Impact of Resolution and Parameterized Convection on the Diurnal Cycle of Precipitation in a Global Nonhydrostatic Model

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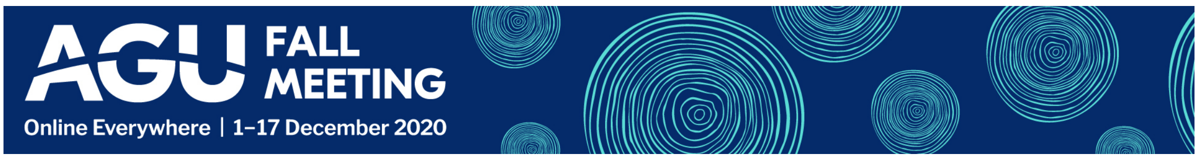
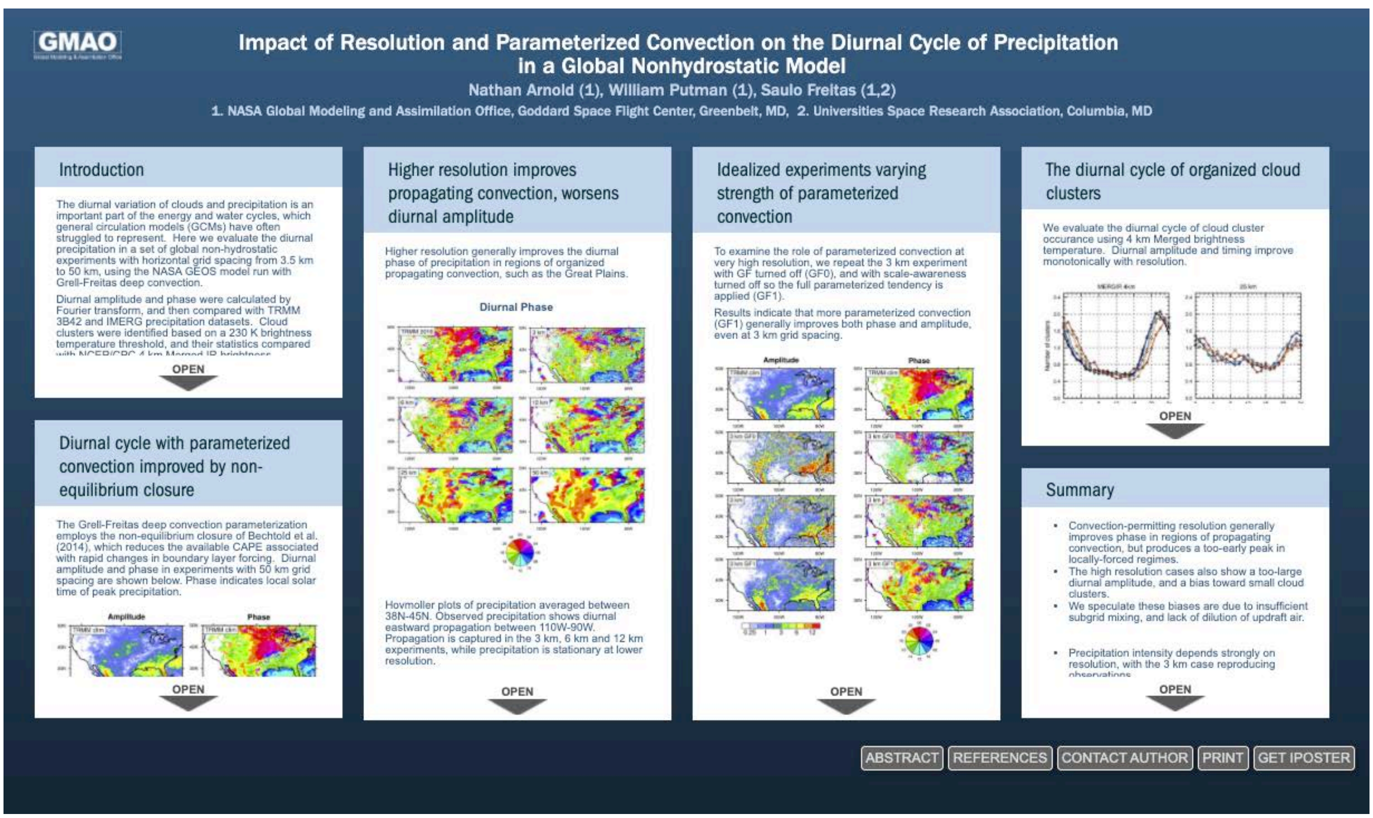




INTRODUCTION

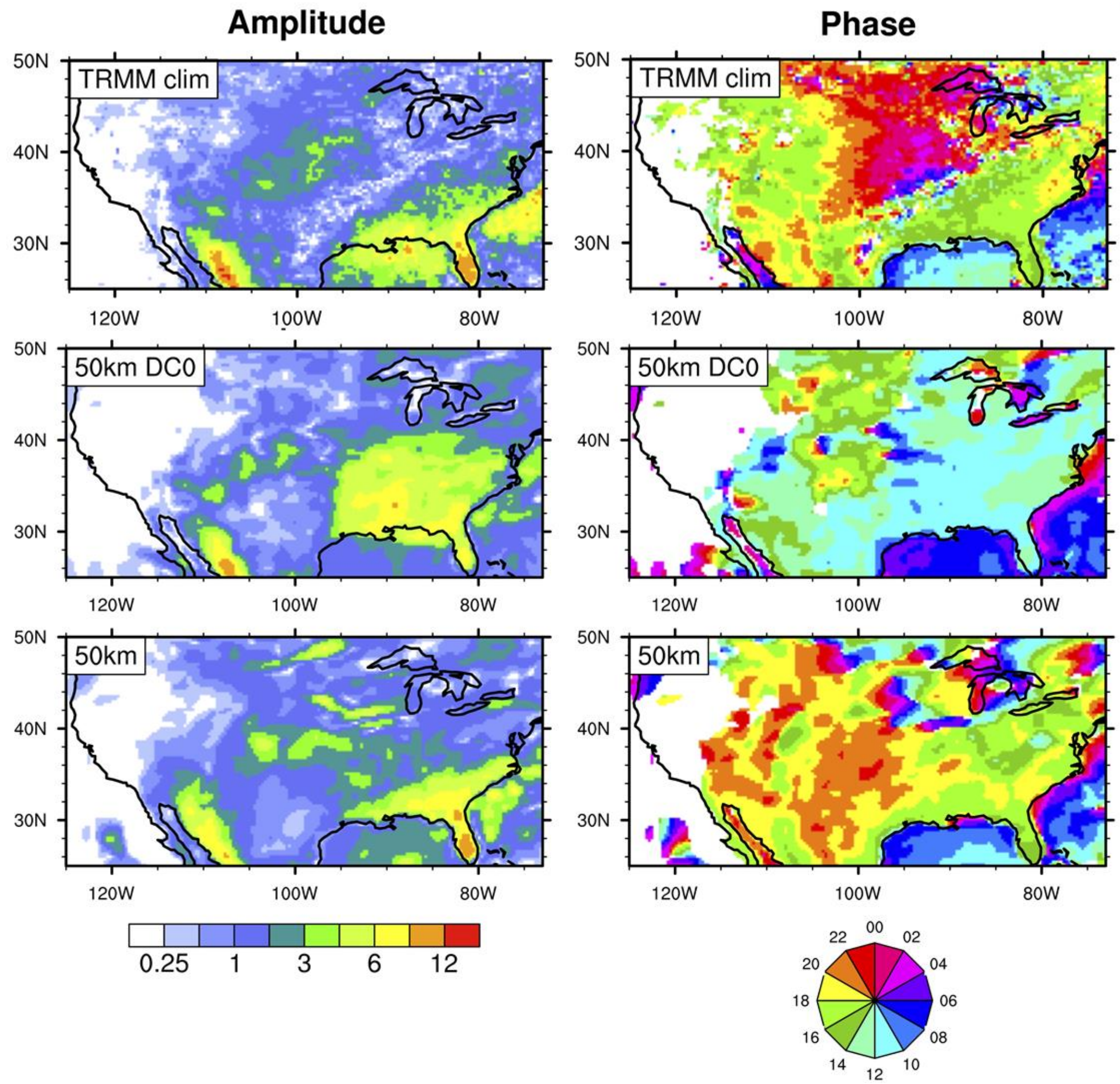
The diurnal variation of clouds and precipitation is an important part of the energy and water cycles, which general circulation models (GCMs) have often struggled to represent. Here we evaluate the diurnal precipitation in a set of global non-hydrostatic experiments with horizontal grid spacing from 3.5 km to 50 km, using the NASA GEOS model run with Grell-Freitas deep convection.

Diurnal amplitude and phase were calculated by Fourier transform, and then compared with TRMM 3B42 and IMERG precipitation datasets. Cloud clusters were identified based on a 230 K brightness temperature threshold, and their statistics compared with NCEP/CPC 4 km Merged IR brightness temperature observations.

The Contiguous United States (CONUS), the Maritime Continent, and Amazonia were analyzed (see reference); here we show results for CONUS. The GEOS experiments follow the DYAMOND protocol, initialized July 30, 2016 and run for 40 days.

DIURNAL CYCLE WITH PARAMETERIZED CONVECTION IMPROVED BY NON-EQUILIBRIUM CLOSURE

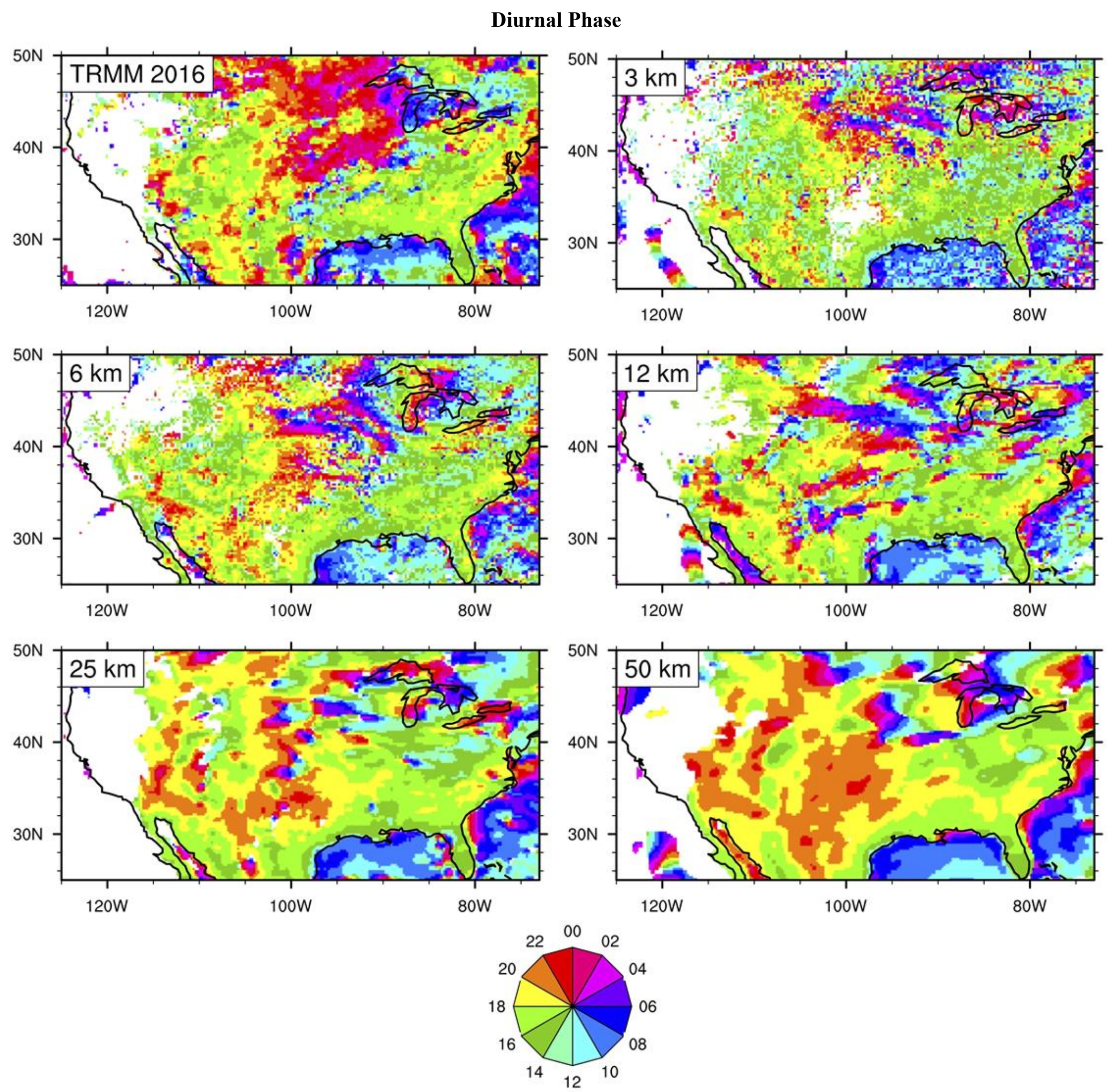
The Grell-Freitas deep convection parameterization employs the non-equilibrium closure of Bechtold et al. (2014), which reduces the available CAPE associated with rapid changes in boundary layer forcing. Diurnal amplitude and phase in experiments with 50 km grid spacing are shown below. Phase indicates local solar time of peak precipitation.



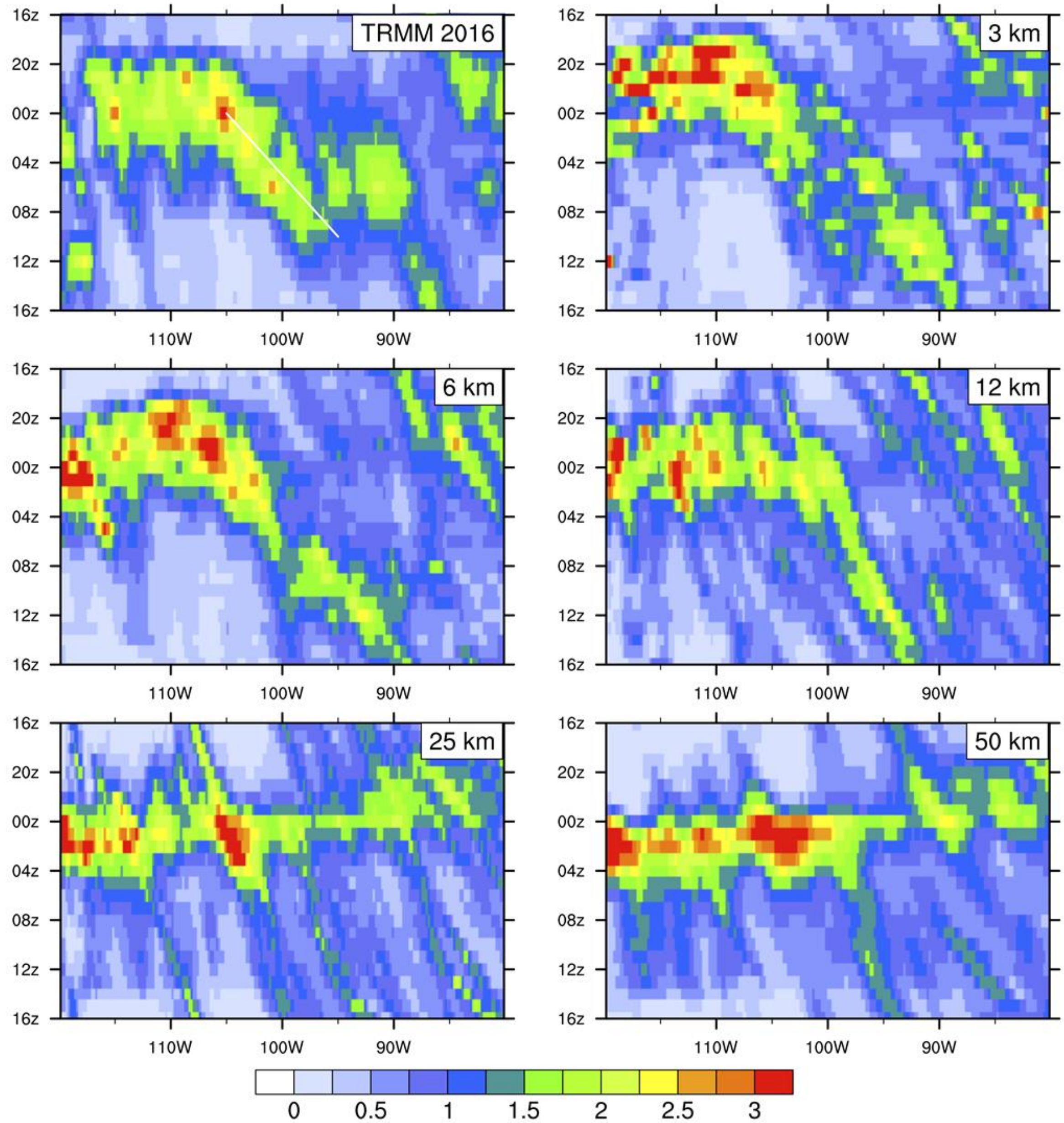
When the non-equilibrium closure is disabled (DC0), the diurnal amplitude is too large in the eastern US, and the peak rainfall is uniformly too early.

HIGHER RESOLUTION IMPROVES PROPAGATING CONVECTION, WORSENS DIURNAL AMPLITUDE

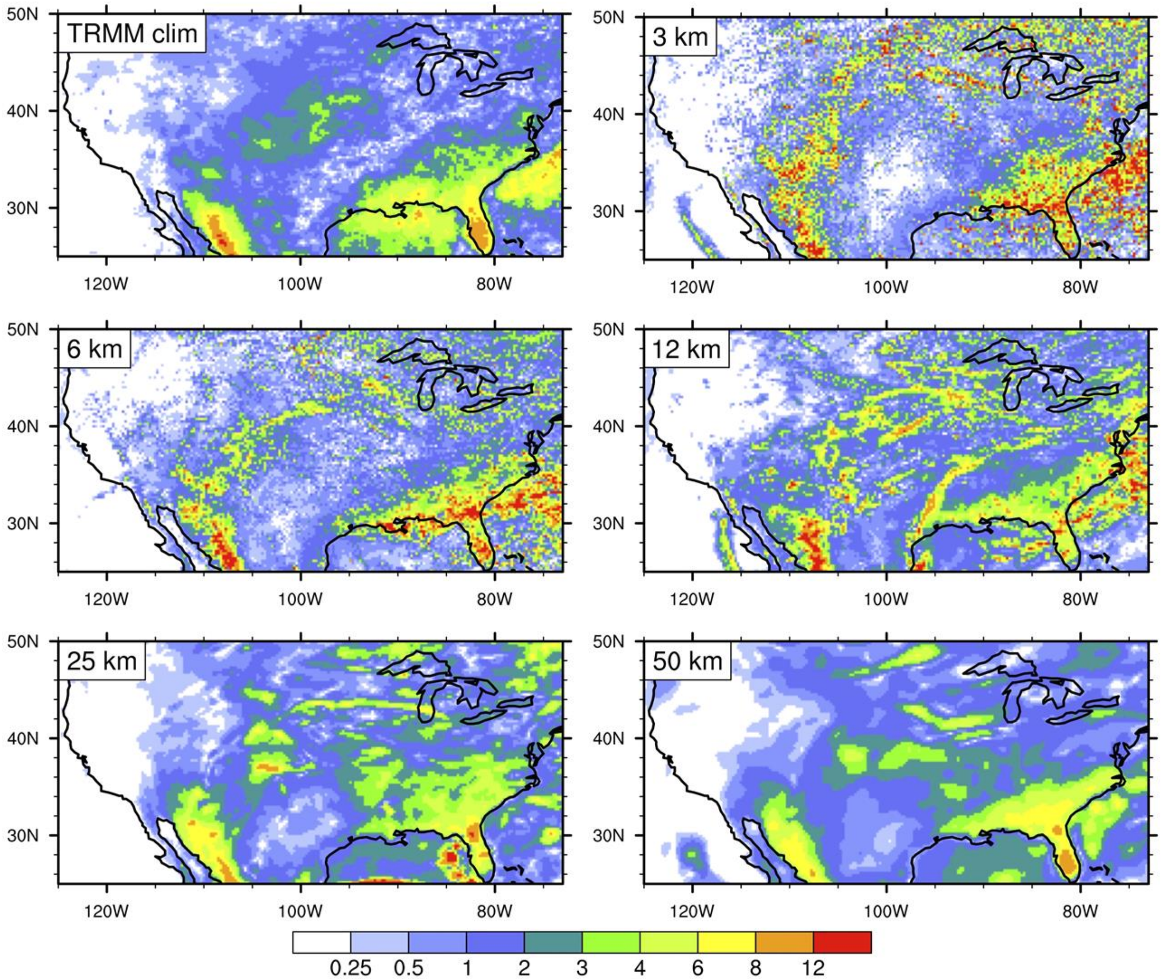
Higher resolution generally improves the diurnal phase of precipitation in regions of organized propagating convection, such as the Great Plains.



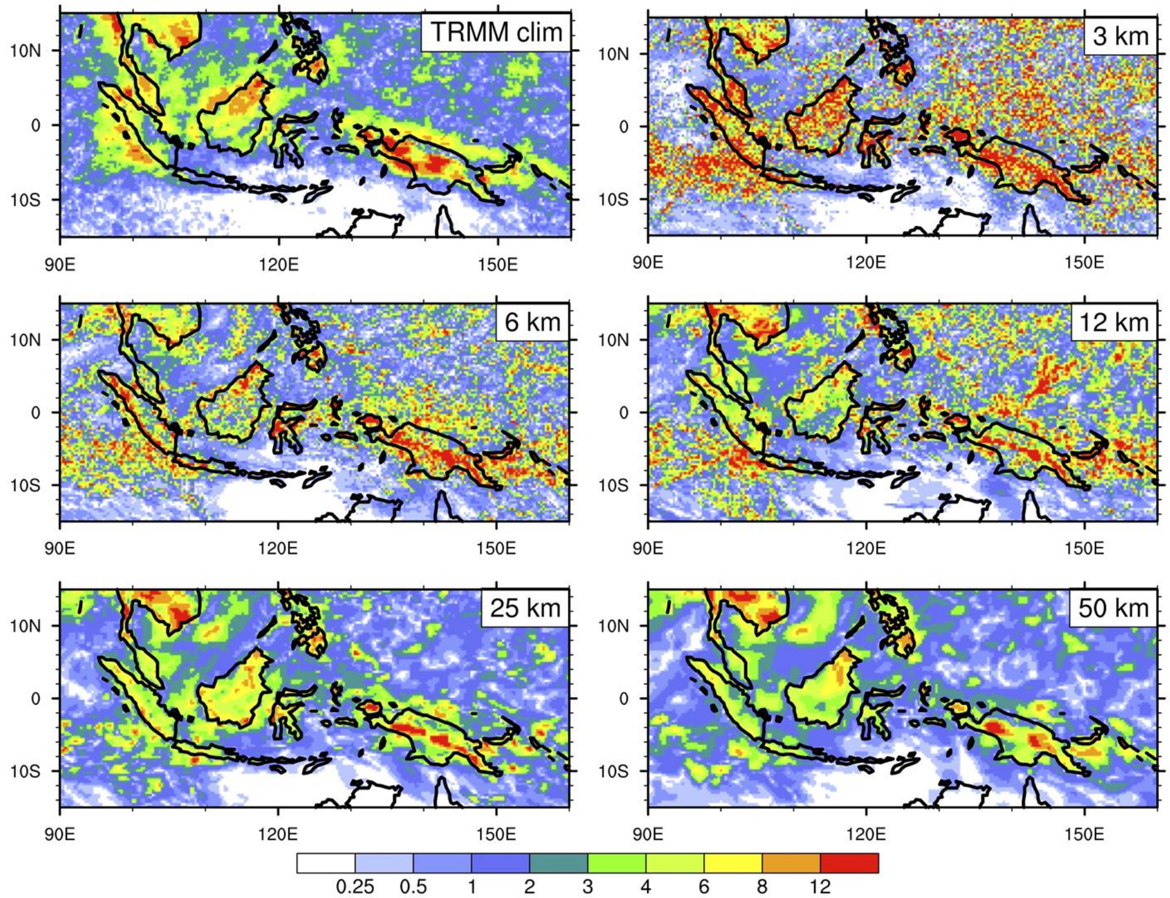
Hovmoller plots of precipitation averaged between 38N-45N. Observed precipitation shows diurnal eastward propagation between 110W-90W. Propagation is captured in the 3 km, 6 km and 12 km experiments, while precipitation is stationary at lower resolution.


TRMM 2016
3 km
6 km
12 km
25 km
50 km
16z
20z
00z
04z
08z
12z
16z
110W
100W
90W
0
0.5
1
1.5
2
2.5
3

Higher resolution shows a bias toward excessive diurnal amplitude and small-scale variability.



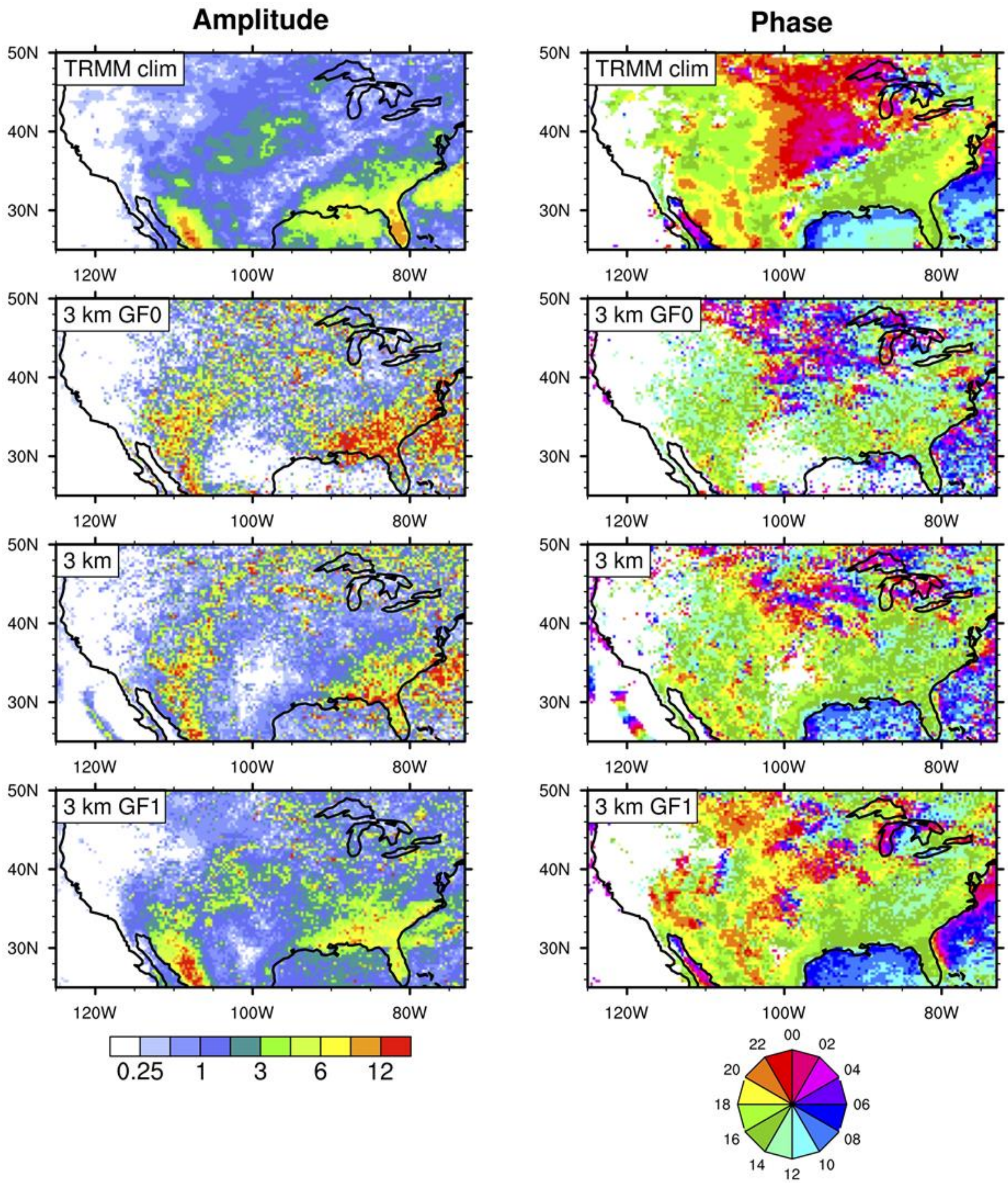
The high diurnal amplitude bias is seen globally, e.g. over the Maritime Continent.


TRMM clim
3 km
6 km
12 km
25 km
50 km
10N
0
10S
90E
120E
150E
0.25 0.5 1 2 3 4 6 8 12

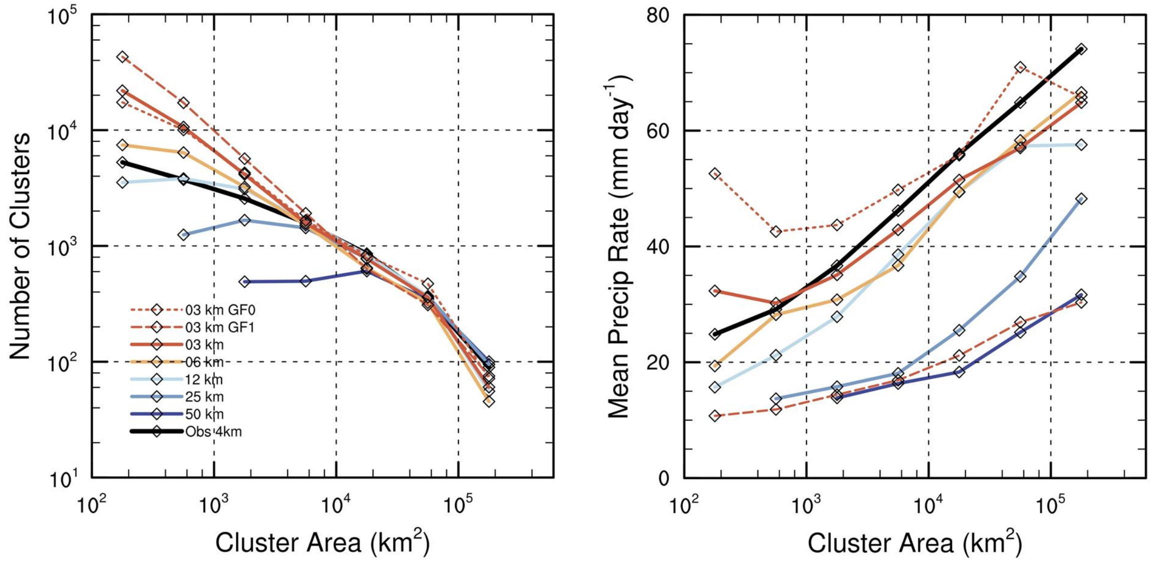
IDEALIZED EXPERIMENTS VARYING STRENGTH OF PARAMETERIZED CONVECTION

To examine the role of parameterized convection at very high resolution, we repeat the 3 km experiment with GF turned off (GF0), and with scale-awareness turned off so the full parameterized tendency is applied (GF1).

Results indicate that more parameterized convection (GF1) generally improves both phase and amplitude, even at 3 km grid spacing.



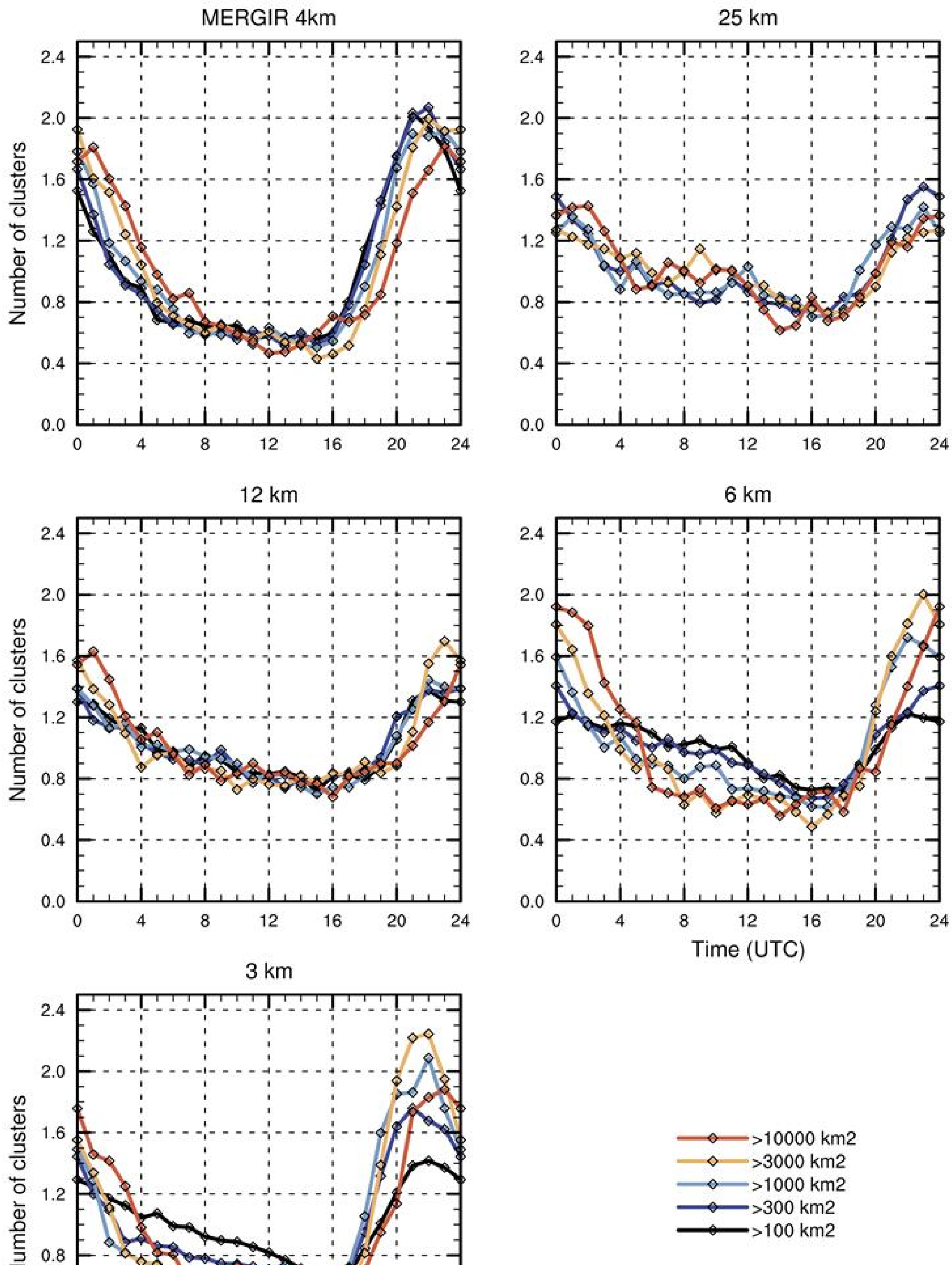
However, more parameterized convection (GF1) also biases the size distribution of cloud clusters further toward small scales, and the precipitation intensity within clusters becomes too weak (similar to intensities at 50 km).



Clouds clusters were identified using a 230 K brightness temperature threshold.

THE DIURNAL CYCLE OF ORGANIZED CLOUD CLUSTERS

We evaluate the diurnal cycle of cloud cluster occurance using 4 km Merged brightness temperature. Diurnal amplitude and timing improve monotonically with resolution.



SUMMARY

- Convection-permitting resolution generally improves phase in regions of propagating convection, but produces a too-early peak in locally-forced regimes.
- The high resolution cases also show a too-large diurnal amplitude, and a bias toward small cloud clusters.
- We speculate these biases are due to insufficient subgrid mixing, and lack of dilution of updraft air.

- Precipitation intensity depends strongly on resolution, with the 3 km case reproducing observations.
- Increasing the strength of parameterized convection at 3 km mitigates the diurnal timing and amplitude biases, but seriously degrades the precipitation intensities.
- Higher resolution monotonically improves the diurnal cycle of cloud cluster number.

- Additional details published in Arnold et. al. (JMSJ, 2020), see references.

ABSTRACT

A series of 40-day non-hydrostatic global simulations was run with the NASA Goddard Earth Observing System (GEOS) model with horizontal grid spacing ranging from 50 km to 3.5 km. Here we evaluate the diurnal cycle of precipitation and organized convection as a function of resolution. For validation we use the TRMM 3B42 and IMERG precipitation products and 4 km Merged Infrared brightness temperature, focusing on three regions: the contiguous United States (CONUS), the Maritime Continent, and Amazonia. We find that higher resolution has mixed impacts on diurnal phase. Regions dominated by non-local propagating convection generally show improvement, with better representation of organized convective systems. Precipitation in regions dominated by local thermodynamic forcing tends to peak too early at high resolution. Diurnal amplitudes in all regions develop unrealistic small-scale variability at high resolution, while amplitudes tend to be underestimated at low resolution. The GEOS model uses the Grell-Freitas scale-aware convection scheme, which smoothly reduces parameterized deep convection with increasing resolution. We find that some parameterized convection is beneficial for the diurnal amplitude and phase even with a 3.5 km model grid, but only when throttled with the scale-aware approach. An additional 3.5 km experiment employing the GFDL microphysics scheme and higher vertical resolution shows further improvement in propagating convection, but an earlier rainfall peak in locally forced regions.

REFERENCES

Nathan P. Arnold, William M. Putman, Saulo R. Freitas, 2020: Impact of Resolution and Parameterized Convection on the Diurnal Cycle of Precipitation in a Global Nonhydrostatic Model, *Journal of the Meteorological Society of Japan. Ser. II*, doi.org/10.2151/jmsj.2020-066.