Cloud-system-resolving large-domain simulations of tropical convection and the MJO

Chris Holloway, Steve Woolnough, and Grenville Lister email: c.e.holloway@reading.ac.uk

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
Walker Institute
University of Reading

1. Introduction

To investigate the effects of convective-scale processes on large-scale tropical dynamics and convective organization, high-resolution UK Met Office Unified Model simulations of a 10-day case study over a large (15,500 km × 4,500 km) tropical domain are analyzed as part of the Cascade project. Some of these simulations have explicit convection, while others use parameterized convection; there are also differences in vertical subgrid mixing (see table below). Simulations with parameterized convection appear to have a preferred scale of rainfall around 0.4 mm h^{-1} (10 mm day^{-1}), unlike TRMM observations and simulations with explicit convection (Fig. 1). The explicit convection runs also generally produce a much more realistic MJO in terms of both intensity and propagation speed (Figs. 2–4). However, the 4 km model with the operational non-local boundary layer mixing scheme, rather than 3D Smagorinsky mixing, loses its MJO and has less mixing across the boundary layer top (Fig. 5). The best MJO simulation (4 km 3Dsmag) has a more realistic relationship between lower-free-tropospheric moisture and precipitation and has explicit shallow convection (Fig. 6).

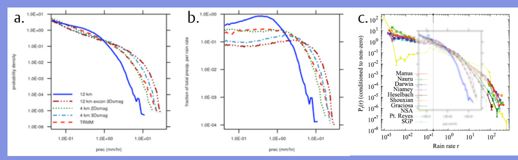

Figure 1 Precipitation distributions: (a) probability densities, and (b) fractional rainfall amount densities for four model runs and TRMM merged precipitation data over sea points, on a 1-deg. grid and 3-hourly time averages, and (c) same probability densities overlaid on distributions from ARM stations taken from O. Peters et al., *J. Stat. Mech.*, 2010.

2. Distribution of precipitation

Figure 1 shows that model runs with explicit convection have more realistic distributions of precipitation than the 12 km *param* run with parameterized convection when compared with TRMM and ARM observations: the bump in the 12 km model around 0.4 mm h^{-1} suggests a preferred scale of rain rate, perhaps because the convective parameterization settles into equilibrium too easily and/or because it has insufficient scale interactions.

Model configurations

	40 km	12 km param	4 km 2Dsmag	4 km 3Dsmag	12 km 2Dsmag	12 km 3Dsmag
Convection nearly all parameterized	✔	✔				
Convection nearly all explicit			✔	✔	✔	✔
Horizontal Smagorinsky subgrid mixing			✔	✔	✔	✔
Vertical boundary layer scheme mixing	✔	✔	✔		✔	
Vertical Smagorinsky subgrid mixing				✔		✔
Vertical levels	38	38	70	70	38	38

3. MJO

Precipitation hovmoeller plots (Fig. 2) show that model runs with explicit convection (except 4 km *2Dsmag*) have more realistic eastward propagation and organized clusters. This corresponds with a better MJO as seen in a principal component phase diagram (Fig. 3) similar to that of Wheeler and Hendon (*MWR* 2004) but for this limited area. Figure 4 shows that, by 10 April, the 40 km and 12 km *param* runs have not shown enough eastward propagation, while the 4 km *2Dsmag* run has lost much of its large-scale organization.

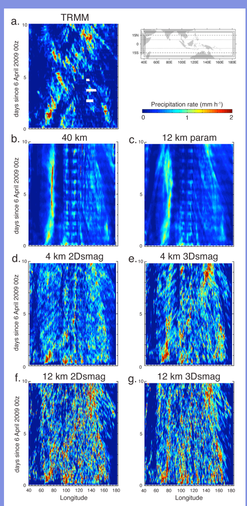

Figure 2 Hovmoeller plots (with time increasing upwards) of precipitation in mm h^{-1} averaged from 7.5°S–7.5°N and in 3-h periods for six Cascade runs and TRMM merged precipitation data for 10 days starting 6 April, 2009. Horizontal averaging is done at 25 km for TRMM, 40 km for the 40 km model, and 24 km for the other model runs. Map shows the 12 km domain (larger box) and 4 km domain (smaller box).

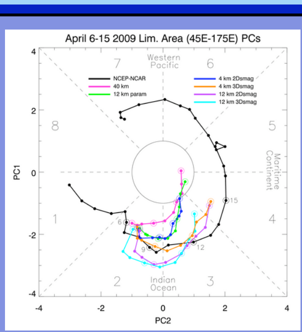

Figure 3 MJO phase diagram (cf. Wheeler and Hendon, *Mon. Wea. Rev.*, 2004) for NCEP-NCAR Reanalysis for all of April 2009 and for six Cascade runs for 10 days starting 6 April, 2009. Principal components are calculated from the limited-domain EOFs. Large circles are placed at 3-day intervals.

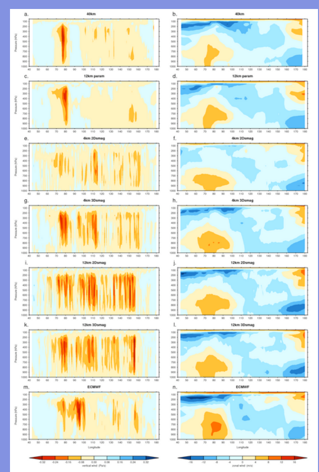

Figure 4 (Left) pressure velocity and (Right) zonal wind for ECMWF forecast analyses and the two 4 km runs for daily averages for 10 April, averaged from 7.5°S–7.5°N and onto a 1° longitude grid.

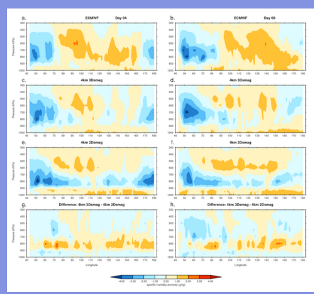

Figure 5 Specific humidity anomalies from the initial state ECMWF zonal mean for ECMWF forecast analyses and the two 4 km runs for daily averages for (Left) 10 April and (Right) 15 April, averaged from 7.5°S–7.5°N and onto a 1° longitude grid.

4. Vertical Mixing

Figure 5 shows that the 4 km *2Dsmag* model has a dry bias above the boundary layer, likely because the boundary layer scheme is not mixing above the LCL. The 4 km *3Dsmag* model produces a more realistic zonal gradient of lower-tropospheric moisture (moister ahead of the MJO and drier behind it) which propagates eastward, somewhat similar to the ECMWF analyses.

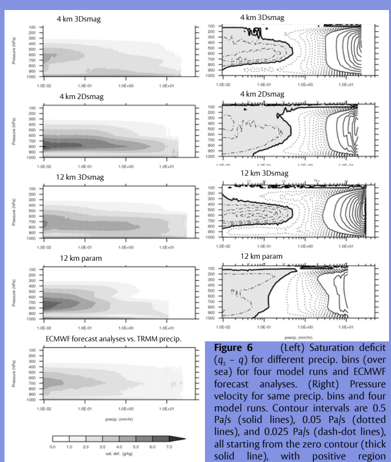

Figure 6 (Left) Saturation deficit ($q_s - q$) for different precip. bins (over sea) for four model runs and ECMWF forecast analyses. (Right) Pressure velocity for same precip. bins and four model runs. Contour intervals are 0.5 Pa/s (solid lines), 0.05 Pa/s (dotted lines), and 0.025 Pa/s (dash-dot lines), all starting from the zero contour (thick solid line), with positive region (downward motion) shaded.

5. Precip. and Environmental Profiles

Composites of saturation deficit and pressure velocity on precipitation (Fig. 6) show that the 4 km *3Dsmag* model has a more realistic relationship between rainfall and lower-free-tropospheric moisture than the other models, suggesting the importance of moisture-convection feedback for the MJO. The 12 km *3Dsmag* run has a similar relationship but biased drier. These two models also have more explicit shallow convection.

6. Summary

- **4 (and 12) km model runs with explicit convection produce more realistic precipitation distributions than parameterized convection runs, without a preferred rain rate.**
- **These explicit convection models also generally produce a better MJO**
    - **(except for the 4 km *2Dsmag* model with the operational boundary layer vertical subgrid mixing scheme, which has too little mixing across the boundary layer top and loses its large-scale convective organization).**
- **The model with the best MJO, the 4 km 3Dsmag model, also has the most realistic relationship between precipitation and lower-free-tropospheric moisture, suggesting the importance of the moisture-convection feedback for MJO propagation.**
- **The models with better MJOs also have more explicit shallow convection—light rainfall is accompanied by shallow upward motion at lower levels.**