

Evolution in Cloud Population Statistics of the MJO: From AMIE Field Observations to Global Cloud-Permitting Models

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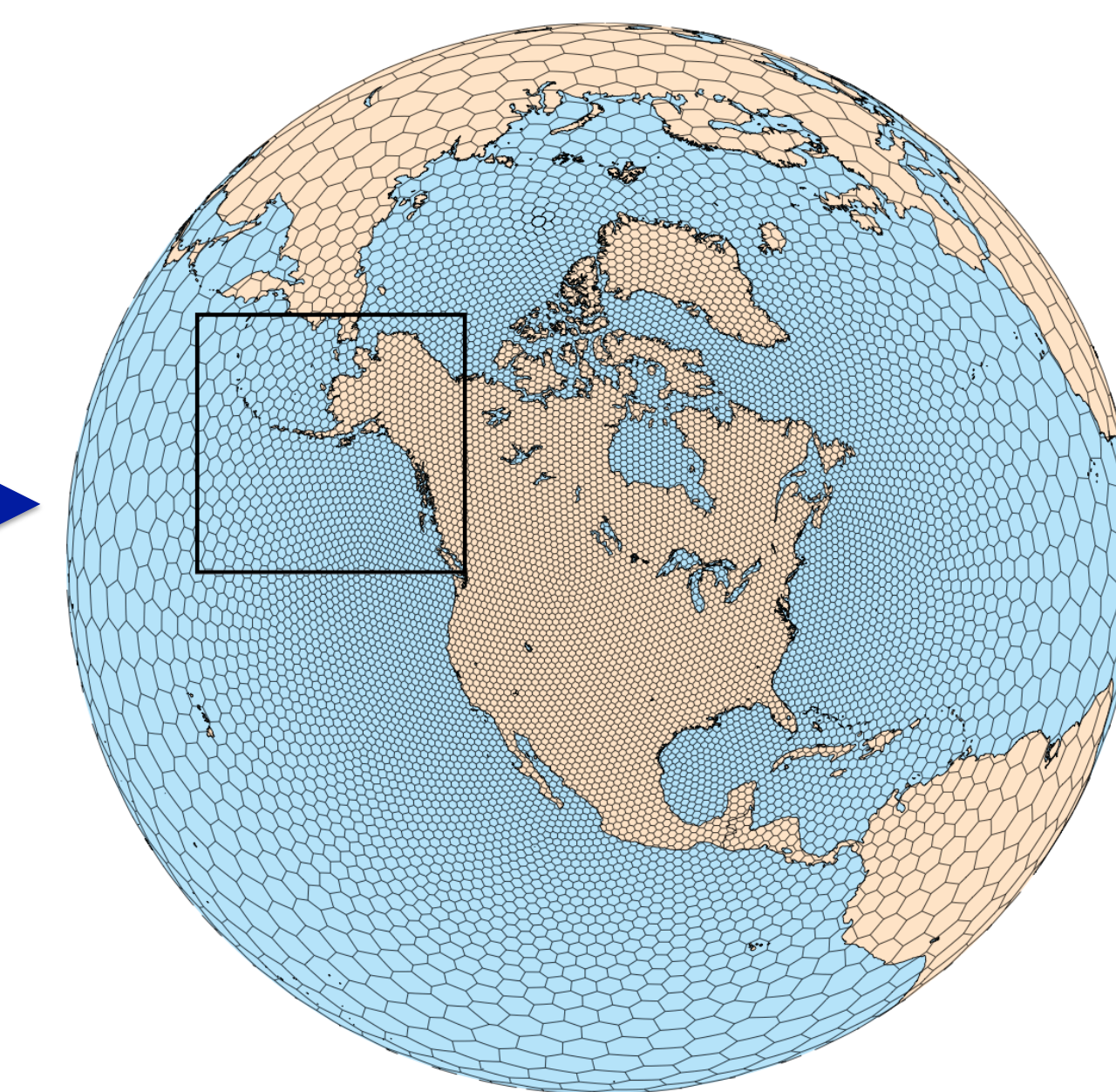
AMIE (ARM MJO Investigation Experiment)/DYNAMO (Dynamics of the MJO) field campaign: International field observations of cloud population evolution and its large-scale environment collected by advanced instruments on multiple platforms from a region crucial to global climate but poor in *in situ* observations.

Issues: How should field observations of detailed cloud structure and evolution in a limited area be applied to benefit the development of global models with explicit and parameterized cumulus convection?

Strategy: Use a three-tier modeling approach to bridge field observations and global cloud-permitting models, with emphases on cloud population structural evolution through various large-scale environments.

Step 1: Data preparation – Combine observations from different instrument to cover the entire cloud spectrum, and derive cloud statistics for model validation;
Step 2: Cloud resolving or permitting model (CRM/CPM) simulations – strongly constrained by observations, flexible in microphysics, direct comparison to observations in vertical structures of cloud and microphysics;
Step 3: Limited area model (LAM) simulations – weakly constrained by observations, flexible in microphysics and cumulus representations (explicit or parameterized), indirect comparison to observations in statistics of cloud and microphysics;
Step 4: CRM/CPM and LAM simulations – constrained by output from global cloud-permitting model simulations.

Anticipated outcome: Identify sensitivity of model biases in cloud and precipitation to microphysics and cumulus parameterization with and without feedbacks from large-scale dynamics.



MPAS (The Model for Prediction Across Scales): Nonhydrostatic atmosphere model based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement, with explicit and parameterized mesoscale convective systems

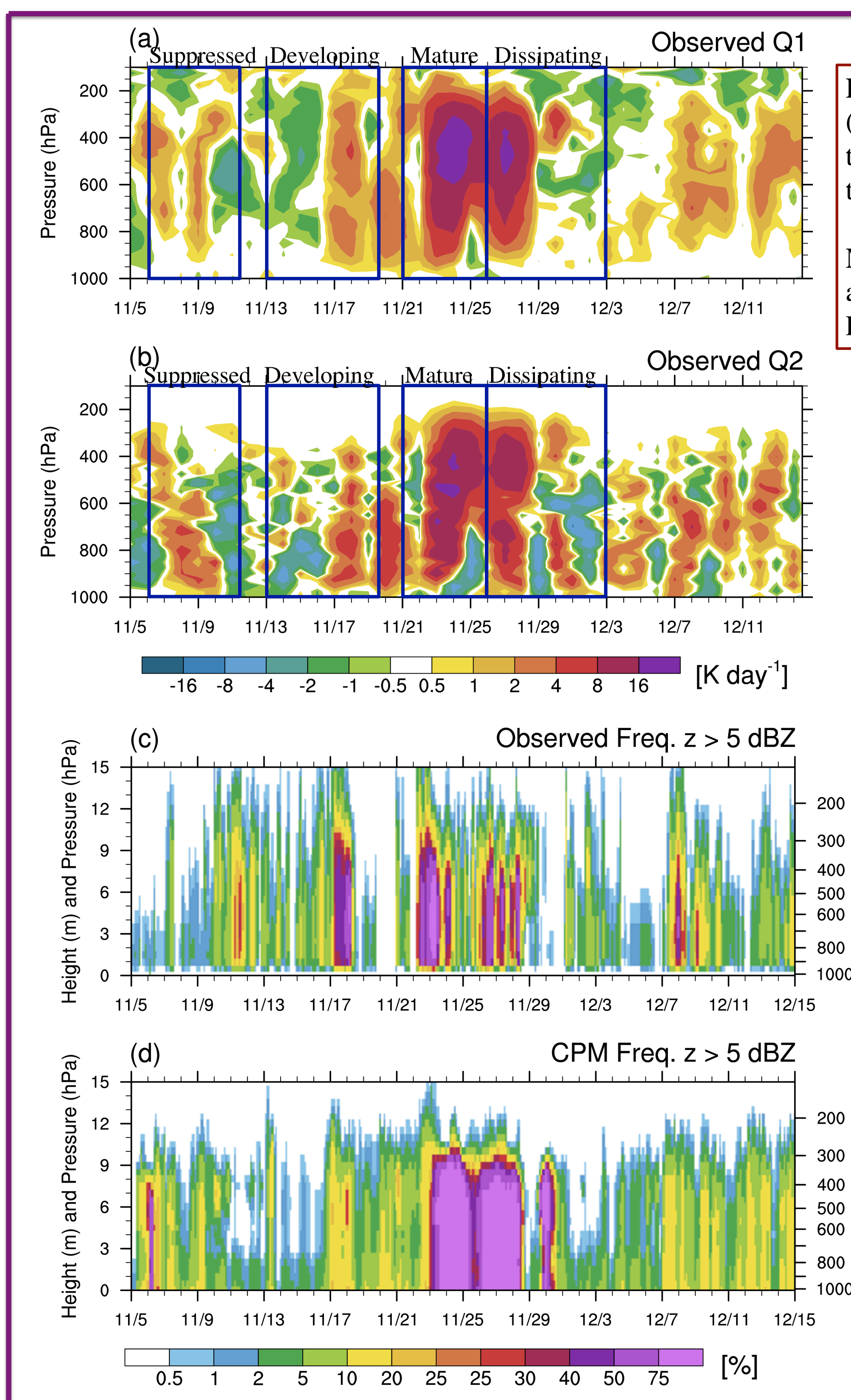


Figure 1 Time series of vertical profiles of observed (a) diabatic heating source (Q1), (b) moisture sink (Q2), and frequency (%) of reflectivity ≥ 5 dBZ from (c) the S-POL radar and (d) the CPM (SAM) for the November 2011 MJO during the AMIE/DYNAMO field campaign.

Message: With strong observational constraints, the CPM is able to produce Q1 and Q2 (not shown) and the bulk features of the observed cloud evolution. Errors are, however, apparent in cloud vertical structures.

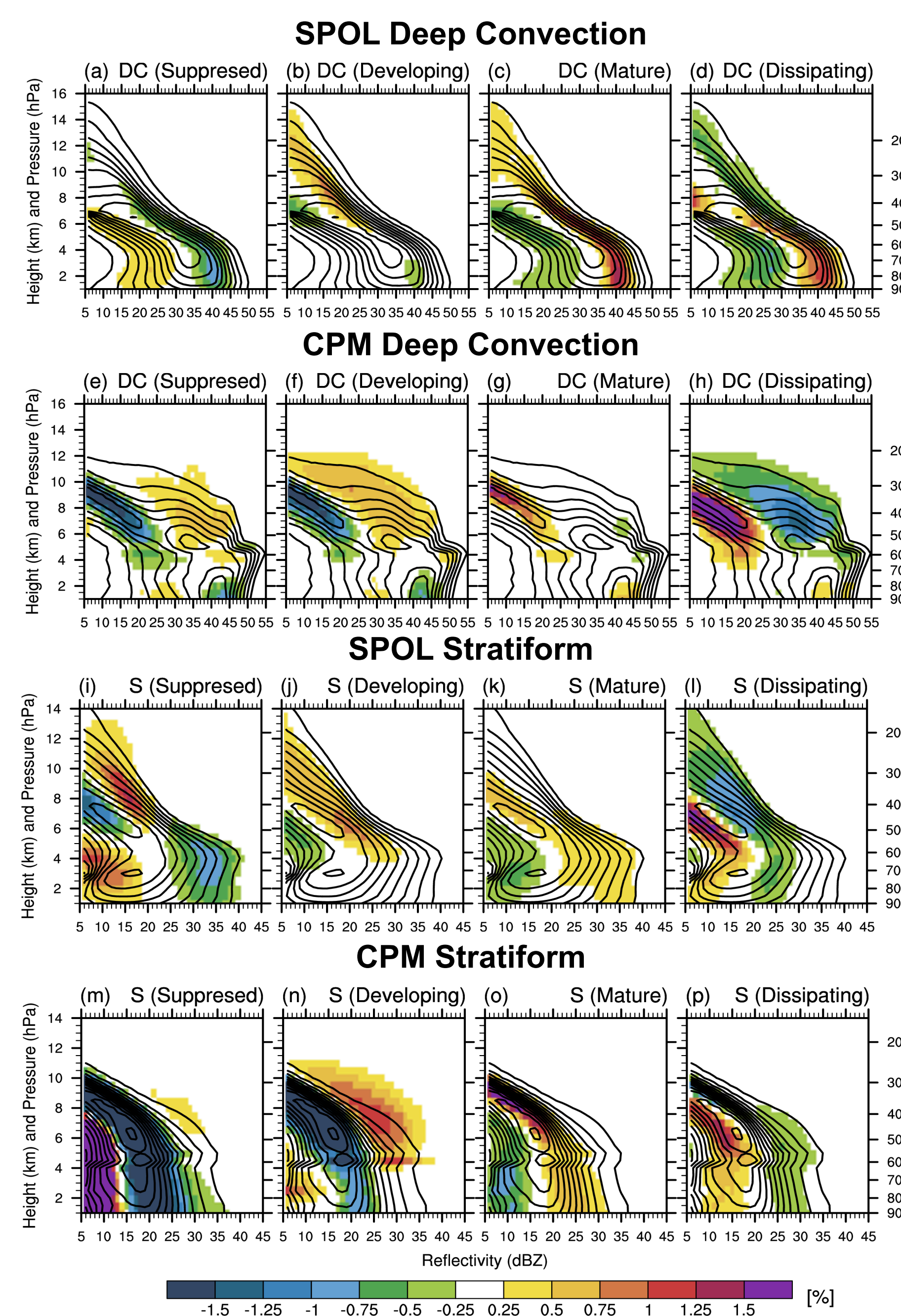


Figure 3 Frequency of reflectivity occurrence for the entire November MJO event (contoured every 0.5%) and its deviations relative to the entire event (shaded) from the S-POL radar and CPM (SAM) in each period: (column 1) suppressed, (column 2) developing, (column 3) mature, (column 4) dissipating, which are marked in Fig. 1.

Message: The CPM can reproduce the overall growth and intensification of convection through the life cycle of the MJO, but show apparent discrepancies from the observations.

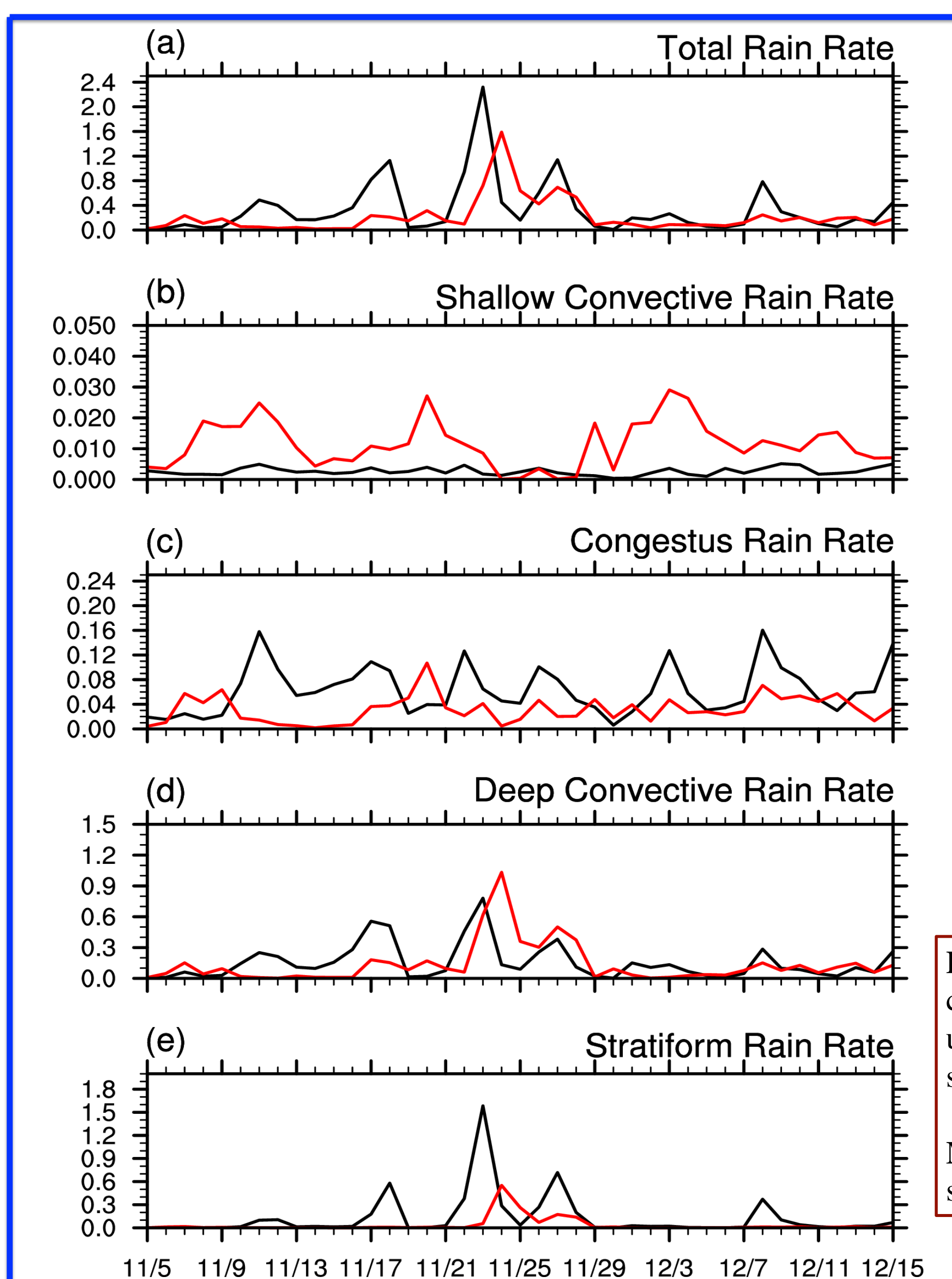


Figure 2 Time series of (a) total, (b) shallow convective (echo top < 6 km), (c) congestus (6 – 8 km), (d) deep convective (> 8 km), and (e) stratiform unconditional rain rate (mm hr^{-1}) estimated by the S-POL radar (black) and simulated by the CPM (red).

Message: The CPM overestimates shallow convective rain and underestimates stratiform rain; the errors are from the microphysics.

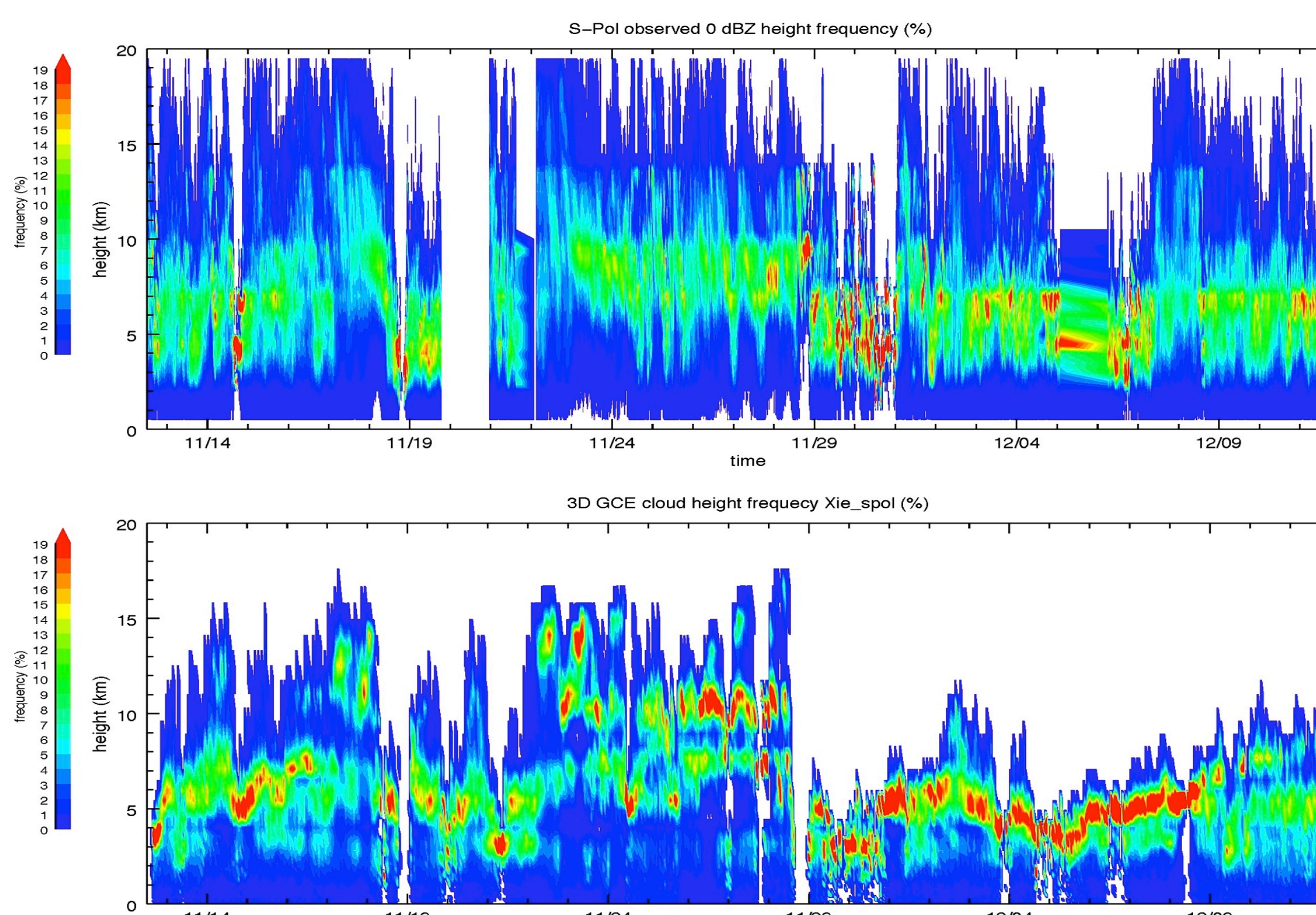


Figure 4 Time series of vertical profiles of observed (by S-Pol, upper panel) and simulated (by GCE CPM, lower) cloud echo (0 dBZ) top height frequency for the November 2011 MJO during the AMIE field campaign.

Message: With strong observational constraint, the CPM can reproduce the overall cloud structural evolution through the life cycle of the MJO, but overestimates anvil cloud during the convective active period.

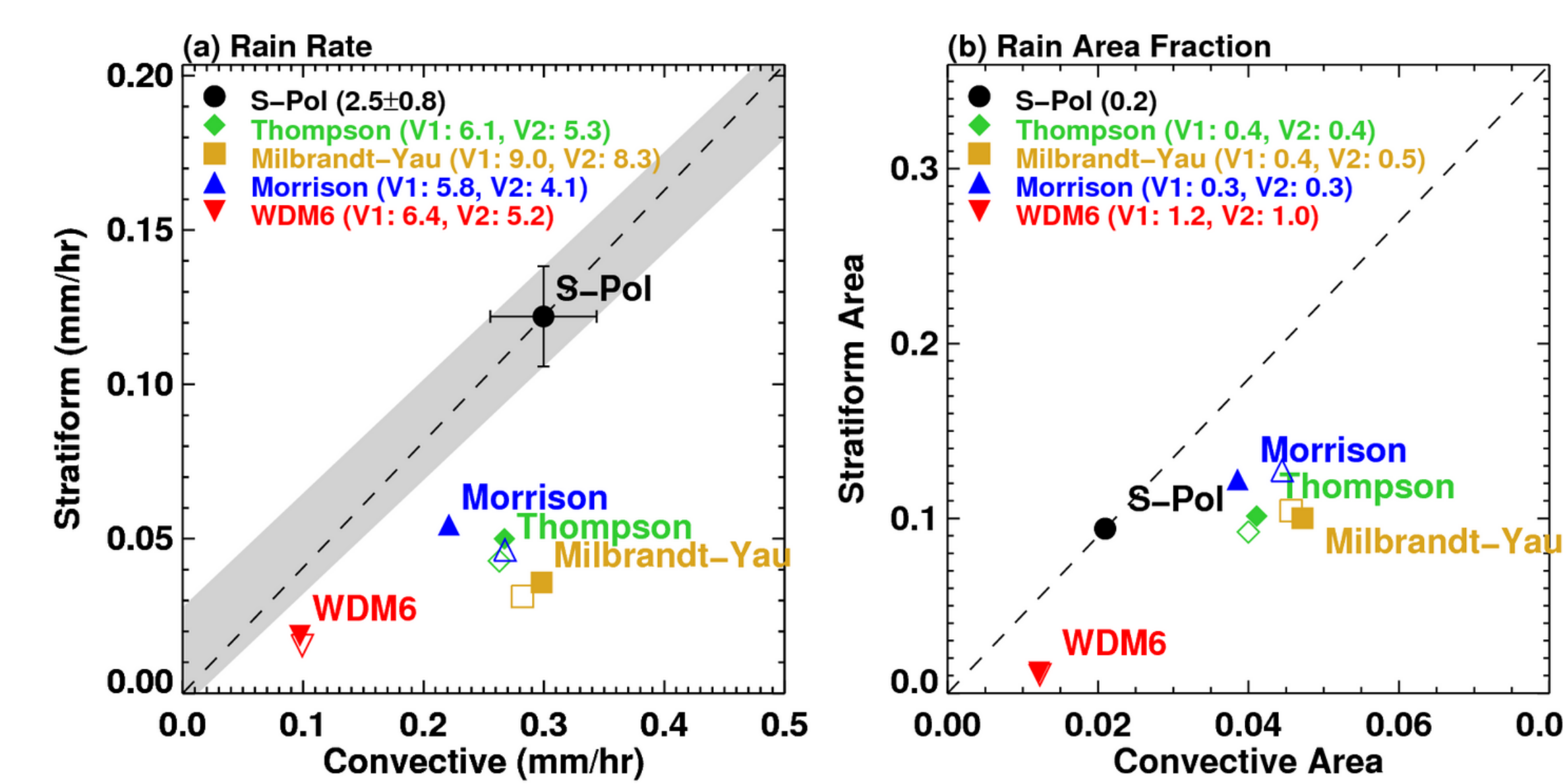


Figure 5 Convective/Stratiform rain rate (a) and rain area fraction (b) measure by the S-Pol radar and simulated by WRF (6.5S-5N, 65-89E, Nov 1-30, 2011) using four 2-moment microphysics schemes with default (open symbols) and enhanced (solid) rain drop breakups.

Message: All microphysics schemes underestimate the observed stratiform rain rate and hence overestimate the observed convective/stratiform rainfall ratio; Enhanced rain droplet breakup reduced this bias.

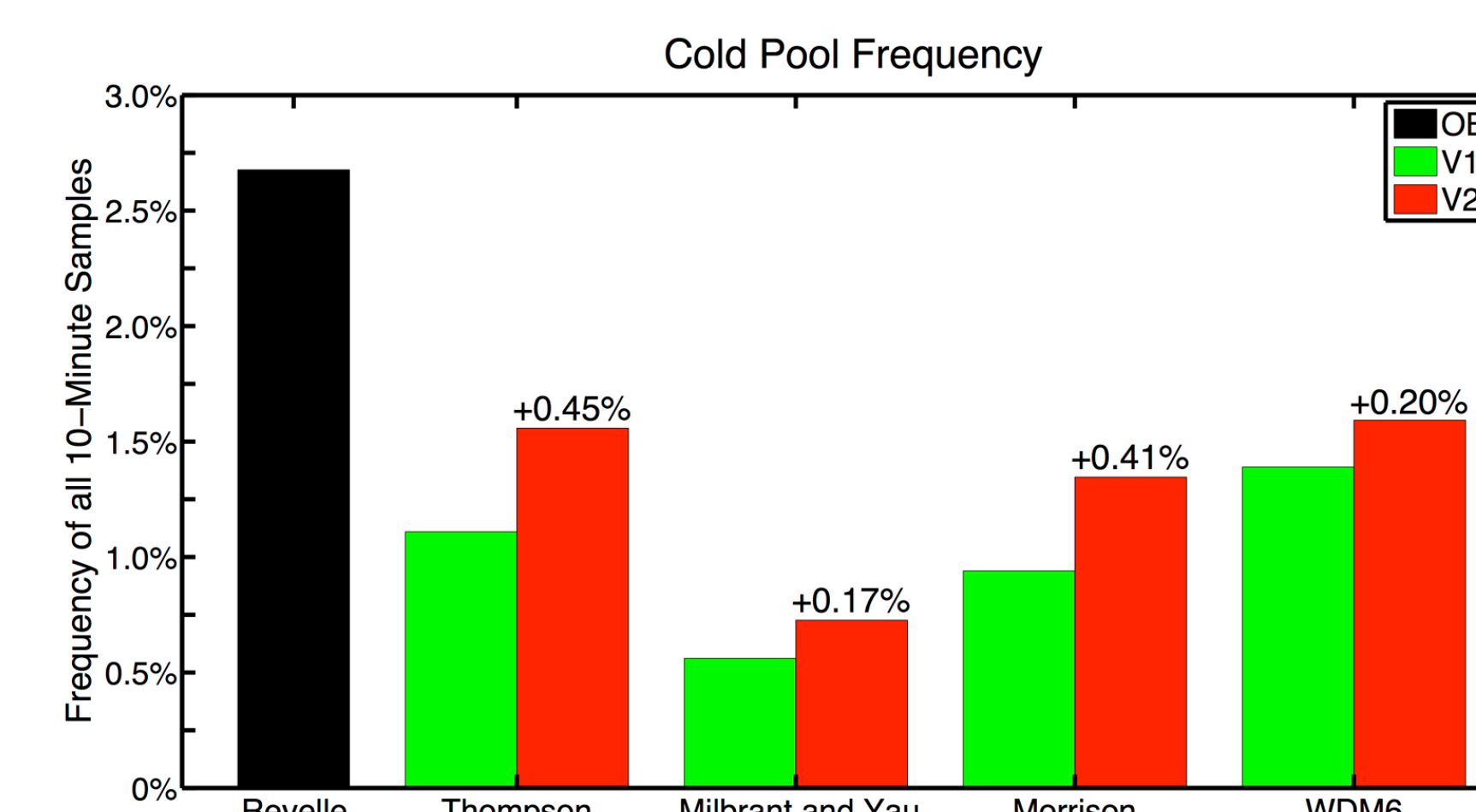


Figure 6 Frequency of observed (at R/V Revelle) and simulated (by WRF) cold pools using all microphysics schemes with default (green) and enhanced (red) droplet breakup.

Message: Smaller droplets enhance evaporative cooling and downdraft frequency, hence more cold pools.

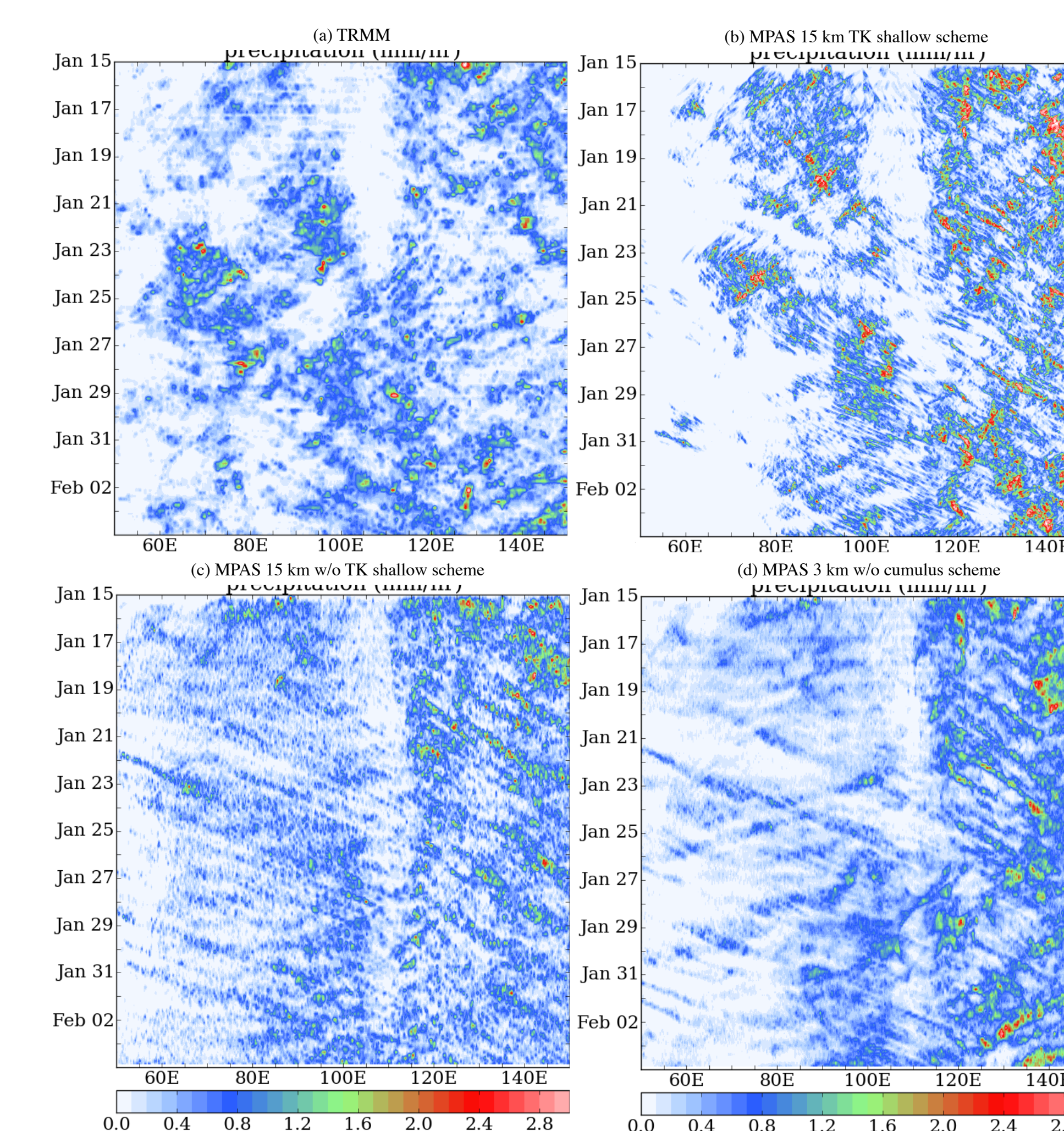


Figure 7 Time-longitude diagrams of precipitation (mm/hr) from (a) TRMM, and MPAS simulations with (b) 15 km grid spacing and Tiedtke (TK) shallow cumulus scheme, (c) 15 km grid spacing without Tiedtke (TK) shallow cumulus scheme, and (d) 3 km grid spacing without cumulus scheme for January 15 – February 4, 2009.

Message: Shallow convection plays a critical role in simulating MJO precipitation in this case. This role is well reproduced by the TK shallow scheme but is not by microphysics in MPAS (WSM6).

Conclusions:

1. The AMIE/DYNAMO field campaign provides excellent observations of cloud structure and its evolution through the entire cycle of MJO initiation that can be used for detailed CRM/CPM validation using radar simulators.
2. With strong observational constraints, CRM/CPM simulations can reproduce the bulk feature of the observed cloud evolution, but differ from the observations in many details, such as shallow and stratiform clouds. These model errors come mainly from microphysics schemes.
3. The deficiency in current microphysics schemes is also evident in MPAS, especially in its capability of reproducing shallow convective clouds, which affect its reproduction of the MJO.
4. Targeted improvement of microphysics can be identified and tested using LAM with weak observational constraints before implemented in MPAS.
5. The procedure of targeting detailed cloud structural evolution through the MJO life cycle in model validation and targeting microphysics in model improvement is the main approach to bridge field observations and development of global cloud-permitting models.

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