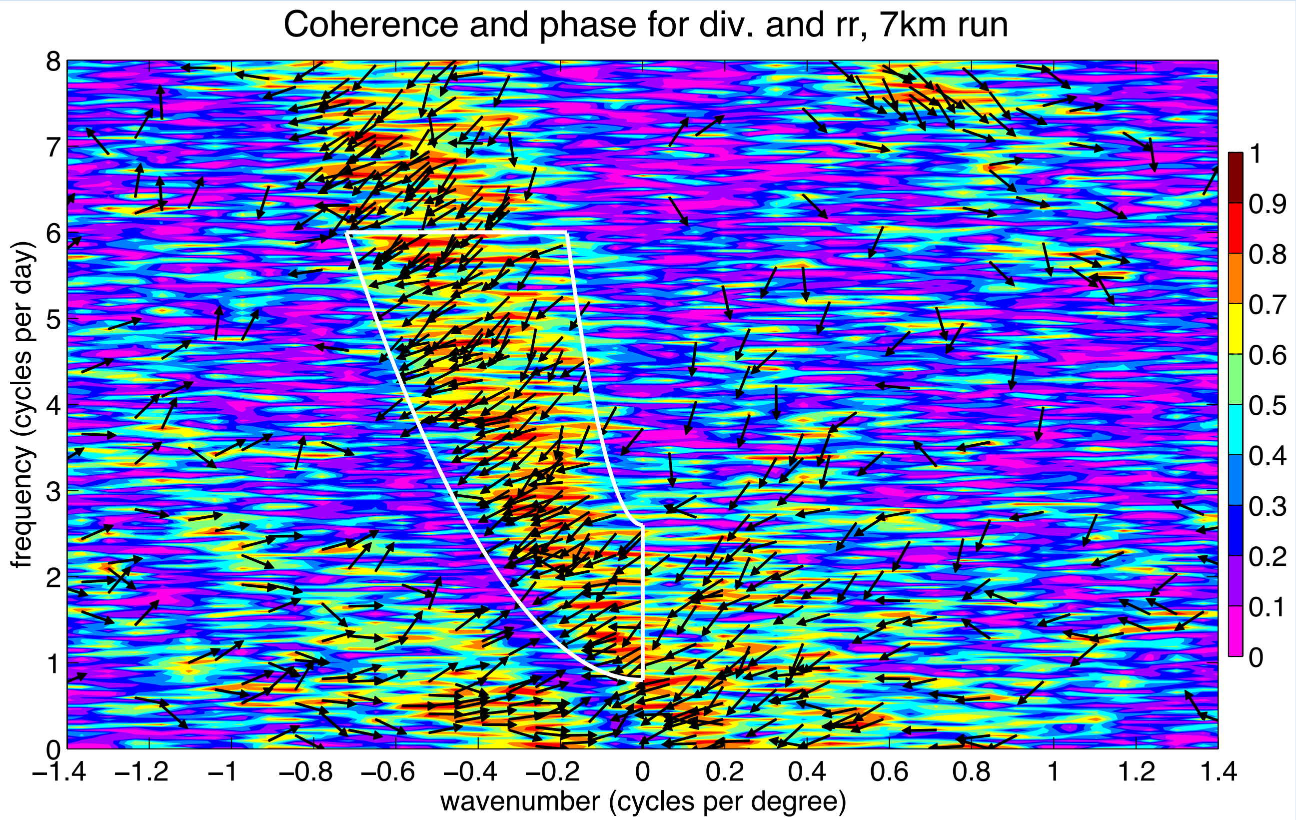
- Wavenumber-frequency coherence analysis of NICAM 7km shows relationship between surface wind divergence and rainfall rate.
- Surface convergence leads rainfall by 40°-80° (~1 hr) in coherent region along *n*=1 IGW dispersion curve.





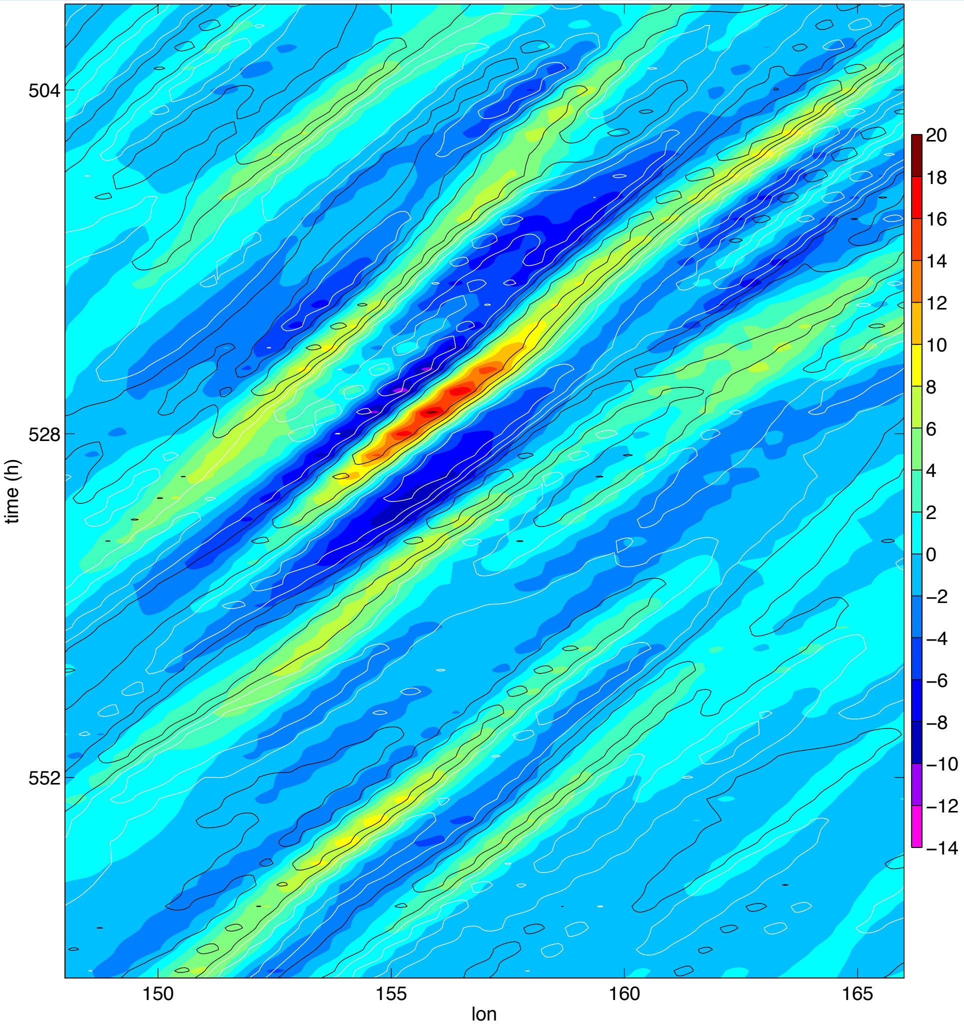


Isolate IGW-like features with k-ω filter



- Next, we set Fourier components outside white box to zero, for both surface divergence and rainfall rate.
- (Unfortunately f>1 cpd for most of signal, and f=1 is Nyquist frequency of scatterometer.)

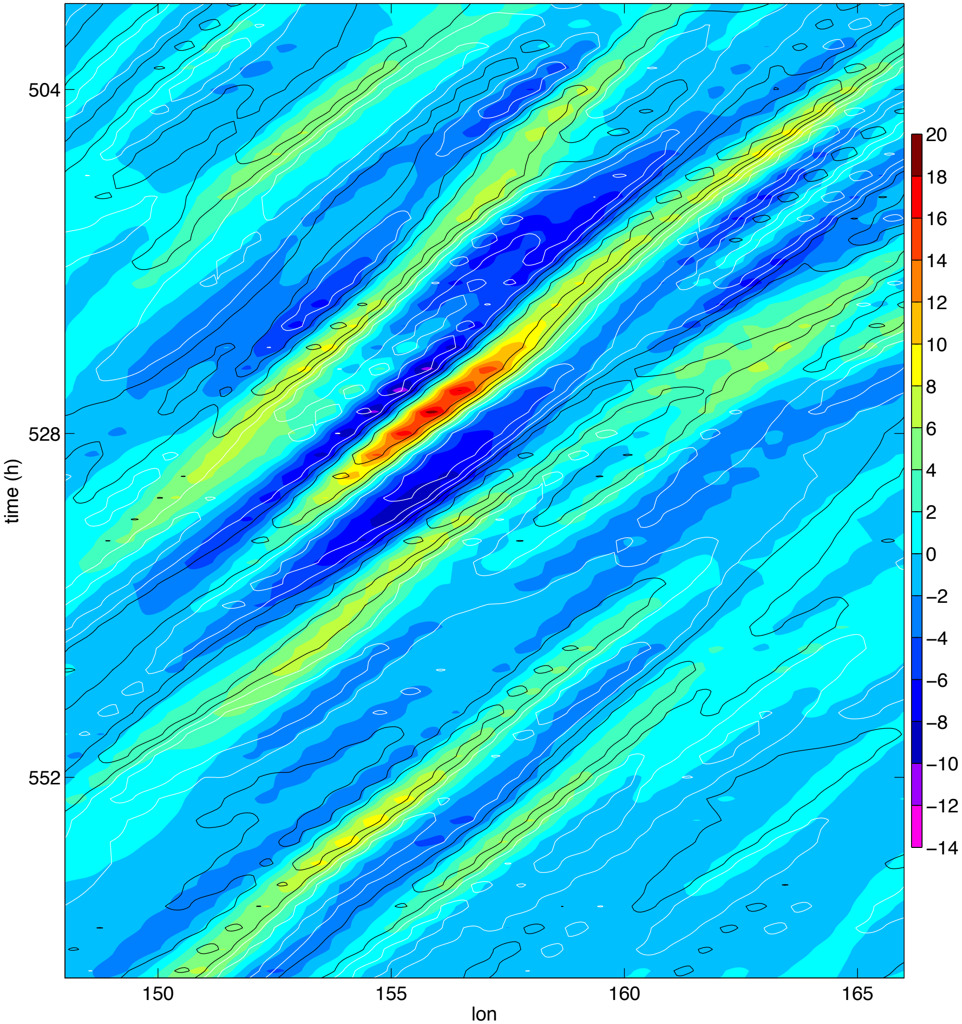
Filtered rainfall

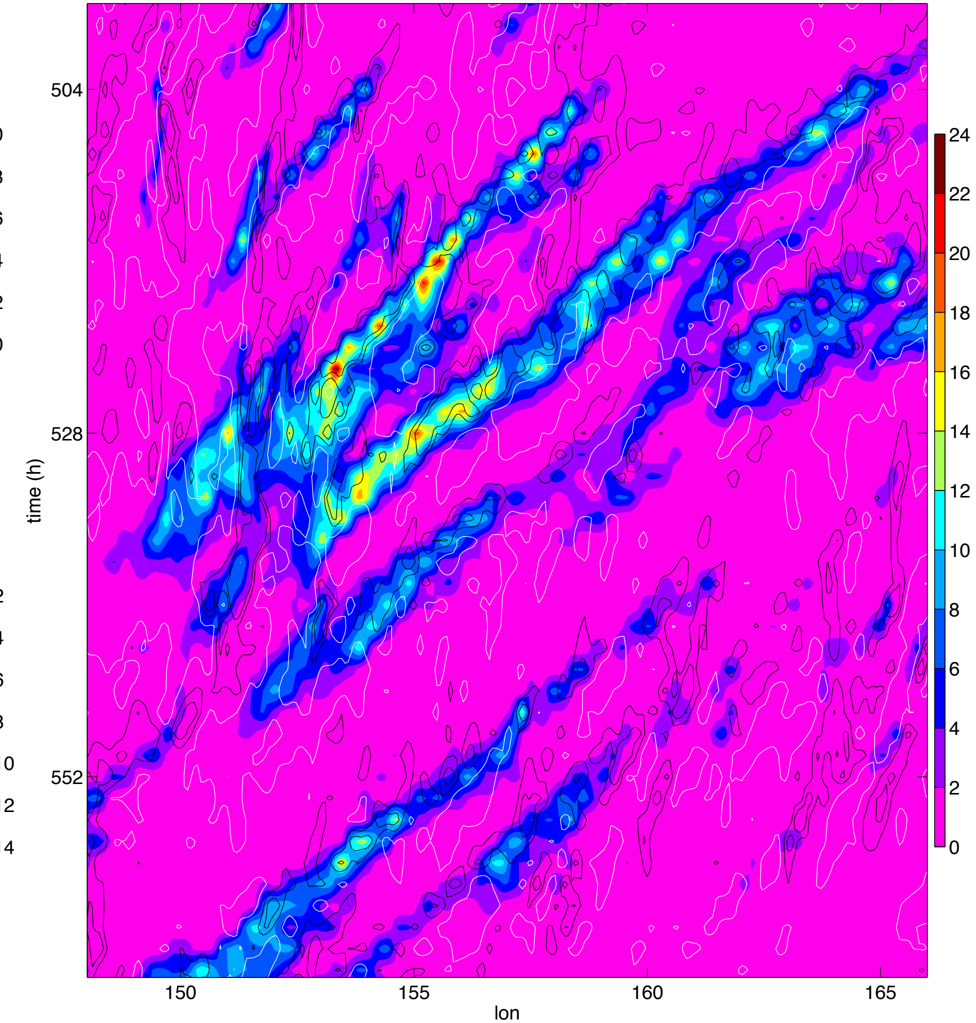


- Left: filtered fields show westward-propagating features our eye picked out before (contours mark div=±1, ±4, ±8×10^{-5} s^{-1})

Filtered rainfall

Unfiltered rainfall

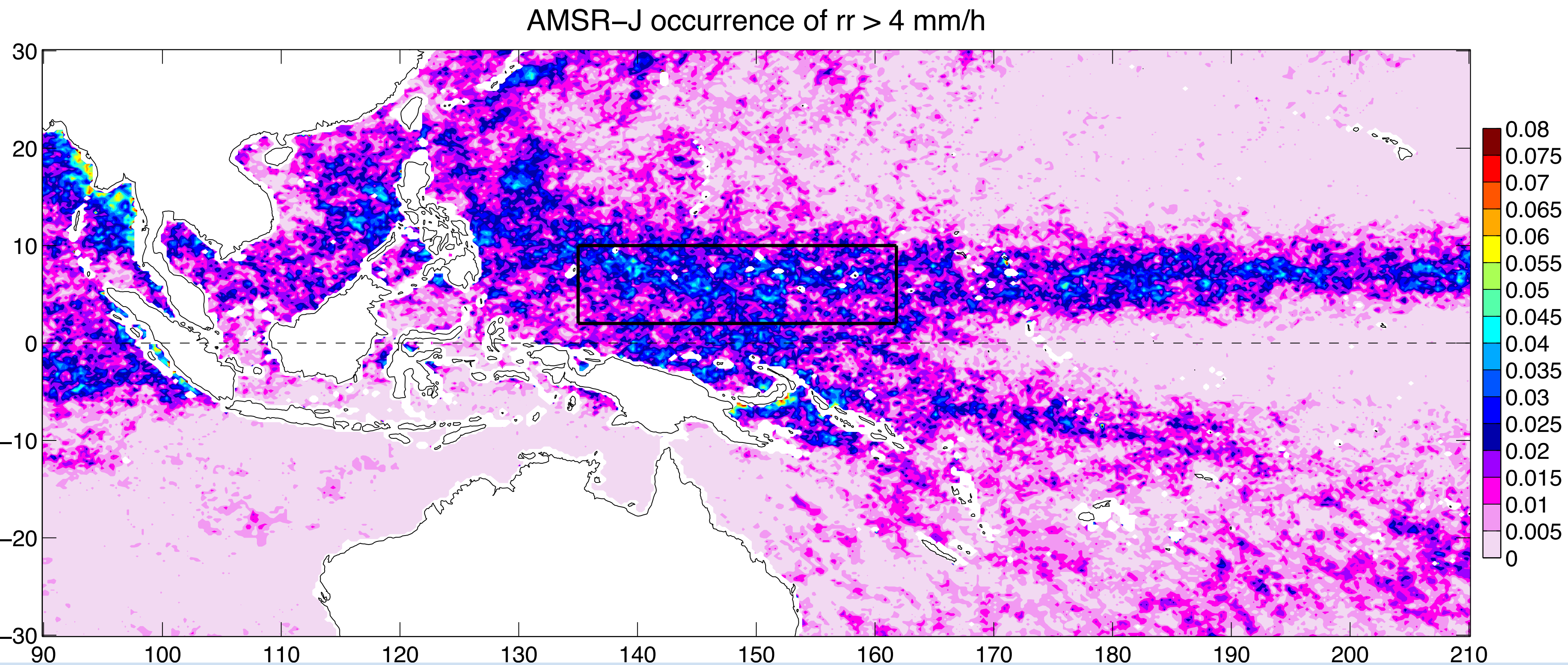




- Left: filtered fields show westward-propagating features our eye picked out before (contours mark div=±1, ±4, ±8×10^{-5} s^{-1})
- Right: unfiltered fields (contours mark div=-8, -4, 2×10^{-5} s^{-1})

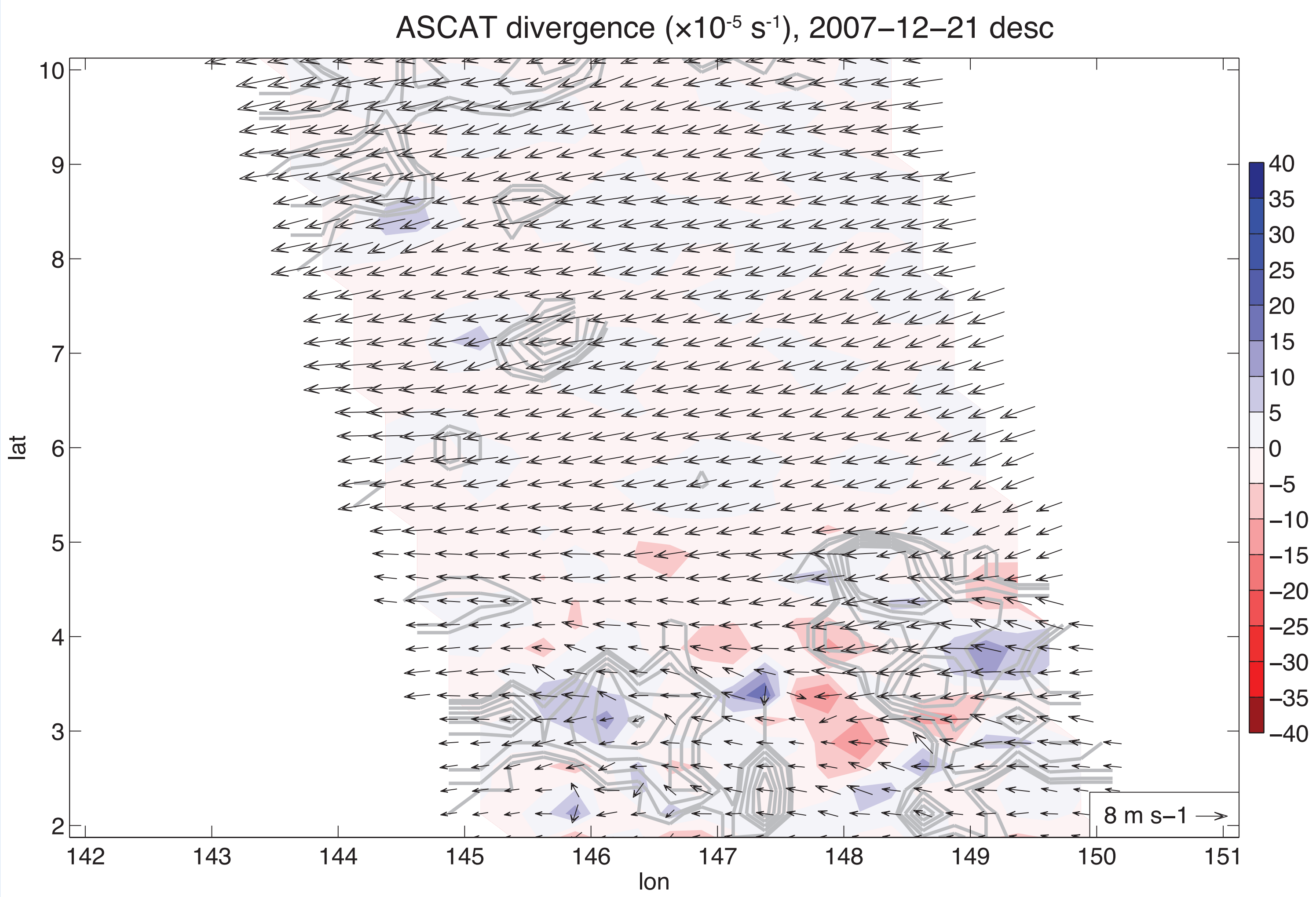
Can scatterometers detect divergent gust fronts?

- The ADEOS-II satellite flew in 2003 with concurrent scatterometer (Seawinds) wind measurements and radiometer (AMSR-J) rainfall measurements.
- Distribution of convective rainfall is consistent with NICAM model.



Can scatterometers detect divergent gust fronts?

- Preliminary analysis suggests that gust fronts are resolved in the (RSS) ASCAT 25 km wind field, but not in Seawinds.



Summary

1. Surface wind divergence and rainfall rate are coherent in regions of k-ω space corresponding to westward propagating inertia-gravity waves, in a global cloud system-resolving model (NICAM).
2. Westward propagating inertia-gravity waves are therefore apparently coupled to *mesoscale* convection (i.e. cold pool physics) in NICAM, consistent with convection analysis based on satellite IR observations (Tulich and Kiladis 2012).
3. The systematic nature of the inertia-gravity wave propagation bodes well for scatterometer detection of surface cold pools and gust fronts.

- Now at 6°N.

Introduction

- Chance to observe new phenomenonology of tropical convection with scatterometer: divergent gust fronts associated with downdrafts (cold pools) of MCS.
- Explore relationship between surface wind convergence and rainfall.
- The convergence patterns associated with equatorial waves are known to strongly influence tropical convection (e.g., *Wheeler and Kiladis 1999*).
- Promise of next-generation scatterometer/radiometer

(Atlas 1994)

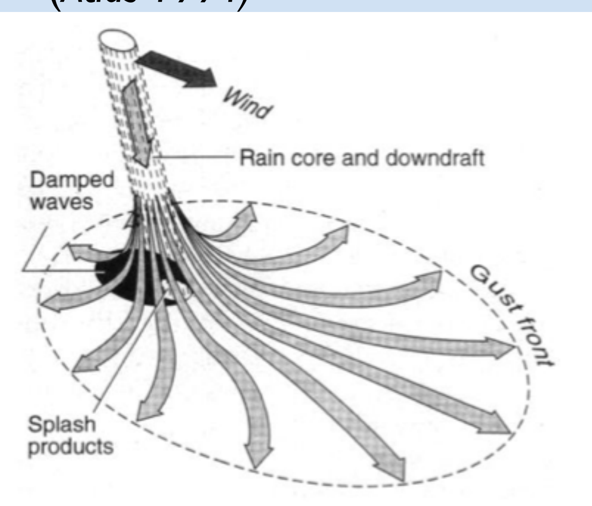
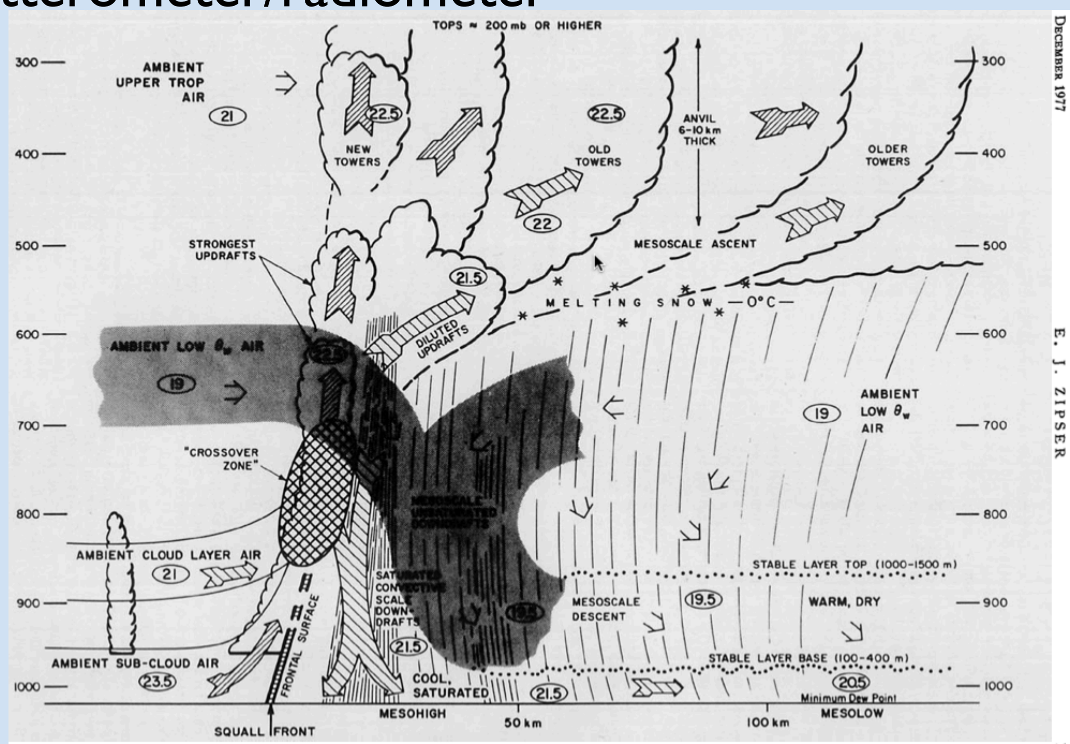
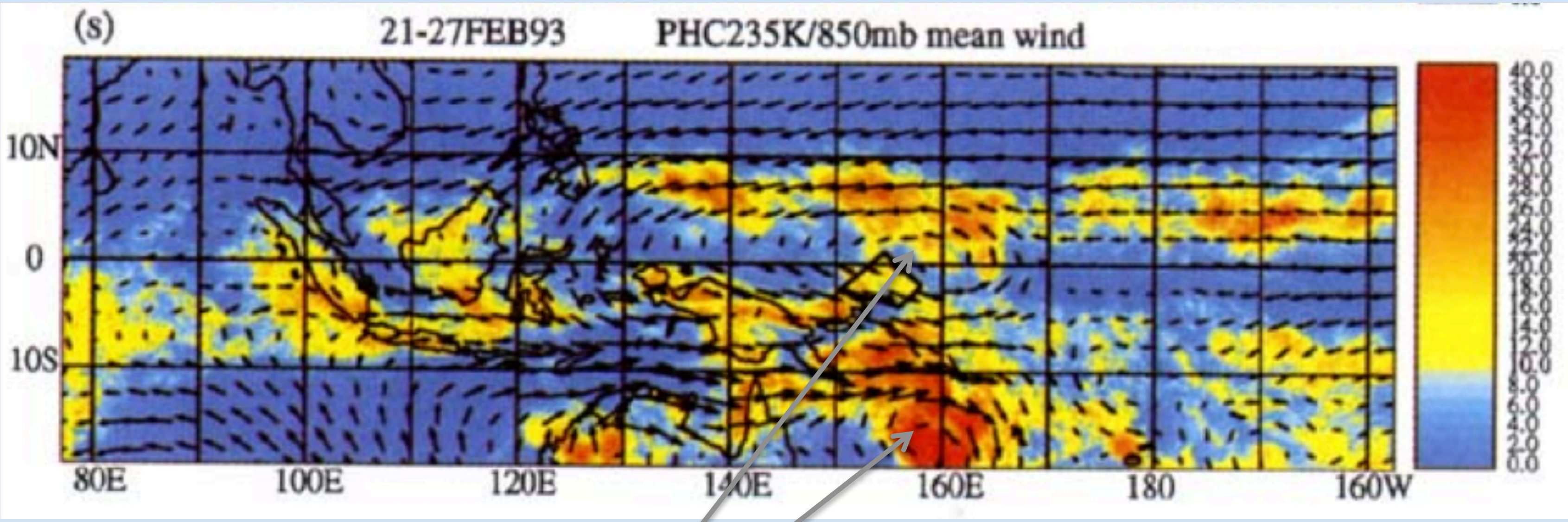


Fig. 3. Schematic of the sea surface footprints and the hypothesized rain and airflow.



Introduction

- At the synoptic/planetary scale, tropical convective precipitation requires low-level/surface wind *convergence* due to the small lateral humidity gradients (e.g. ITCZ, SPCZ)
- The convergence patterns associated with equatorial waves also have a strong effect on tropical convection (e.g., *Wheeler and Kiladis 1999*)



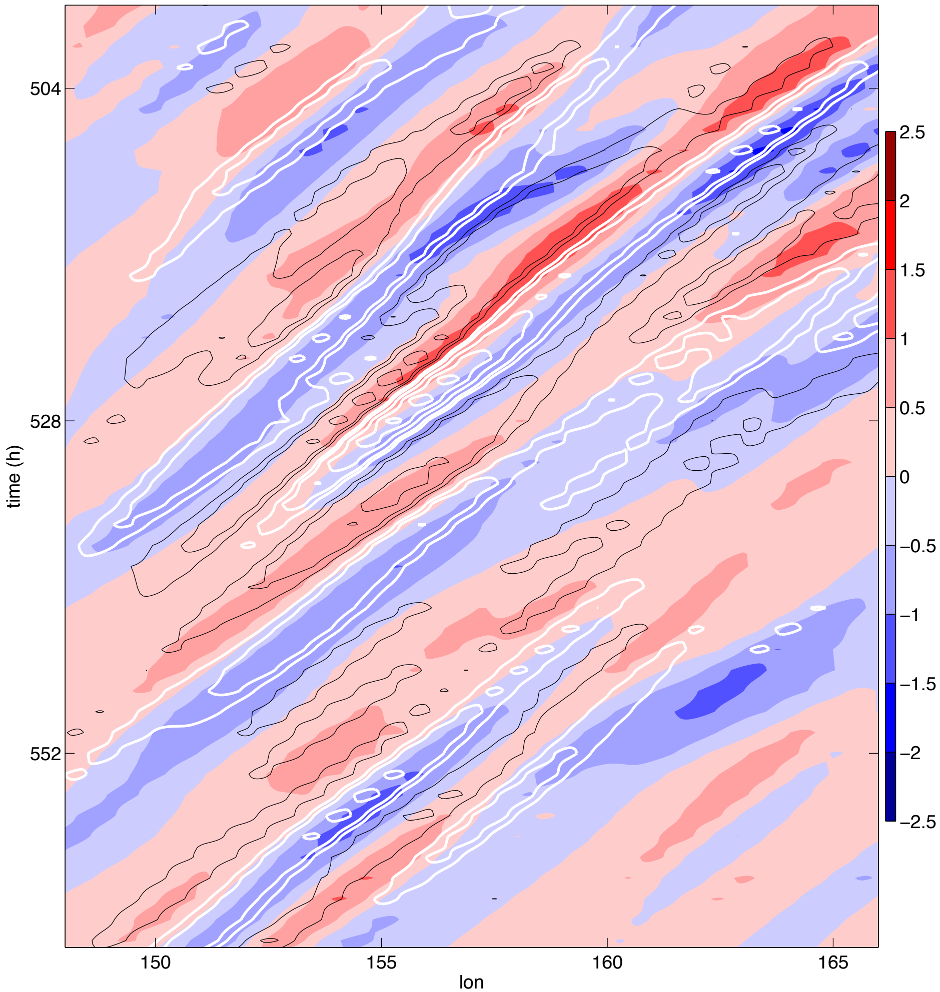
Rossby wave-like cyclonic gyres with strong westerly winds between

Percent high cloudiness (color) and 850 hPa winds, TOGA-COARE (*Chen et al 1996)*

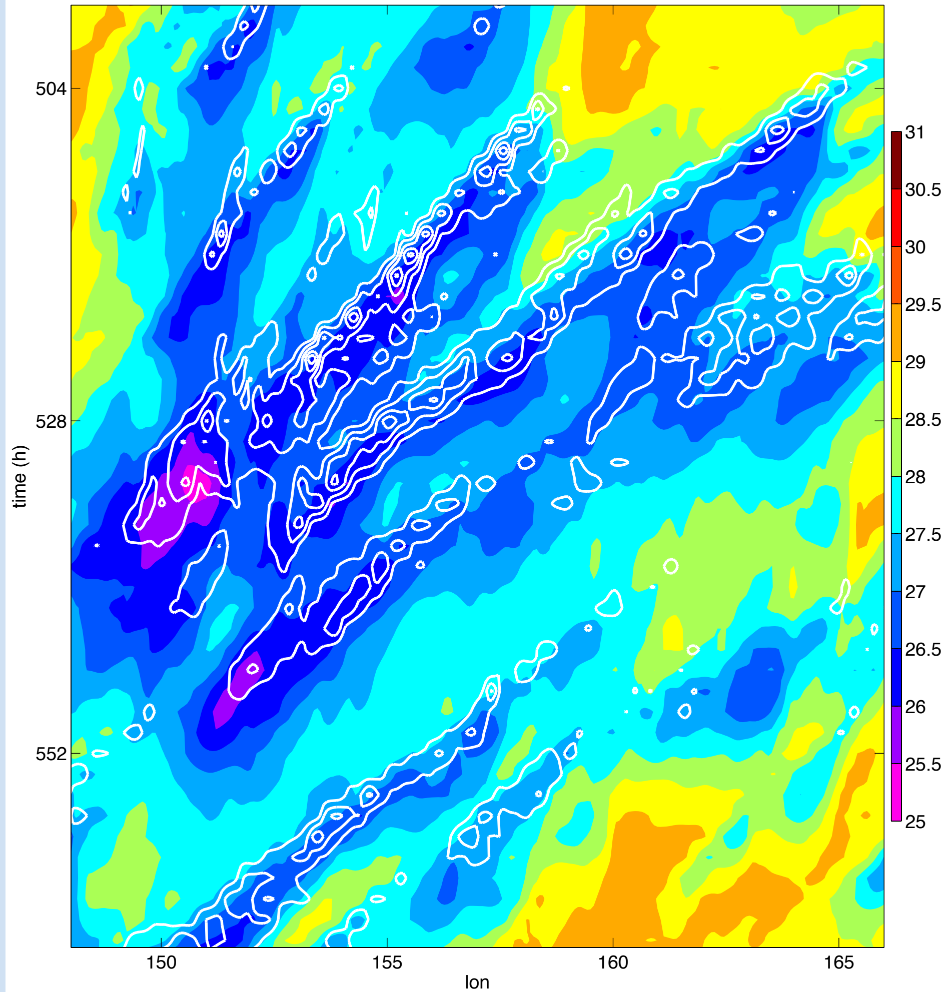
Method

- “Train” with model: utilize global 3.5 km- and 7 km-mesh, cloud-resolving model (NICAM) to characterize the surface wind divergence (gust front) signal associated with tropical rainfall.
- Wavenumber-frequency spectra and cross-spectra are the main diagnostic (Wheeler and Kiladis 1999).
- Eventually apply this diagnostic to satellite observations.

Filtered SAT

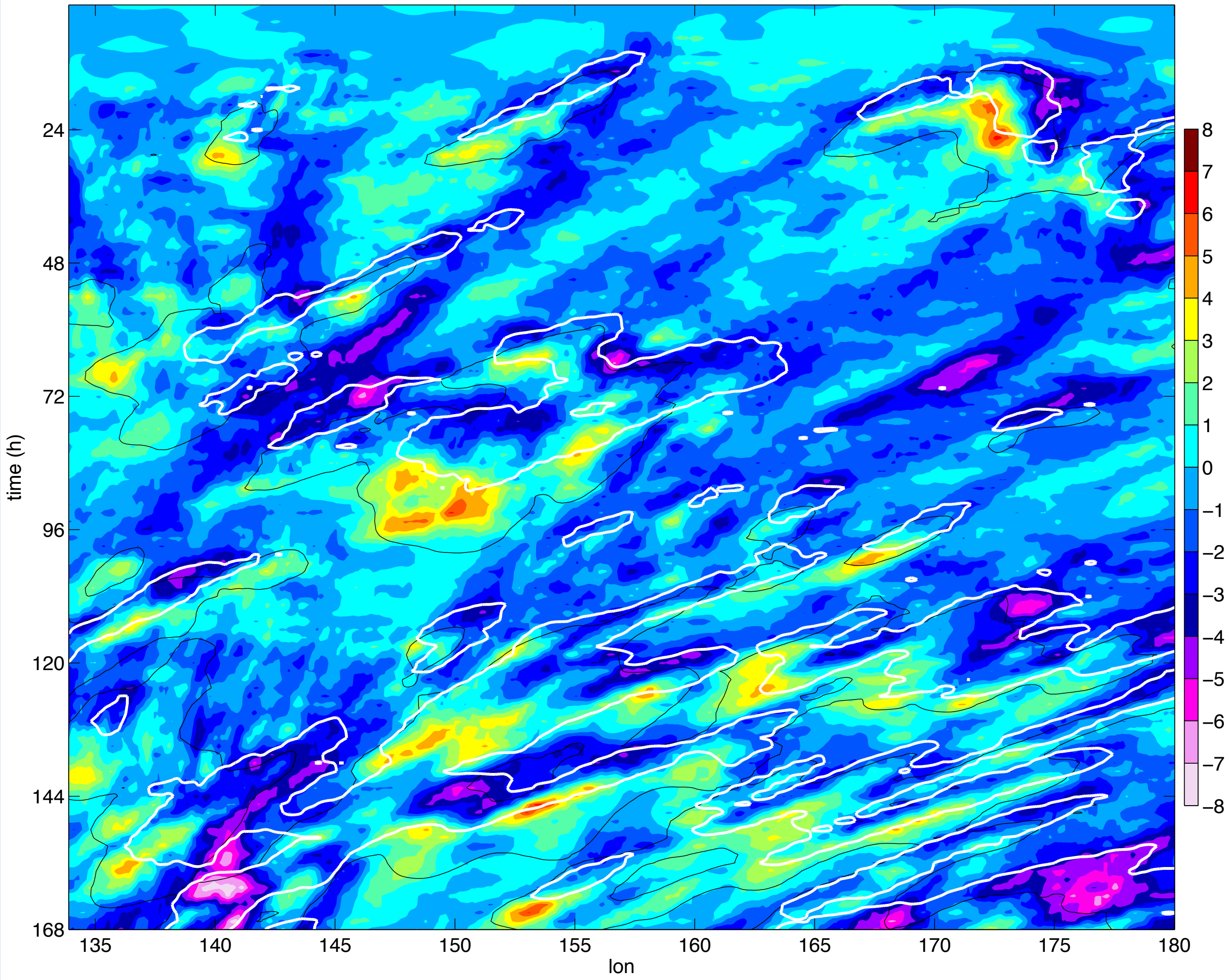


Unfiltered SAT



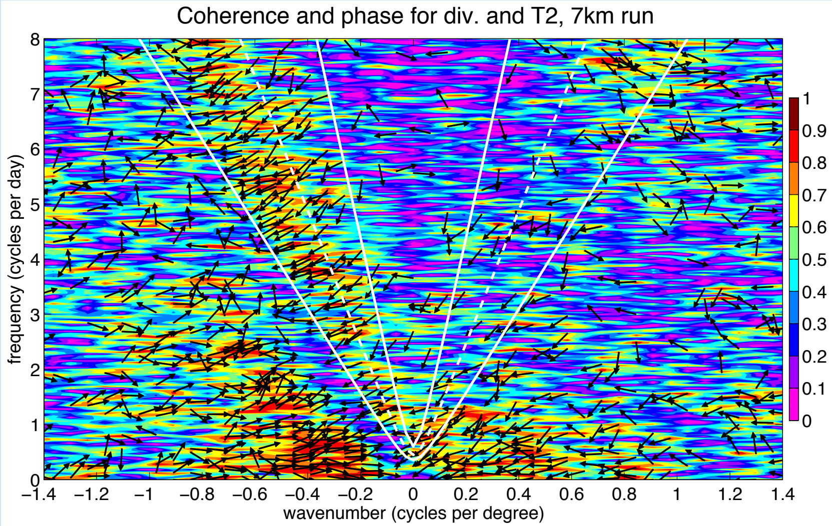
- Cold pools evident in filtered and unfiltered plots.
- Contours = rainfall rate.

Hovmoller of 2°×2° smoothed rainfall rate



- Color = surface divergence, white contour = 2 mm/h rainfall
- Black contour = 28°C, marking cold pool.

Filtered surface air temperature



- It would be nice to have coh(rr,T2) as well.

Can scatterometers detect divergent gust fronts?

- However, preliminary analysis suggests that divergent gust fronts are not apparent in the Quikscat wind fields.