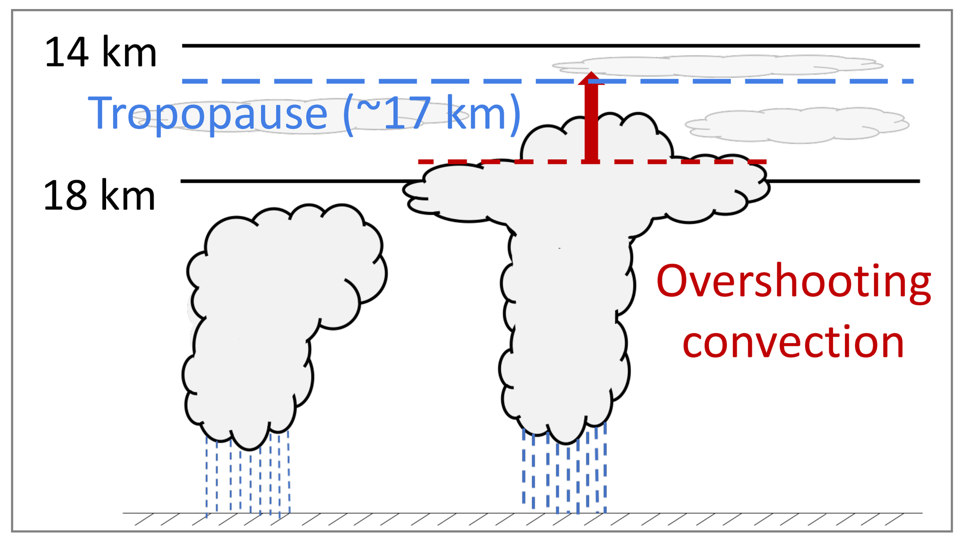
Overshooting Convection and Tropical Cirrus in the DYAMOND Global Storm-Resolving Models

Jacqueline Nugent[1], Sami Turbeville[1], Chris Bretherton[1,2], Tom Ackerman[1], Peter Blossey[1]
[1]University of Washington Department of Atmospheric Sciences, Seattle, WA; [2]Allen Institute for Artificial Intelligence, Seattle, WA

1. Background and Motivation

- Cirrus in the Tropical Tropopause Layer (TTL; 14-18 km)[1] influence the climate through altering the top-of-atmosphere radiation balance[2] and stratospheric water vapor[3]
- Overshooting convection that reaches the TTL or higher can inject water vapor and ice into the TTL to support cirrus formation[4,5] and alter the stratospheric water vapor budget[6]



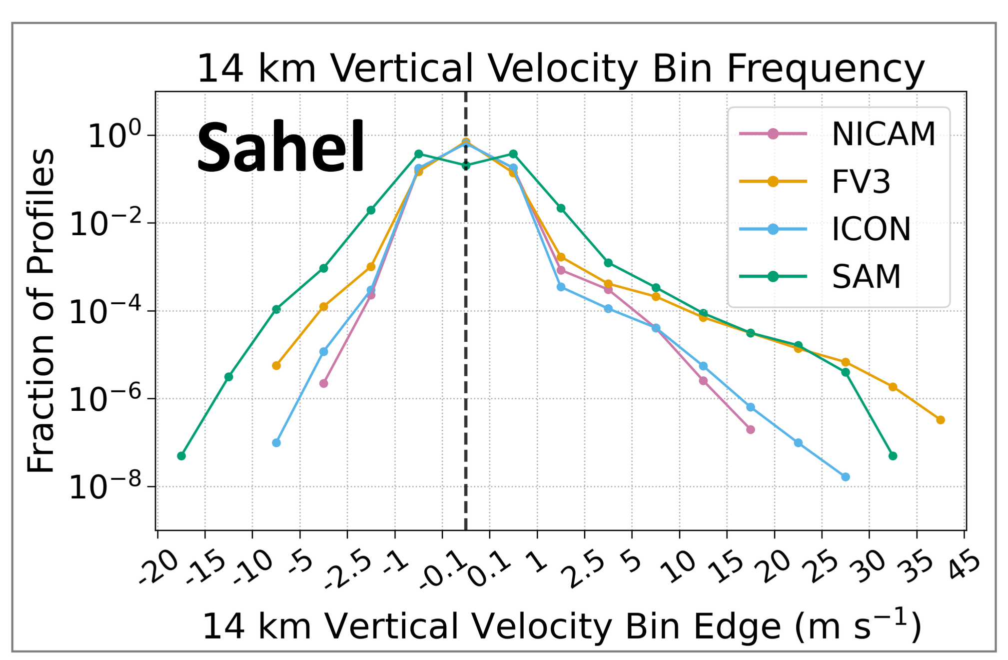
Schematic of the TTL and overshooting convection.

How are deep convection and the convective injection of water into the TTL simulated in GSRMs?

2. DYAMOND GSRMs and Observations

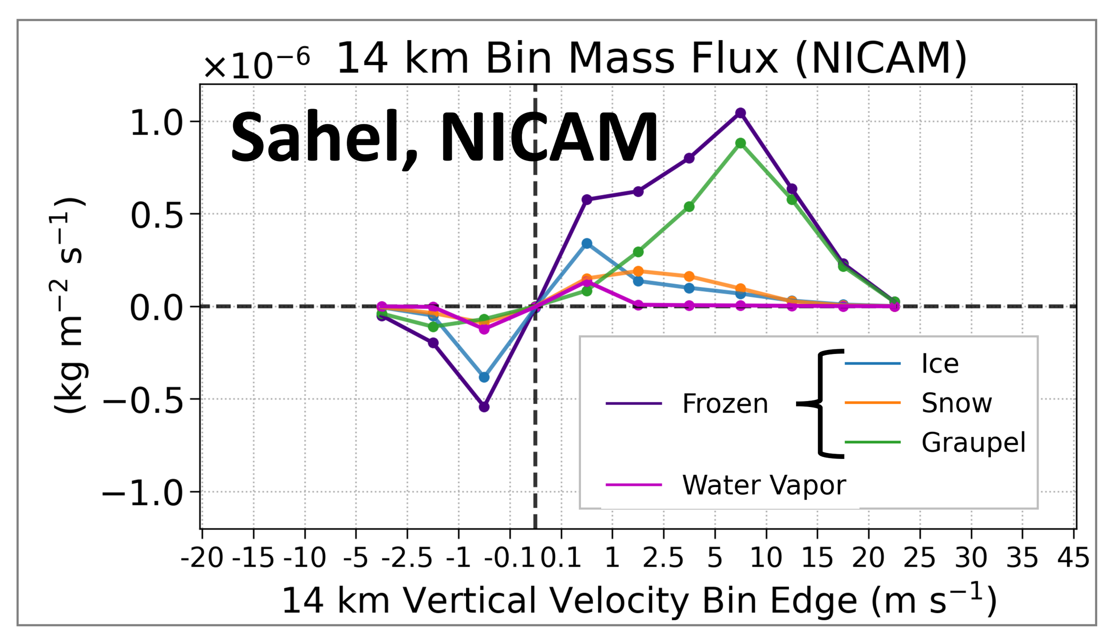
- GSRMs = global storm-resolving models
  - Can **explicitly resolve deep convection** because of sub-5 km horizontal resolutions
- **DYAMOND project**[7]: intercomparisons of 9-11 GSRMs with 2.5-5 km horizontal grid spacing
  - DYAMOND-1 (boreal summer): August 1 to September 10, 2016
  - DYAMOND-2 (boreal winter): January 20 to March 1, 2020
  - Initialized from same conditions and run freely for 40 days (i.e., not nudged to observations or reanalysis)
- We compare to observations: IMERG precipitation (2011-2020)

3. Regional Convective Injection into the TTL in DYAMOND-1



14 km vertical velocity histogram for 4 GSRMs in a 10°x10° region in the Sahel in western Africa. Note that bins are unevenly spaced.

- Models agree on overall histogram shape and that the TTL is typically quiescent
- The most extreme updrafts and downdrafts differ greatly between models but are infrequent
- Histograms for a Tropical West Pacific (TWP) region are qualitatively similar (not shown)



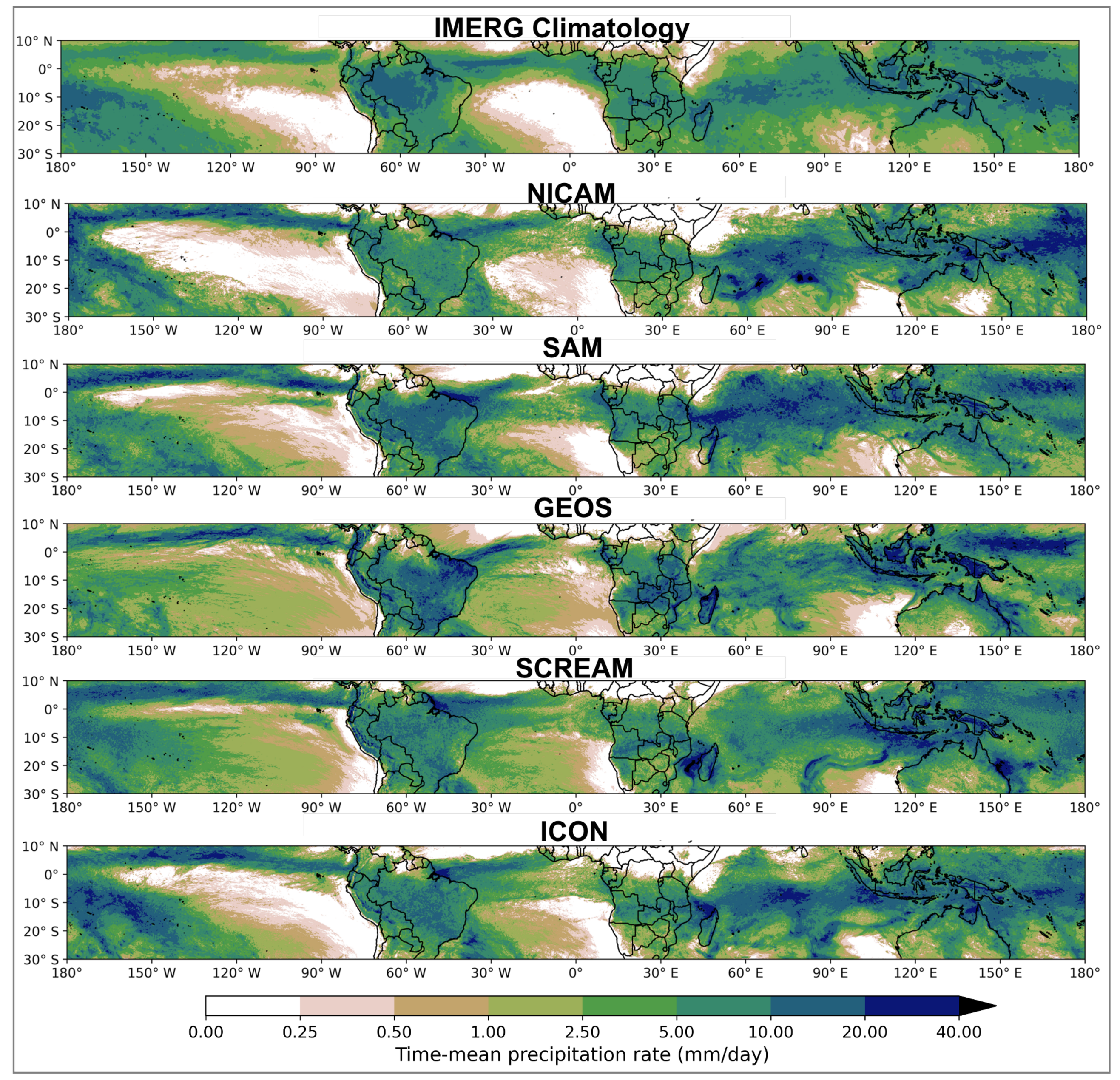
Mass fluxes into the TTL (14 km) binned by 14 km vertical velocity for NICAM only. Values are weighted by bin frequency.

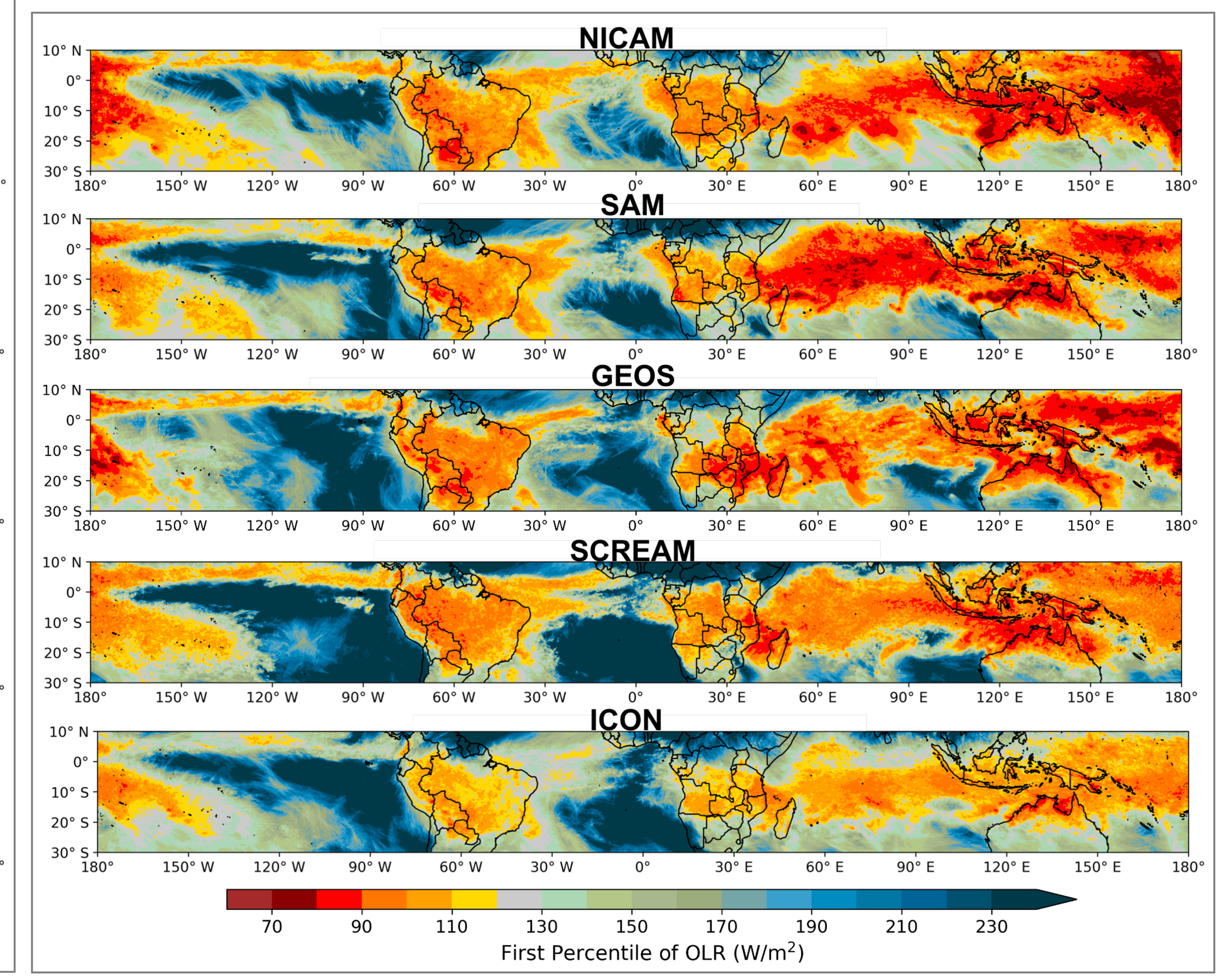
NICAM is the only DYAMOND-1 model that saved full 3D output of all frozen hydrometeors.

- Frozen water flux exceeds vapor flux
- Most mass flux into the TTL comes from the infrequent columns of deep convection
- TWP fluxes are slightly smaller (not shown)

4. Deep Convection in the Global Tropics in DYAMOND-2

Following Dauhut and Hohenegger (2022)[8], we use the first percentile of outgoing longwave radiation (OLR) to evaluate deep convection in the GSRMs.

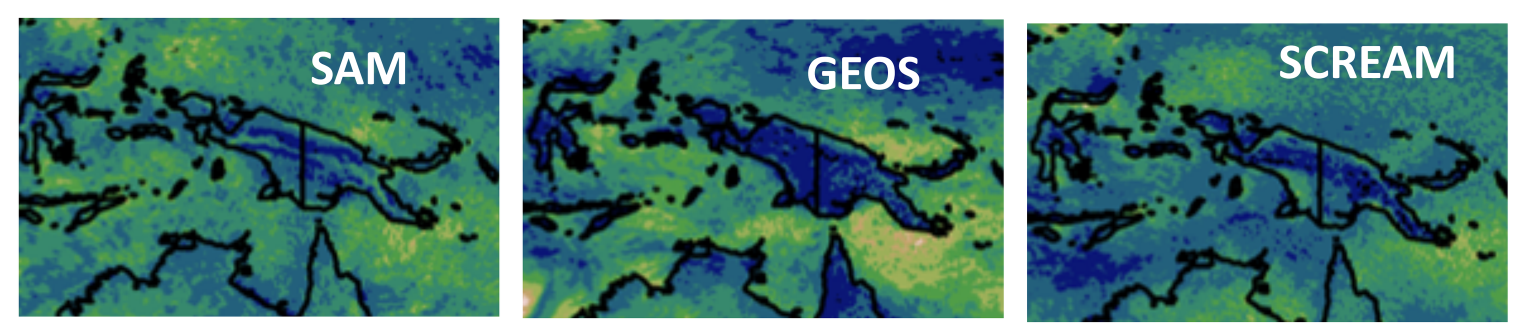




Left: Time-mean precipitation rate for IMERG observations and five GSRMs in DYAMOND-2 coarsened to match IMERG (0.1° grid, 30 min). **Right:** First percentile of OLR for the same five GSRMs (native grid, 15 min). Figure modeled after Fig. 3 in DH22[8].

- Overall spatial distribution of deep convection is consistent between models
- ICON has consistently higher OLR values; convection is not as deep (opposite for NICAM)
- Land-ocean differences in precipitation are reflected in OLR
  - Models disagree on where the deepest convection is, particularly over southern Africa
  - The models that simulate more intense convection over oceans do not necessarily do the same for land regions

- Spatial distribution of simulated precipitation matches the observations, but is more intense
- SAM, GEOS, and SCREAM simulate enhanced precipitation over islands in the Maritime Continent not seen in the other GSRMs



Close-up of time-mean precipitation in the Maritime Continent.

5. Take-Home Messages

- **DYAMOND-1:** Deep convection dominates water transport into the TTL and consists mostly of frozen water; there are substantial intermodel differences in the most intense updraft and downdraft speeds
- **DYAMOND-2:** Models disagree on the locations and intensity of the deepest convection, esp. land vs. oceans
- **Next steps:** conduct further comparisons between GSRMs and observations and examine the influence of convection that overshoots the cold point tropopause in DYAMOND-2

6. Acknowledgements and Contact

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Nugent et al. (2022), *ESS*:

Contact: jnug@uw.edu

References: [1]Fueglistaler et al. (2009), *RG*; [2]Haladay and Stevens (2009), *JGR*; [3]Jensen et al. (2009), *RG*; [4]Krämer et al. (2016), *ACP*; [5]Luo and Rossow (2004), *JC*; [6]Ueyama et al. (2018), *JGRA*; [7]Stevens et al. (2019), *PEPS*; [8]Dauhut and Hohenegger (2022), *JGRA*.