Evolution of Precipitation Structure During the November DYNAMO MJO Event: Cloud-Resolving Model Intercomparison and Cross Validation Using Radar Observations

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Introduction

- 2 approaches for the limited area cloud-resolving simulations (usually with horizontal resolution of less than 4 km):
  - Use CRMs in the forecast mode, where time-variant large-scale influences come from lateral boundaries.
  - Use the observed large-scale forcing and apply it uniformly in the model domain with cyclic lateral boundary conditions.
  - Wang et al. (2016) demonstrated important roles of horizontal advection of moisture and radiative feedback in driving the MJO in their WRF simulations with parameterized large-scale dynamics. The technique guarantees accurate simulations of domain-mean moisture budget and surface precipitation.

Introductions: 3 goals in this paper

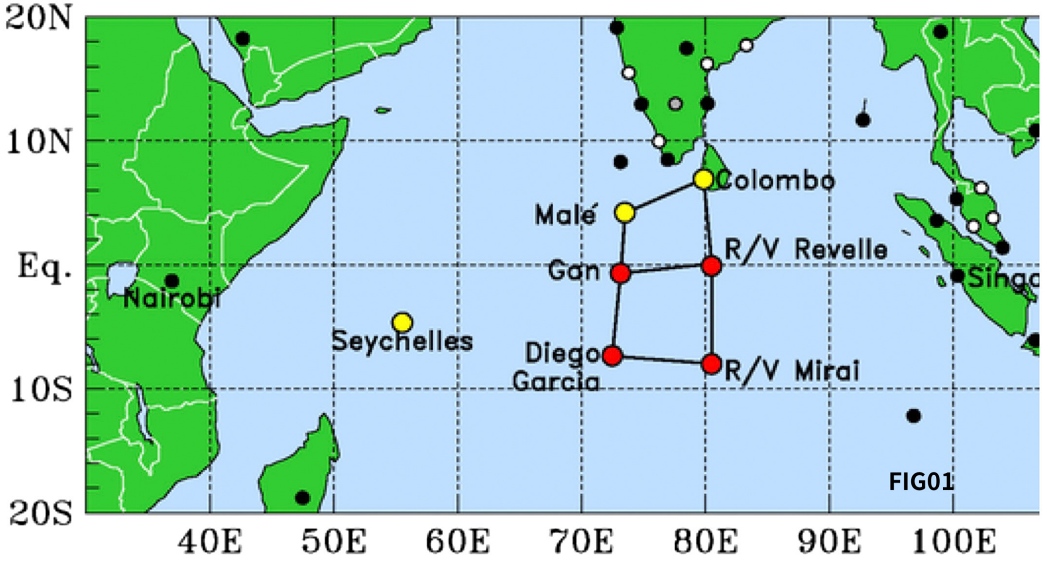
- Find out if, and to what extent, a CRM is able to simulate subtle differences in precipitation evolution of the same MJO event observed by radars at different locations with different sampling sizes. (S-PolKa / C-band / TRMM PR)

- Quantify differences in simulated cloud structure and their variability during an MJO event resulting from using different CRMs and different model configurations.

- Cross-compare simulations by different CRMs to observations from different DYNAMO radars.

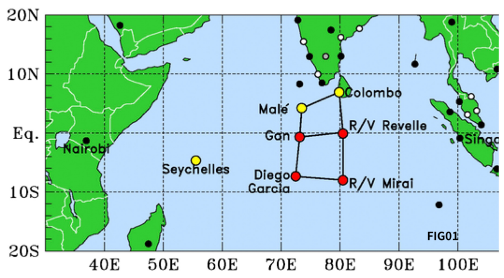
Observations

- DYNAMO: radars
  - Addu Atoll, Gan: S-Pol (λ=10cm)
  - R/V Revelle: TOGA C-band (λ= 5cm)
  - Resolutions: 2.0km[x&y] and 0.5km [z]
- Spaceborne radars:
  - TRMM PR 2A25: Ku-band (λ= 2cm)
  - TRMM 3B42
- Sounding : NSA (northern sounding array)



https://www.flickr.com/photos/armgov/6501854573/in/album-72157626175484558/ https://radarmet.atmos.colostate.edu/dynamo/

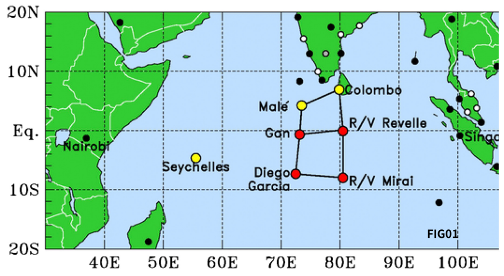
Large-scale forcing



- 3 large-scale forcing data sets derived by two research groups independently using different methods are used to drive CRMs. (NSA / SPol / C-band)

- NSA forcing:
  - It was derived using objective budget analyses (Ciesielski et al., 2014; Johnson et al., 2015).
  - Use 4 soundings to derive water vapor and momentum tendencies. Surface rainfall was derived from the water vapor budget. The temporal resolution is 4 times daily.
  - Advantage: large spatial coverage (7*7 degree) and representative of the mean budget characteristics during the DYNAMO November MJO event.

Large-scale forcing



- Addu (Spol) and Revelle (C-band):
  - They were derived by the Lawrence Livermore National Laboratory, using variational analysis (Xie et al., 2010; Zhang et al., 2001; Zhang & Lin, 1997).
  - The variational analysis uses domain-average surface and top-of-the-atmosphere radiation, surface fluxes, and precipitation as constraints to adjust atmospheric state variables from sounding profiles by the smallest possible amount to conserve column-integrated mass, moisture, and static energy.
  - Surface precipitation amount uses radar-retrieved surface rainfall from the SUR scans.

Models

Table 1
Summary of CRM Simulations' Setup and Model Parameters

Model	Equations	Microphysics	Radiation	Surface fluxes	Subgrid mixing	Forcing	Domain (km)	$\Delta x, \Delta y, \Delta z$ (km)
SAM	Anelastic	Morrison	RRTM	Calculated with SST	Smagorinsky	NSA	256 × 256 × 30	1, 1, 0.25
WRF	Compressible	Morrison	RRTMG (shortwave) Goddard (longwave)	Calculated with SST	Smagorinsky	NSA	256 × 256 × 30	1, 1, 0.25
GCE	Anelastic	Morrison or Goddard 3-ICE	Goddard	Prescribed with Observation	Prognostic TKE	NSA Addu Revelle	256 × 256 × 30 or 1,024 × 1,024 × 30	1, 1, 0.25 or 1, 1, 0.5

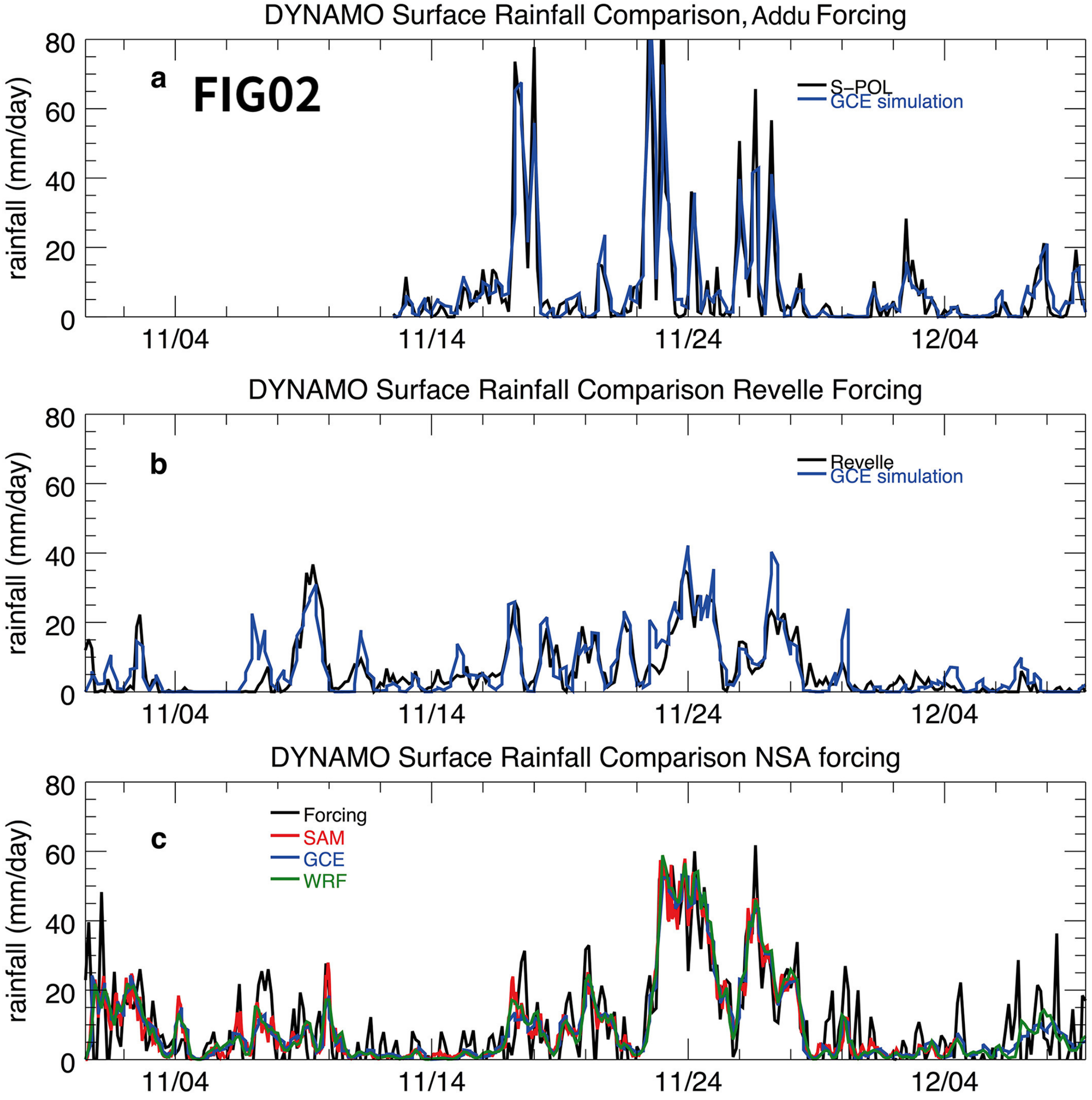
Note. CRM = cloud-resolving model; SAM = System for Atmospheric Modeling; WRF = Weather Research and Forecasting; GCE = Goddard Cumulus Ensemble; NSA = northern sounding array; RRTM = Rapid Radiative Transfer Model; RRTMG = RRTM GCM; SST = Sea Surface Temperature; TKE = Turbulence Kinetic Energy.

- All 3 models are driven by the same large-scale forcing (NSA), which includes advection of moisture and temperature, as well as domain mean horizontal winds. They use the same domain size, grid spacing, and start at the same time.
- Inter-comparison: 256 ╳ 256 ╳ 106 grids, dx=1km, dz=0.25km
- Sensitivity (GCE only): varying domain size and vertical spacing.
- Observations (radar frequency), location (model using radar-specific LSF.)

GCE and radar observations: (0) general

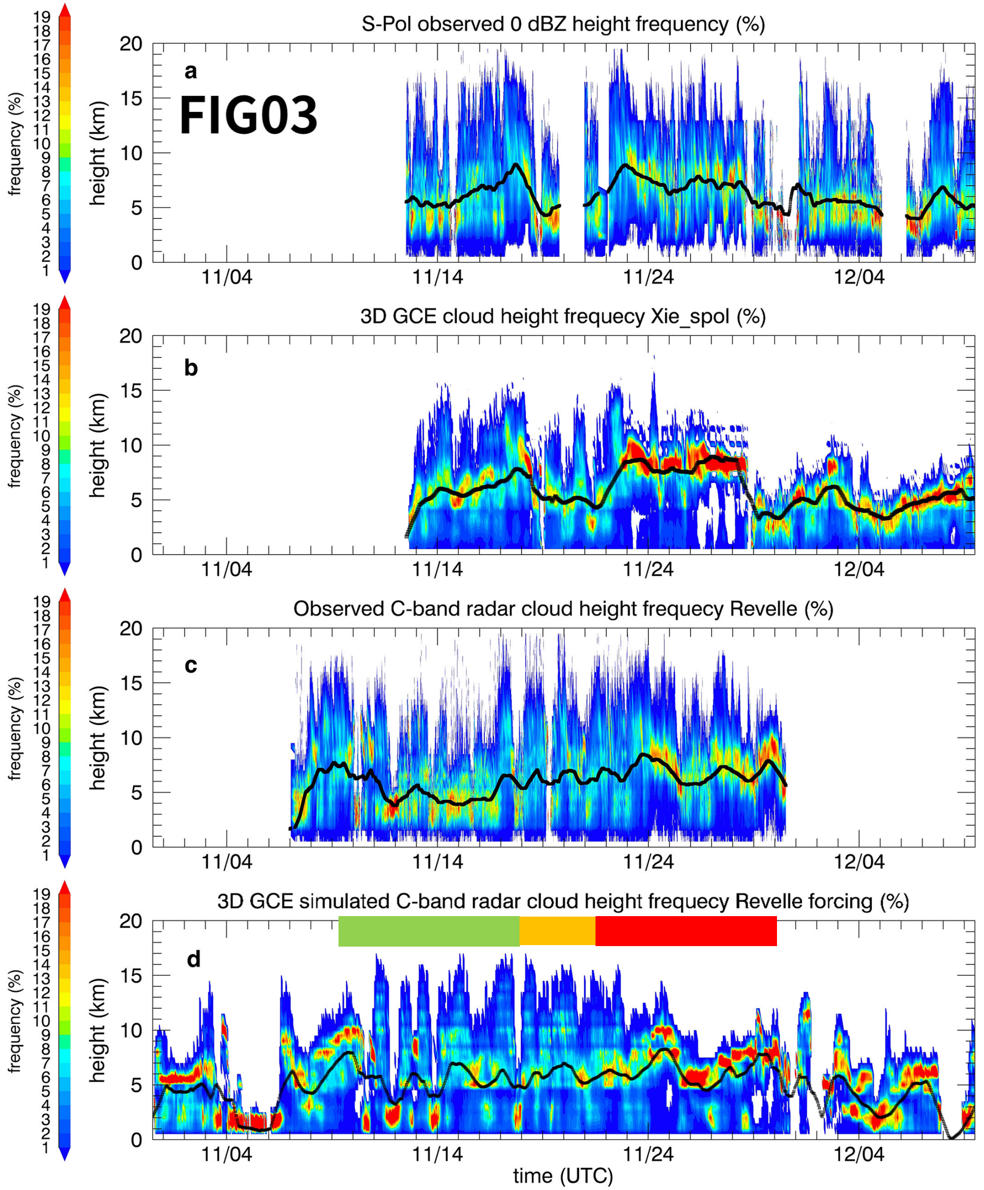
- Apple-to-apple comparison: use a forward radar simulator (Matsui et al., 2009, 2013) to derive reflectivity from model.
  - Rayleigh approximation: S-band.
  - Mie scattering: C- and Ku band.
- They have a domain size of 256 km *256km. dx=1 km,dz=0.5 km. Single-moment Goddard 3-ICE scheme.
- Horizontal dimension:
  - Convective/stratiform separation, and precipitation feature size.
- Vertical dimension:
  - 0-dbZ echo top height.

GCE and radar observations: (1) surface rainfall



- GCE models agree with each other.
- C-band rainfall peak lags S-band and NSA by about 20 hr. (location of Revelle)
- Given the differences in surface rainfall observed at different locations, and ground-based radar's limited spatial coverage, it would be optimal to use location specific large-scale forcing, as in this study, to ensure accurate model and observation comparisons.

GCE and radar observations: (2) vertical structure



- Contour: frequencies of 0-dbZ echo-top height occurrences.
- Black line: median frequencies of 0-dbZ echo-top height occurrences. (24hr running mean)
- Both: transition from mixed with low clouds (10-22 Nov), to deep convection (22-29 Nov)
- The temporal variations are more gradual in C-band radar.
- Radar observation have larger variability (mature phase).
- GCE rarely produce the strongest convections (echo top height >15km)

GCE and radar observations: (3) horizontal structure

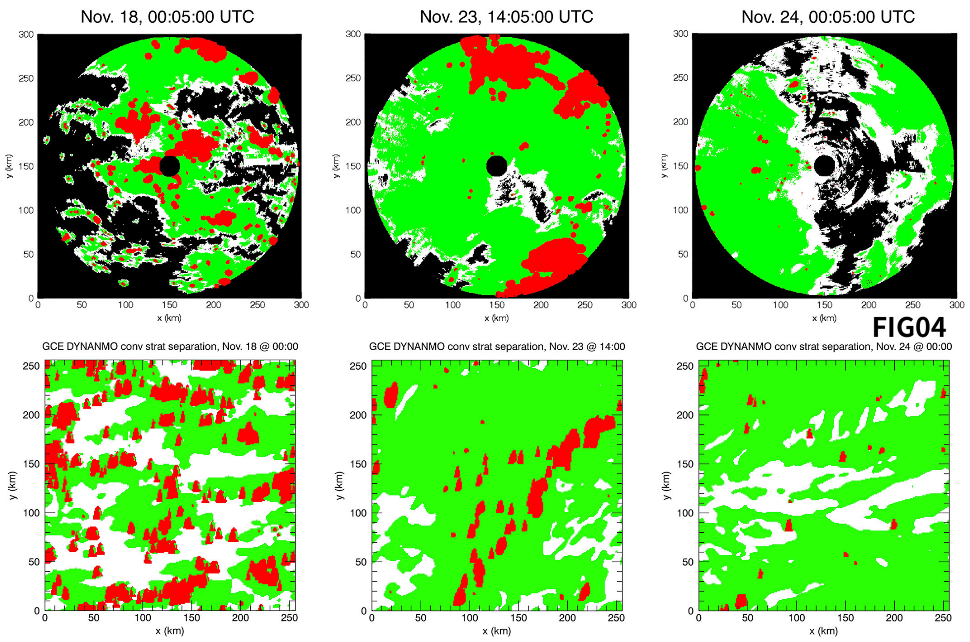
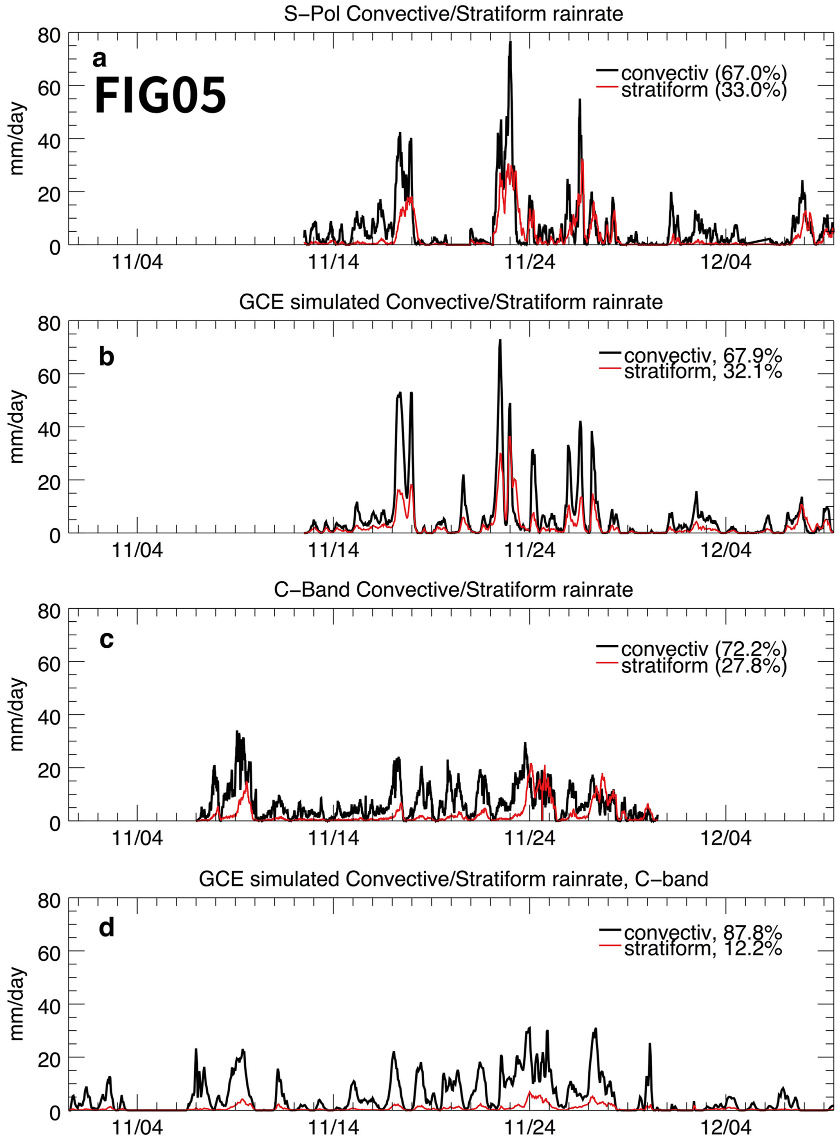
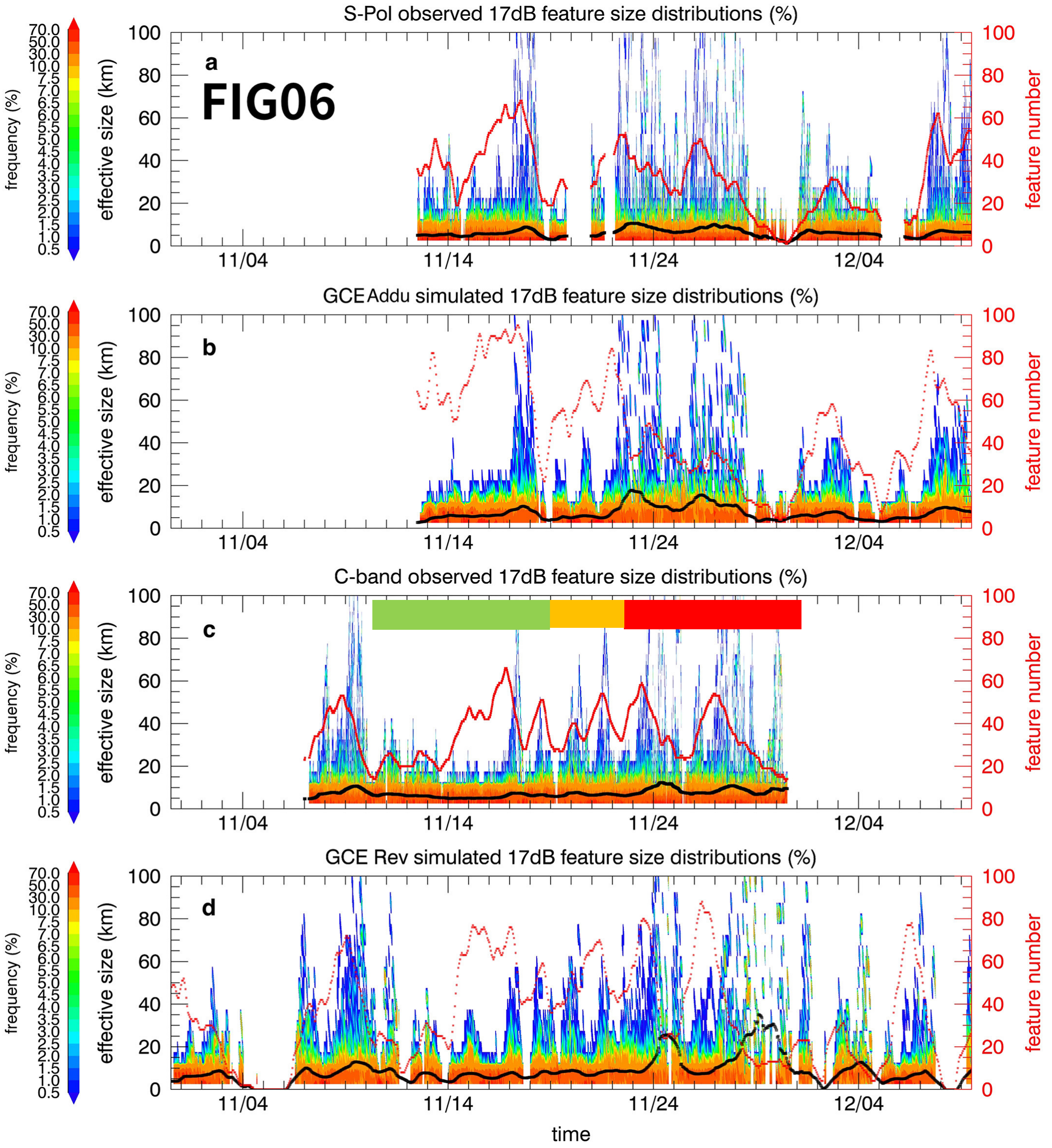


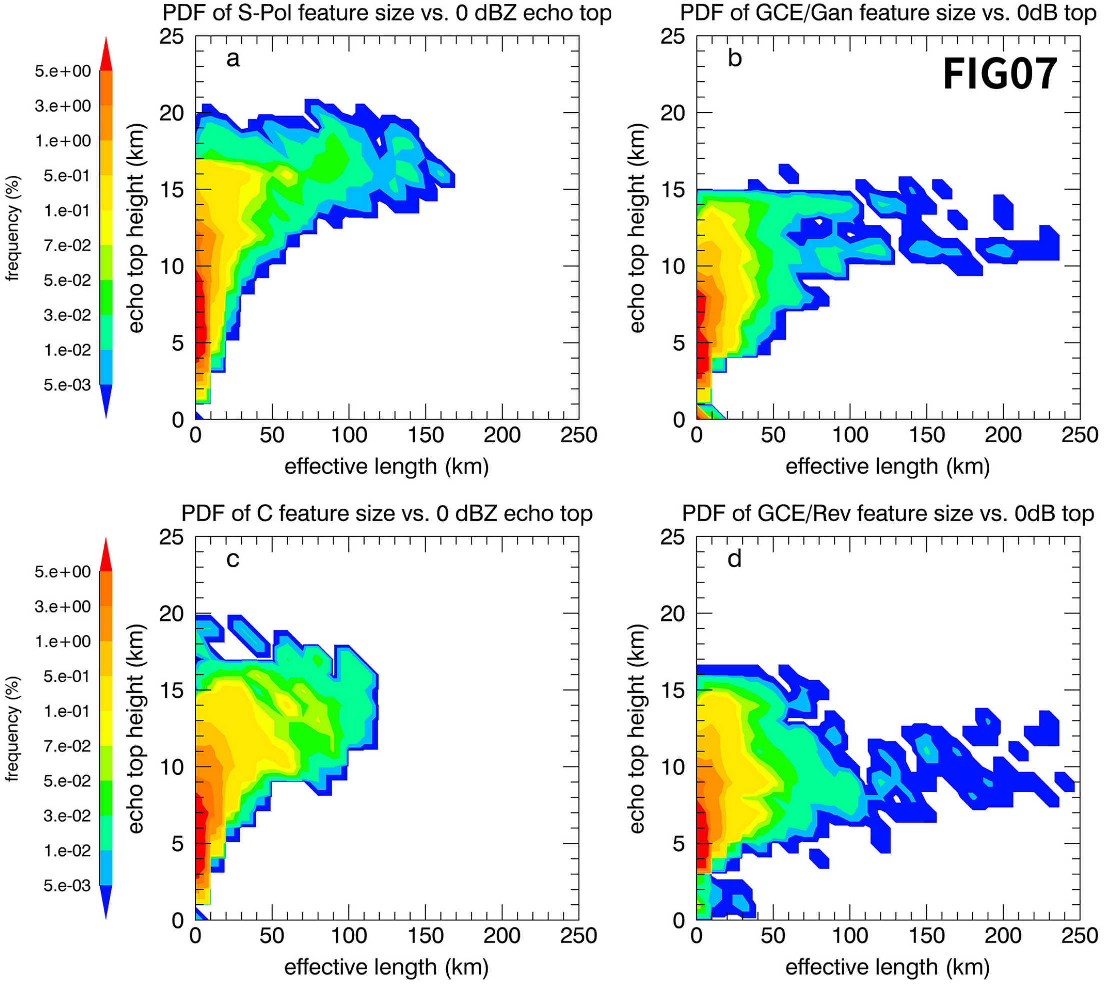
FIG04



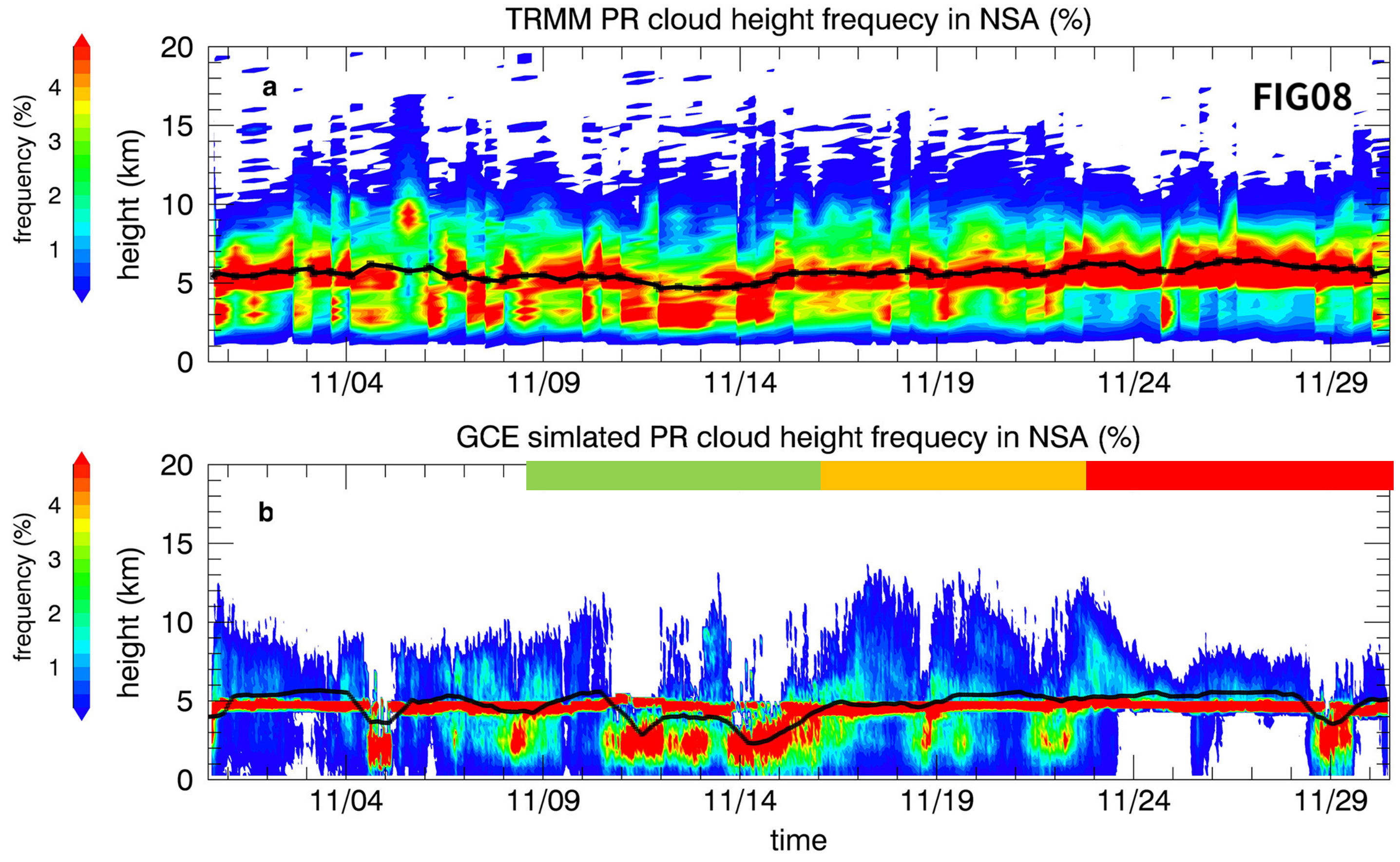
- Steiner et al. (1995)
- Green: stratiform area
- Red: convective area

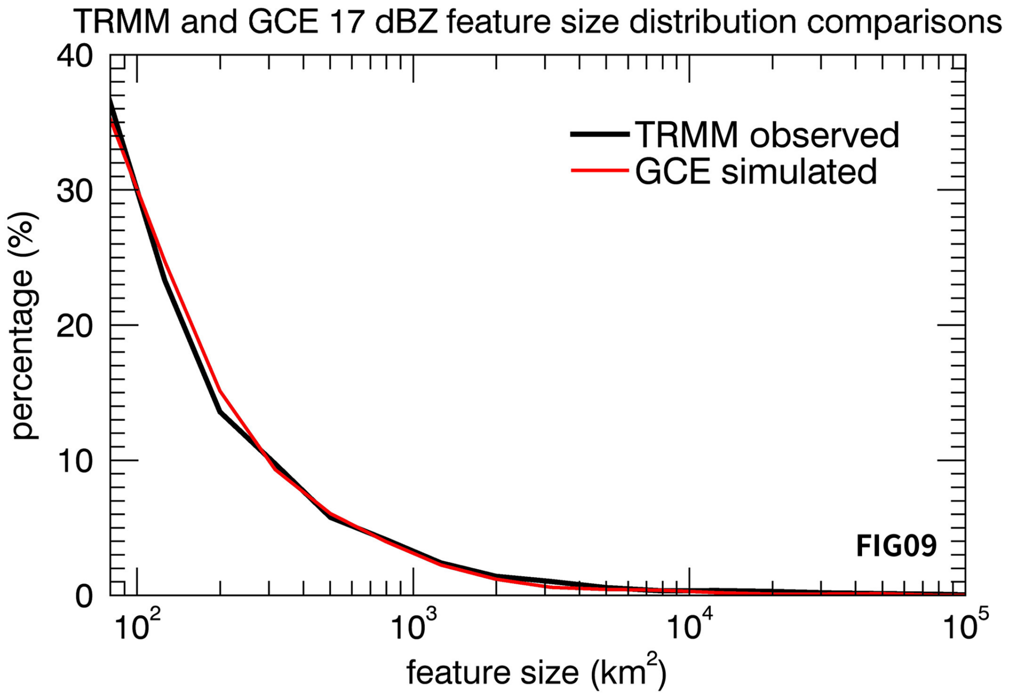
GCE and radar observations: (3) horizontal structure



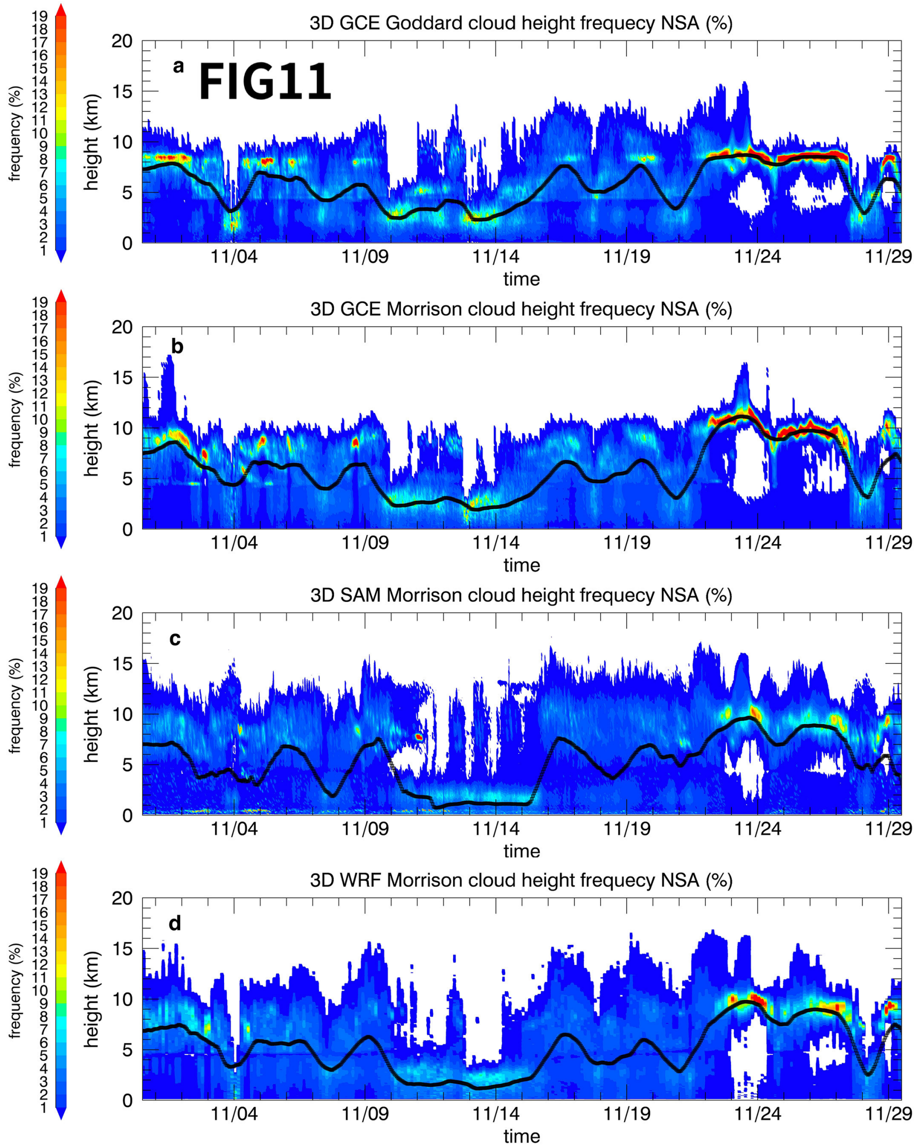


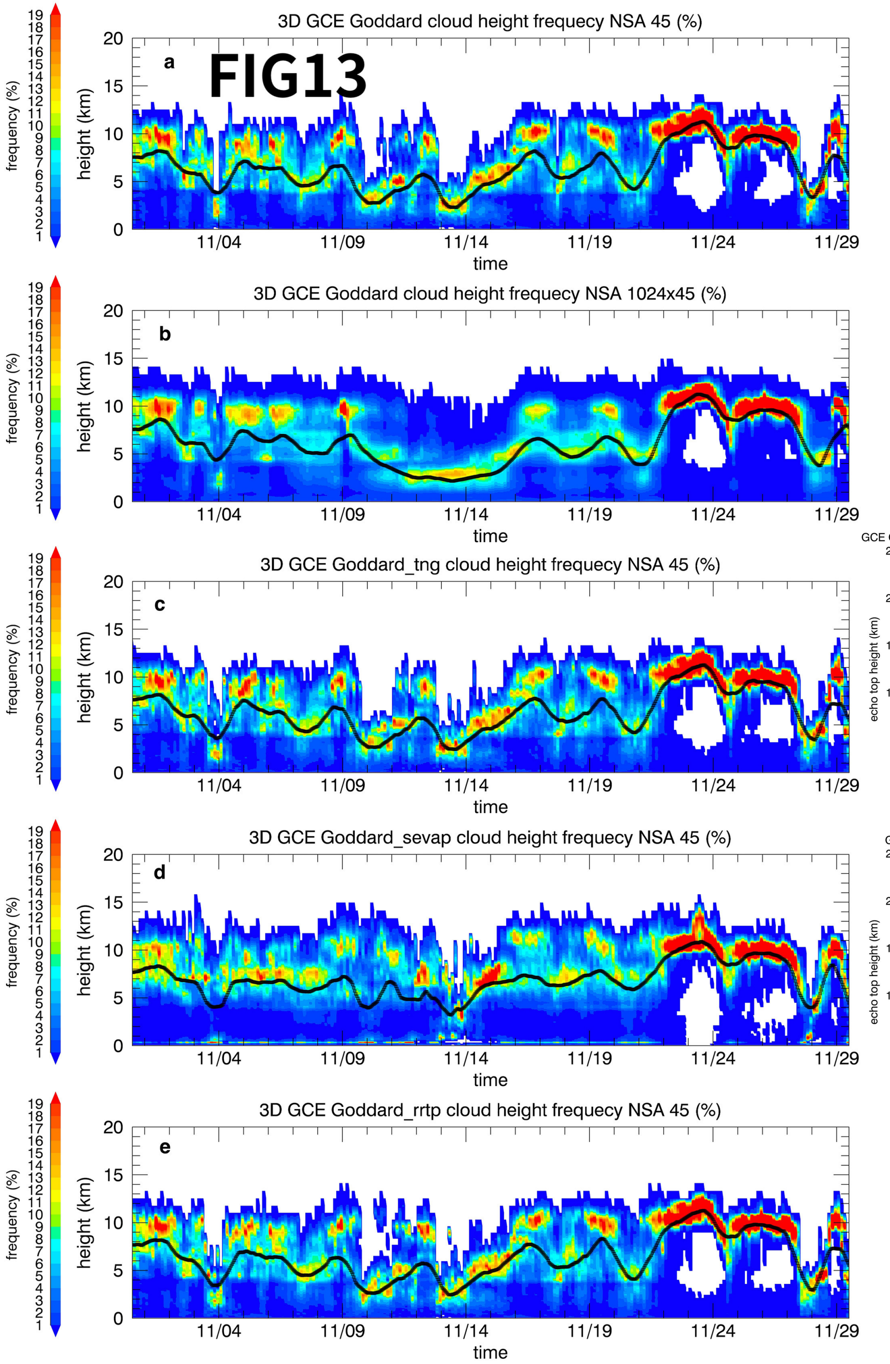
GCE and radar observations: (4) TRMM PR

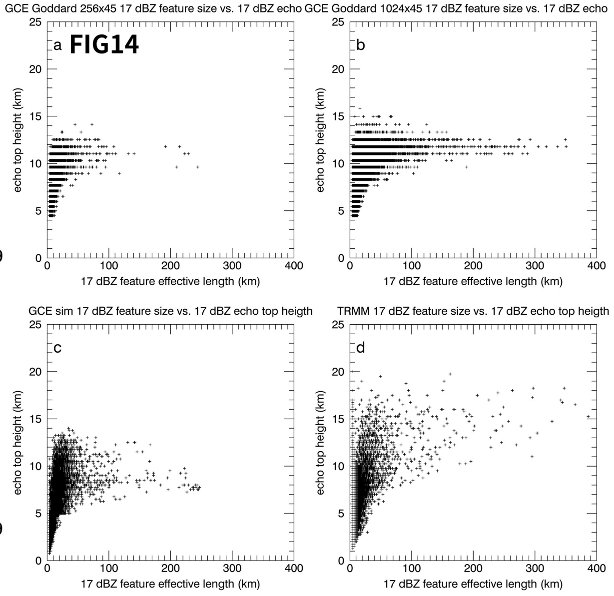


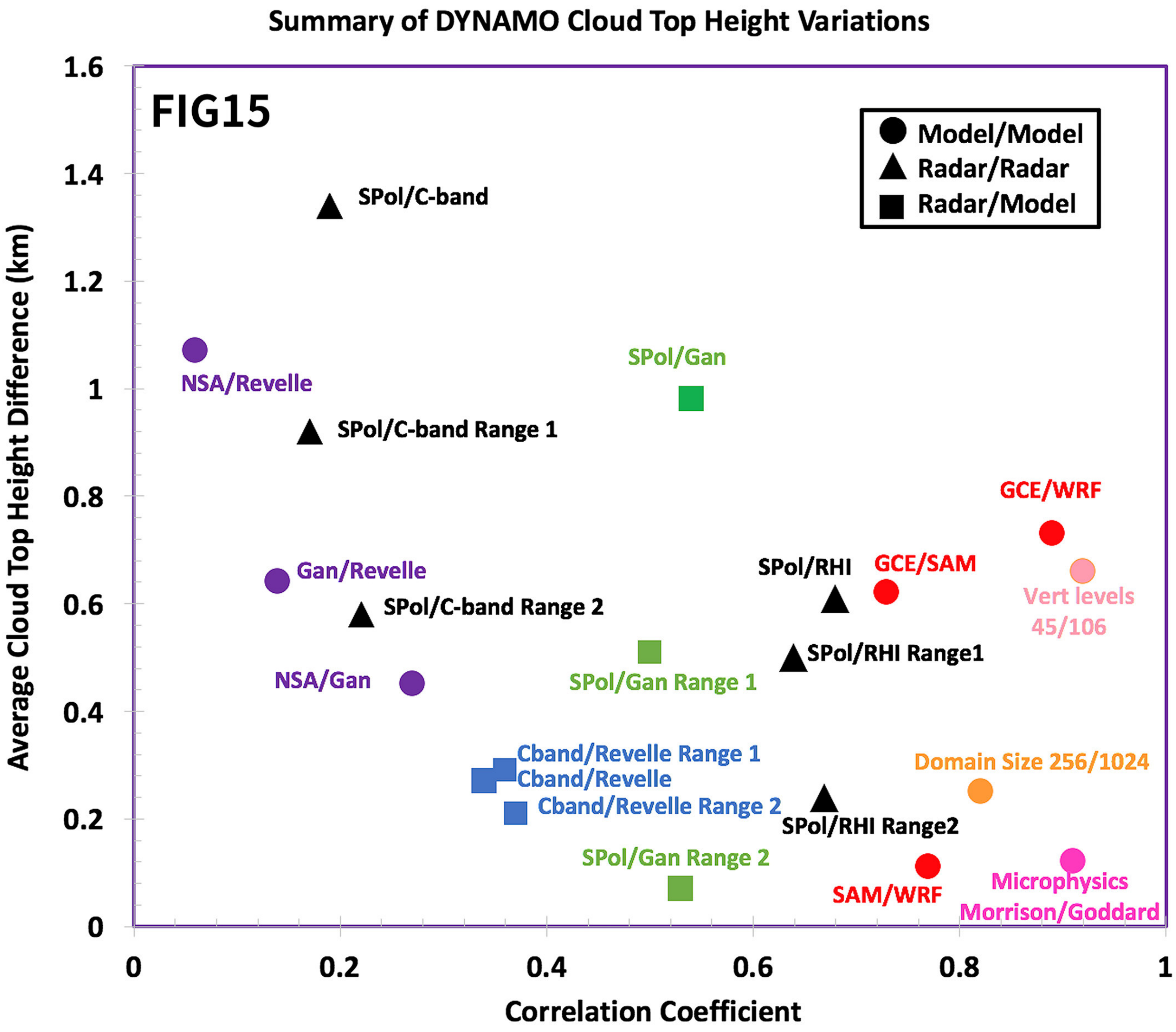


Sensitivity test








Summary of DYNAMO Cloud Top Height Variations
FIG15
Model/Model
Radar/Radar
Radar/Model
SPol/C-band
NSA/Revelle
SPol/Gan
SPol/C-band Range 1
GCE/WRF
SPol/RHI
GCE/SAM
Gan/Revelle
Vert levels
45/106
SPol/C-band Range 2
SPol/RHI Range1
NSA/Gan
SPol/Gan Range 1
Cband/Revelle Range 1
Cband/Revelle
Domain Size 256/1024
Cband/Revelle Range 2
SPol/RHI Range2
SPol/Gan Range 2
Microphysics
SAM/WRF
Morrison/Goddard
Average Cloud Top Height Difference (km)
Correlation Coefficient
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

Summary

- This study provides a new opportunity for additional model validations and cross comparisons.
- CRMs forced by site-specific large-scale forcing can reproduce not only common features in cloud populations but also subtle variations observed by different radars.
- CRM simulations underestimate radar echo-top heights for the strongest convection within large, organized precipitation features.
- The multiradar, multimodel framework benefits quantitative sensitivity studies to highlight common model strength and weakness.

Summary

- Echo-top heights observed by the S-PolKa strongly depended on sampling ranges due to its limited sampling. Combining C-band observations and model simulations, we have identified S-PolKa subset data with a 20 to 100 km sampling range as the best match, and subsequently used the results to help model validations.