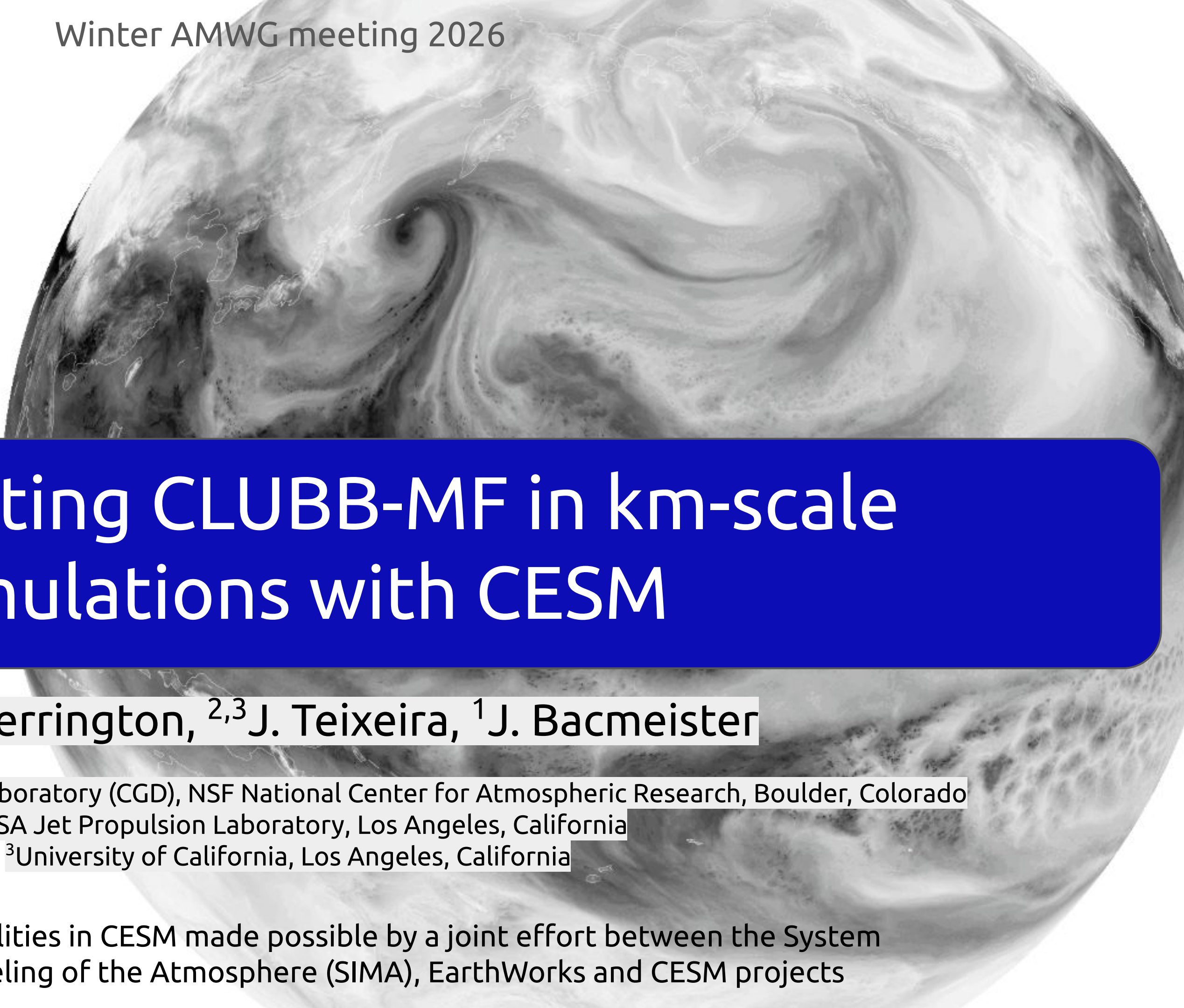


Winter AMWG meeting 2026

Incorporating CLUBB-MF in km-scale simulations with CESM

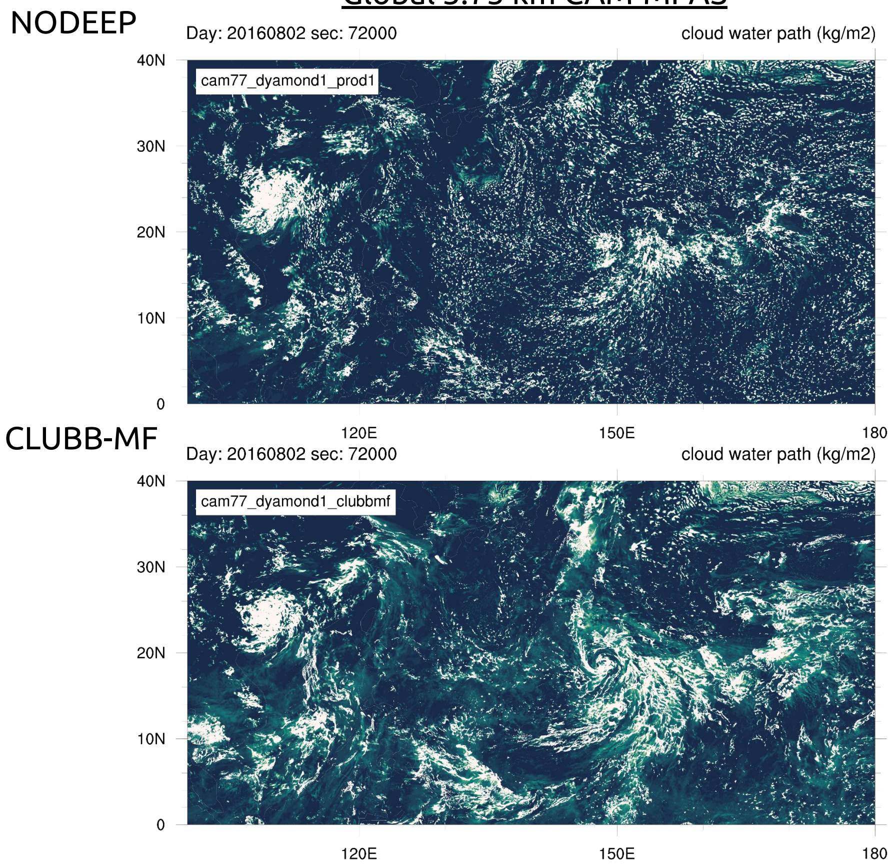
[1]Adam Herrington, [2,3]J. Teixeira, [1]J. Bacmeister

[1]Climate and Global Dynamics Laboratory (CGD), NSF National Center for Atmospheric Research, Boulder, Colorado
[2]NASA Jet Propulsion Laboratory, Los Angeles, California
[3]University of California, Los Angeles, California

Kilometer-scale capabilities in CESM made possible by a joint effort between the System for Integrated Modeling of the Atmosphere (SIMA), EarthWorks and CESM projects

More parameterized convection?

Global 3.75 km CAM-MPAS



In NODEEP, CLUBB is the only convection scheme active (CAM's deep scheme is off)

Incorporating CLUBB-MF results in less 'patchy' convection and a more realistic spectrum of clouds

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Eddy diffusivity mass flux (EDMF) and CLUBB-MF

EDMF

(Suselj, Teixeira & Chung, JAS, 2013)
(Suselj, Kurowski & Teixeira, JAS 2019)

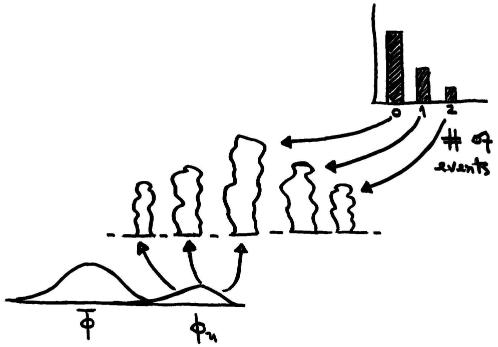
$$\overline{w'\varphi'} = -k\frac{\partial\overline{\varphi}}{\partial z} + M(\varphi_u - \overline{\varphi})$$

CLUBB-MF

(Witte et al. 2022, Teixeira et al. in prep)

$$\overline{w'\varphi'} = \overline{w'\varphi'}_{CLUBB} + M(\varphi_u - \overline{\varphi})$$

Explicit ensemble of mass flux plumes (ϕ_u) undergo stochastic lateral entrainment



Mean entrainment rate determined by a time-space varying entrainment length scale L_ε, spanning dry PBL, shallow, mid-level and deep convective regimes

$$\varepsilon_{u_n}(\Delta z) = \frac{\varepsilon_0}{\Delta z}\mathscr{P}\left(\frac{\Delta z}{L_\varepsilon}\right)$$

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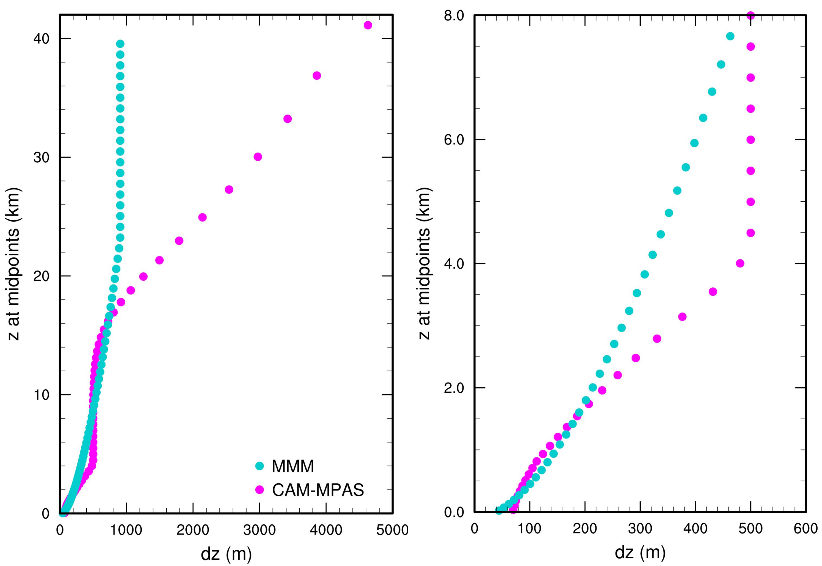
DYAMOND1 Simulations

DYAMOND: **DY**namics of the **A**tmospheric general circulation **M**odeled **O**n **N**on-hydrostatic **D**omains

Three global 3.75 km MPAS DYAMOND1* runs:

- **NODEEP**: CAM-MPAS, 58 vertical levels
  - CAM7 physics, deep scheme (ZM) off
  - Convection scheme: CLUBB
- **CLUBB-MF**: CAM-MPAS, 58 vertical levels
  - CAM7 physics, deep scheme (ZM) off
  - Convection scheme: CLUBB-MF
- **MMM**: MPAS-A standalone, 75 vertical levels
  - MMM Convection Permitting Suite
  - Convection scheme: Tiedke shallow/mid-level
  - Courtesy of Falko Judt

Vertical grid comparison



*DYAMOND1 – 08-01-2016 through 09-10-2016 (40 days; Stevens et al. 2019)

Tracking Clouds

Data:

GPM_MERGIR IR brightness temperature from NOAA* half hourly, 4 km grid, near global coverage (60S-60N)

Method:

Christensen and Driver (2021) estimate cloud top IR brightness temperature (Tct) as:

- OLR = a*Trad + b (De Guélis et al.,2017)
- Trad = c*Tct + d (from ICON)

VIZ click here

TempestExtremes (Ullrich et al. 2021) to track clouds:

- Cloud objects defined as Tct < 230 K
- Tropical domain 30S-30N

*John Janowiak, Bob Joyce, Pingping Xie (2017): https://disc.gsfc.nasa.gov/datasets/GPM_MERGIR_1/summary

Merged from the European, Japanese, and U.S. geostationary satellites over the period of record (GOES-8/9/10/11/12/13/14/15/16/17/18/19, METEOSAT-5/7/8/9/10/11, and GMS-5/MTSat-1R/2/Himawari-8/9)

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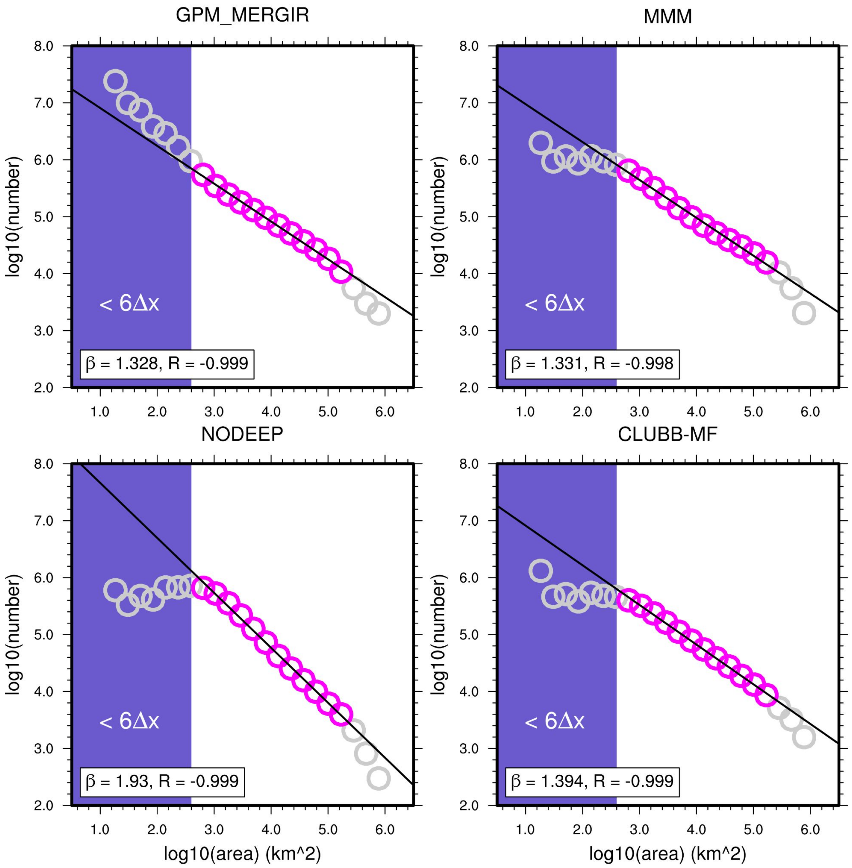
Cloud area-number relationship in the Tropics

Cloud area-number distribution fitted to a power law $n(A) = \alpha A^{-\beta/2}$

Slopes in CLUBB+MF & MMM similar to OBS, NODEEP is too steep: $\beta \sim 2$

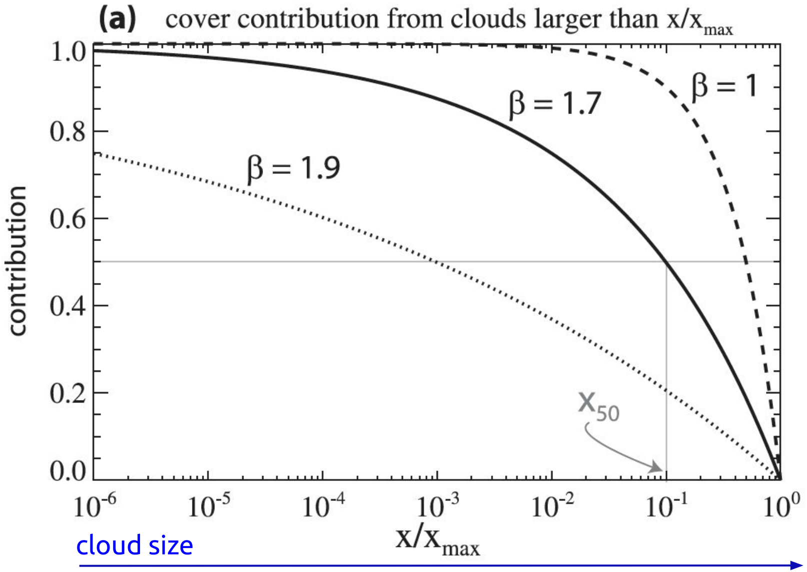


Cloud coverage

Cloud area-number distribution fitted to a power law $n(A) = \alpha A^{-\beta/2}$

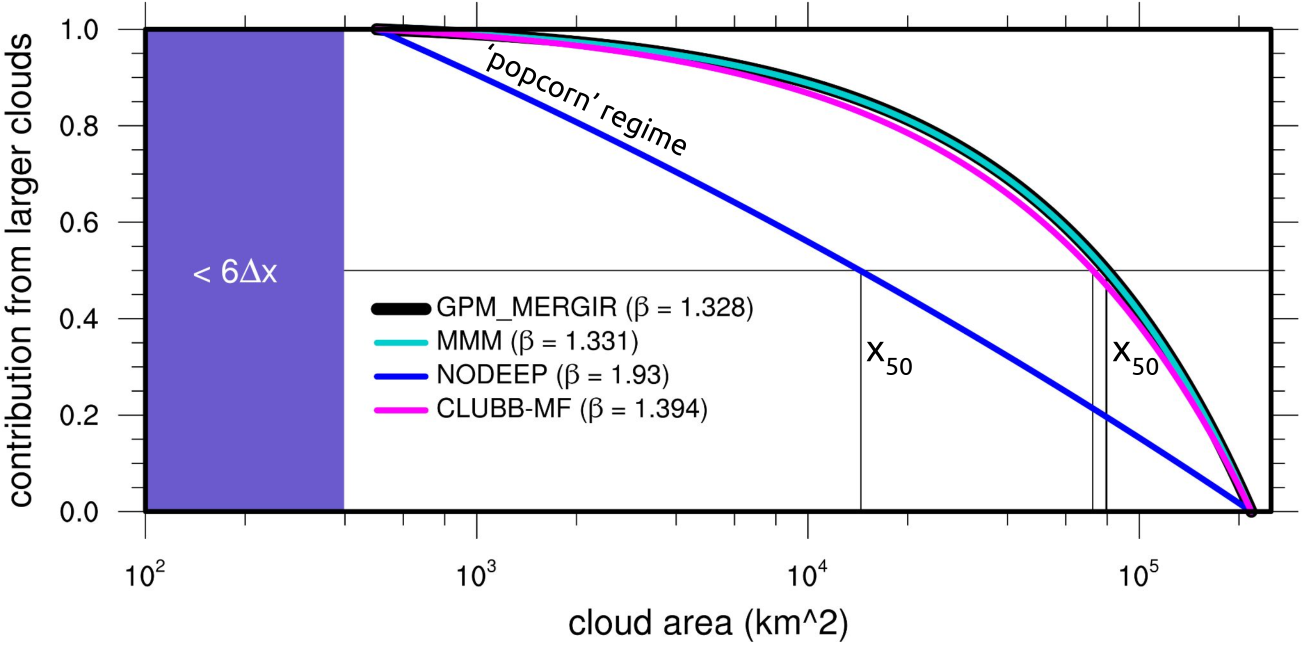
Total cloud cover contribution as a function of cloud area bin can be expressed as:

$$C(x) = \frac{1 - (x/x_{max})^{2-\beta}}{1 - (x_{min}/x_{max})^{2-\beta}}.$$



Wood and Field 2011

Tropical cloud coverage



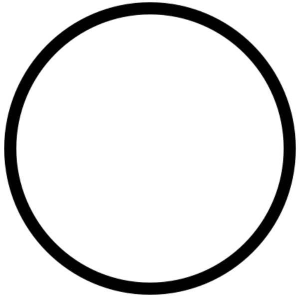
Useful tool for determining whether the size of clouds are realistic in models

Cloud area-perimeter relationship

Area-perimeter relationship quantifies the ‘crinkliness’ of clouds

$P = \alpha A^{D/2}$ where D = is the fractal dimension

Circle



D = 1

Koch Snowflake

D = 1.26

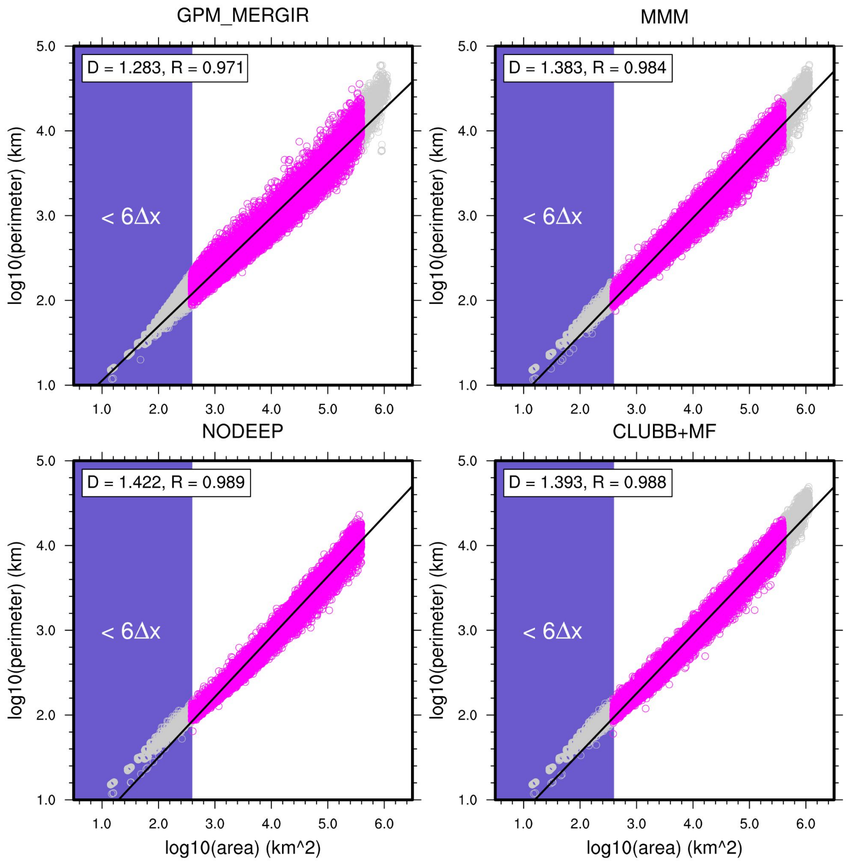
Area-perimeter relationships in the Tropics

$P = \alpha A^{D/2}$

D = fractal dimension

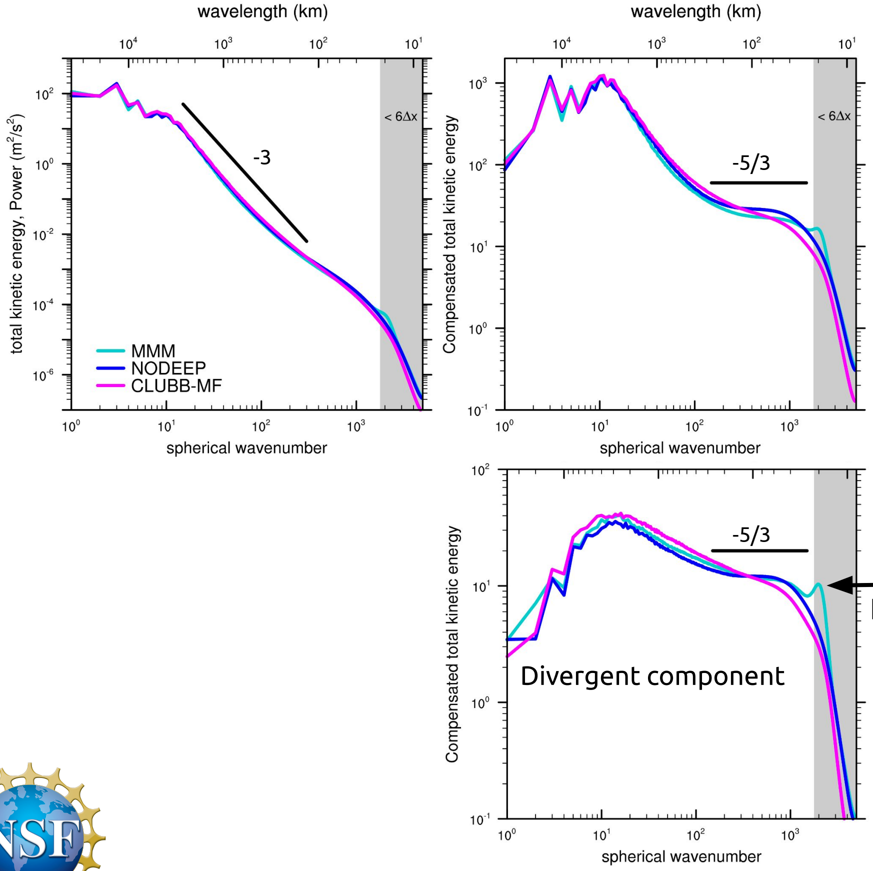
(for circular objects, D=1)

For OBS, D=1.28, whereas CLUBB-MF & MMM are 1.39 & 1.38, respectively. NODEEP has largest value D=1.42



See Christensen and Driver (2021) for D values from several other DYAMOND models

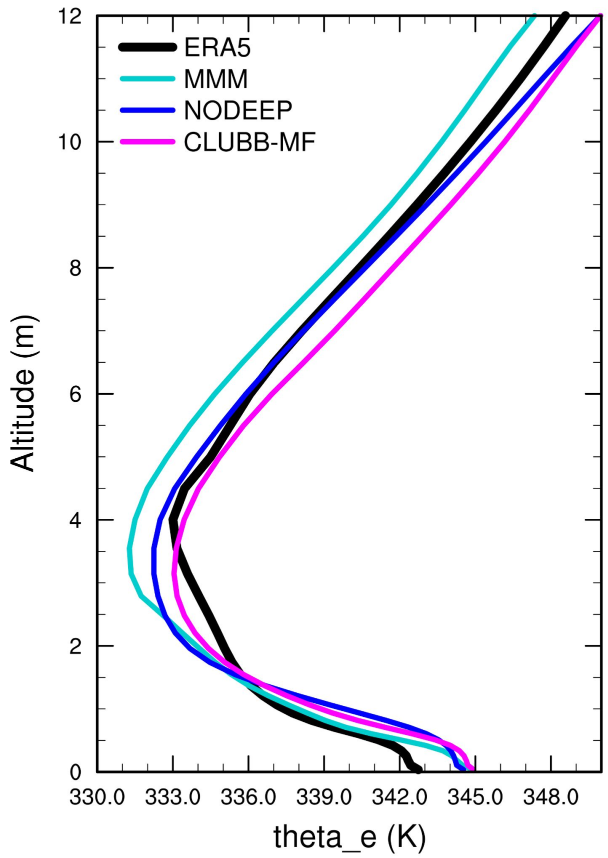
200 hPa kinetic energy spectrum



Energy build up in MMM

NODEEP & MMM have more realistic energetic scaling at the mesoscale due to greater resolved divergence (more "permitted" convection than CLUBB-MF)

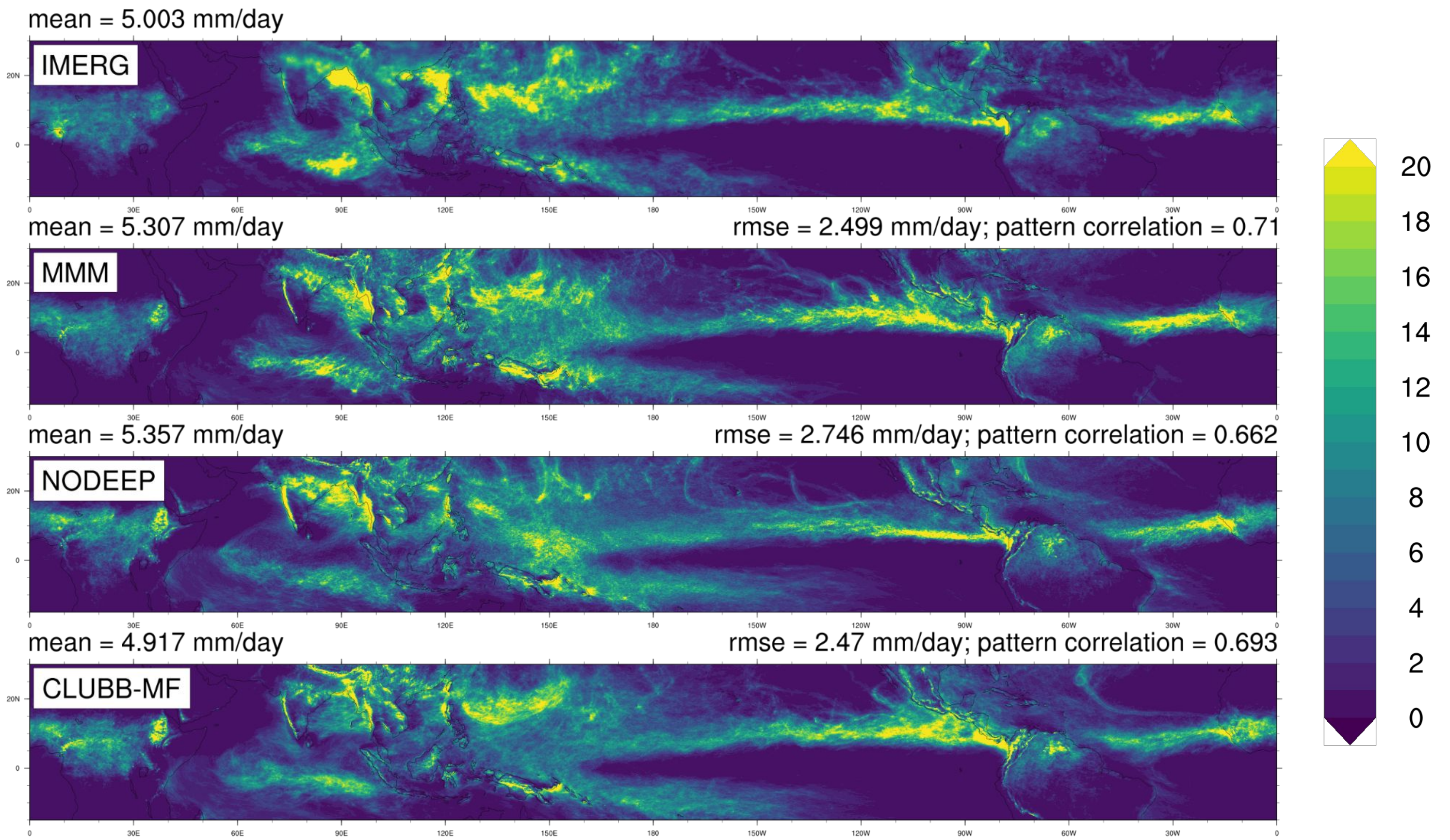
Equivalent potential temperature (5N-15N; ocean only)



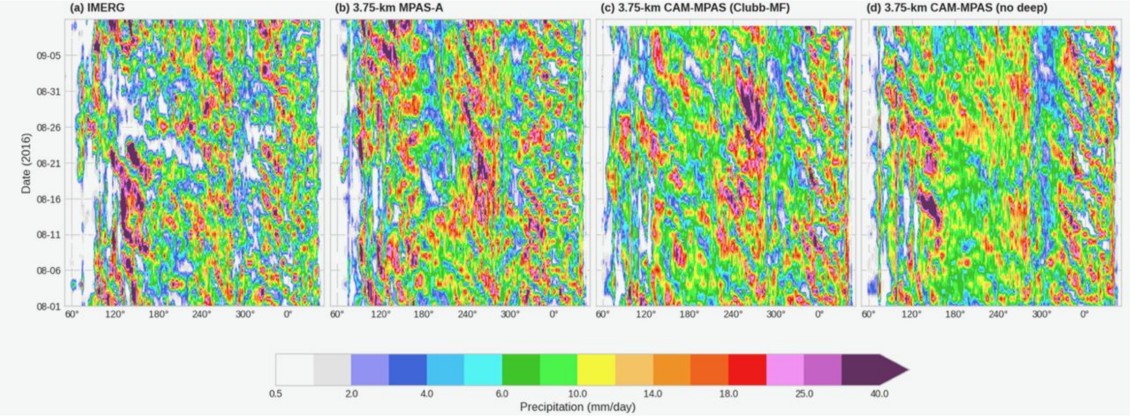
MMM theta_e minimum shifted upwards relative to CAM–MPAS, has cooler and drier troposphere compared to ERA5. NODEEP too stable aloft, CLUBB+MF warmer than ERA5

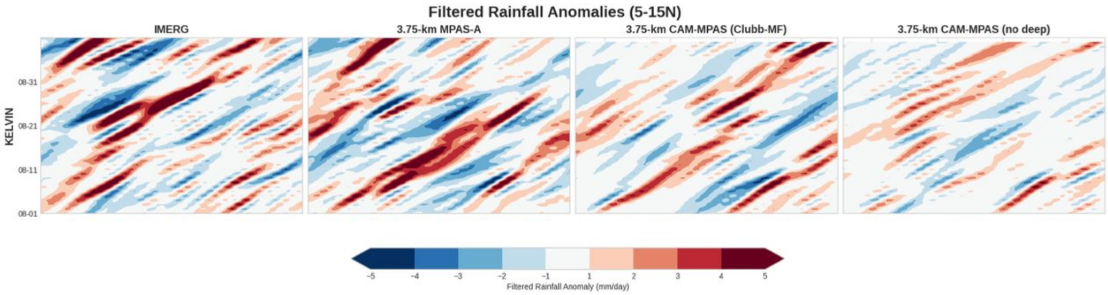
Tropical Precipitation (40 day mean)

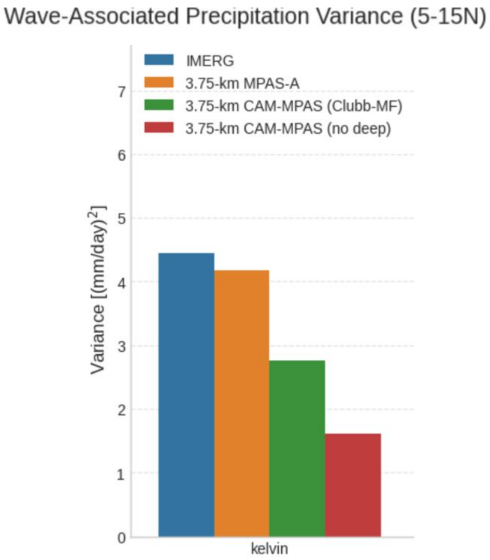
Pattern correlations and RMSE improved in CLUBB-MF over NODEEP, similar to MMM.



Kelvin Waves (5N-15N)

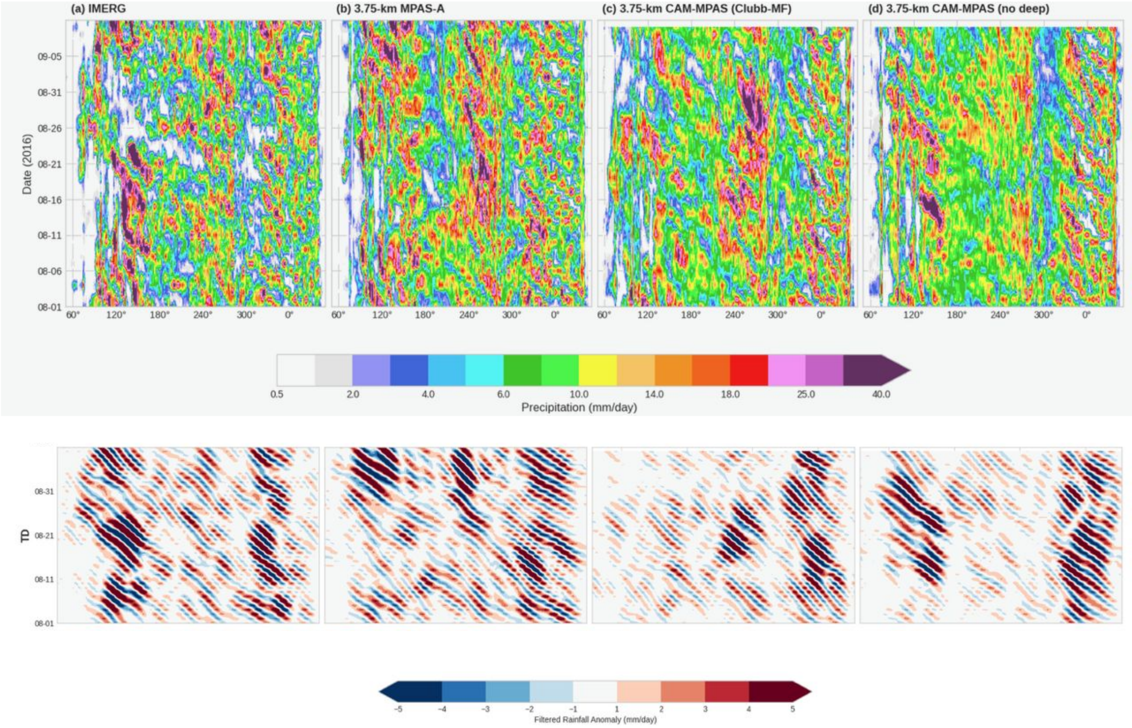


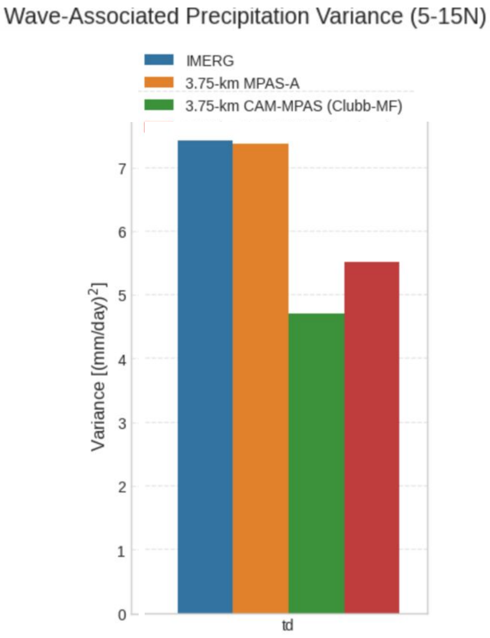




Courtesy of Falko Judt

Tropical Depressions (African Easterly Waves; 5N-15N)

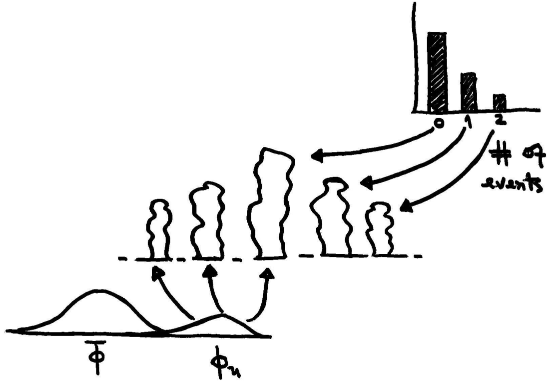




Courtesy of Falko Judt

CLUBB-MF

- Eddy diffusivity represents mixing by small-scale turbulence
- Mass flux plumes represent mixing due to asymmetric turbulence
  - Explicit ensemble initialized by sampling PDF (derived from host model sfc fluxes)
  - Individual plumes undergo stochastic lateral entrainment
  - Entrainment length-scale (L_ε) dynamic in time-space
    - Small L_ε = dry boundary layer convection, moist shallow convection
    - Medium L_ε = mid-level convection (trade cumulus, congestus)
    - Large L_ε = deep convection
- CLUBB-MF: replace eddy diffusivity with prognostic turbulence
  - Cloud Layers Unified by Binormals (Golaz et al. 2002; Larson and Golaz 2005)



EDMF

(Suselj, Teixeira & Chung, JAS, 2013)
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$$\overline{w'\varphi'} = -k\frac{\partial\bar{\varphi}}{\partial z} + M(\varphi_u - \bar{\varphi})$$

CLUBB+MF

(Witte et al. 2022)

$$\overline{w'\varphi'} = \overline{w'\varphi'}_{CLUBB} + M(\varphi_u - \bar{\varphi})$$

Lateral Entrainment

(Romps & Kuang 2009)

$$\varepsilon_{u_n}(\Delta z) = \frac{\varepsilon_0}{\Delta z}\mathscr{P}\left(\frac{\Delta z}{L_\varepsilon}\right)$$

NSF

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Cloud area-perimeter relationship

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$P = \alpha A^{D/2}$ where D = is the fractal dimension

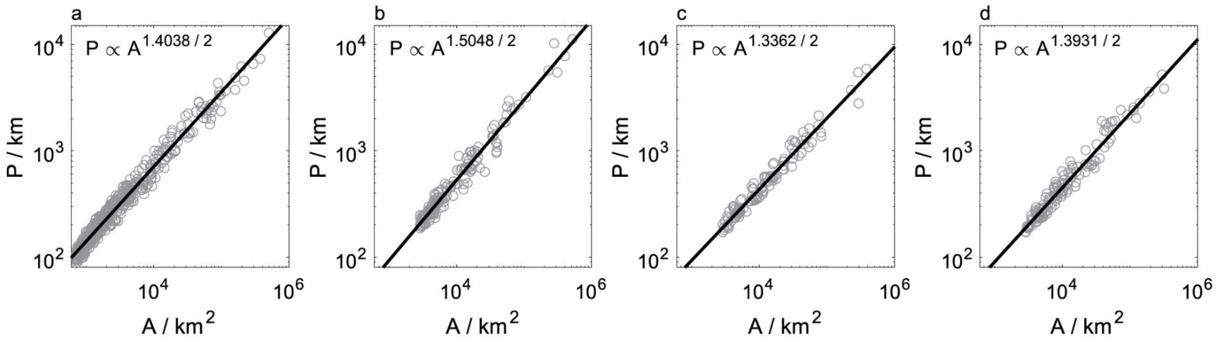

Figure 1. Cloud object perimeter as a function of area for (a) Himawari satellite data, and for (b) ICON 2.5 km, (c) IFS 4.8 km, and (d) NICAM 3.5 km simulations. The data correspond to fields at 0200 UTC on 11 August 2016, using $T_{CT} = 230$ K.

Christensen and Driver (2021)

Tropical Precipitation (40 day mean)

Pattern correlations and RMSE improved in CLUBB-MF over NODEEP, not quite as good as MMM.