Three Dimensional Structure of Convectively Coupled Equatorial Waves in MPAS-Atmosphere

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With many thanks to George Bryan, Brian Medeiros, Falko Judt, Wei Wang, NCAR MMM, and NCAR CISL

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Tropical convection: important, yet poorly predicted

- Tropical rainfall is an important component of the global hydrological cycle
- Many communities in the tropics are incredibly sensitive to tropical rainfall *variability*, which can be critical for their economy or disastrous to their communities

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courtesy of EOS

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courtesy of EOS

courtesy of SciDevNet

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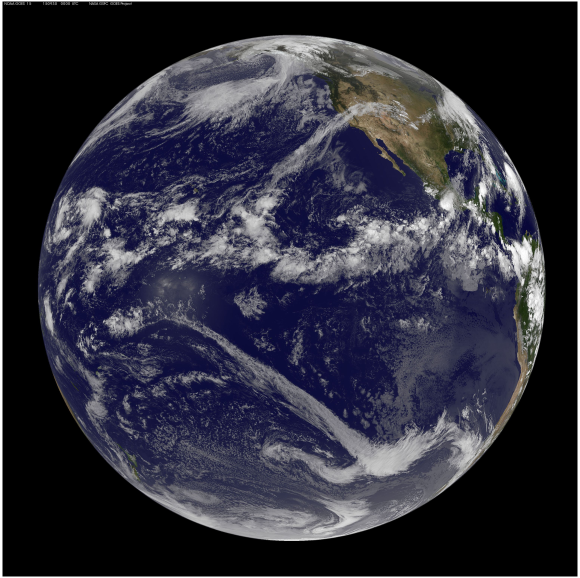
"We have **difficulties with reliable representations** of tropical convection in our global weather/climate models, partly because of the **complex hierarchy of interacting scales, processes, and phenomena**"

Moncrieff et al. 2012, BAMS



courtesy of NASA

Tropical convection: modeling challenges

- Double ITCZ problem
  (e.g., Mechoso et al., 1995; Hwang and Frierson 2020)
- **Poor representation of equatorial waves and MJO** (e.g., Straub et al. 2010, Dias et al. 2018)
- Too much light rain too frequently
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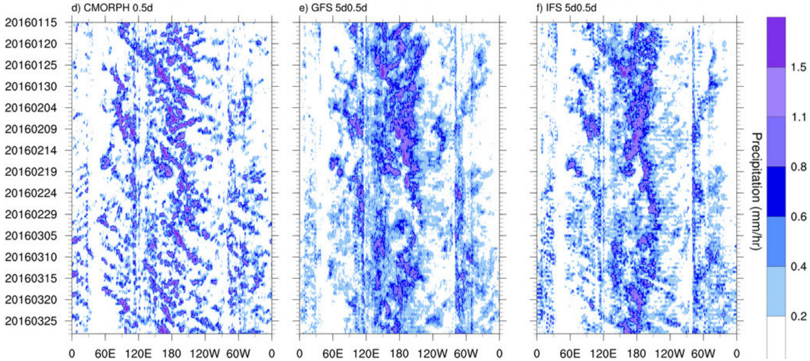

Dias et al. (2018), MWR

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These issues are believed to stem, at least partially, from:

- deficiencies in the **convection parameterizations**,
- **poor knowledge about multi-scale interactions** in the tropics

motivating questions

1. Can **explicitly resolved deep convection** alleviate some of the modeling issues regarding tropical rainfall?

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approach

modeling experiments using MPAS-A

Rios-Berrios, et al. (2020), JAMES

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Rios-Berrios, et al. (2020), JAMES

analysis

comparison of equatorial waves with resolved or parameterized convection

Judt and Rios-Berrios (2021),

Rios-Berrios et al., revised for *JAMES*

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Equatorial waves in a simplified yet realistic framework

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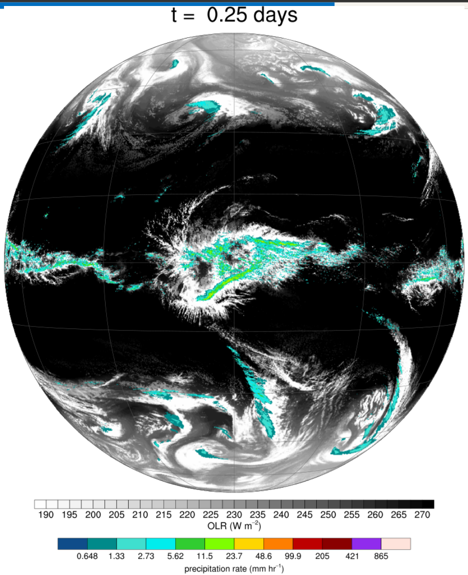

MPAS
Model for Prediction Across Scales

Earth-like aquaplanet

- × land
- × sea-ice
- × seasons
- ✓ diurnal cycle
- ✓ rotation
- ✓ meridional ΔSST

Model physics from the real world

WSM6 microphysics | YSU PBL | RRTMG radiation | scale-aware Tiedtke cumulus*

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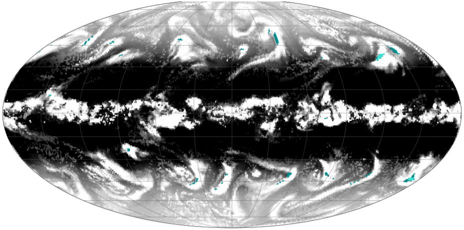
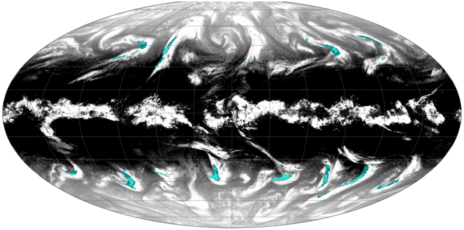
A hierarchy of experiments

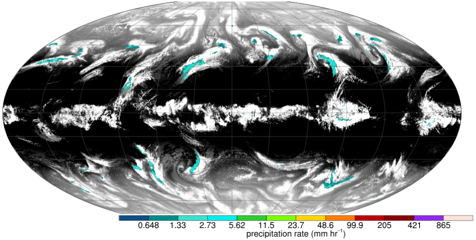
120-km cell spacing



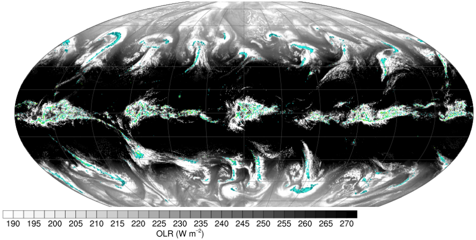
30-km cell spacing



15-km cell spacing



3-km cell spacing (in the tropics)



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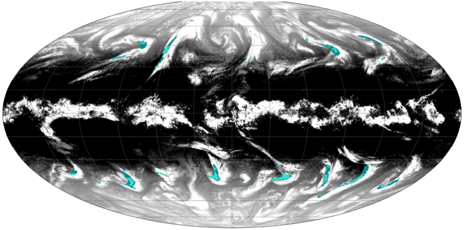
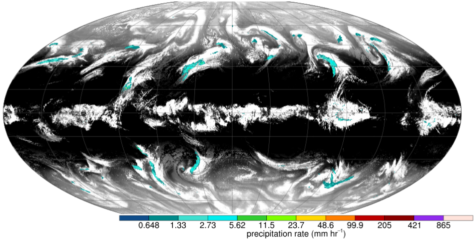
A hierarchy of experiments

Analysis based on the
last 100 simulation days

30-km cell spacing



15-km cell spacing



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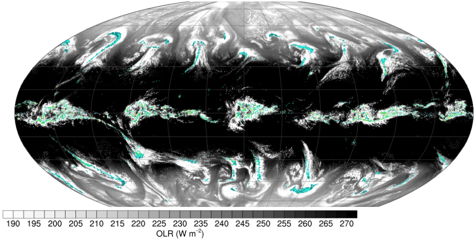

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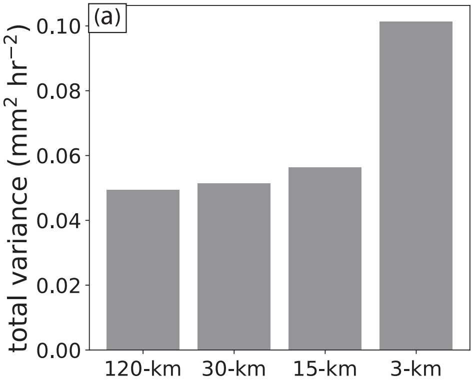
Resolved deep convection captures more tropical rainfall variability



Rios-Berrios et al., revised for JAMES

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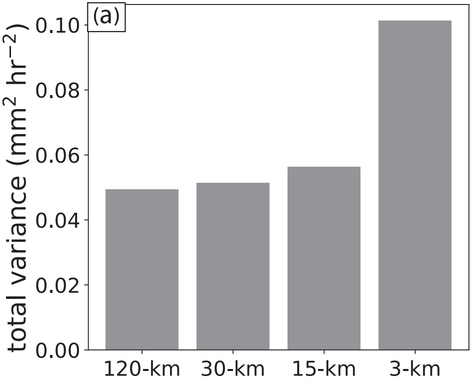

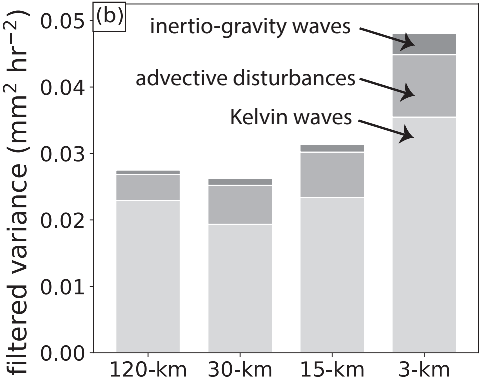

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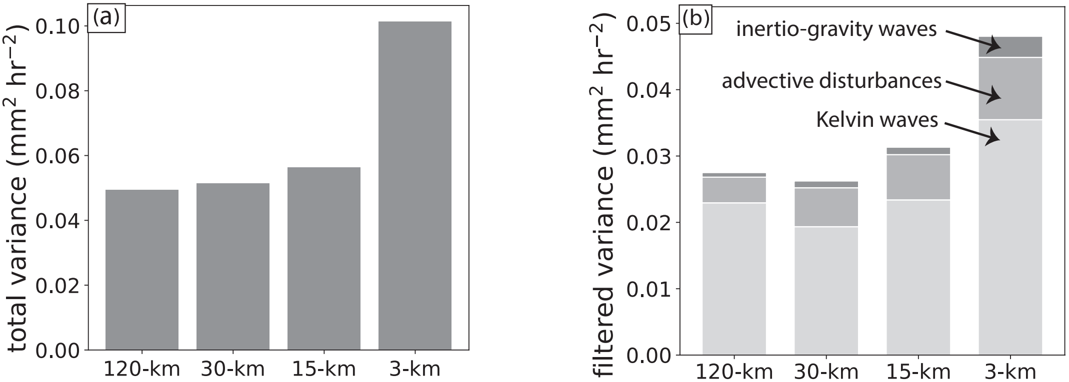

Rios-Berrios et al., revised for JAMES

These results are consistent with real-data forecasts (Judt and Rios-Berrios 2021)

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All experiments capture the overall rainfall structure, but the waves are stronger when deep convection is resolved

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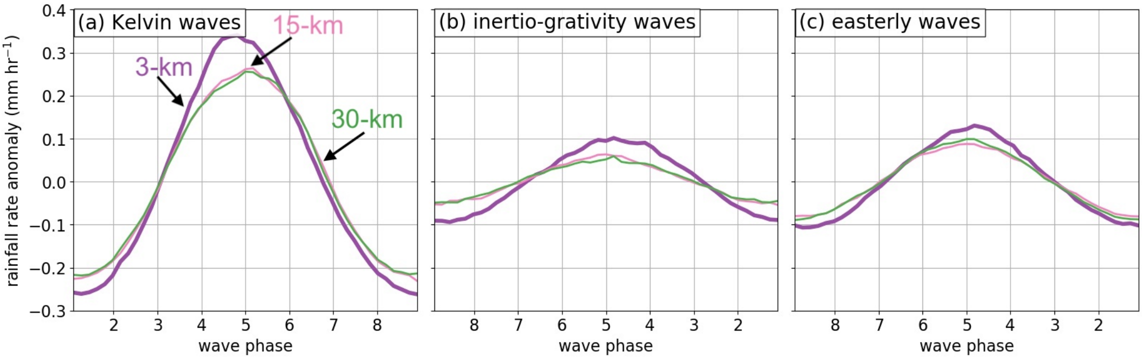

Rios-Berrios et al., in prep for J. Climate

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Hypothesis:
different wave-relative rainfall rates result from differences in the vertical structure of the waves

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$$\text{rainfall rate} \approx -\epsilon q_v \omega_{up}$$

ϵ: precipitation efficiency
q_v: specific humidity
ω_{up} : *upward* vertical velocity

Doswell (1996)

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Doswell (1996)

Analysis:

- compare the wave-relative vertical structure of q_v and ω
- compare against reanalysis (ERA5) for waves only in the Pacific Ocean

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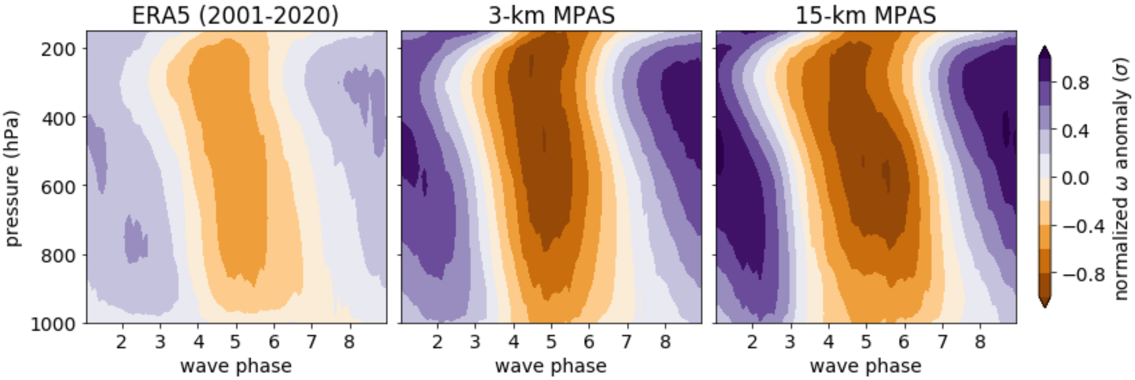
Composite vertical velocity (ω) for Kelvin waves



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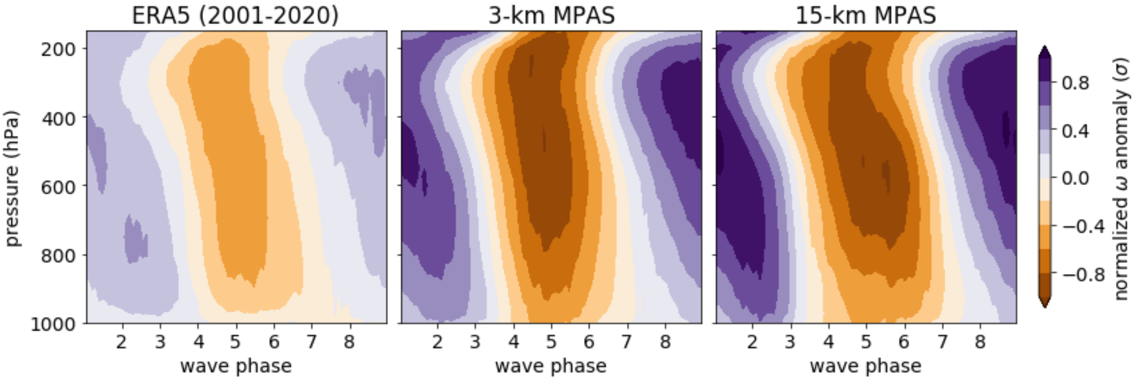

Overall consistent structure between ERA5 and MPAS,
but much stronger ascent and descent in the 3-km experiment

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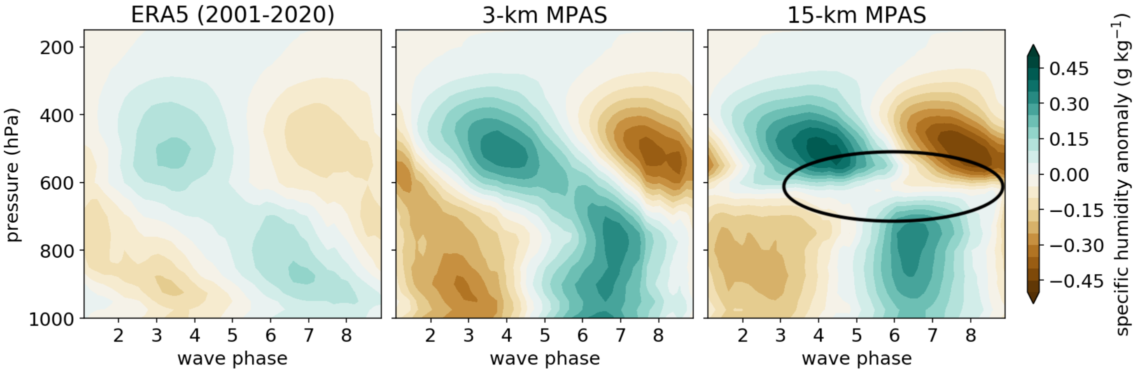
Composite specific humidity (q_v) for Kelvin waves



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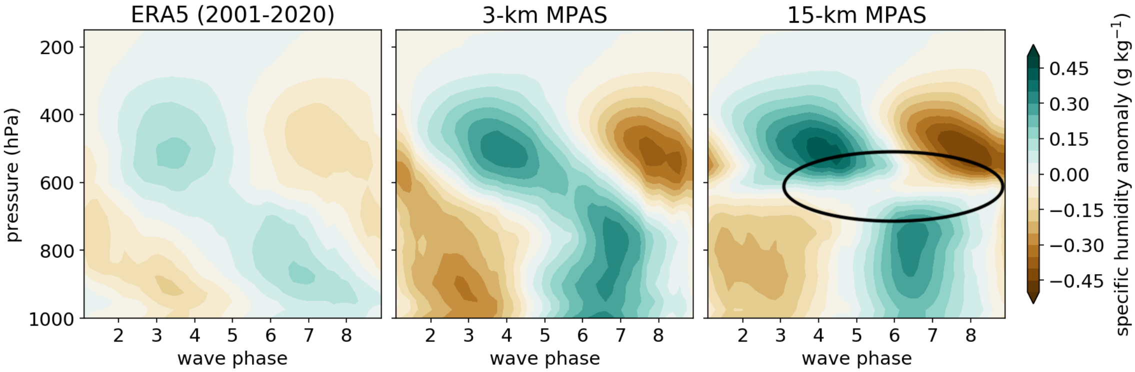

Overall consistent structure between ERA5 and MPAS,
but dry layer present in the 15-km (and 30-km) experiments

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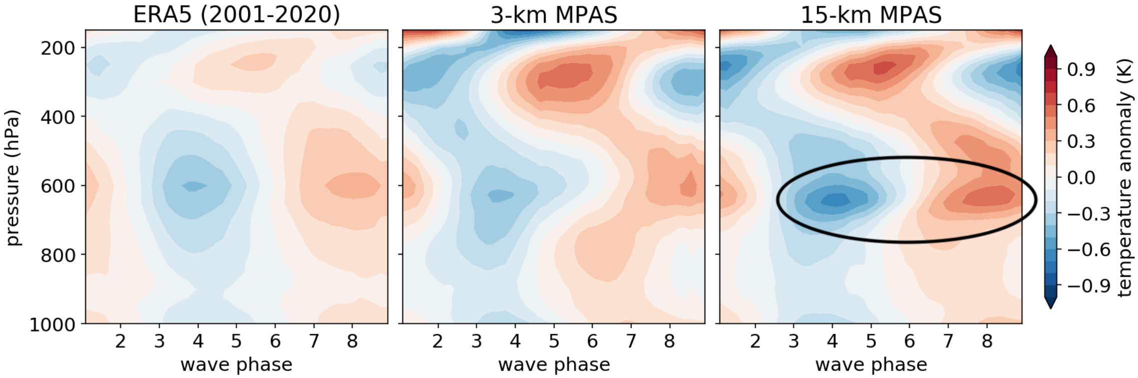
Composite temperature for Kelvin waves



Stronger temperature anomalies also present in the 15-km (and 30-km) experiment

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Potential explanation: different heating profiles, especially near and below the *melting level*

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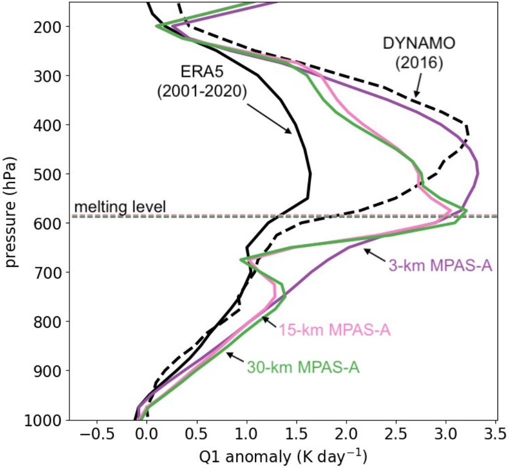
Kelvin waves



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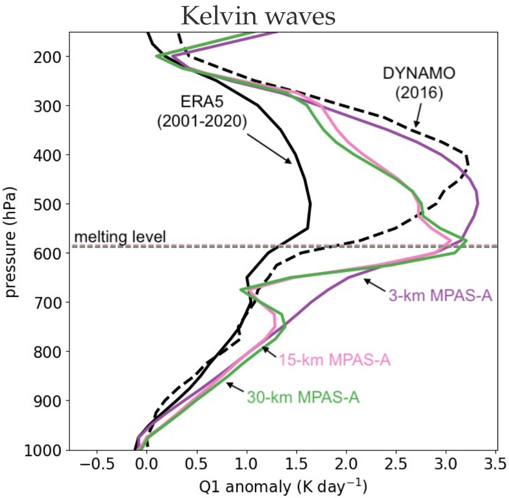

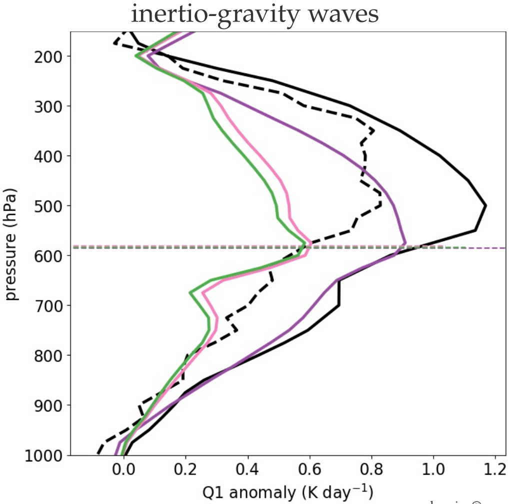

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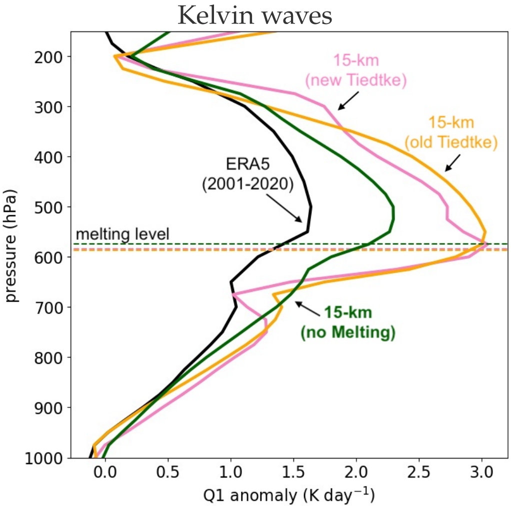
Parameterized melting in the *new* Tiedtke scheme affects the vertical structure of heating/cooling



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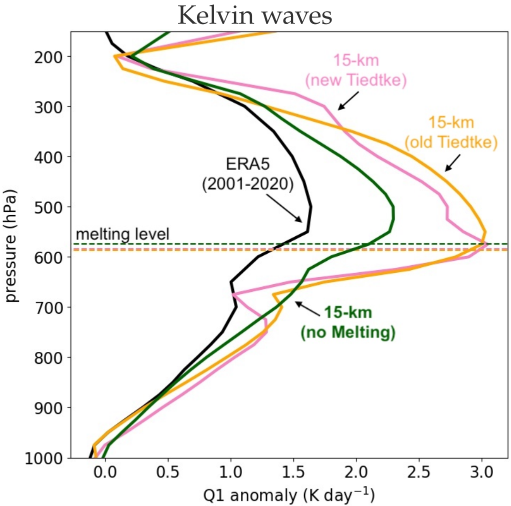

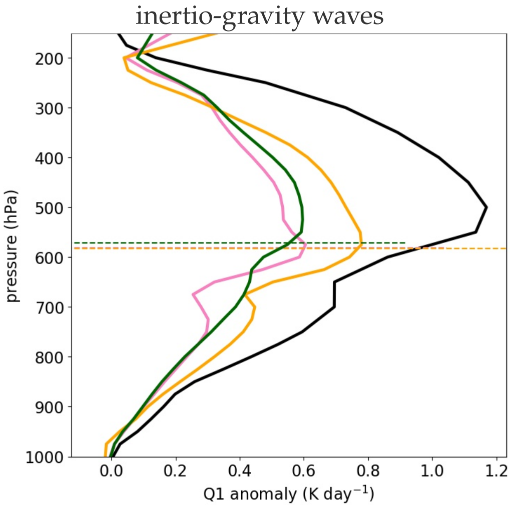

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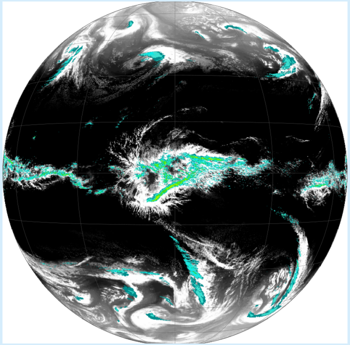
approach



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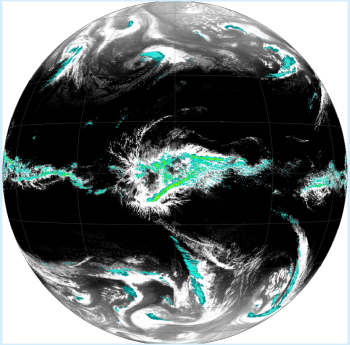

results

- Resolved deep convection (with WSM6+YSU) captures:
  - more tropical rainfall variability
  - stronger equatorial waves
  - more accurate vertical structure
- Processes around the melting level seem critical

****These results are also valid for real-data simulations (i.e., DYAMOND).****

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