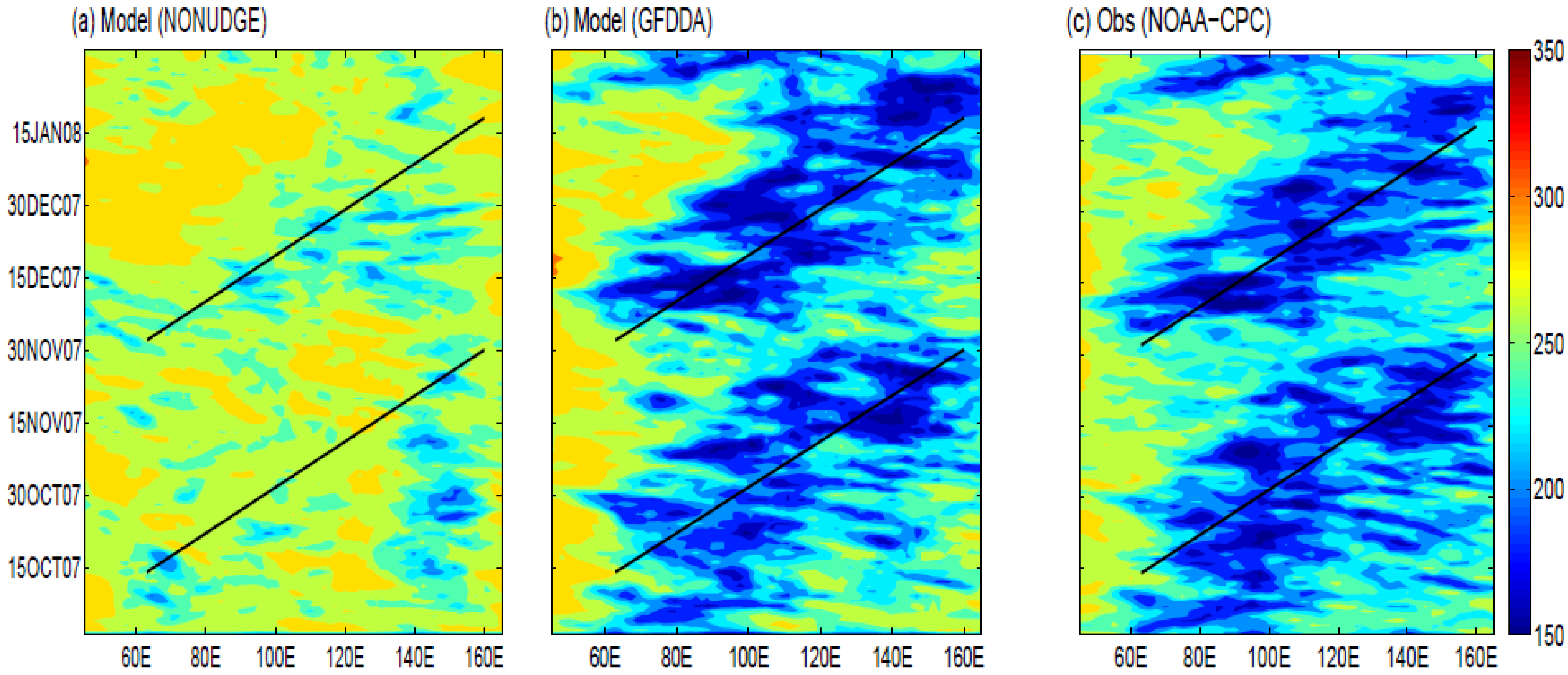
On the use of observations and cloud resolving models in the evaluation and design of cumulus parameterizations.

Samson M. Hagos and L. Ruby Leung
Pacific Northwest National Laboratory

Strategies for using observations and cloud resolving models simulations

- Observational nudging.
- High-resolution regional modeling.
- Vector approach to representing convection - environment interaction.

(a) Observational Nudging



The OLR (Wm^{-2}) signals from the NONUDGE and GFDDA (moisture nudged) experiments, and NOAA-CPC satellite observations. The lines mark propagation speed of 4m/s.

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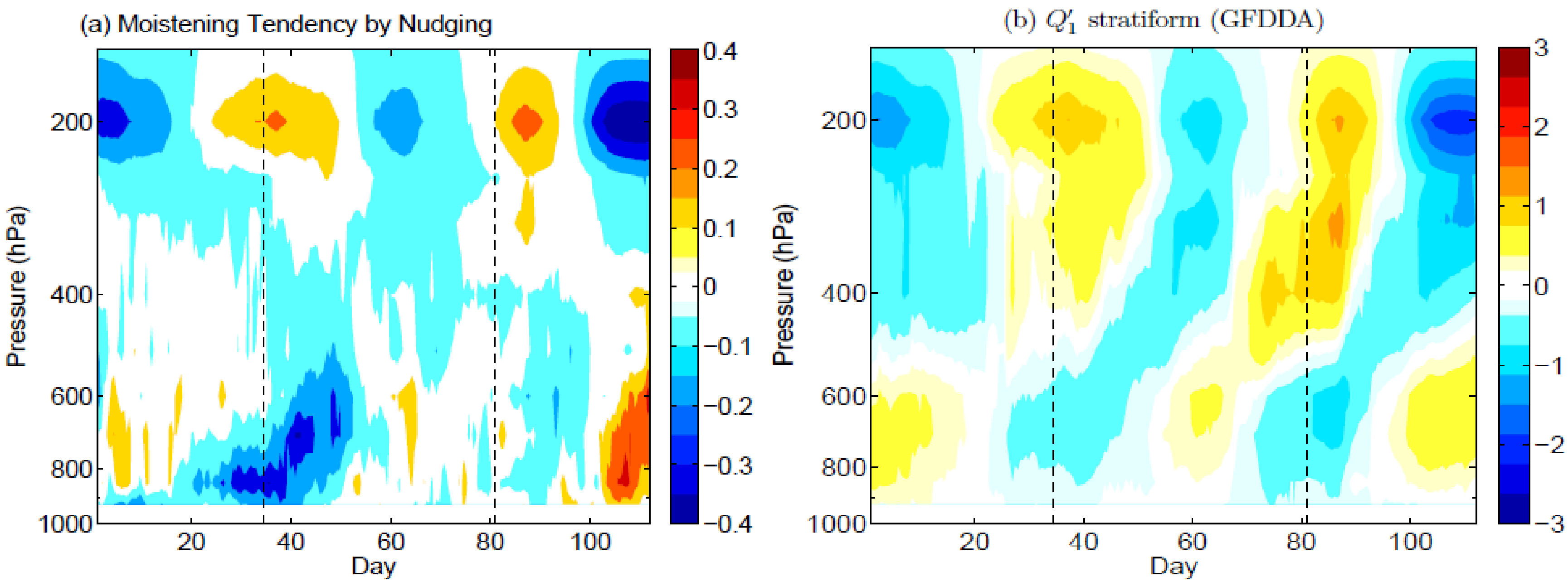
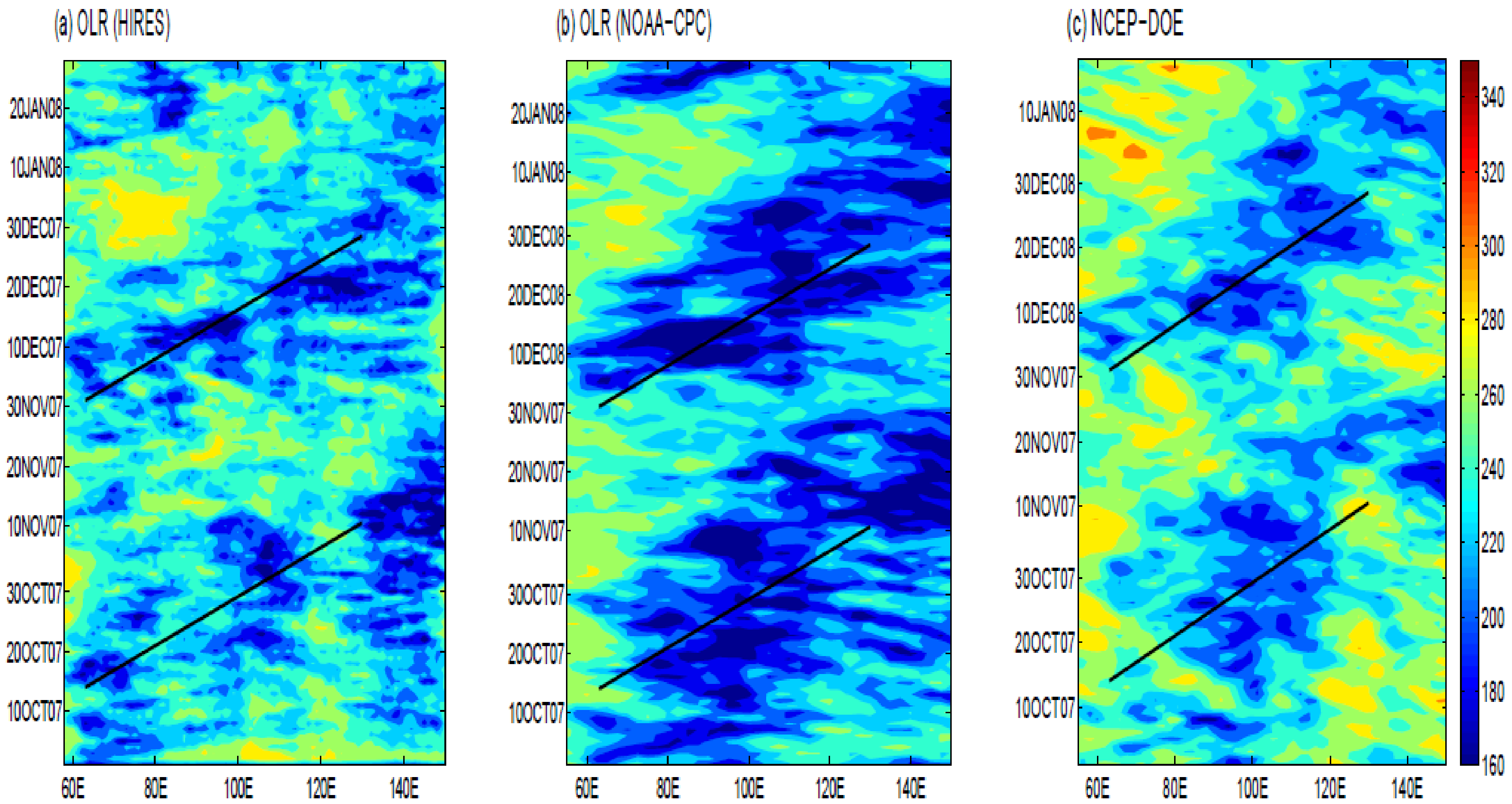
The nudging moisture tendency and associated heating.



The perturbation of the moistening by observational nudging term ($g(kgday)^{-1}$) and the perturbation stratiform heating ($Kday^{-1}$).

► The stratiform heating variability associated with low-level (and upper level) moistening during early (and late) stages of the MJO active phase would be missing without nudging moisture.

(b) High resolution regional modeling



OLR (W m^{-2}) signals (top) from the high resolution experiment, and NOAA-CPC satellite observations and NCEP-DOE reanalysis. The lines mark propagation speed of 5 m/s.

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The slow moistening of mid-troposphere

The time-scale of MJO is estimated from the moisture budget equation of the high resolution simulation as follows;

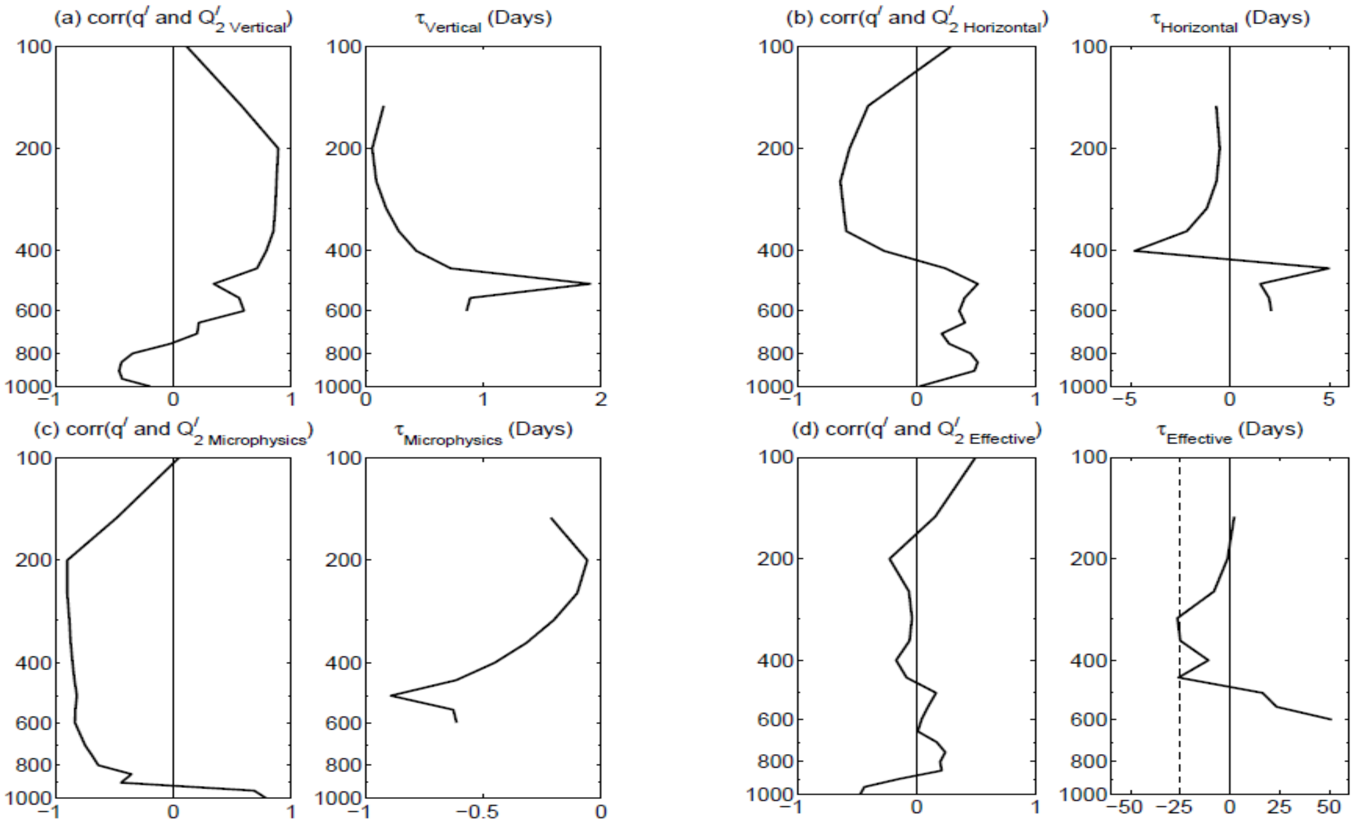
$$\frac{\partial q'}{\partial t} \approx Q'_{2(vertical)} + Q'_{2(horizontal)} + Q'_{2(condensation)}$$

$$\frac{\partial q'}{\partial t} \approx \frac{q'}{\tau_{vertical}} + \frac{q'}{\tau_{horizontal}} + \frac{q'}{\tau_{condensation}}$$

$$\tau_{effective} = \frac{\tau_{vertical}\tau_{horizontal}\tau_{condensation}}{\tau_{vertical}\tau_{horizontal} + \tau_{vertical}\tau_{condensation} + \tau_{horizontal}\tau_{condensation}}$$

$$\frac{\partial q'}{\partial t} \approx \frac{q'}{\tau_{effective}}$$

Low frequency variability in moistening



- The effective timescale is 15-25 days which corresponds to 30-50 day period of the MJO.
- It arises from small differences among the timescales of convective updraft, horizontal mixing and condensation.

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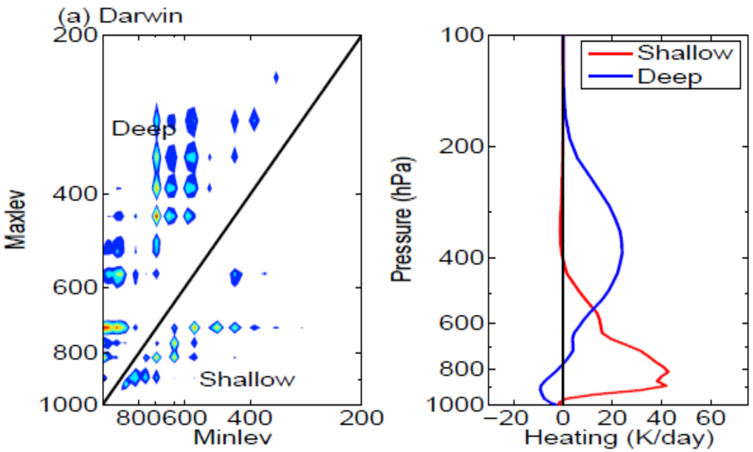
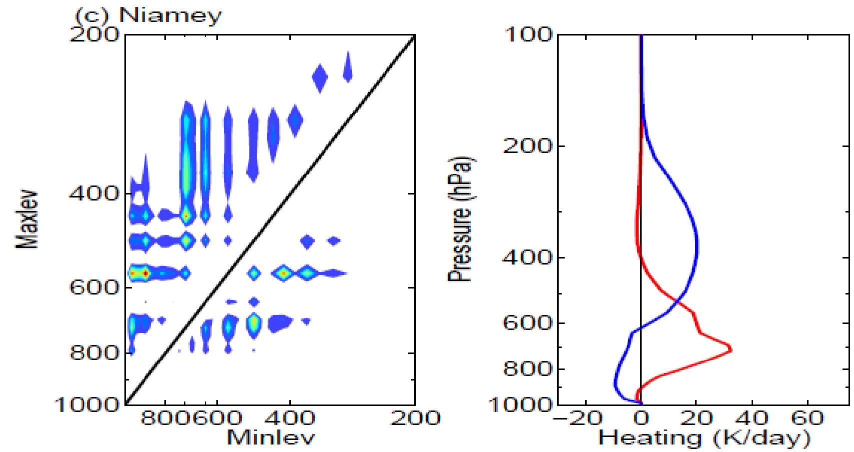
c) Vector formulation of the convection – environment interaction problem

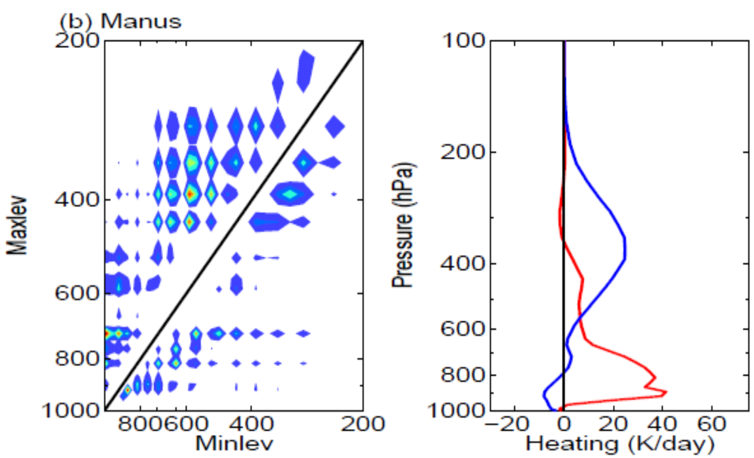
- **Model:** WRF V3.2 at 2km resolution. $2^0 x 2^0$ box.
- **Domains:**
  - TWP-Darwin, Nov 1 2005 - April 15 2006 (TWP-ICE period).
  - Manus Oct 1 2007 - Jan 31 2008 (two MJO episodes).
  - Niamey June 1 2006 – Sep 30 2006 (AMMA period).
- **Initial and boundary conditions:** GFS forecast data are used for lateral, initial, and surface boundary conditions.
- **Physics :** RRTM radiation, MYJ PBL and NOAH LSM WSM6 microphysics respectively. No cumulus parameterization.

Convection and Environment

(a) Cloud Scale







Cloud Types:

Clouds are categorized as deep (convective + stratiform) or shallow (shallow + congestus) depending on their level of maximum and minimum latent heating.

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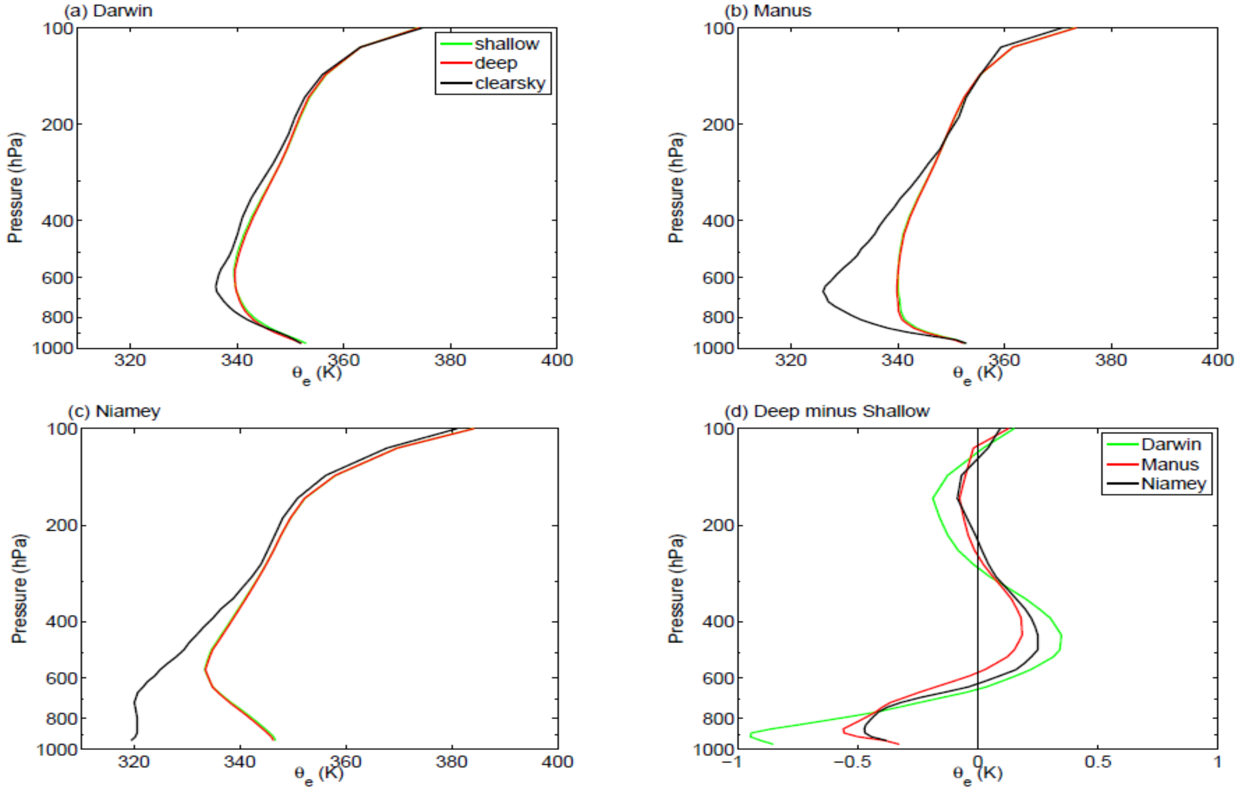


- ► **Equivalent Potential Temperature:**
- The model minimum potential temperature of convective environment is at least 10ºK higher than a clear sky environment.
- For deep convective environment the equivalent potential temperature (moist static energy) is higher in the mid-troposphere and lower in the lower troposphere.

Convection and Environment

(b) Large scale

- ► Relationship between the cloud scale and the large scale:
- • Large-scale environment is an aggregate of the cloud scale environment and large scale convection is aggregate of the cloud scale convection.
- • Assumption: $\boldsymbol{\theta}_e \rightleftarrows \boldsymbol{H}$
- ► The problem:
- • Given large-scale equivalent potential temperature profile, can we determine large scale convective heating and moistening?
- ► The strategy:
- • Calculate the contributions of each type of environment and assign the corresponding heating.

$$\boldsymbol{H} = \begin{pmatrix} H_{cs} & H_s & H_d \end{pmatrix}$$

$$\boldsymbol{\theta}_e = \begin{pmatrix} \theta_{cs} & \theta_s & \theta_d \end{pmatrix}$$

$$\boldsymbol{N} = \begin{pmatrix} N_{cs} & N_s & N_d \end{pmatrix}$$

$$\boldsymbol{H}_{ls} = \boldsymbol{N} \bullet \boldsymbol{H}$$

$$\boldsymbol{\theta}_{els} = \boldsymbol{N} \bullet \boldsymbol{\theta}_e$$

► Vector Formulation:

- The set of θ_e is Gram-Schmidt orthogonalized.
- The contributions of the new basis vectors can be calculated.

► The solution:

- Large scale heating can be represented by a product of large scale equivalent potential temperature and a matrix.
- The "physics" matrix maps cloud scale equivalent potential temperature to a cloud scale heating.

$$H_{ls} = \theta_{els} \bullet P$$

$$P = \theta_{eo} \bullet H_o$$

$$\theta_e = G \bullet \theta_{eo}$$

$$\theta_{els} = N_o \bullet \theta_{eo}$$

$$N_o = \theta_{els} \bullet \theta_{eo}$$

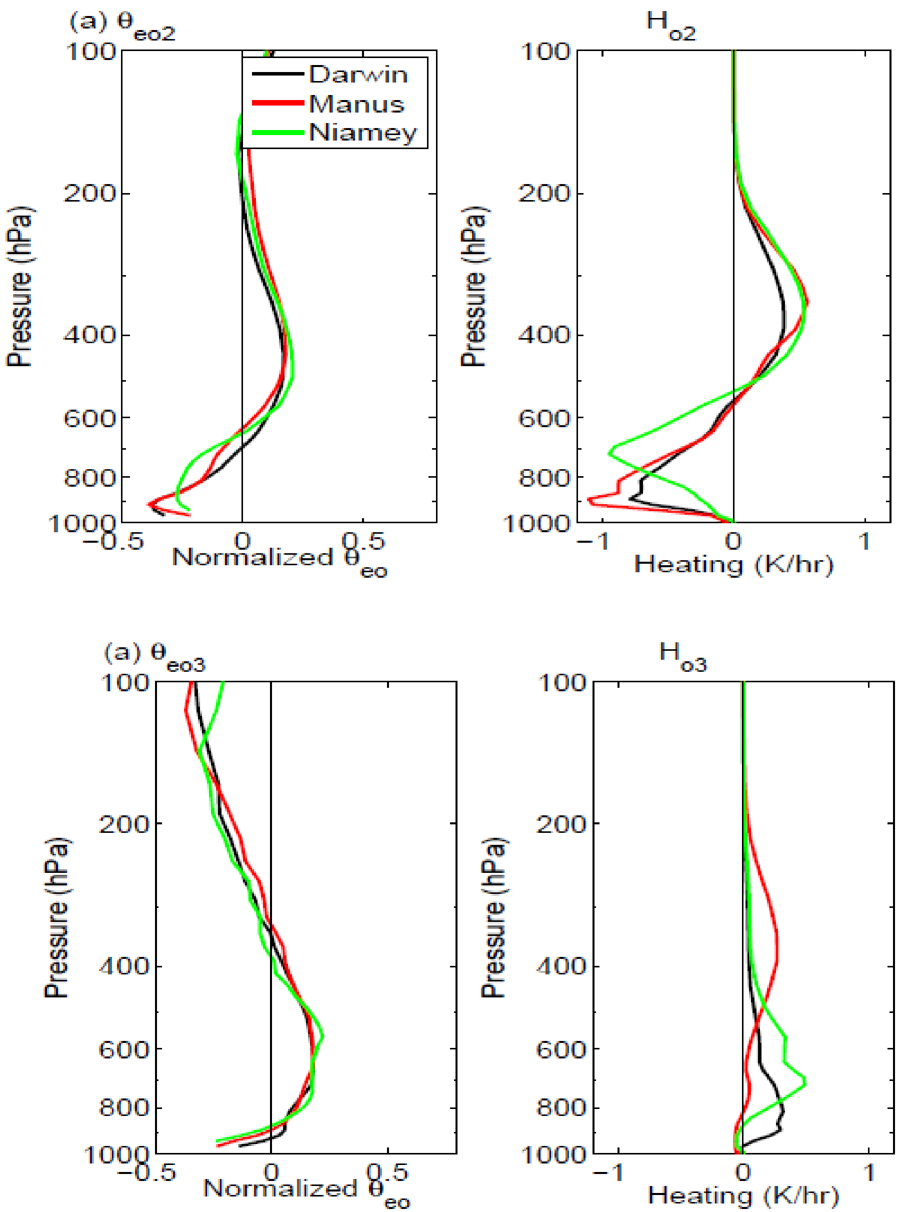
$$N_o = N \bullet G$$

$$N = N_o \bullet G^{-1}$$

$$H_{ls} = \theta_{els} \bullet \theta_{eo} \bullet G^{-1} \bullet H$$

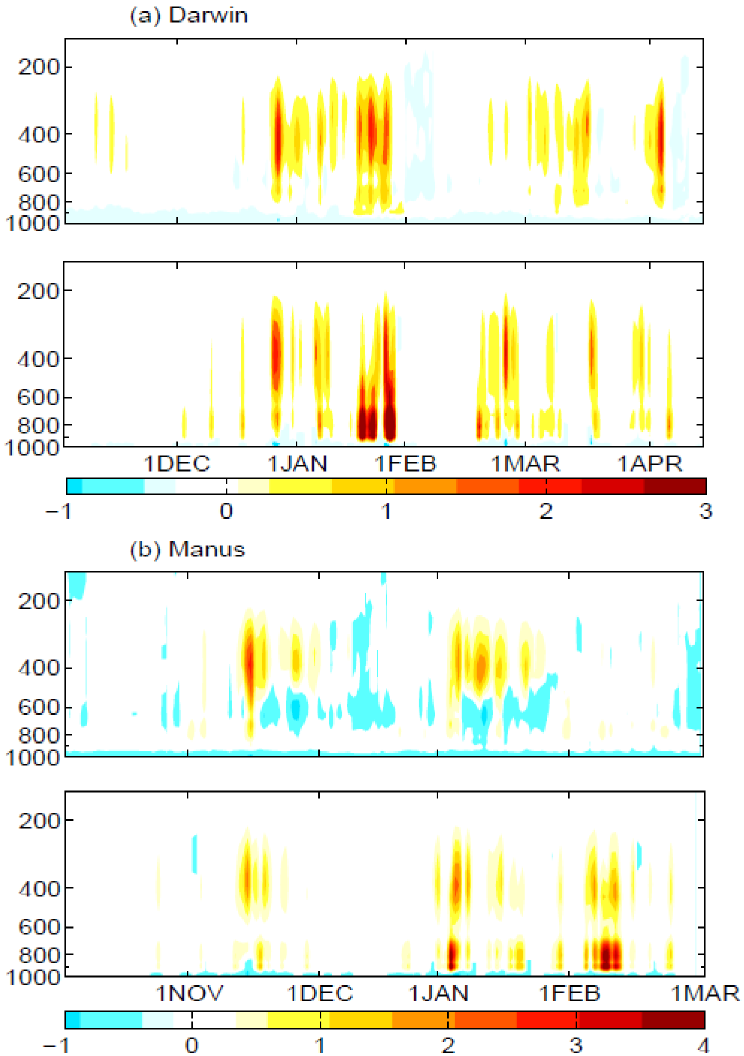
$$H_o = G^{-1} \bullet H$$

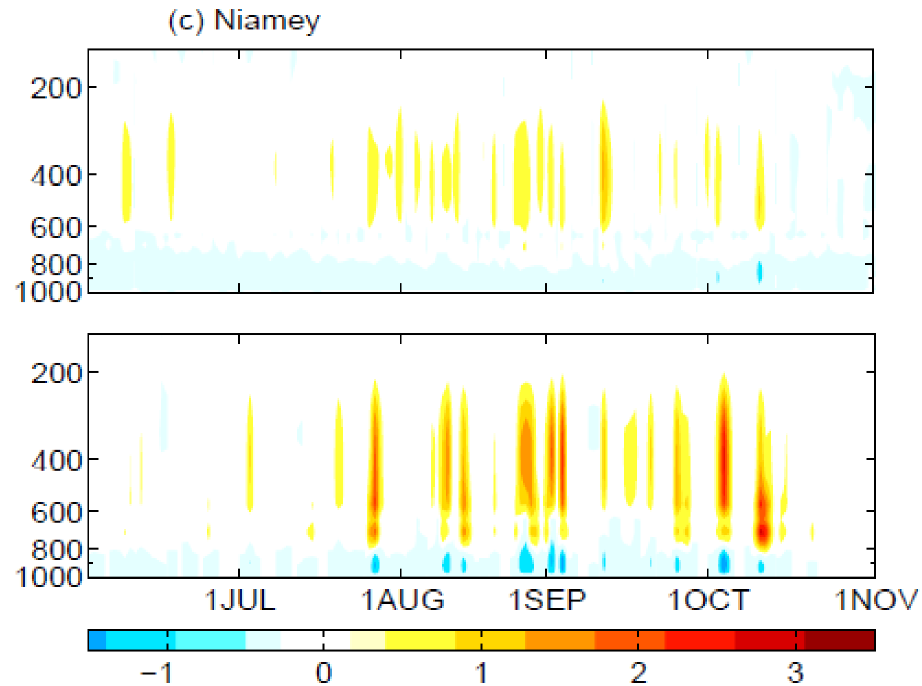
$$H_{ls} = (\theta_{els} \bullet \theta_{eo}) \bullet H_o$$



- ▶ The orthogonal set of equivalent potential temperature vectors and their corresponding heating vectors

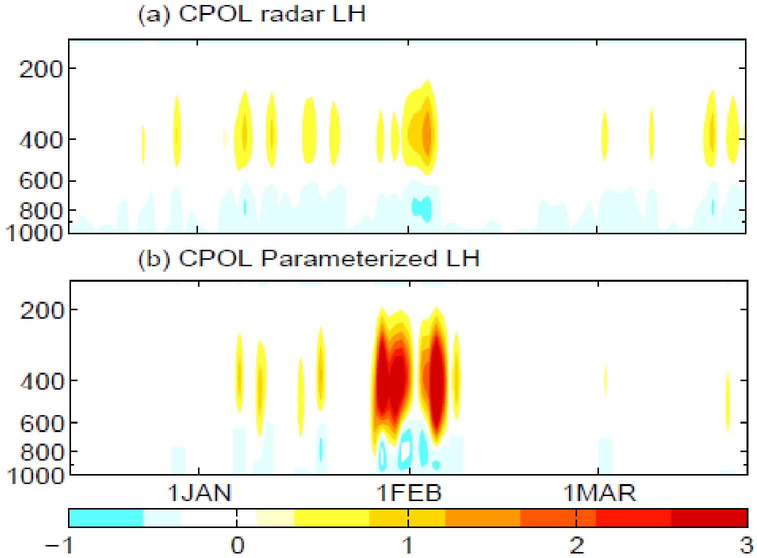
- If large scale equivalent potential temperature projects on to a component of θ_{eo}, the large scale heating has the same projection on the corresponding component of H_{σ}

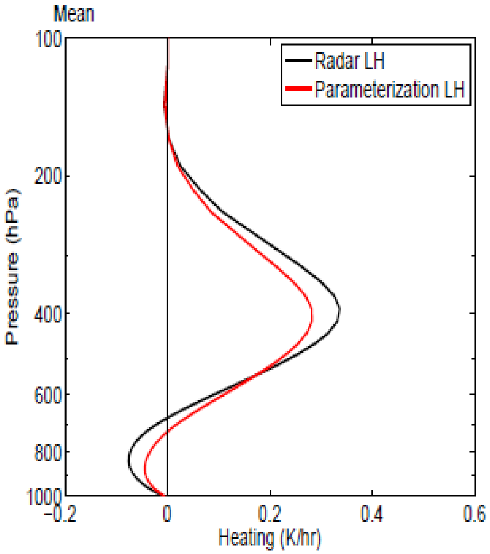




- Comparison of CRM heating (K/day) (top) with that derived from large scale equivalent potential temperature using the "physics" matrix P (bottom).

- The matrix does a reasonable job of representing heating variability.
- It overestimates shallow heating though.





- Comparison of Latent Heating derived radar observation (Top) with a parameterization using equivalent potential temperature from CPOL best-estimate (Bottom).
- Some of the variability is captured. Heating in early February overestimated.

Radar latent heating data provided by Courtney Schumacher.

Discussion

- In this talk some examples of using observational data and cloud resolving models in the evaluation and design of parameterizations of tropical convection are presented.
- Documenting observations of the various types of clouds and the environments that favor them is crucial for gaining better understanding of large scale environment-convection interaction and improving the parameterizations in low resolution regional and global models.
- By coordinated and creative utilization of the extensive amount of data expected from CINDY/DYNAMO/AMIE, major advance in understanding and modeling MJO is possible.