Modeling Tropical Anvil Clouds and Their Roles in Tropospheric Humidification

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1. Introduction

- Anvil clouds extending from deep convective clouds likely play some role in the humidification of the troposphere in the Indian Ocean prior to onset of the Madden-Julian Oscillation (MJO).

- Anvil clouds also play an important role in upper-tropospheric radiative heating, which impacts the tropical general circulation[1].

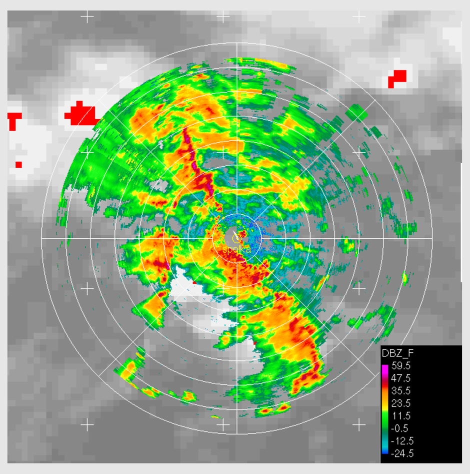
- We can model the impacts of anvil clouds on radiative heating and moistening processes by anchoring microphysics schemes to radar observations of precipitating and non-precipitating clouds[2].

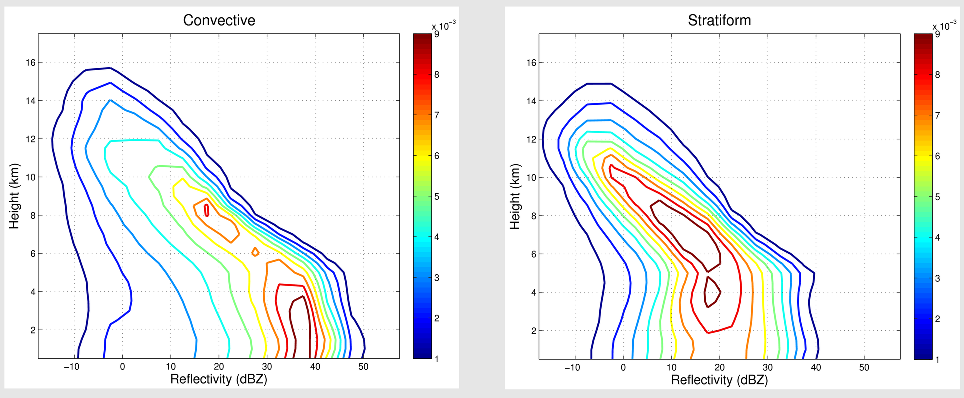
2. Radar Observations

a. S-PolKa

- 3-dimensional dataset collected by scanning precipitation radar (S-band) during DYNAMO details tropical maritime convection.

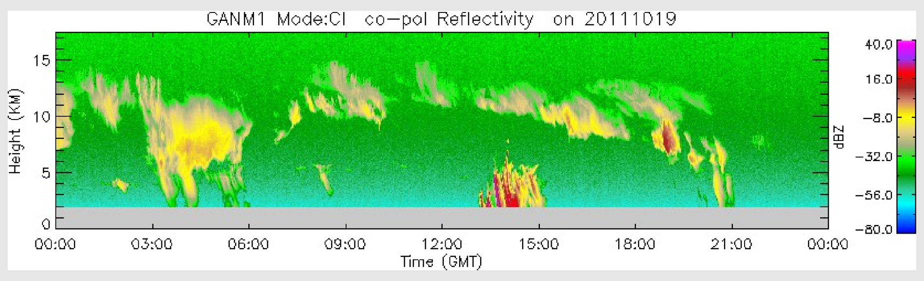
- Separation of cloud population into widespread, lightly precipitating stratiform clouds and deep convective cores yields information about the structure of each.



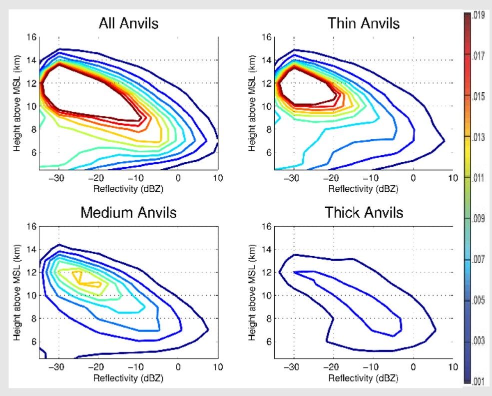


b. KAZR

- A Ka-band vertically pointing radar was located 9 km from S-Polka during the Atmospheric Radiation Measurement (ARM) Program's AMIE campaign. KAZR provides details observations of anvil cloud structure, while S-PolKa provides 3-dimensional observations of the environment in which such anvils occur.

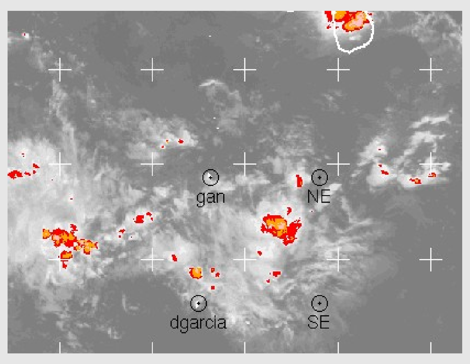


Contoured frequency by altitude diagrams (CFADs) showing reflectivity structure of anvils observed by KAZR. Anvils are categorized by thickness: thin anvils (<2 km), medium anvils (2-6 km), and thick anvils (>6 km).

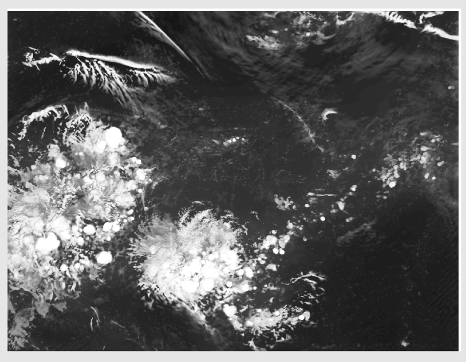


3. Comparisons of outgoing longwave radiation between modeled and observed maritime MCSs

METEOSAT IR

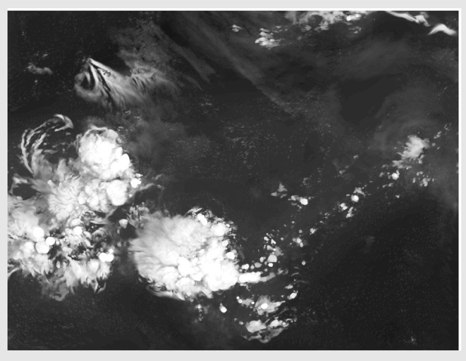


Goddard

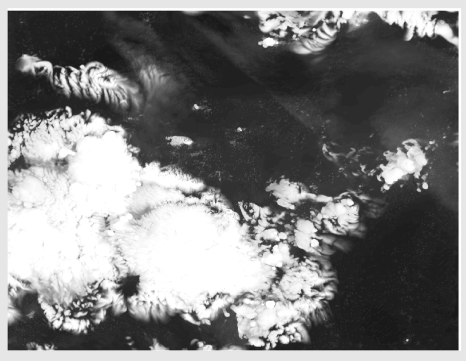


Morrison

Thompson



Milbrandt

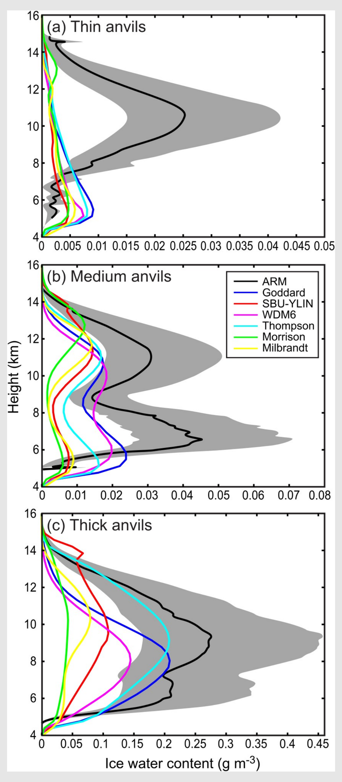


Model: WRF V3.3
- Radiation: RRTM (Longwave) and Dudhia (Shortwave)
- NCEP FNL Forcing every 6 hours
- Resolution: 3km with 630x630 grid points and 61 vertical levels
- Kain-Fritsch cumulus parameterization
- YSU PBL scheme
- Dates: 15 – 16 October, 2011
- Domain centered over Gan Island (0.7S, 73.15E)

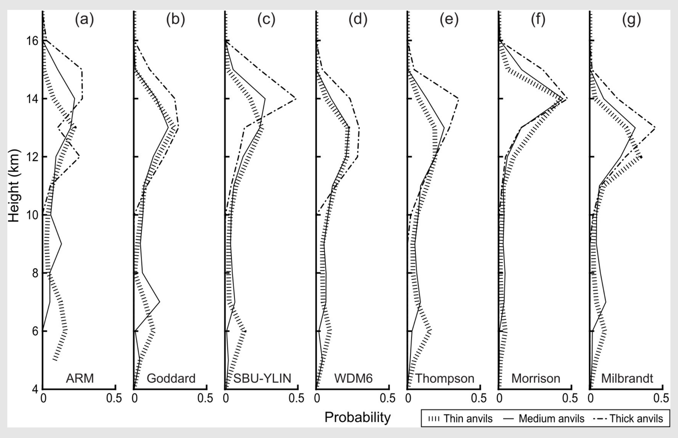
Observed and simulated OLR occurred at 15 October 2011, 1500 UTC.

4. Sensitivity of ice water content, cloud top height, and radiative heating to microphysics[2,#]

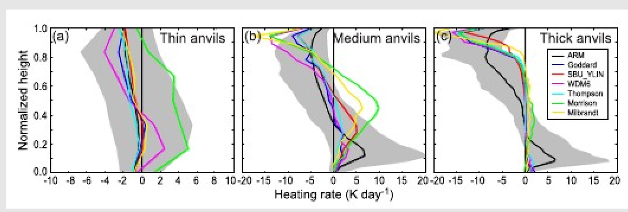
a. Ice Water Content*



b. Anvil-top height



c. Radiative Heating†



*Gray area represents rmse of observed ice water content estimate. Mean profiles shown.

#Results seen in this section are for continental clouds over west Africa. However, biases seen in simulated OLR for continental clouds are similar for each scheme as noted for maritime clouds.

†Gray area represents middle 80% of observed radiative heating rates. Median profiles shown.

- Ice water content (IWC) and radiative heating rates (black with gray shading) are derived from ARM radar observations.

- Ice present in anvils underestimated or spread over too large an area.

- Anvil-top heights are mostly comparable; although, Morrison anvils extend higher than those observed.

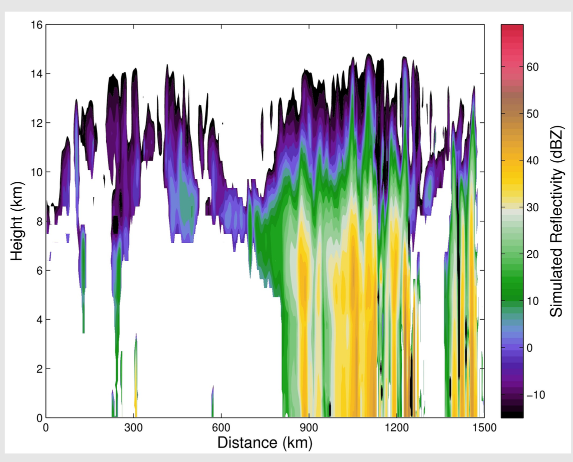
- Heating profiles demonstrate strong cooling near cloud top and strong warming near cloud base. Simulated thick anvils, however, lack warming near cloud base.

5. Simulating reflectivity with SDSU[3]

A radar simulator offers a way to compare model data to radar observations.

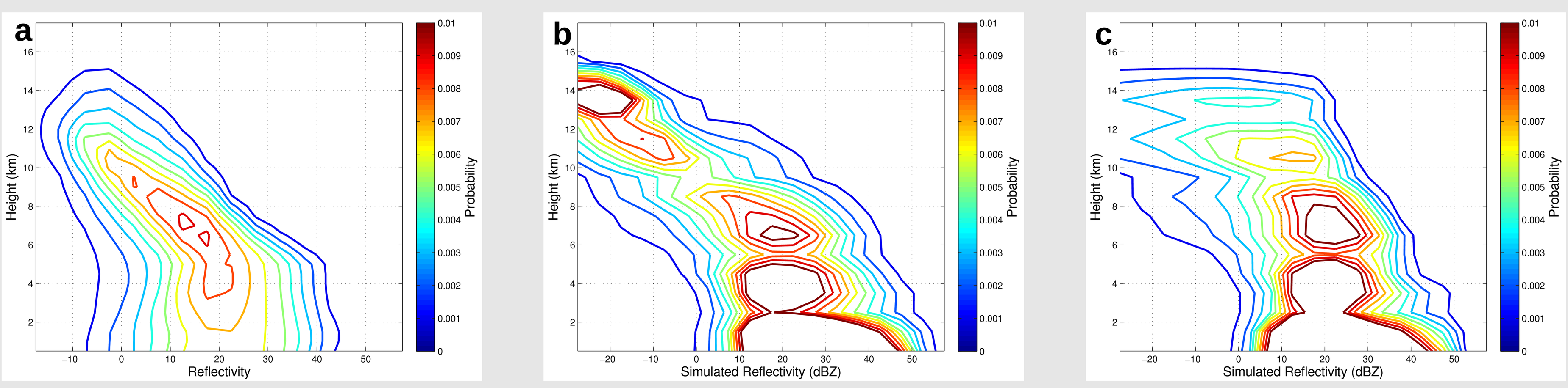
The UW Satellite Data Simulator Unit (SDSU[3]) package is among, if not the first to match the particle size distributions in two-moment microphysics schemes to the assumed particle size distribution in the radar simulator.

SDSU simulates reflectivity that would be observed by a radar aboard a satellite. Since millimeter wavelength radar beams are highly attenuated by water, one cannot compare ground-based radar estimates to SDSU. However, S-band precipitating radar is not attenuated heavily by the atmosphere or liquid water, and we can roughly compare the ground-based S-band observations to a simulated reflectivity of a non-existent space-borne S-band radar.

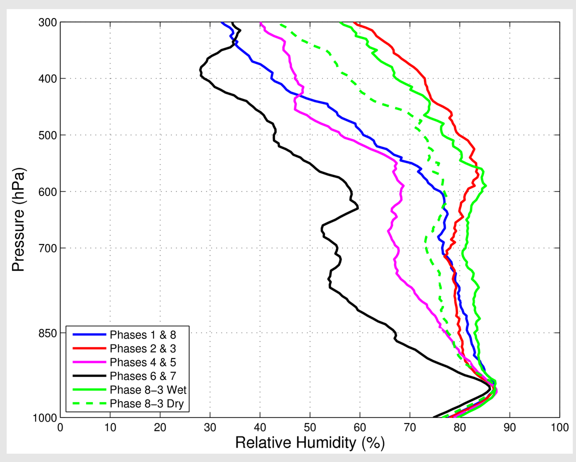


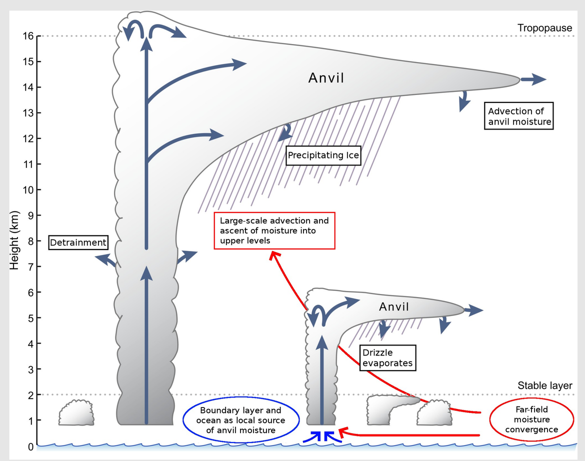
Top-Right: Reflectivity cross-section using Morrison microphysics: 16 October 2011, 0000 UTC

Bottom: a) CFADs of reflectivity for precipitating clouds observed by S-PolKa throughout DYNAMO. *b)* and *c)* CFADs for clouds simulated using *b)* Morrison and *c)* Thompson microphysics for 16 October 2011 in a domain described in Section 3. Note that S-PolKa rarely observed clouds below -15dBZ.



6. Toward exploring the roles of anvil clouds in tropospheric humidification





- Observational evidence shows that 1) column-averaged tropospheric humidity changes significantly at a single location during the period of one MJO, and 2) widespread stratiform precipitation and anvils occur before humidification is observed through a deep layer during the active MJO phases.

- Detrainment, advection, and precipitation all play some role in transport of water from clouds to the environment; however, the relative importance of each process must be determined.

- Ongoing and future modeling studies will determine the relative importance of local and far-field moisture sources that support clouds that act as agents to moisten the troposphere.

7. References

[1]Schumacher, C., R. A. Houze, Jr., and I. Kraucunas, 2004: The tropical dynamical response to latent heating estimates derived from the TRMM precipitation radar. *J. Atmos. Sci.*, **61**, 1341-1358.
[2]Powell, S.W., R. A. Houze, Jr., A. Kumar, and S. A. McFarlane, 2012: Comparison of simulated and observed continental tropical anvil clouds and their radiative heating profiles. *J. Atmos. Sci.*, in press.
[3]Masunaga, H., and Coauthors, 2010: Satellite Data Simulator Unit: A multisensor, multispectral satellite simulator package. *Bull. Amer. Meteor. Soc.*, **91**, 1625-1632.