The Effects of Explicit versus Parameterized Convection on the MJO in a Large-Domain High-Resolution Tropical Case Study. Part II: Processes Leading to Differences in MJO Development*

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H12

Precipitation distributions for explicit versus parametrized convection in a large-domain high-resolution tropical case study

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H13

The Effects of Explicit versus Parameterized Convection on the MJO in a Large-Domain High-Resolution Tropical Case Study. Part I: Characterization of Large-Scale Organization and Propagation*

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B14

Gross Moist Stability and MJO Simulation Skill in Three Full-Physics GCMs

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outline

- Model setup and data
- Moisture budget
- Vertical profiles of heating
- Moist entropy budget

Table 1. (H13)

TABLE 1. Main differences in the six model configurations used. "Smagorinsky" refers to the Smagorinsky–Lilly-type turbulence scheme used in some of the model versions, and "boundary layer" refers to the standard boundary layer subgrid mixing scheme.

	Horizontal grid spacing (km)	Vertical levels	Convection	Horizontal subgrid mixing	Vertical subgrid mixing
40 km	40	38	Parameterized	None	Boundary layer
12-km param	12	38	Parameterized	None	Boundary layer
12-km 3Dsmag	12	38	Explicit	Smagorinsky	Smagorinsky
12-km 2Dsmag	12	38	Explicit	Smagorinsky	Boundary layer
4-km 3Dsmag	4	70	Explicit	Smagorinsky	Smagorinsky
4-km 2Dsmag	4	70	Explicit	Smagorinsky	Boundary layer

Added in H15:
12-km param (1.5 ent)
40-km param (1.5 ent)

1.5 ent:
The convective parameterization with 1.5 times the mixing entrainment (and mixing detrainment) rate of the other parameterized convection runs.

and 12-km param models, we define a subgrid heating term Q_C, not including radiation, as in Eq. (5) of H12 (except, in that paper, Q_C was labeled as Q_1):

$$\frac{1}{c_p}Q_C = \frac{L}{c_p}(c-e) - \frac{\Pi}{\overline{\rho}}\frac{\partial \overline{\rho w'\theta'}}{\partial z}, \qquad (1)$$

where c_p is the specific heat capacity for dry air at constant pressure, L is the latent heat of condensation, c is condensation, e is evaporation of condensate (only liquid–vapor phase transitions are included in the equations for simplicity, although, in the model calculations, ice-phase transitions are also accounted for), θ is potential temperature, w is the vertical velocity, ρ is the density, z is height, Π is the Exner function defined as

$$\Pi = \left(\frac{\overline{p}}{p_0}\right)^{R/c_p},$$

R is the gas constant for dry air, p is the pressure, and $p_0 = 1000$ hPa is the reference pressure. We designate X' as the anomaly of quantity X from $\overline{X}$, which is the horizontal average of X at a single level and time over the large scale (1° in latitude and longitude in this case). As

First term (RHS):

- convective parameterization
- boundary layer/large-scale cloud (vertical subgrid turbulence mixing, surface sensible heat flux)
- large-scale precipitation
- horizontal subgrid turbulence mixing (only 4-km 3Dsmag model).

Last term (RHS):

- advection scheme
- subgrid vertical transport

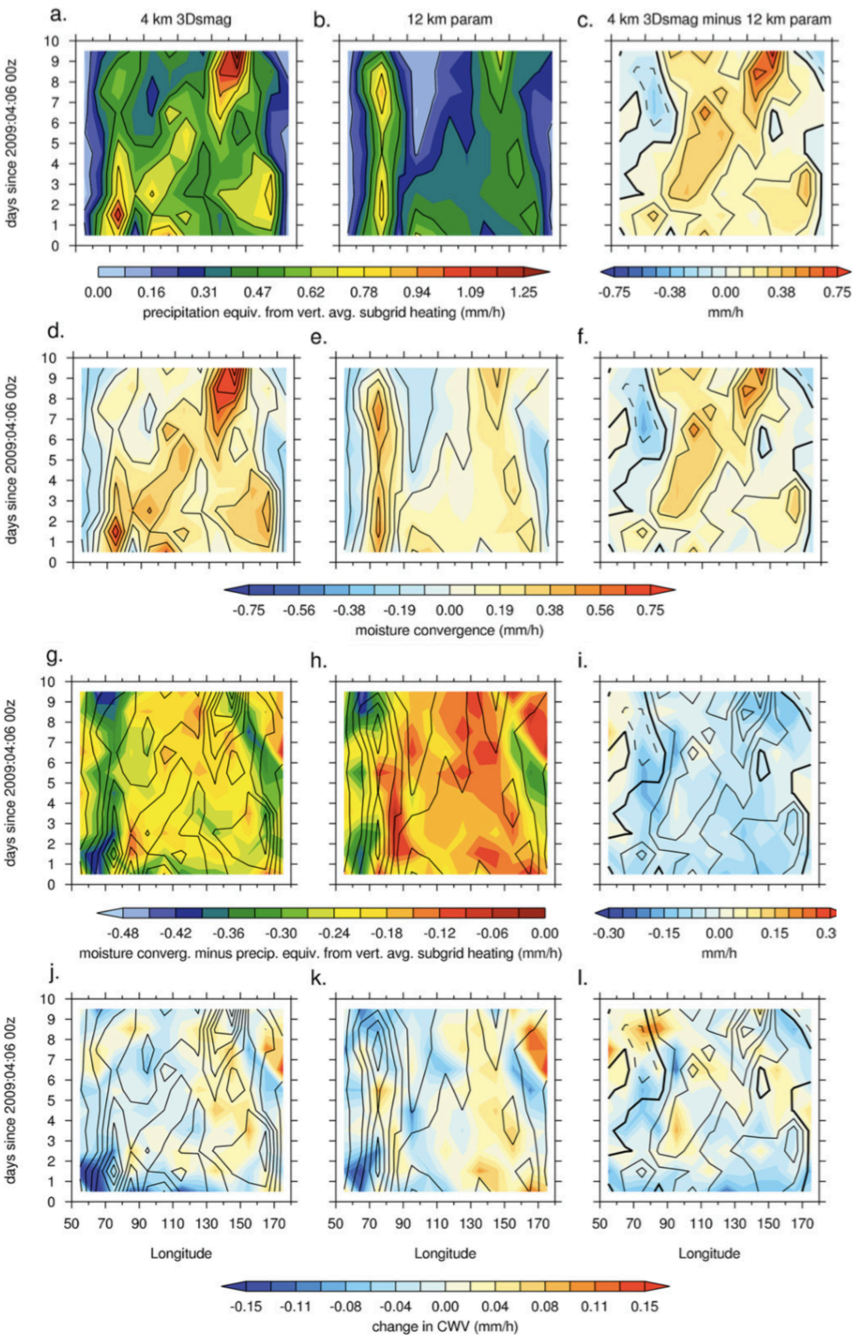


FIG. 1. Daily mean (a)–(c) precipitation equivalent calculated from vertically integrated subgrid heating, (d)–(f) MC, (g)–(i) MC minus this precipitation equivalent, and (j)–(l) change in column water vapor for (left) the 4-km 3Dsmag and (center) the 12-km param runs and for (right) their difference for 10° longitude boxes between 7.5°S and 7.5°N for the 10-day case study. Line contours of vertically averaged subgrid heating are overlaid, with a contour interval of 1 K day^{-1}, negative contours dashed, and zero contour thick.

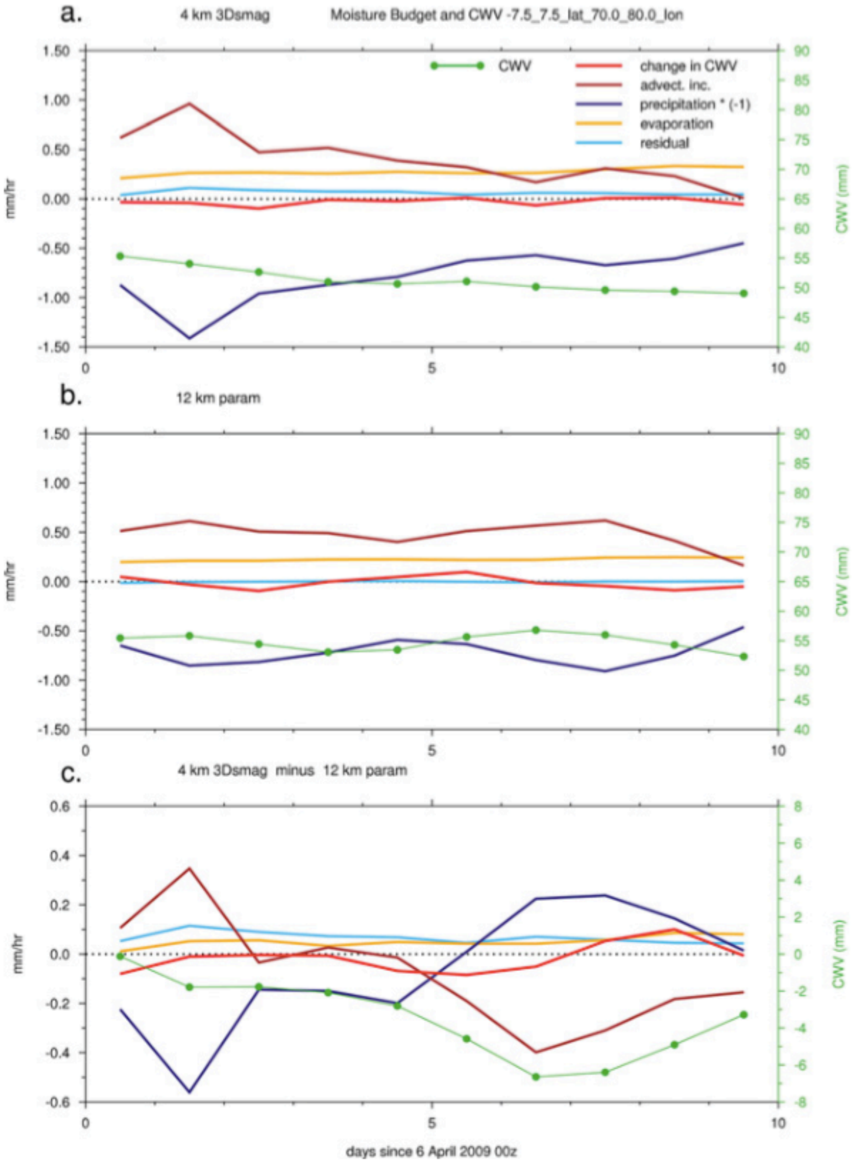


FIG. 2. Daily mean moisture budget terms (left axes) and total CWV (right axes), for (a) the 4-km 3Dsmag model, (b) the 12-km param model, and (c) their difference for a box covering 7.5°S–7.5°N, 70°–80°E for the 10-day case study. The total advective increment (advect. inc.) is the MC.

70-80E

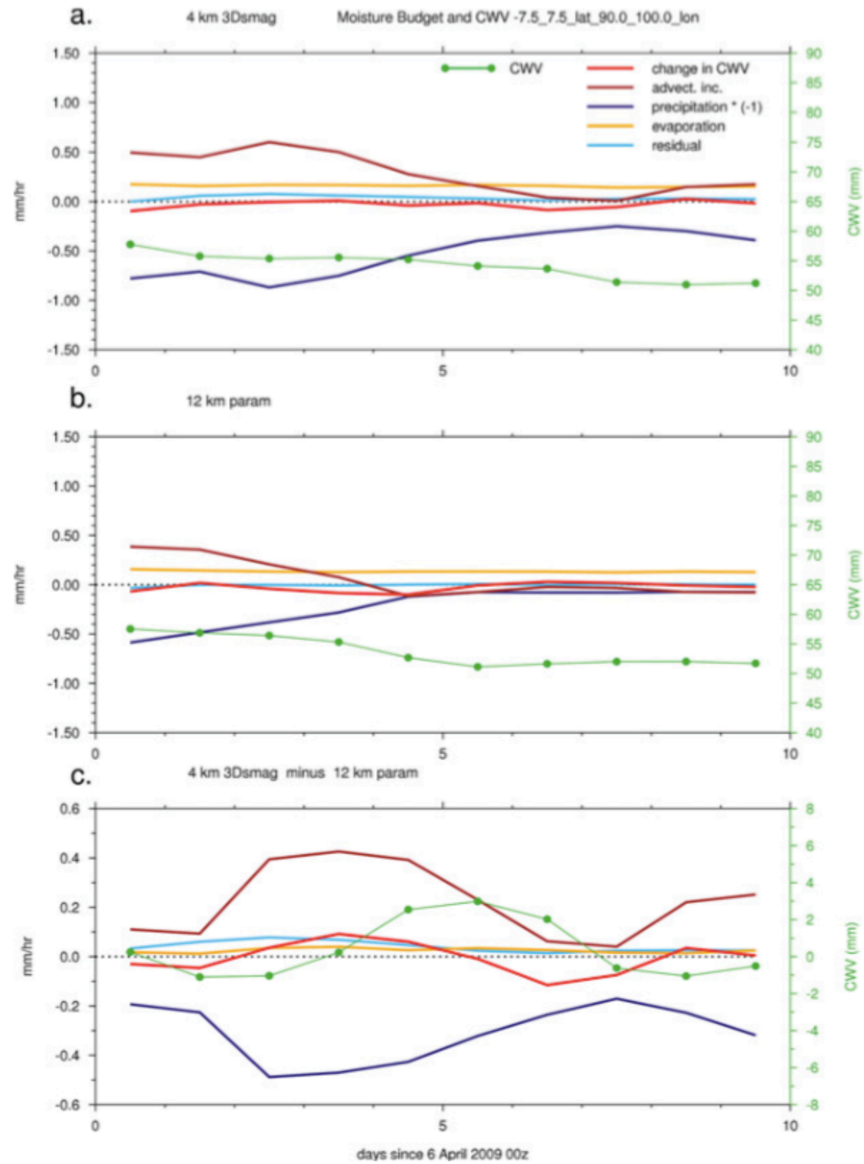
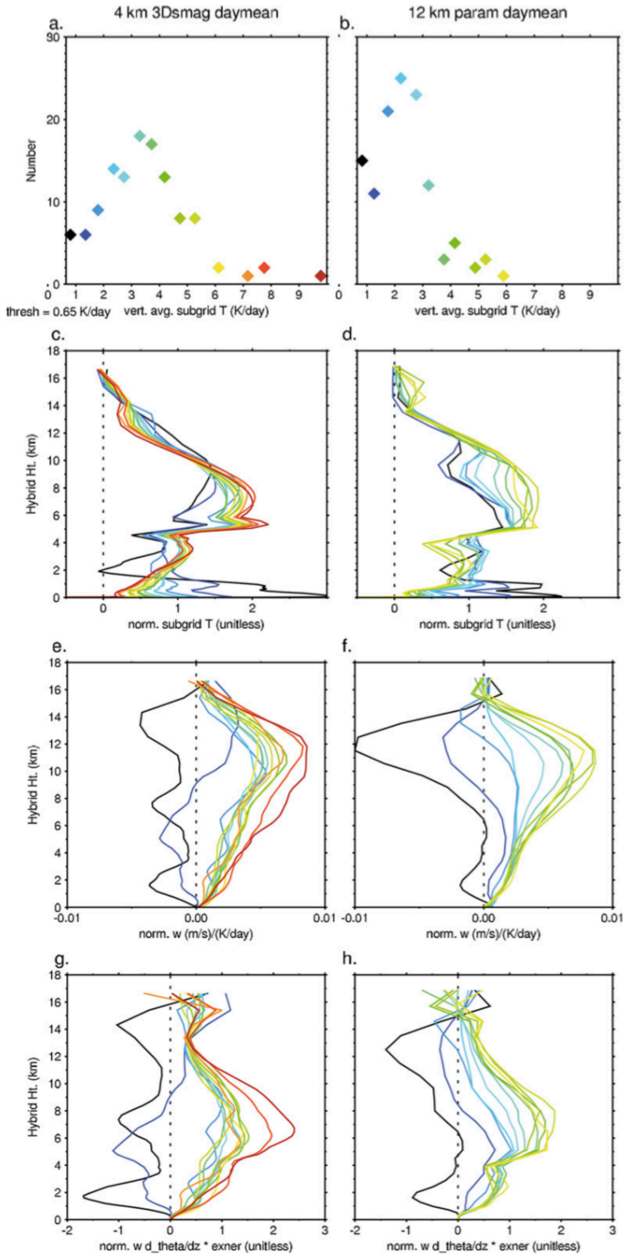


FIG. 3. Daily mean moisture budget terms (left axes) and total CWV (right axes), for (a) the 4-km 3Dsmag model, (b) the 12-km param model, and (c) their difference for a box covering 7.5°S–7.5°N, 90°–100°E for the 10-day case study. The total advective increment is the MC.

90-100E



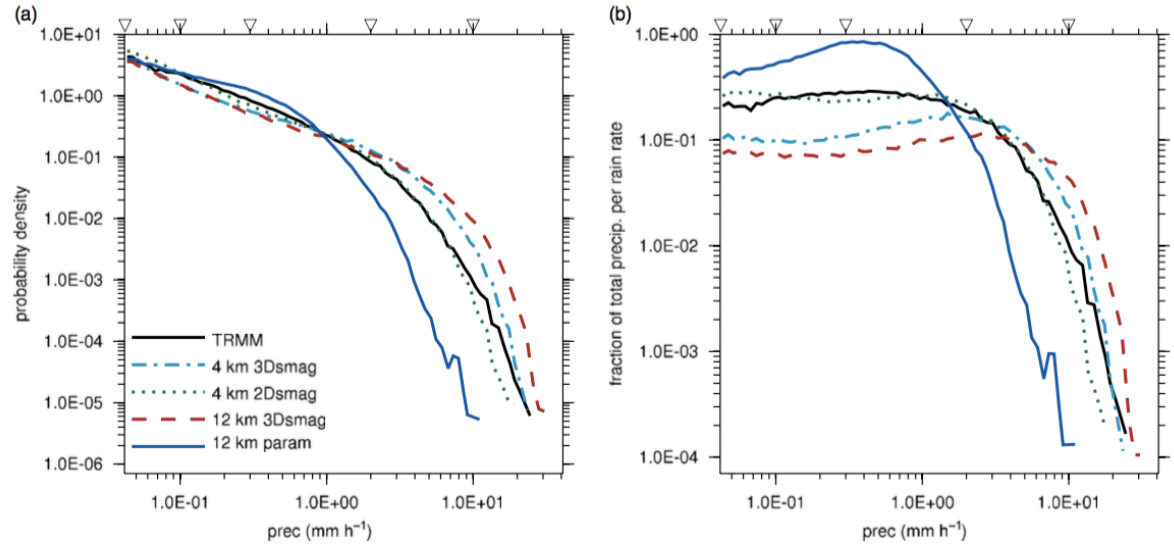
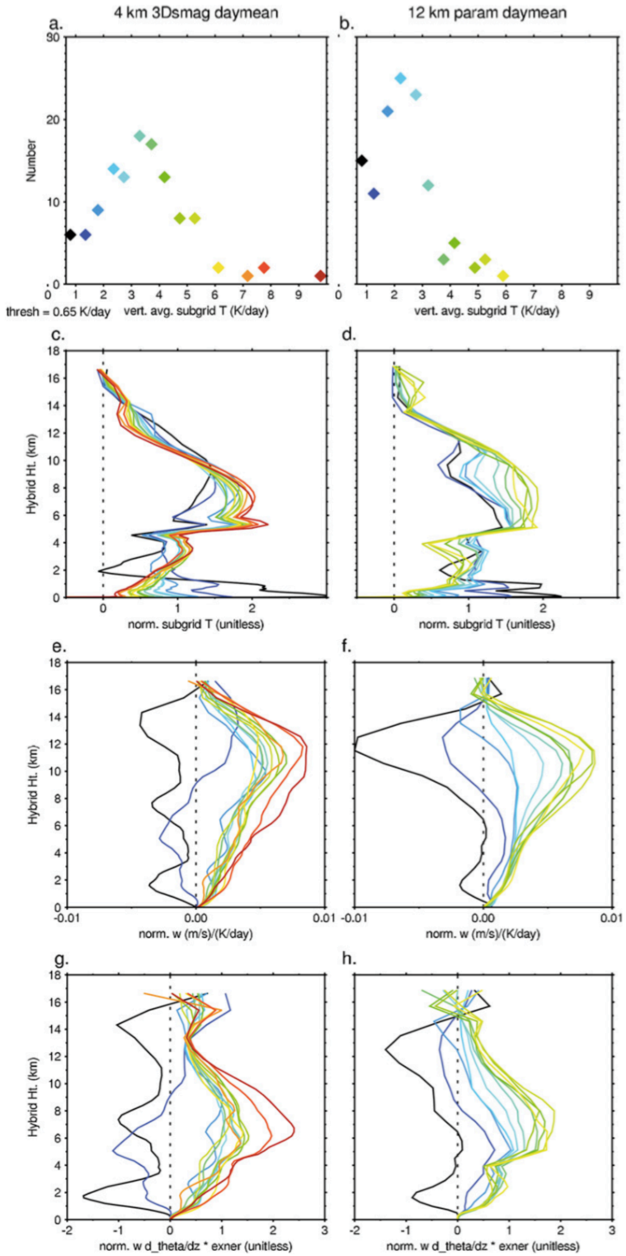


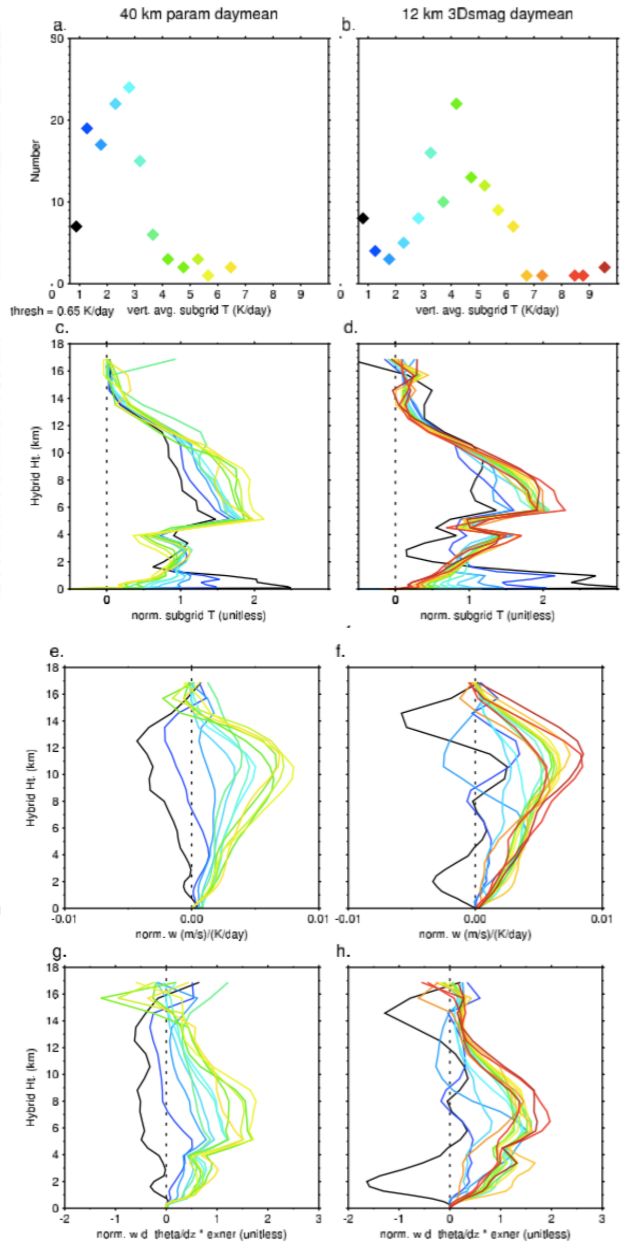
Figure 2. Precipitation distributions: (a) probability densities in (mm h^{-1})$^{-1}$, and (b) fractional rainfall amount densities in (mm h^{-1})$^{-1}$ for two 12 km Cascade runs, two 4 km Cascade runs and TRMM merged precipitation data over sea points, on a 1° latitude/longitude grid and 3 h time averages for 9 days starting on 7 April 2009. Triangles indicate specific rain rates discussed in the article.

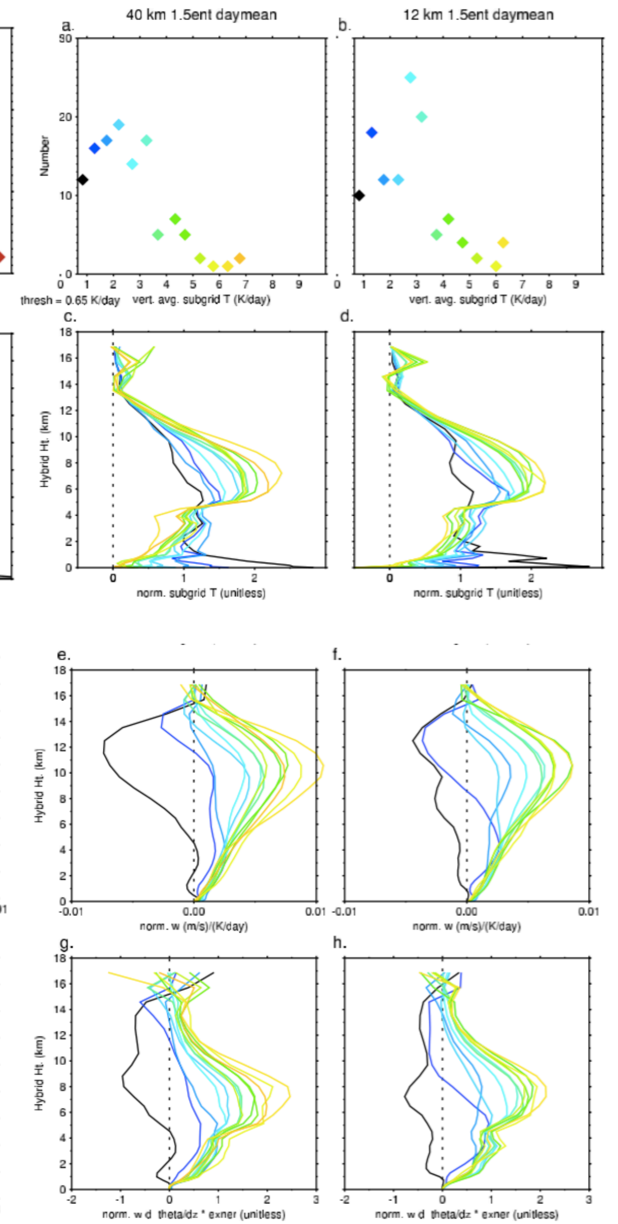
Right: Fig2. (H12)

FIG. 4. (a),(b) Histograms of vertically averaged subgrid heating increments conditionally averaged by the column vertical average (0–18 km); (c),(d) vertical profiles of subgrid heating increments composited and normalized by these vertically averaged heating values; (e),(f) composited and normalized vertical velocity; (g),(h) as in (e) and (f), but multiplied by $\Pi \partial\theta/\partial z$ for (left) the 4-km 3Dsmag and (right) the 12-km param models for 10° longitude boxes covering 7.5°S–7.5°N and daily means for the 10-day case study.

Left: Fig4.







Left: Fig4. / Right: Fig S5 and S6

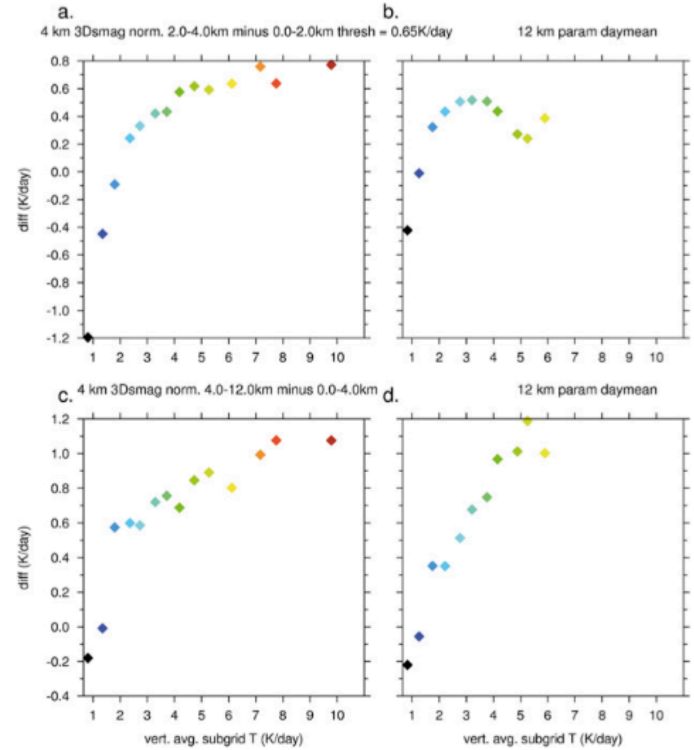


FIG. 7. Difference between layers of vertically averaged normalized subgrid heating for (a),(b) 2–4-km height minus 0–2-km height and (c),(d) 4–12-km height minus 0–4-km height (with values taken as missing where the vertically averaged subgrid heating is below 0.65 K day^{-1}), conditionally averaged in bins of vertically averaged subgrid heating for (left) the 4-km 3Dsmag and (right) the 12-km param runs on daily mean time scales for 10° longitude boxes covering 7.5°S–7.5°N for the 10-day case study.

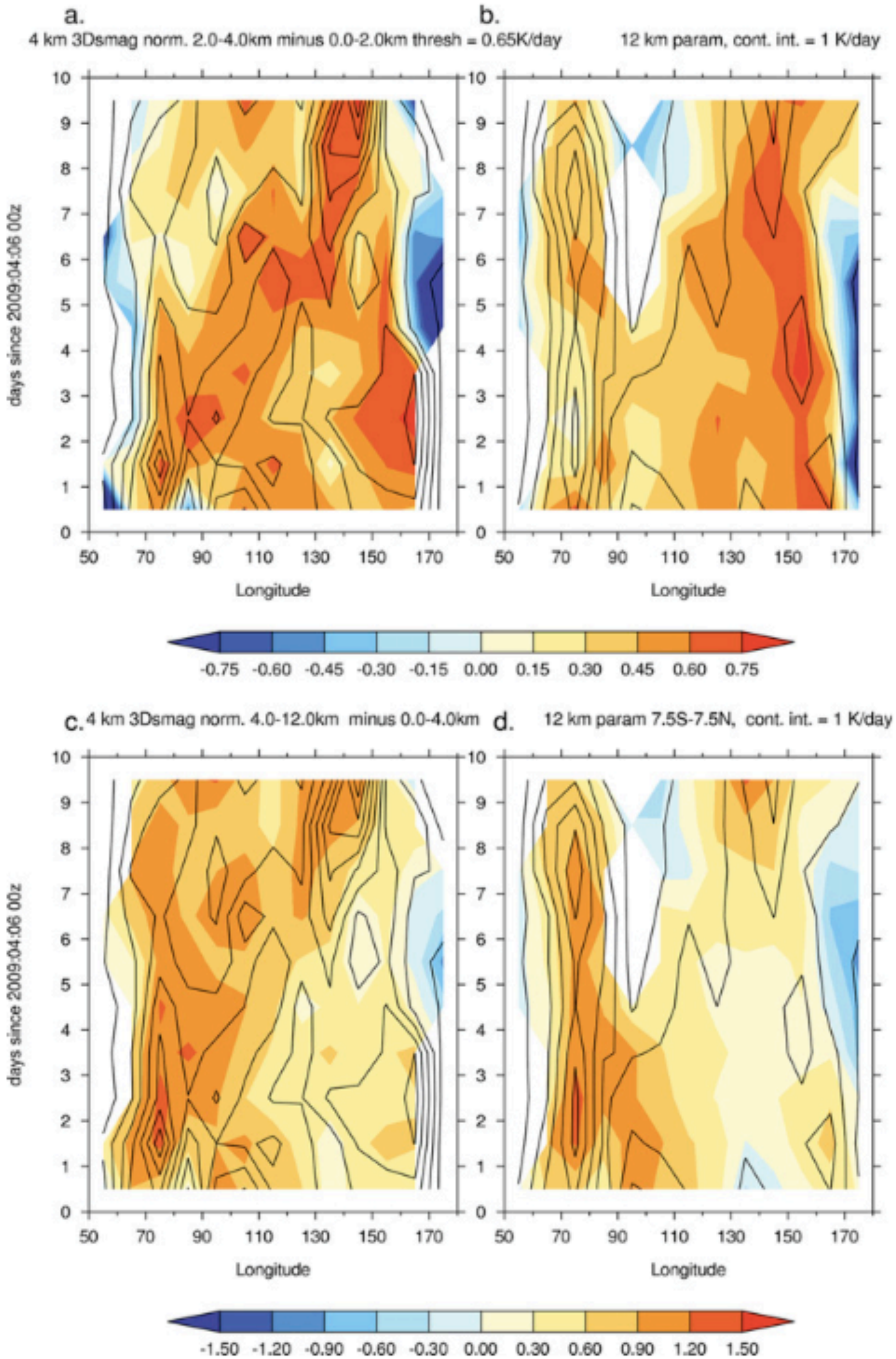


FIG. 5. Hovmöller plots of the difference between layers of vertically averaged normalized subgrid heating for (a),(b) 2–4-km height minus 0–2-km height and (c),(d) 4–12-km height minus 0–4-km height (with values taken as missing where the vertically averaged subgrid heating is below 0.65 K day^{-1}), along with line contours of vertically averaged subgrid heating (with a contour interval of 2 K day^{-1}) for (left) the 4-km 3Dsmag and (right) the 12-km param runs on daily mean time scales for 10° longitude boxes covering 7.5°S–7.5°N for the 10-day case study.

The moist entropy s is defined following Raymond (2013) and Benedict et al. (2014):

$$s = (c_p + r_V c_{pV}) \ln(T/T_R) - R \ln(p_D/p_0) - r_V R_V \ln(p_V/e_{SF}) + (L_V r_V / T_R), \quad (2)$$

the total (Γ_T), horizontal (Γ_H), and vertical (Γ_V) components of NGMS can be defined as follows:

$$\Gamma_T = -\frac{T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s} + \rho\overline{w}(\partial\overline{s}/\partial z)]}{L[\nabla \cdot (\rho r_V \mathbf{v})]}, \quad (3)$$

$$\Gamma_H = -\frac{T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}]}{L[\nabla \cdot (\rho r_V \mathbf{v})]}, \quad \text{and} \quad (4)$$

$$\Gamma_V = -\frac{T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]}{L[\nabla \cdot (\rho r_V \mathbf{v})]}, \quad (5)$$

where $[X] = \int_0^{z_1} X\,dz$, $z_1 \approx 20\,\text{km}$, ρ is the density, $\mathbf{v}$ is the horizontal vector wind, and $\text{MC} = -L[\nabla \cdot (\rho r_V \mathbf{v})]$ is calculated from advective increments of moisture directly output by the model

The budget of $\overline{s}$ can be written:

$$T_R[\partial\overline{s}/\partial t] = -T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}] - T_R[\rho\overline{w}(\partial\overline{s}/\partial z)] + \text{LH} + \text{SH} + [\text{LW}] + [\text{SW}] + \text{Res}, \quad (6)$$

where LH and SH are the latent and sensible surface heat fluxes, respectively, LW and SW are the net longwave and shortwave heating, and Res is the residual when all the other terms on the rhs are subtracted from the lhs. For ease of reference later on, we

Moist entropy (moist static energy) is nearly conserved during the moist adiabatic processes.

- advection terms
- source terms
  - surface latent fluxes (LH)
  - sensible heat fluxes (SL)
  - atmospheric radiative fluxes

NGMS = normalized gross moist stability

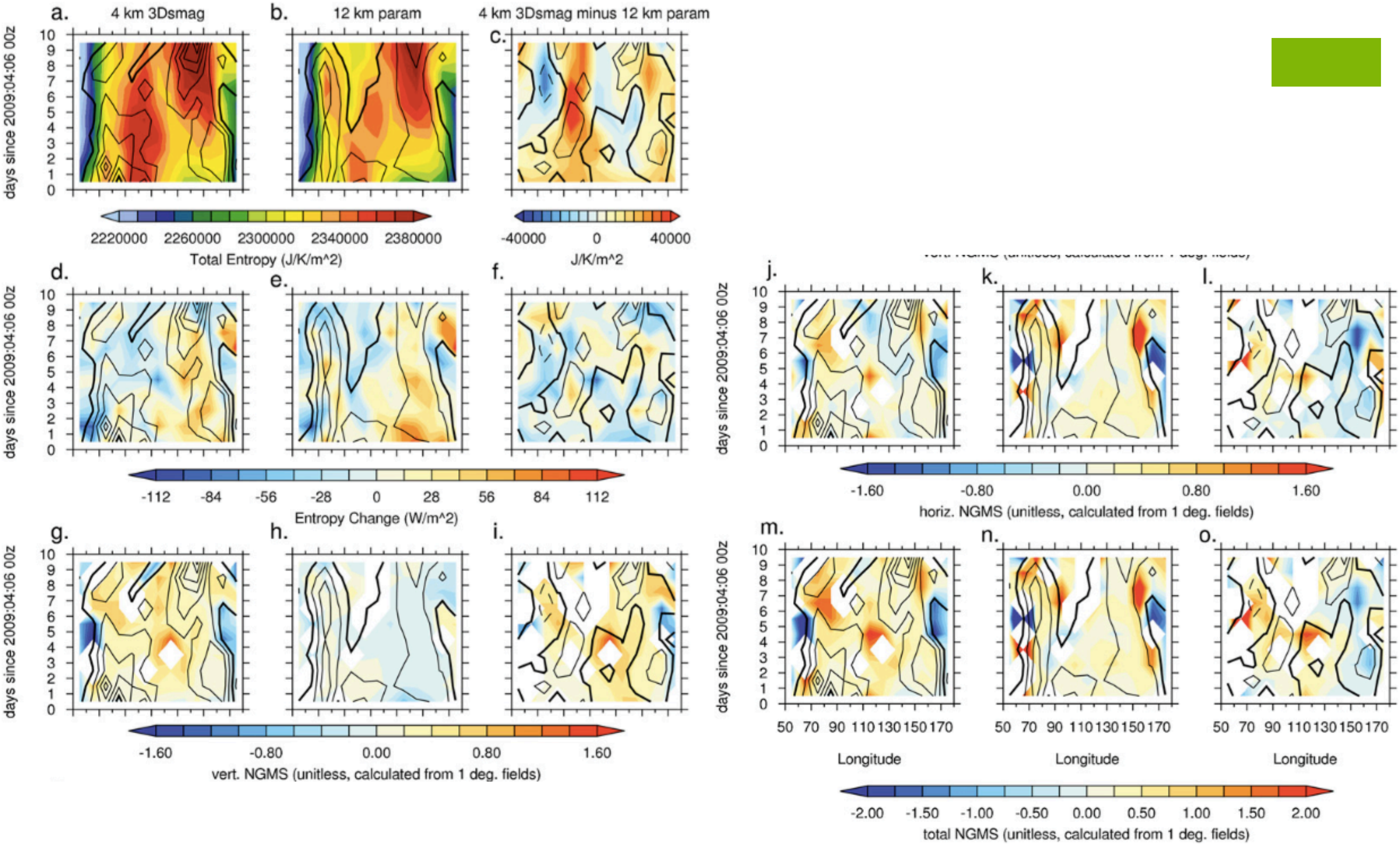


FIG. 8. Daily mean values over sea of (a)–(c) entropy, (d)–(f) entropy change ($\times T_R$), (g)–(i) vertical component of NGMS, (j)–(l) horizontal component of NGMS, and (m)–(o) total NGMS for (left) the 4-km 3Dsmag and (center) the 12-km param runs and for (right) their difference for 10° longitude boxes covering 7.5°S–7.5°N for the 10-day case study. Contour lines are moisture convergence with a thick zero line and dashed negative contours; contour spacing is 150 W m^{-2}. NGMS advection terms are calculated from fields averaged on a 1° grid.

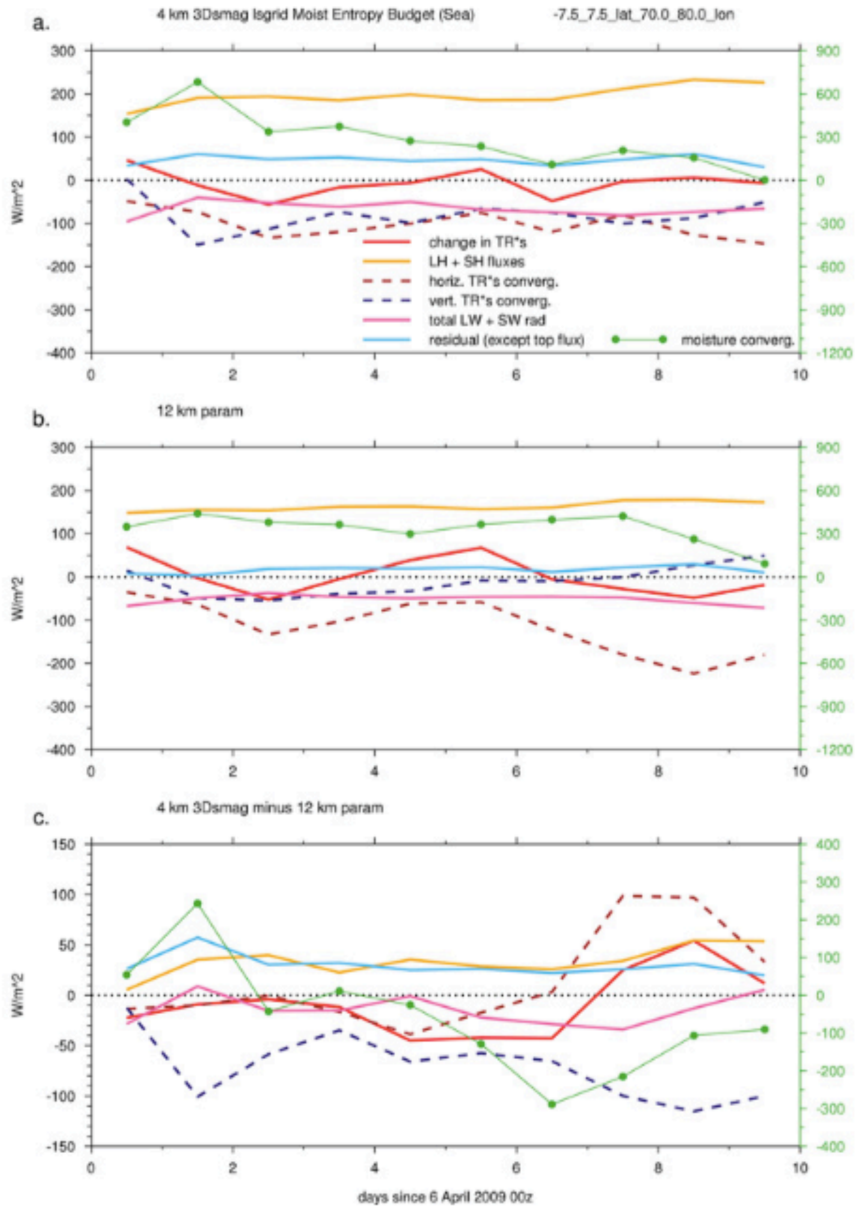


FIG. 9. Daily mean moist entropy ($\times T_R$) budget terms and total MC for (a) the 4-km 3Dsmag model, (b) the 12-km param model, and (c) their difference for a box covering 7.5°S–7.5°N, 70°–80°E for the 10-day case study. The advective terms have been calculated using fields averaged onto a 1° grid.

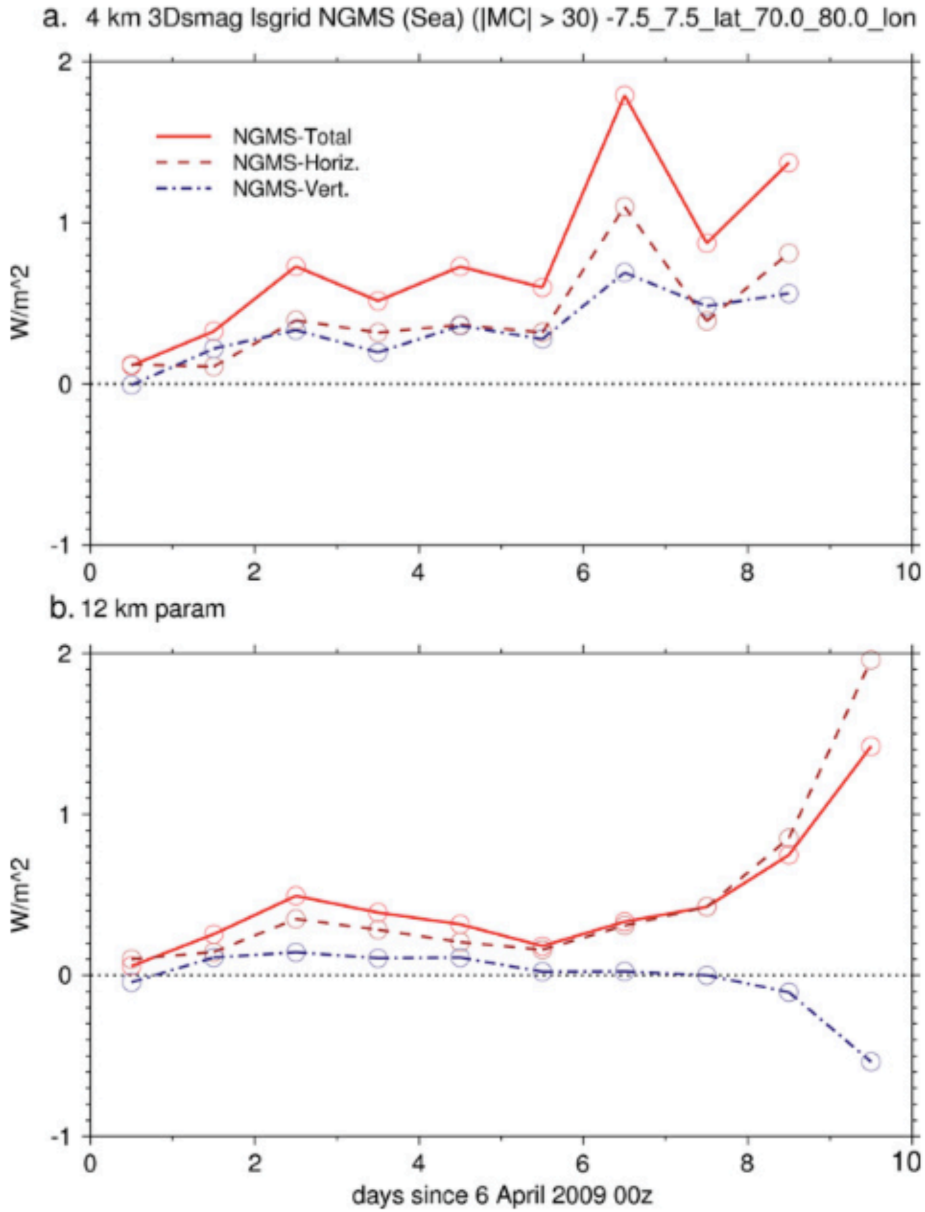


FIG. 10. Daily mean total, horizontal, and vertical NGMS for (a) 4-km 3Dsmag and (b) 12-km param runs, for a box covering 7.5°S–7.5°N, 70°–80°E for the 10-day case study. The advective terms have been calculated using fields averaged onto a 1° grid, and times with MC magnitudes below 30 W m^{-2} are not included.

TABLE 1. Linear regression coefficients m and correlation coefficients r for various moist entropy budget terms (or combinations of terms) from Eq. (6) regressed on MC for MC > 0, along with mean values of these terms normalized by MC (for MC > 30 W m^{-2}) for each model version; the first two rows of values are for the regression of horizontal vs vertical entropy divergence from Fig. 13. Note that the signs of terms including advection are opposite to those in Eq. (6) to be consistent with definitions of NGMS.

	4-km 3Dsmag	12-km 3Dsmag	12-km param	40-km param	12-km 1.5ent	40-km 1.5ent
$T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}]$ vs $T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]$						
m	0.17	0.11	0.00	−0.12	−0.01	−0.03
r	0.30	0.26	−0.01	−0.27	−0.03	−0.08
$T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}]$ vs MC						
Mean Γ_H	0.16	0.21	0.33	0.18	0.37	0.33
m	0.06	0.06	0.10	0.15	0.03	0.04
r	0.19	0.18	0.18	0.32	0.06	0.09
$T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]$ vs MC						
Mean Γ_V	0.64	0.19	−0.09	−0.11	−0.07	−0.13
m	0.10	0.09	0.07	−0.02	0.15	0.12
r	0.54	0.59	0.32	−0.13	0.60	0.53
$T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}] + T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]$ vs MC						
Mean Γ_T	0.54	0.40	0.24	0.07	0.30	0.20
m	0.16	0.15	0.16	0.13	0.18	0.16
r	0.38	0.35	0.28	0.27	0.33	0.29
[LW] + [SW] vs MC						
Mean $-\Gamma_R$	−0.73	−0.51	−0.68	−0.94	−0.48	−0.47
m	0.08	0.08	0.13	0.07	0.14	0.11
r	0.60	0.69	0.76	0.65	0.69	0.67
LH + SH vs MC						
Mean $-\Gamma_{SF}$	1.10	0.82	1.02	0.97	0.94	0.81
m	0.01	−0.01	0.02	0.05	−0.03	0.00
r	0.04	−0.04	0.09	0.26	−0.12	−0.02
$T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]$ − ([LW] + [SW]) vs MC						
Mean $\Gamma_V + \Gamma_R$	1.11	0.70	0.59	0.83	0.41	0.34
m	0.03	0.01	−0.06	−0.10	0.01	0.01
r	0.18	0.10	−0.32	−0.52	0.06	0.03
$T_R[\rho\overline{\mathbf{v}} \cdot \nabla\overline{s}] + T_R[\rho\overline{w}(\partial\overline{s}/\partial z)]$ − ([LW] + [SW]) vs MC						
Mean $\Gamma_T + \Gamma_R$	1.27	0.91	0.92	1.01	0.79	0.66
m	0.09	0.07	0.04	0.06	0.04	0.05
r	0.24	0.20	0.07	0.14	0.09	0.10
$T_R[\partial\overline{s}/\partial t]$ vs MC						
Mean $\Gamma_{\overline{s}_t}$	0.04	0.05	0.12	0.06	0.22	0.20
m	0.01	−0.01	0.03	0.03	−0.03	−0.02
r	0.04	−0.02	0.07	0.10	−0.09	−0.05

Upper: Fig 13 / Bottom: Fig8 (B14)

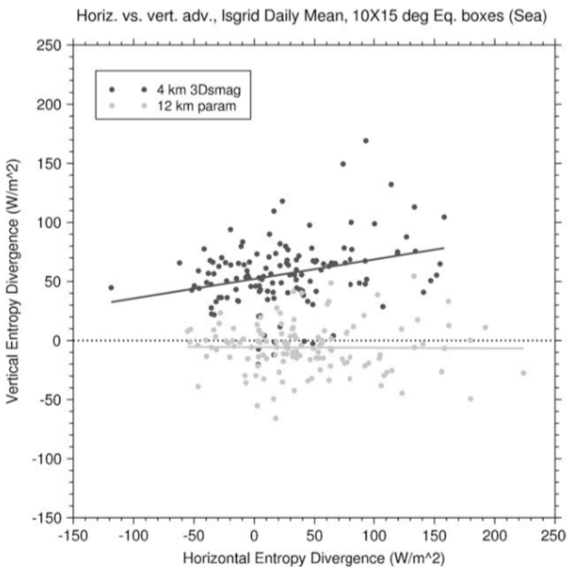
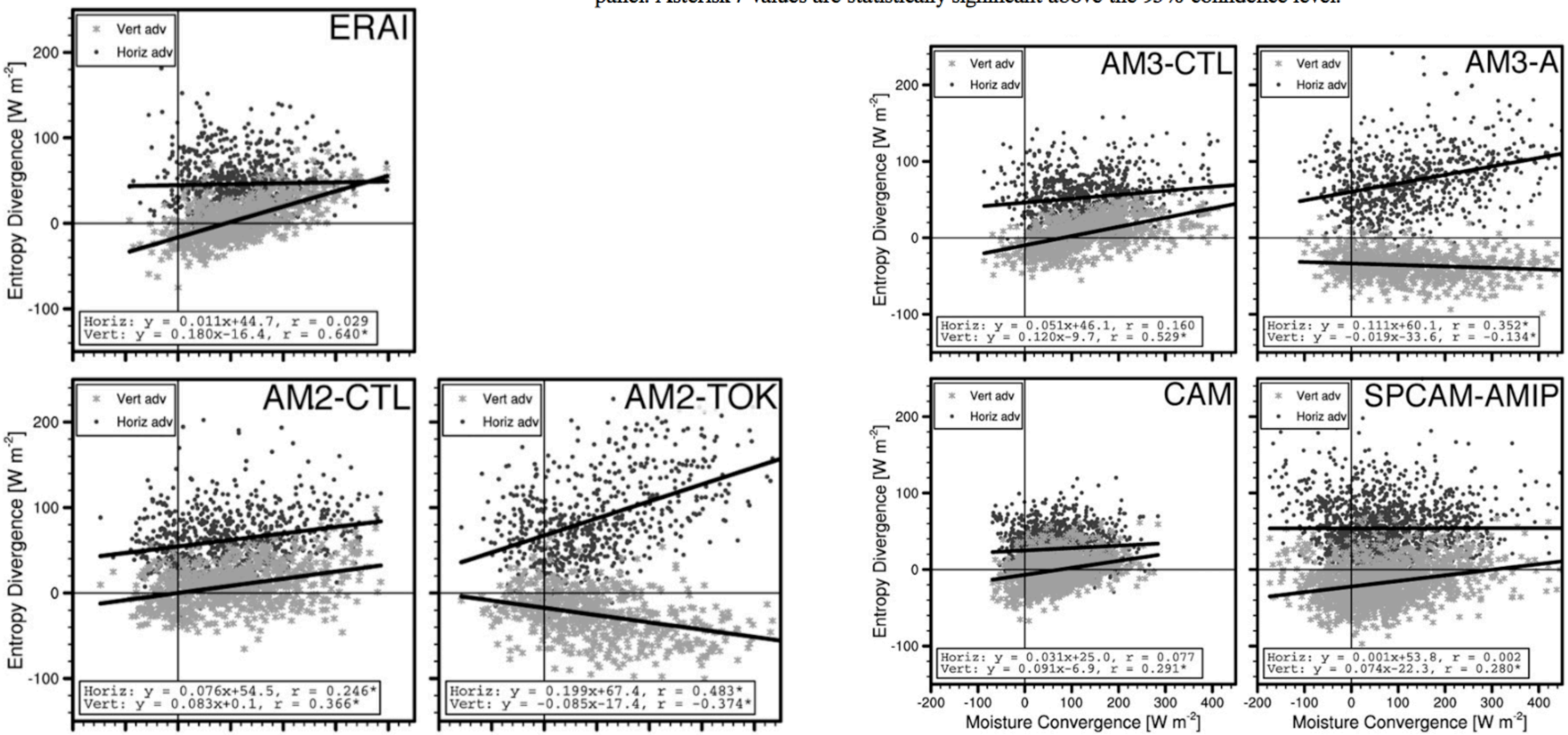


FIG. 13. Horizontal vs vertical advective terms for 4-km 3Dsmag and 12-km param runs for 10° longitude boxes covering 7.5°S–7.5°N and daily means over sea for the 10-day case study. The advective terms have been calculated using fields averaged onto a 1° grid. Linear regression fit shown for all values (solid), with regression and correlation coefficients shown in Table 1.

FIG. 8. Horizontal (dark bullets) and vertical (asterisks) advective components of vertically integrated moist entropy divergence vs VIMC averaged over the east Indian Ocean region during boreal winter. Conditional sampling has been done to include only times when the 91-day windowed variance of a precipitation index is greater than its winter average value. Land points are omitted from the spatial averages. Each point represents a single day. Thick black best-fit lines are overlaid, and the corresponding equations and correlation coefficients *r* appear at the bottom of each panel. Asterisk *r* values are statistically significant above the 95% confidence level.



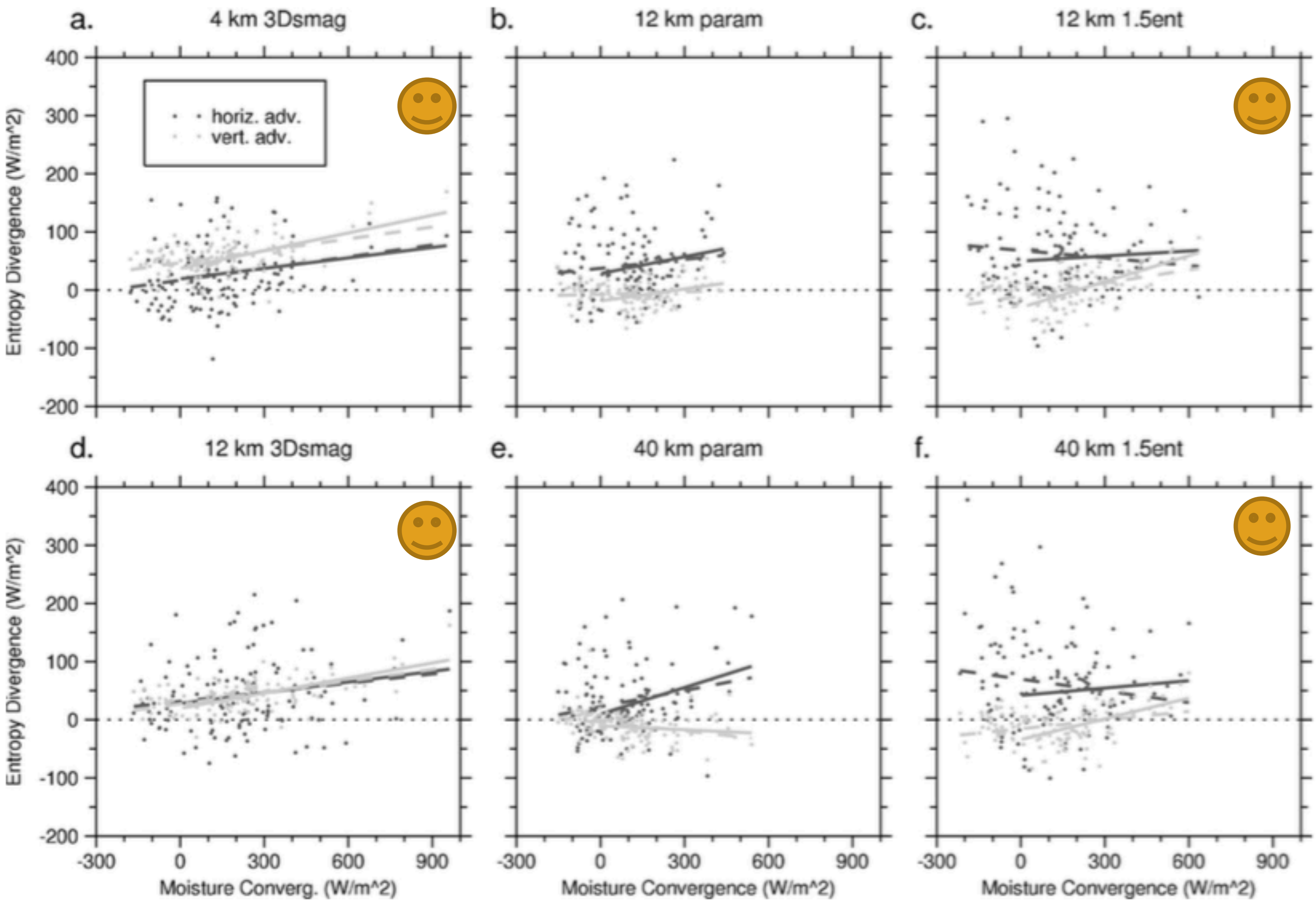


FIG. 14. Horizontal (black) and vertical (gray) advective terms plotted against MC for (a) the 4-km 3Dsmag, (b) the 12-km param, (c) the 12-km 1.5ent, (d) the 12-km 3Dsmag, (e) the 40-km param, and (f) the 40-km 1.5ent models for 10°-longitude boxes covering 7.5°S–7.5°N and daily means over sea for the 10-day case study. The advective terms have been calculated using fields averaged onto a 1° grid. Linear regression fit shown for all values (dashed) and for only values with positive MC (solid), with regression and correlation coefficients and mean Γ_H and Γ_V for positive MC shown in Table 1 (and for all values in Table S1).

Summary

- 4km-explicit
  - Top-heavy heating profile
  - Higher vertical component of NGMS
  - Increasing normalized heating between 0-4 km.
  - Better connection between MC and vertical component of NGMS.
- 12km-parameterization
  - Too much light rain
  - Less propagation
  - Lower vertical component of NGMS