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

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

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.
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.
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:

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

\[
\frac{\partial q'}{\partial t} \approx \frac{q'}{\tau_{\text{vertical}}} + \frac{q'}{\tau_{\text{horizontal}}} + \frac{q'}{\tau_{\text{condensation}}}
\]

\[
\tau_{\text{effective}} = \frac{\tau_{\text{vertical}} \tau_{\text{horizontal}} \tau_{\text{condensation}}}{\tau_{\text{vertical}} + \tau_{\text{horizontal}} + \tau_{\text{condensation}}}
\]

\[
\frac{\partial q'}{\partial t} \approx \frac{q'}{\tau_{\text{effective}}}
\]
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.
c) Vector formulation of the convection – environment interaction problem

► **Model:** WRF V3.2 at 2km resolution. 2°x2° box.

► **Domains:**
  - 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.
Equivalent Potential Temperature:

- The model minimum potential temperature of convective environment is at least 10°K 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: $\theta_e \leftrightarrow H$

- 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.

\[ H = \begin{pmatrix} H_{cs} & H_s & H_d \end{pmatrix} \]

\[ \theta_e = \begin{pmatrix} \theta_{cs} & \theta_s & \theta_d \end{pmatrix} \]

\[ N = \begin{pmatrix} N_{cs} & N_s & N_d \end{pmatrix} \]

\[ H_{ls} = N \cdot H \]

\[ \theta_{els} = N \cdot \theta_e \]
Vector Formulation:

- The set of $\theta_e$ 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.

\[
\theta_e = G \cdot \theta_{eo} \\
\theta_{els} = N_o \cdot \theta_{eo} \\
N_o = \theta_{els} \cdot \theta_{eo} \\
N = N_o \cdot G^{-1} \\
H_{ls} = \theta_{els} \cdot \theta_{eo} \cdot G^{-1} \cdot H \\
H_o = G^{-1} \cdot H \\
H_{ls} = (\theta_{els} \cdot \theta_{eo}) \cdot H_o
\]
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 $\theta_{eo}$, the large scale heating has the same projection on the corresponding component of $H_o$. 
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.