Evaluating Convection and Tropical Tropopause Layer Cirrus in the DYAMOND Simulations

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Session 1: Very High-Resolution Modeling

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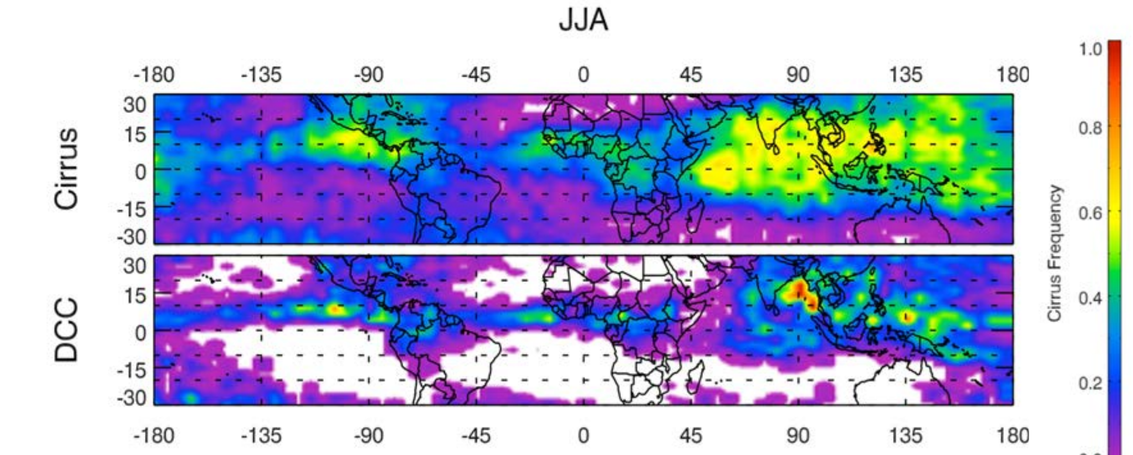
TTL cirrus have a significant contribution to the climate.

- Definition: **TTL ≈ 14-18 km layer** (Schoeberl et al. 2019)
- TTL cirrus:
  - Net warming effect locally
  - Prevalent over tropics
  - Long lifetime, and can be advected large distances (600-1000 km)
- However, the role of TTL cirrus in climate change is still uncertain



DCC = Deep Convective Cloud

Modified from Fig. 2: Sassen et al. (2009), *JGR*

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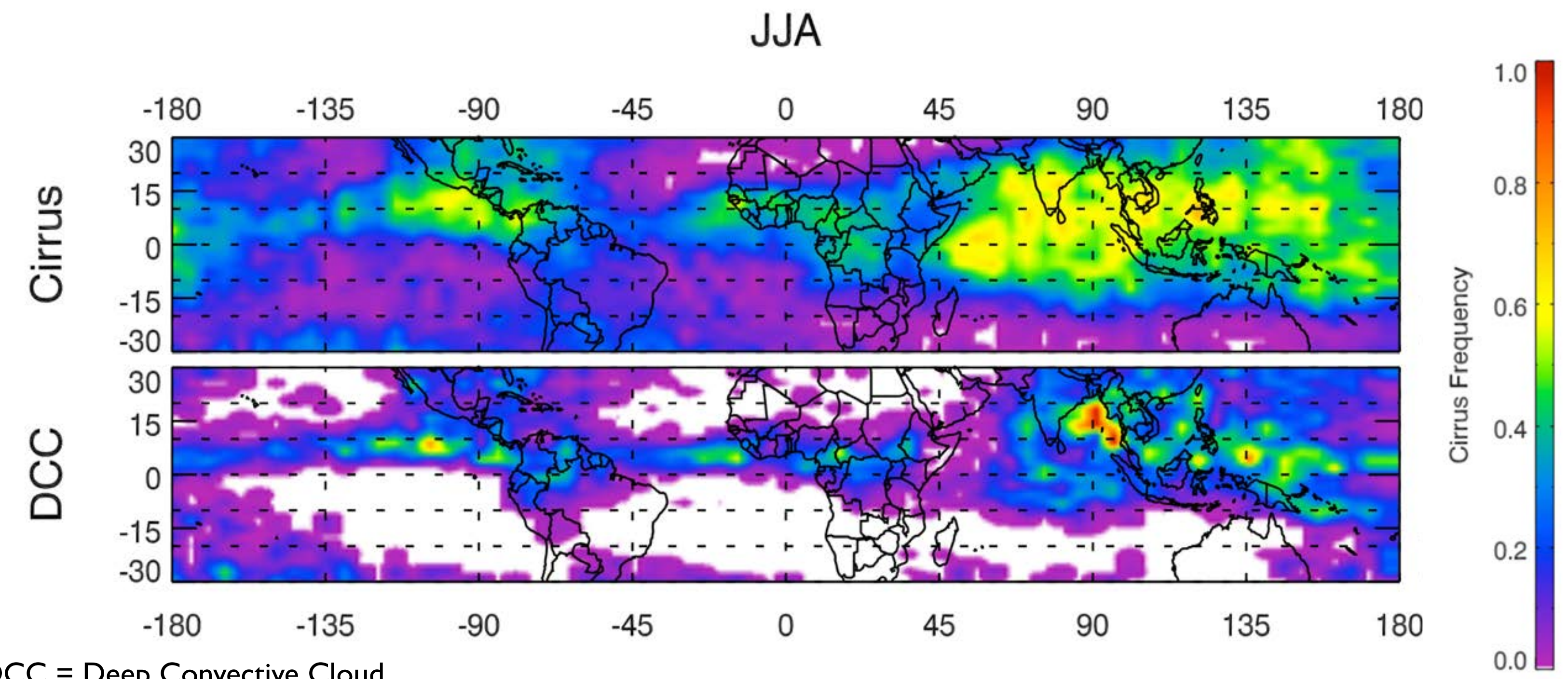

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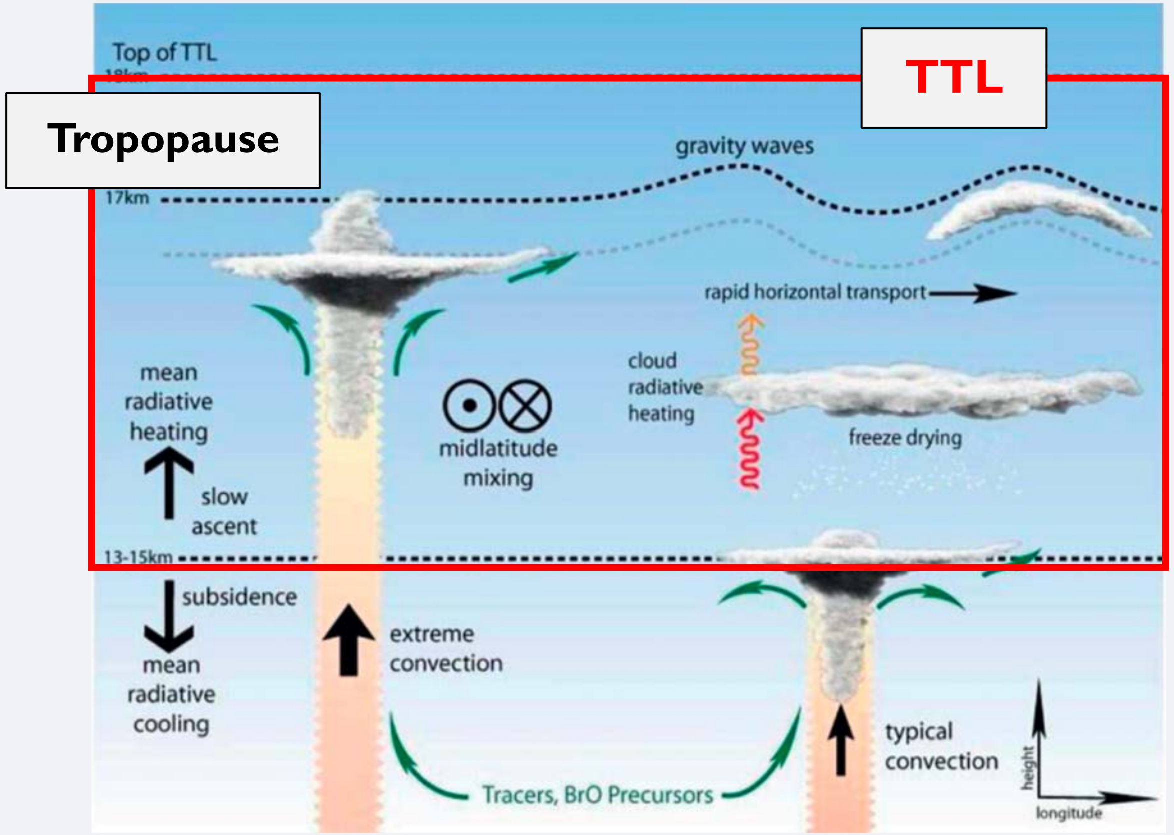
TTL cirrus are strongly related to convection.

- TTL cirrus can form from convective detrainment
- Overshooting convection (>14km) provides moisture, lift, and ice in TTL
  - Thicker cirrus more frequent near deep convection
  - Growth often occurs after deep convection decays
- … but not much is known about the rest of their life cycle



Modified from Fig. 1: Jensen et al. (2017), *BAMS*

There are several challenges with studying TTL cirrus.

- Observations are difficult to obtain:
  - Occur at a high altitude and often over strong convection
  - Very optically thin ($\tau \approx 0.02$-0.3)

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- Previous modeling studies have been limited:
  - A high spatiotemporal resolution is needed
  - TTL cirrus generally have **poor representation in GCMs**:
  - Accurate representation of diurnal cycle of deep convection is particularly difficult, especially over land
  - Improves with non-parameterized convection (e.g. Berthou et al. 2019, 4.5 km resolution)

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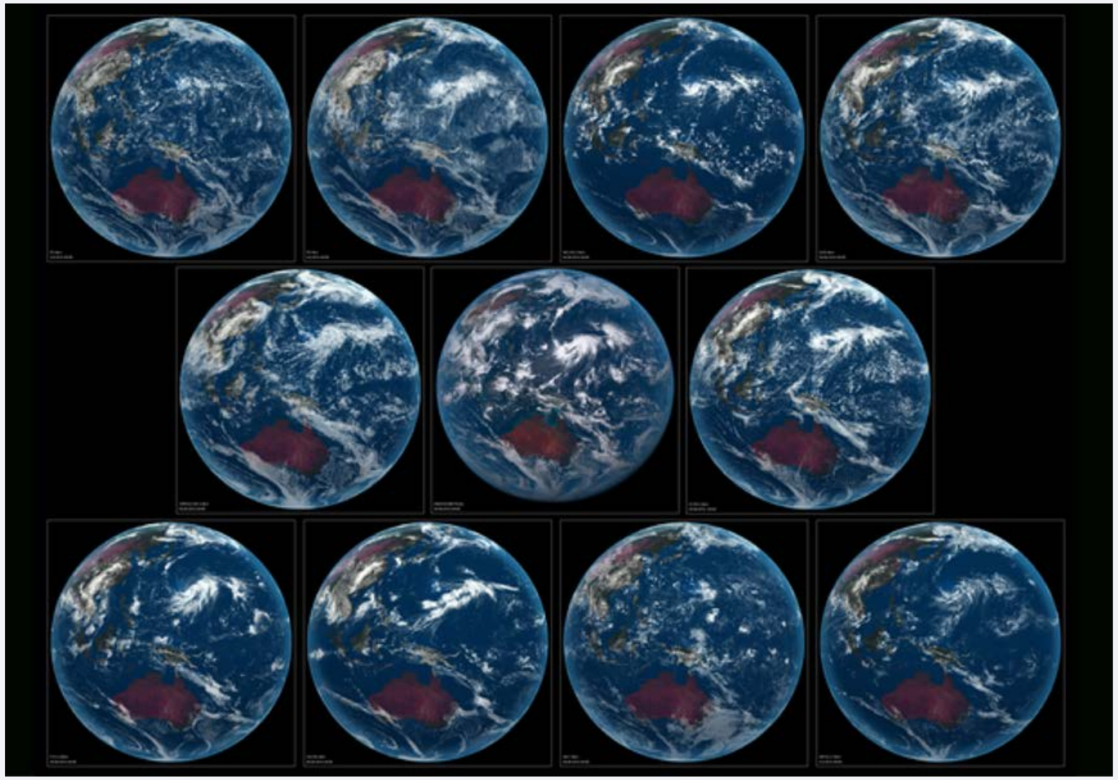
<u>Solution:</u> **DYAMOND intercomparison -** high resolution, explicit convection

DYAMOND Analysis

DYnamics of the **A**tmospheric general circulation **M**odeled **O**n **N**on-hydrostatic **D**omains

- 9 global storm-resolving models
- Initialized with same conditions
- Run for 40 days
  - Hindcast: Aug 1 - Sep 10, 2016



Most importantly:

- High resolution: **<5 km horizontal**; 15 min (2D fields) and 3h (3D fields) temporal
- Deep convection **not** parameterized

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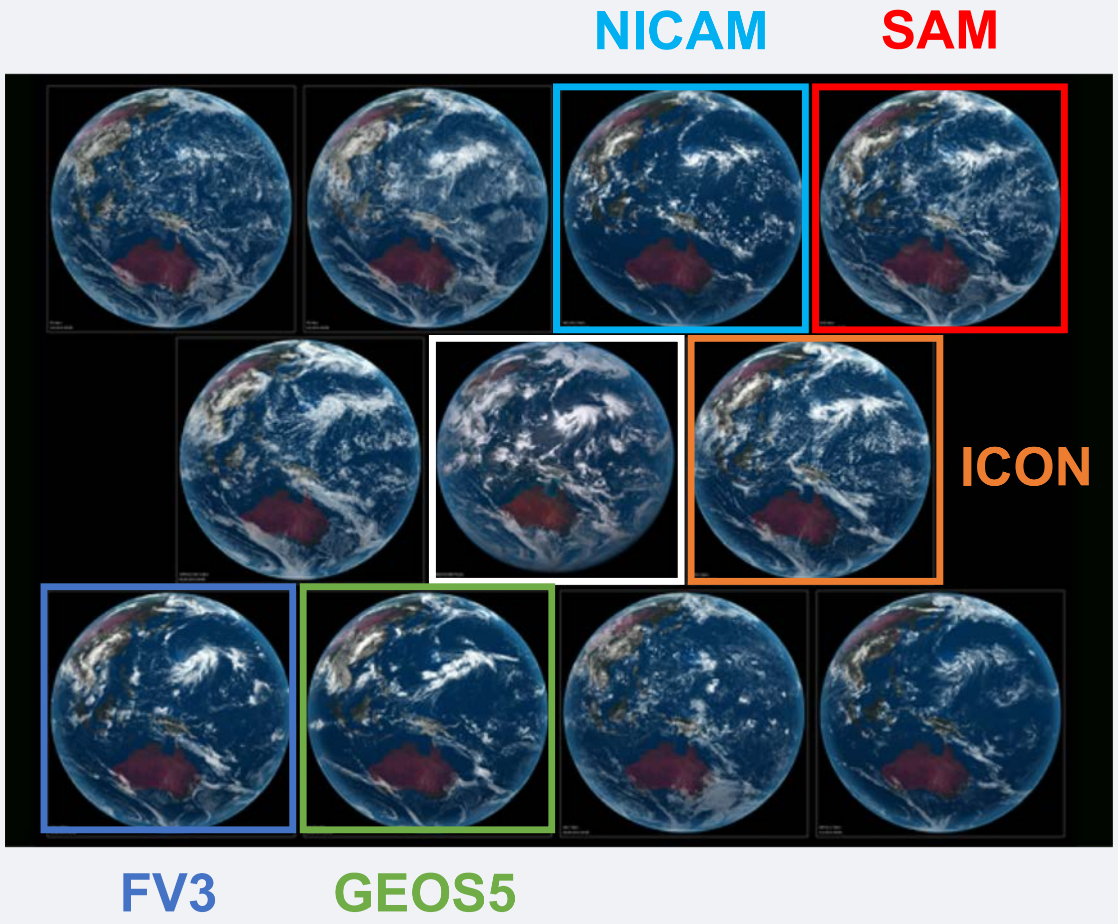

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DYAMOND Analysis Overview

Model	Grid	Horizontal Resolution	Vertical Resolution (number of levels)	Microphysics
FV3	cubed sphere	3.25 km	79 (8 in TTL)	GFDL single-moment cloud microphysics
ICON	icosahedral	2.5 km	77 (8 in TTL)	COSMO single-moment scheme
GEOS5	cubed sphere	3 km	132 (13 in TTL)	GFDL microphysics
SAM	latitude-longitude	4 km	74 (8 in TTL)	Single-moment
NICAM	icosahedral	3.5 km	78 (10 in TTL)	NICAM single-moment

Other models: ARPEGE-NH (2.5 km), IFS (4 km), MPAS (3.75 km), and UM (5 km)

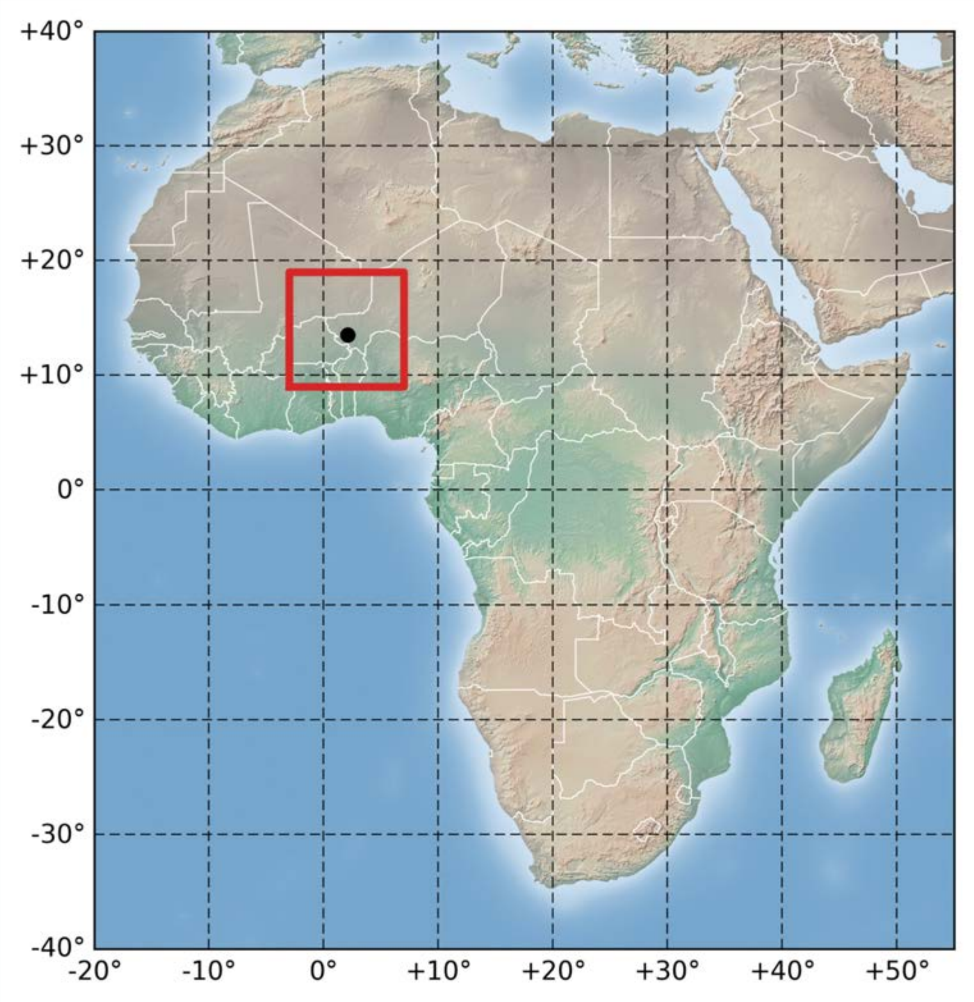
Stevens et al. (2019), *PEPS*

Analysis Region: 10°x10° box in West Africa (Sahel)

<u>Focus on convection over land:</u>

- Less frequent, but more intense
- More variation, especially diurnal cycle (afternoon peak)
- More overshooting convection (Liu and Zipser 2005)
    - A large proportion occurs over Africa (Fierli et al. 2011)

- Frequent deep convection during summer (West African Monsoon)
- Transitions from moist to arid climate regions



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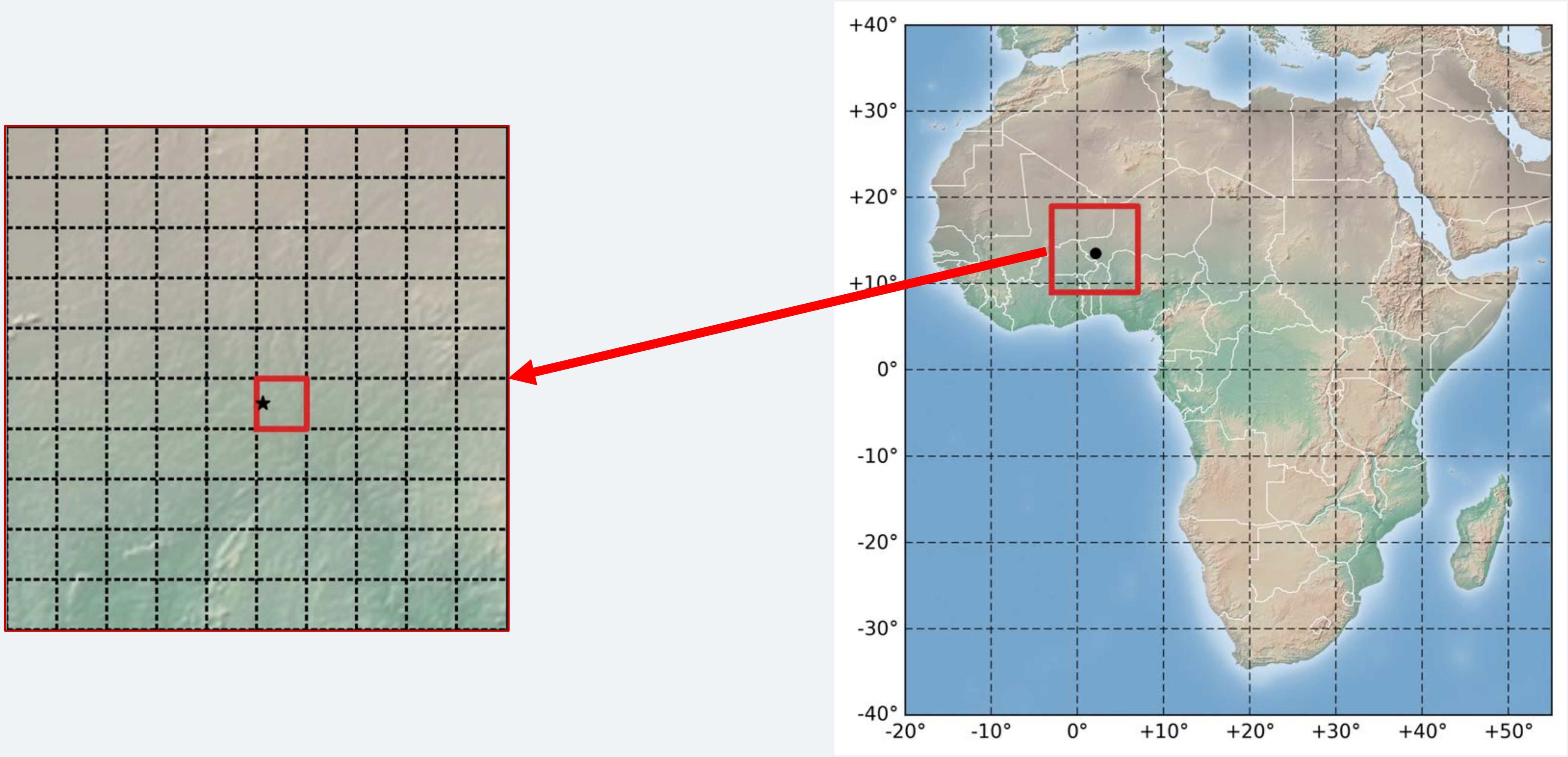
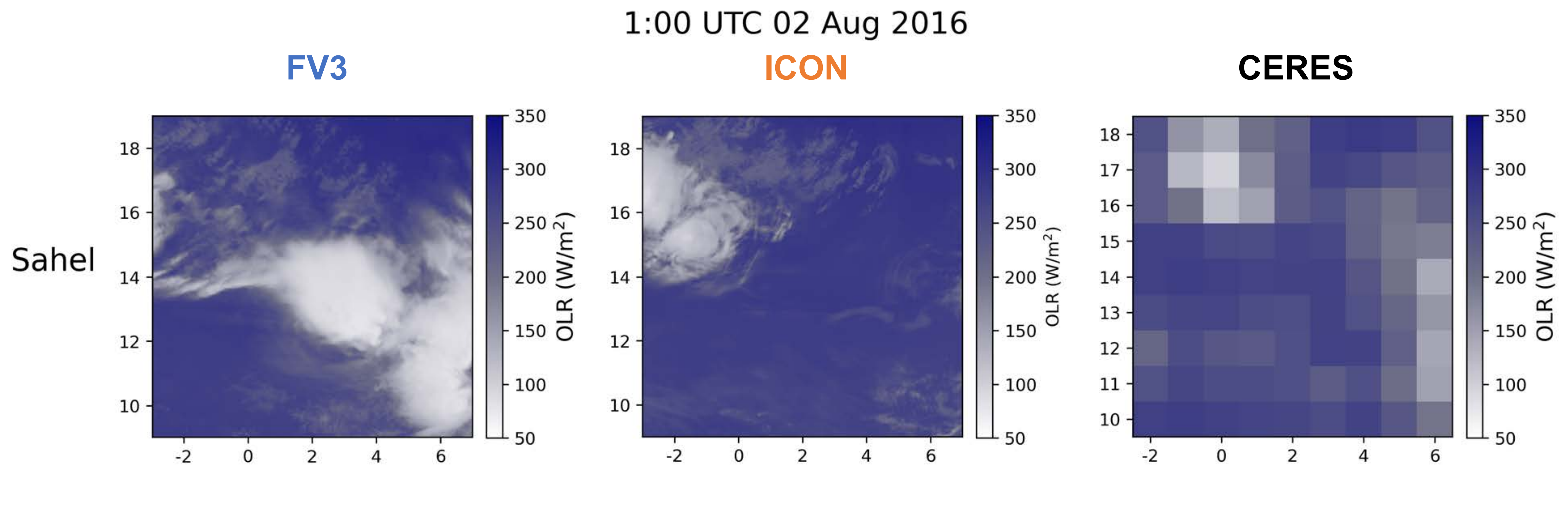


Main Questions

- Can we use very high-resolution models as a tool to study how TTL cirrus evolve in relation to convection?
  - How well do the DYAMOND models simulate TTL cirrus and convection?
  - What are the similarities and differences between models?

Outgoing longwave radiation (OLR) agrees well with observations.



CERES: 1° grid, hourly data
DYAMOND: native grid, hourly mean

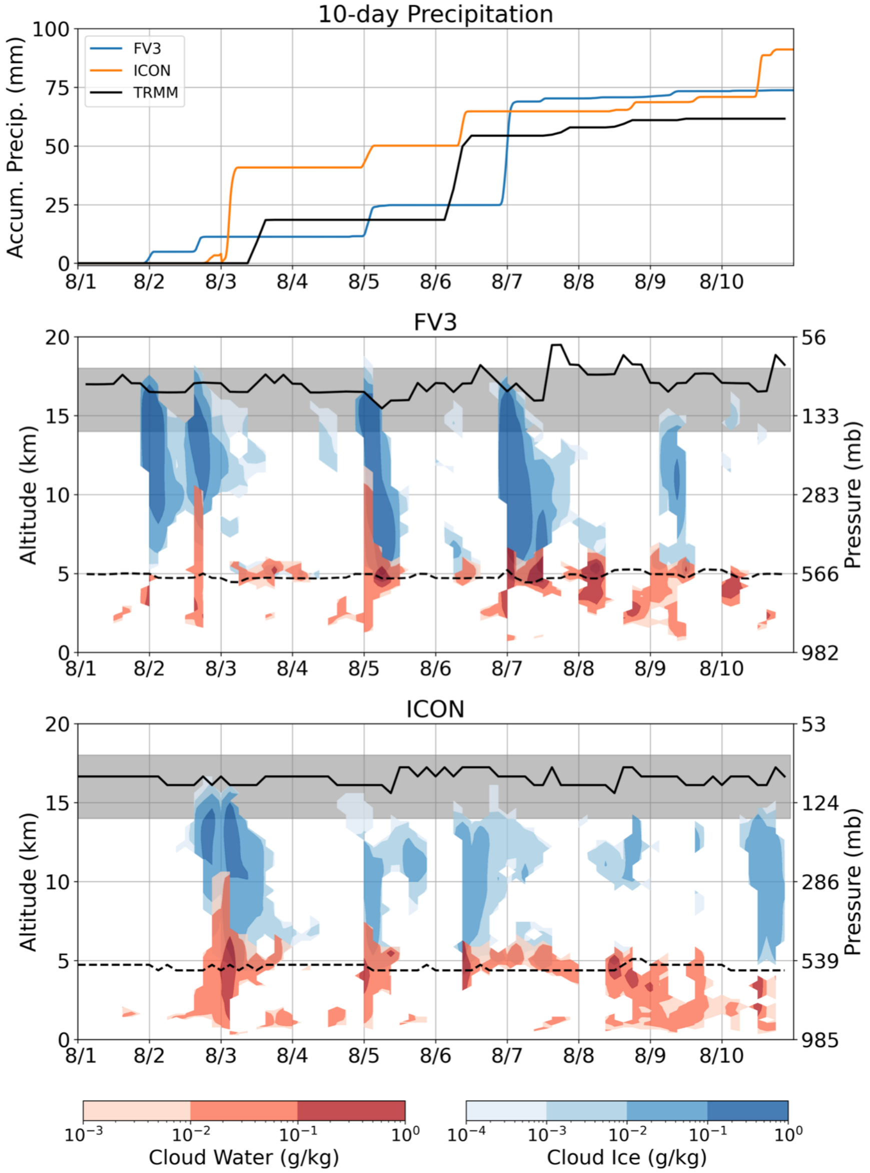
Average OLR: 1-10 August		
FV3: 247.72 Wm^{-2}	**ICON**: 248.56 Wm^{-2}	**CERES**: 238.90 Wm^{-2}

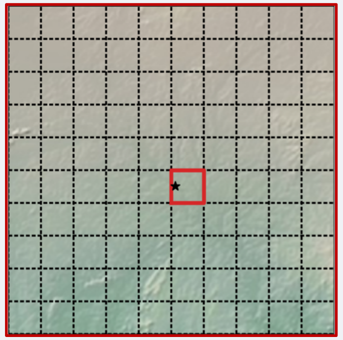
FV3 and ICON have similar cloud structure…

Single 1°x1° box, native grid

TTL (14-18 km)
Cold-point tropopause
Freezing level

TRMM: 2006-2016 combined instrument rainfall estimate; 0.25°, 3 hourly



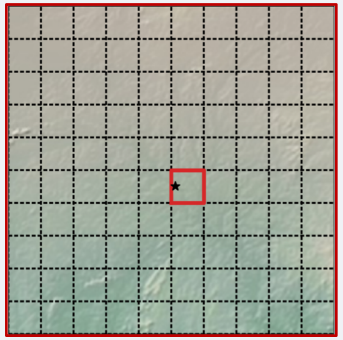


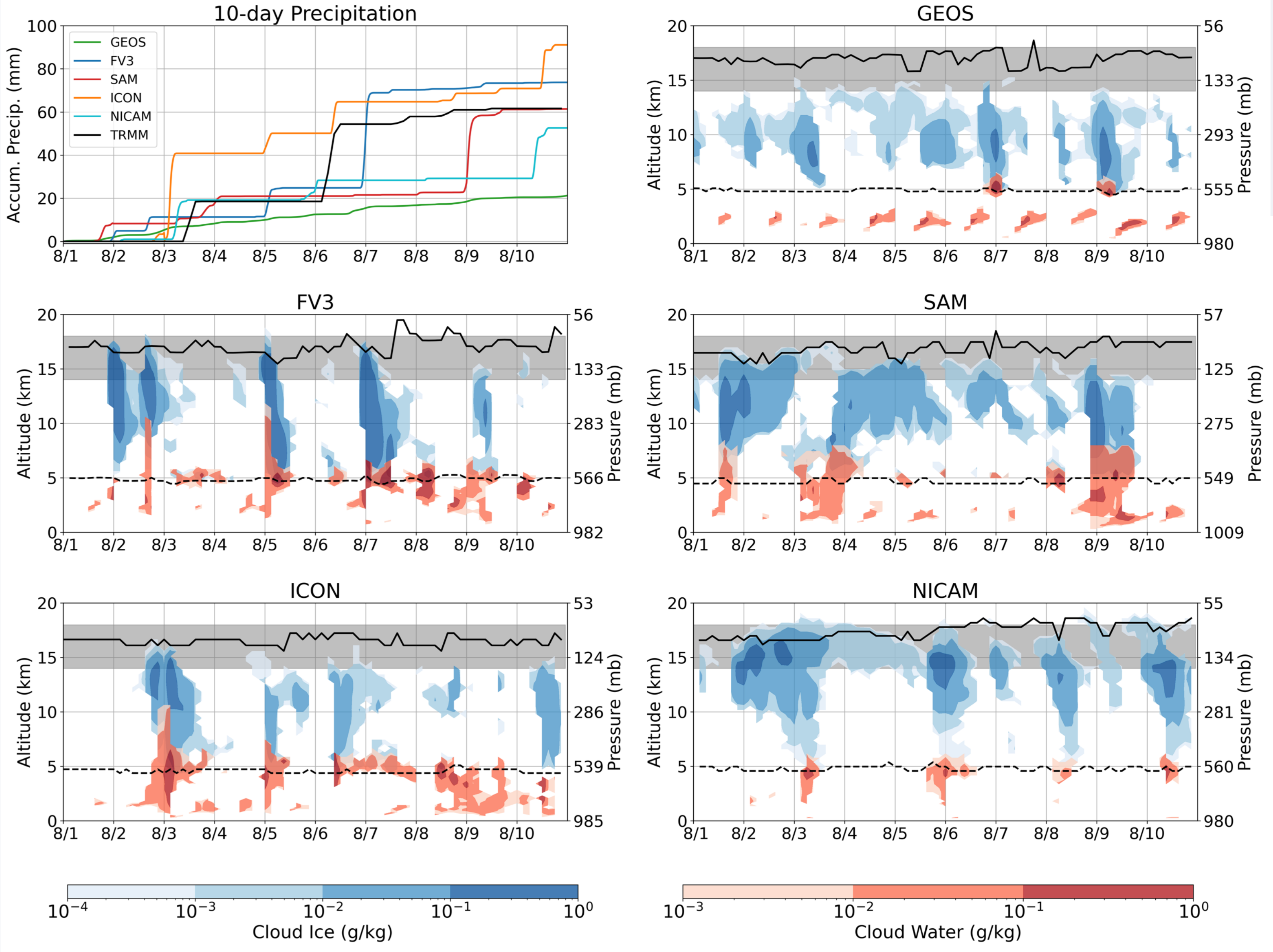
…but the other models are very different.

Single 1°x1° box, native grid

(grey band)	TTL (14-18 km)
(solid line)	Cold-point tropopause
(dashed line)	Freezing level

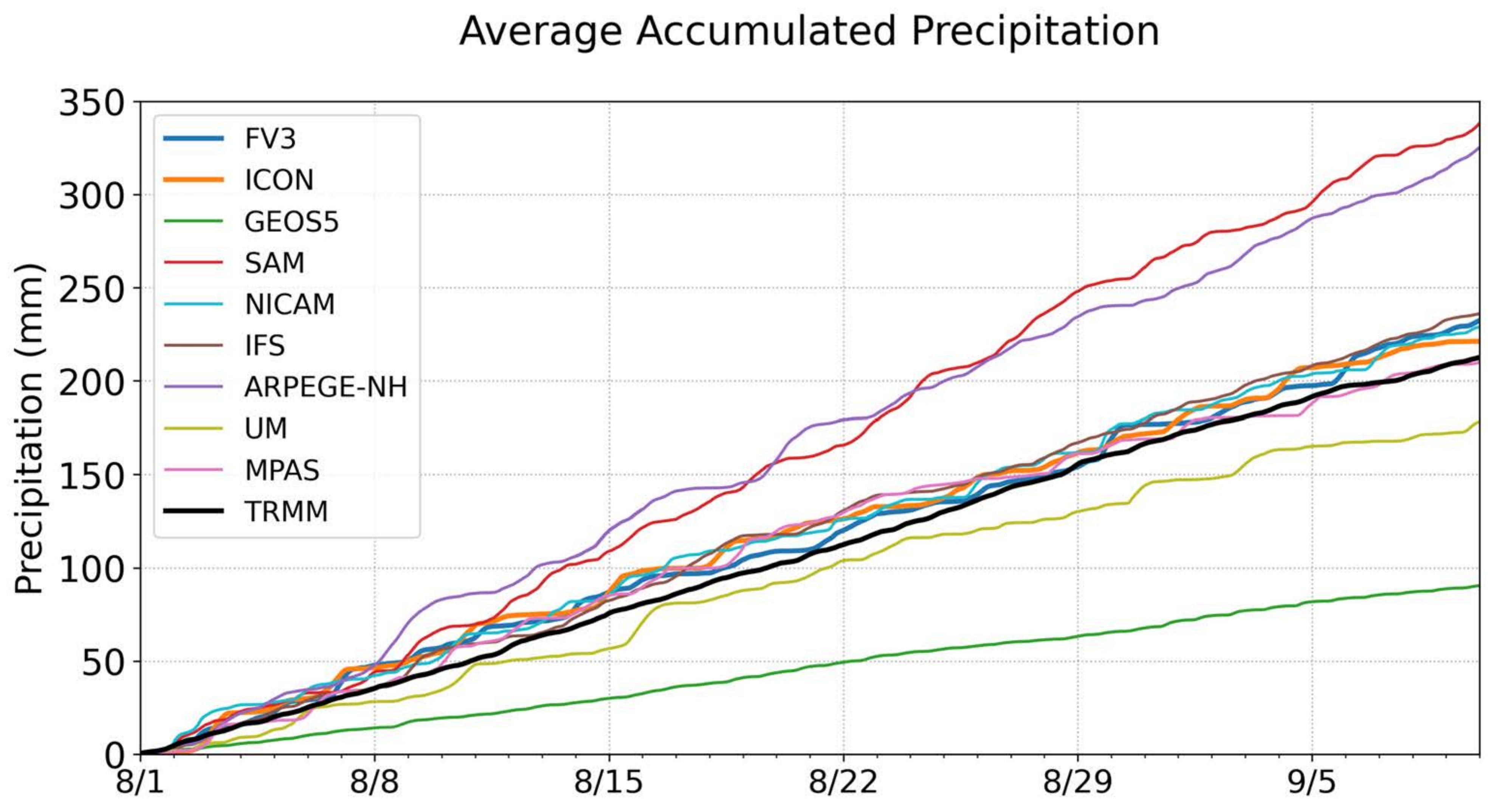
TRMM: 2006-2016 combined instrument rainfall estimate; 0.25°, 3 hourly





Most models agree on accumulated precipitation.

10°x10° box, 0.1° grid



The texture of convection is realistic.

10°x10° box, native grid (precip), 0.1° grid (IWP)

FV3

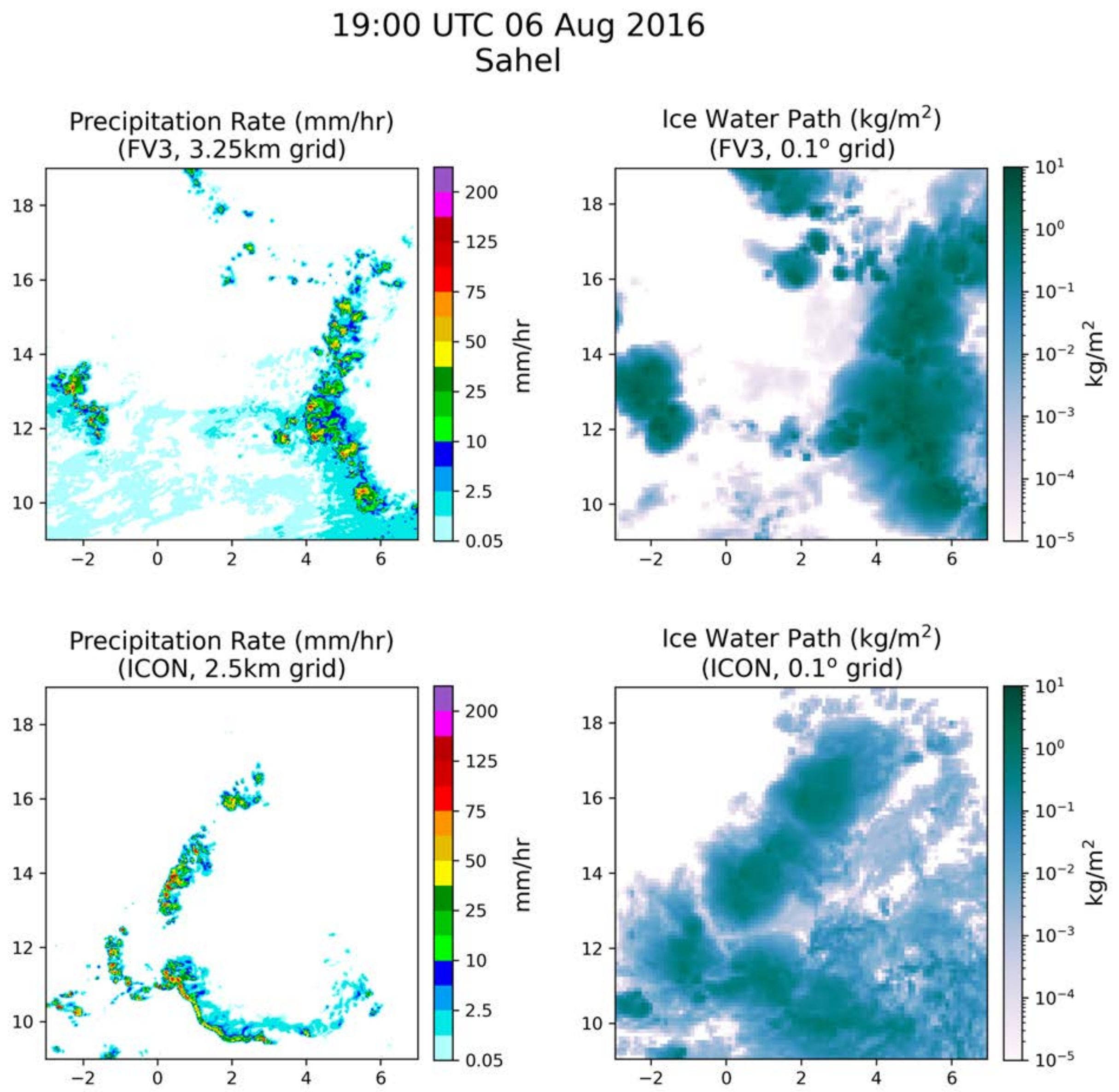
40-day average:

87.98% convective, 12.02% stratiform

ICON

40-day average:

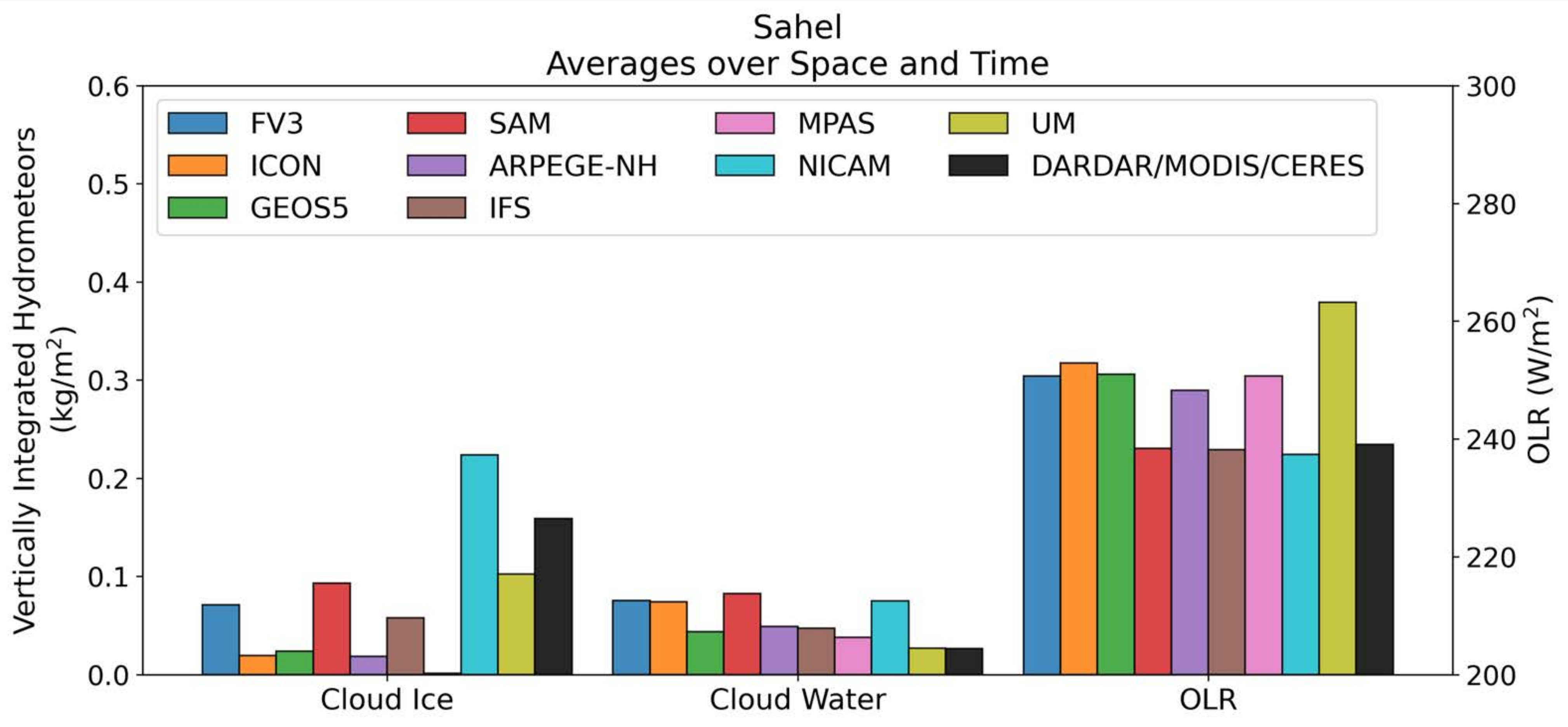
99.86% convective, 0.14% stratiform



***Definition**: stratiform < 1 mm/hr*

There are very large differences in IWP.

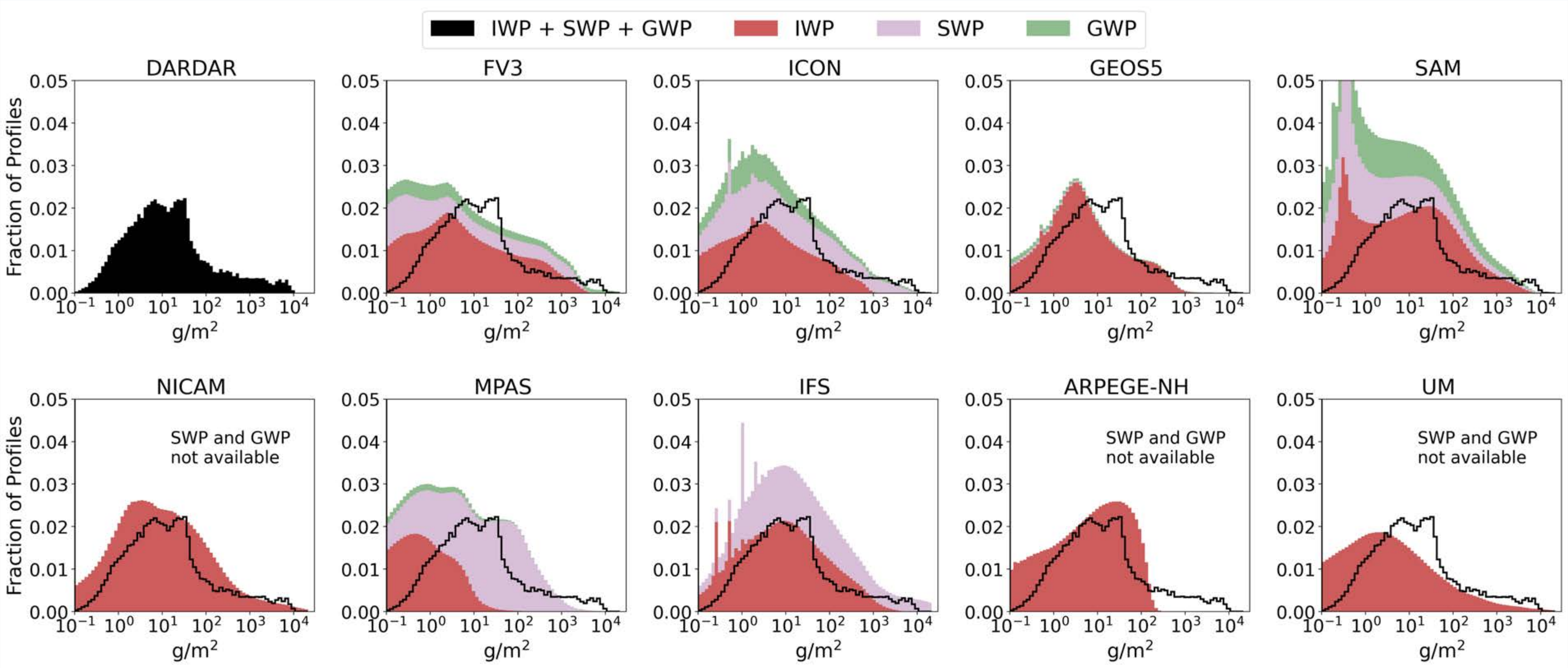
10°x10° box, 0.1° grid



DARDAR: Aug 2009 combined radar/lidar retrievals
MODIS/CERES: JAS 2007-2010, 0.3° footprint

Models miss the total ice water path distribution.

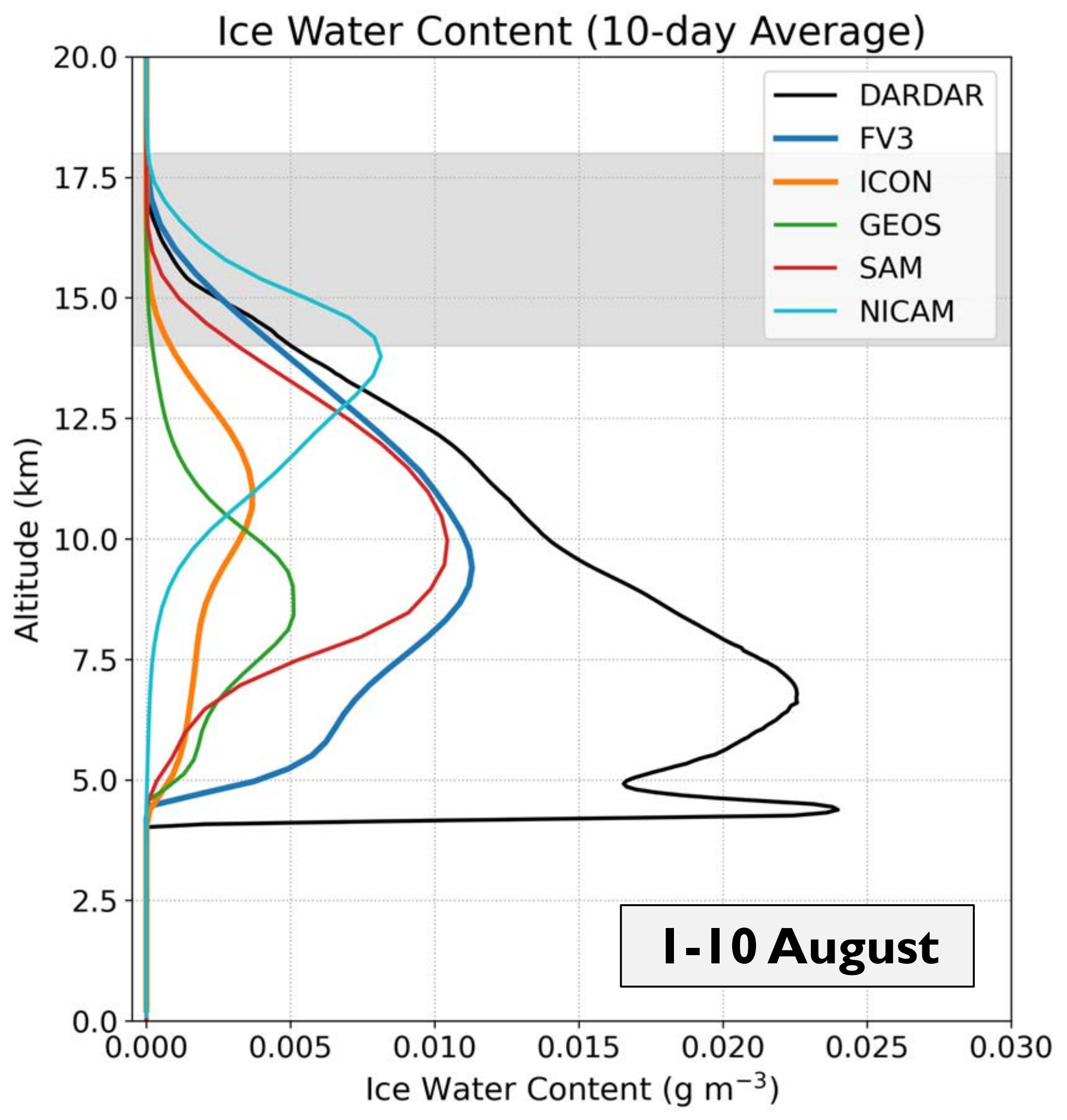
10°x10° box, 0.1° grid



DARDAR: August 2009 combined radar/lidar retrievals

Models disagree on the vertical distribution of ice.

10°x10° box, native grid



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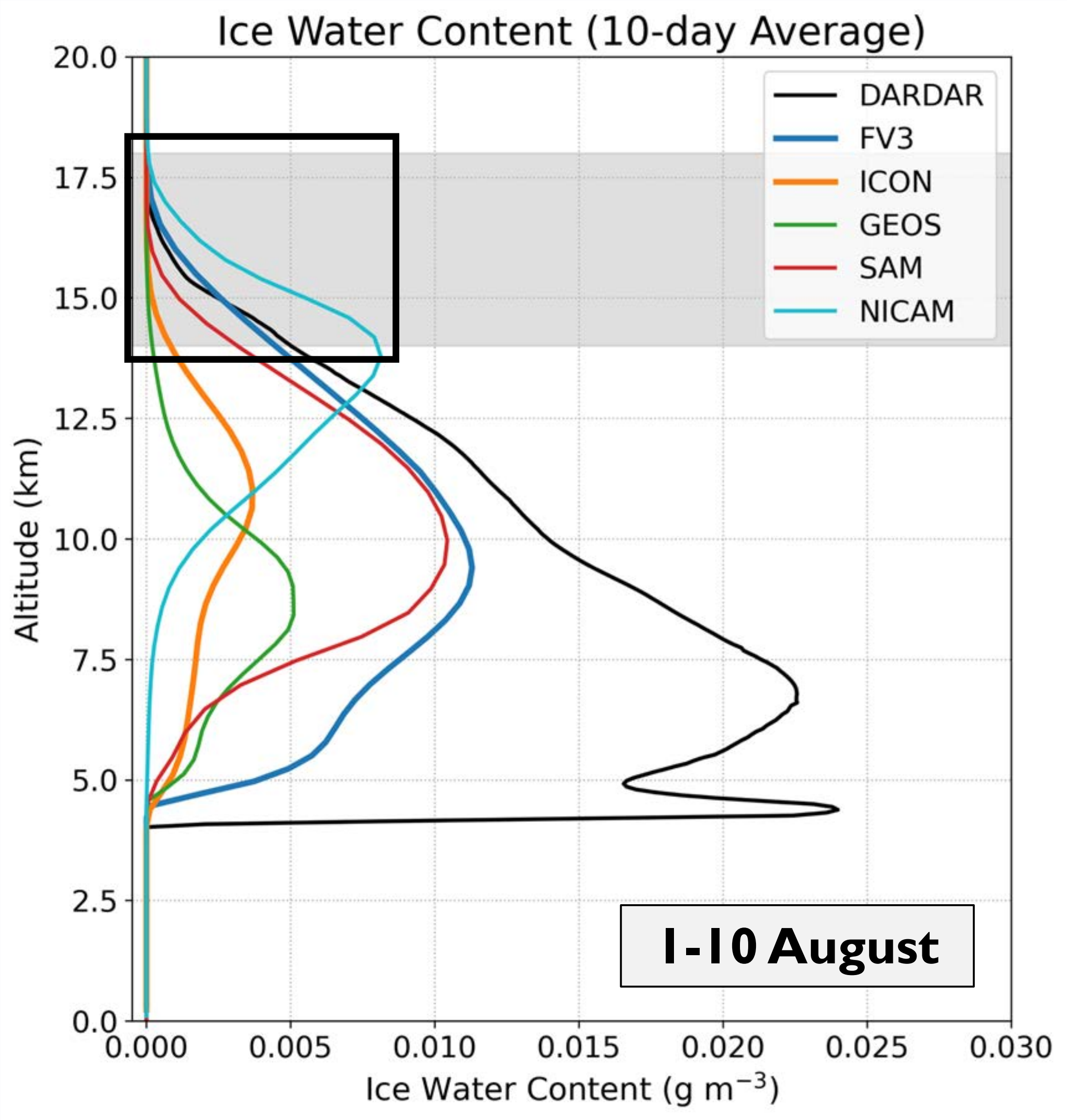
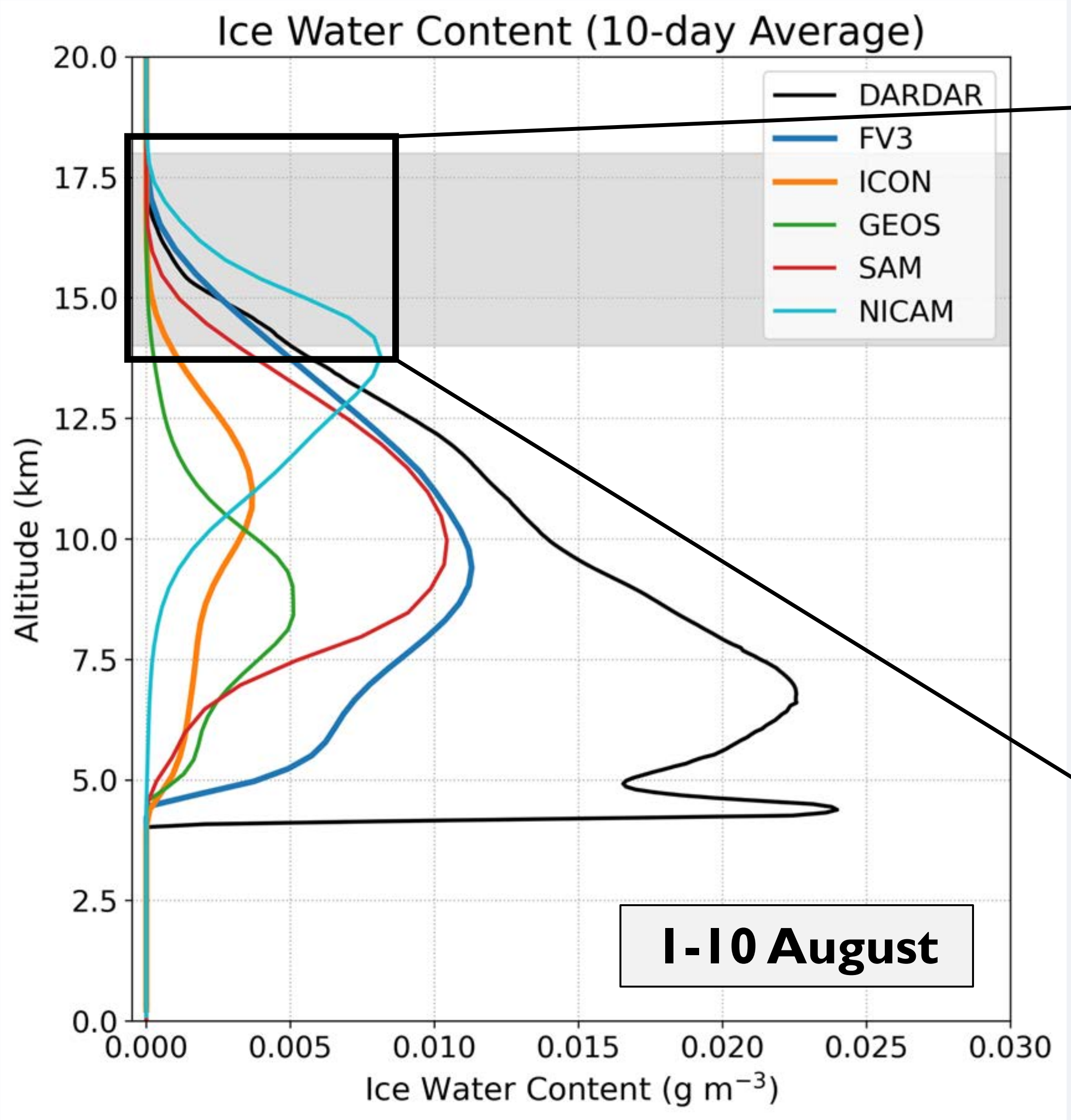
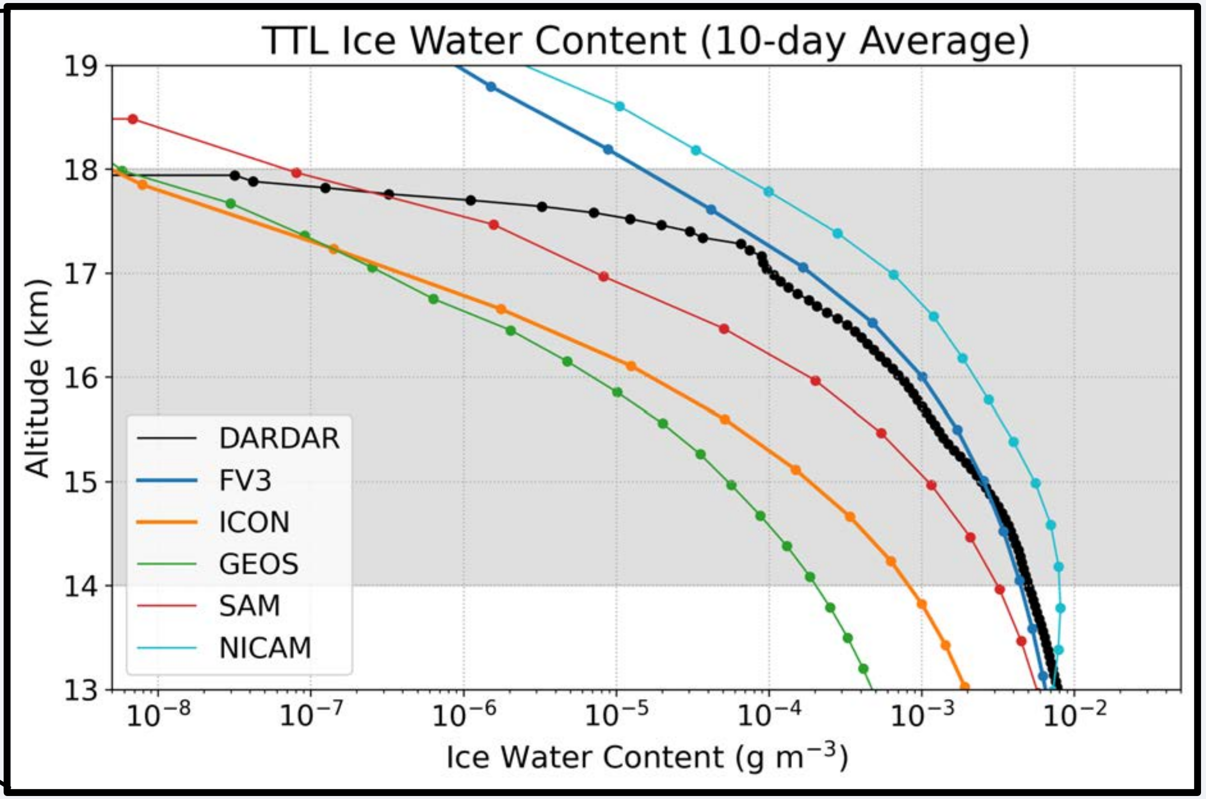


DARDAR: August 2009 combined radar/lidar retrievals

TTL ice water content is even less consistent.

10°x10° box, native grid

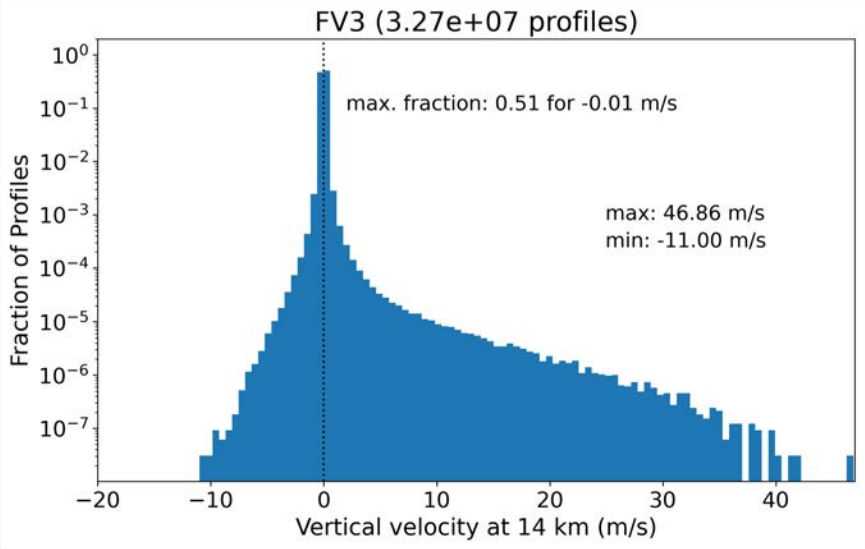


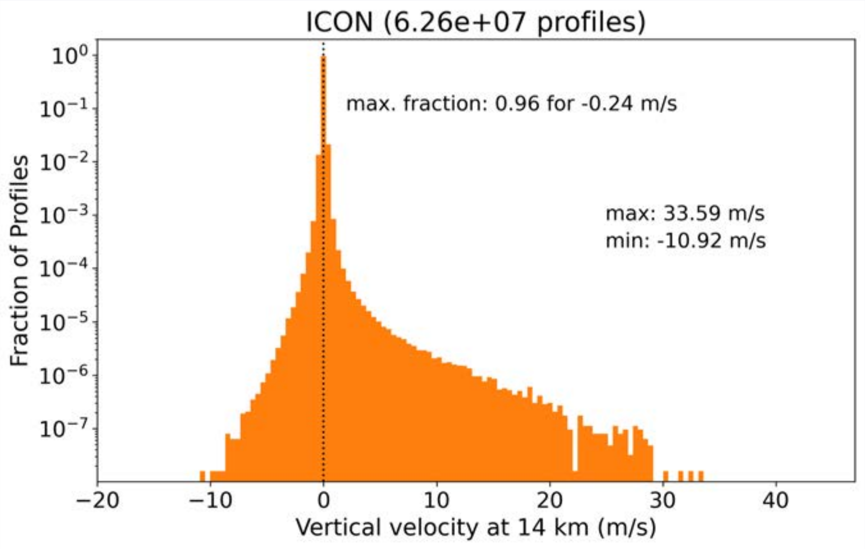


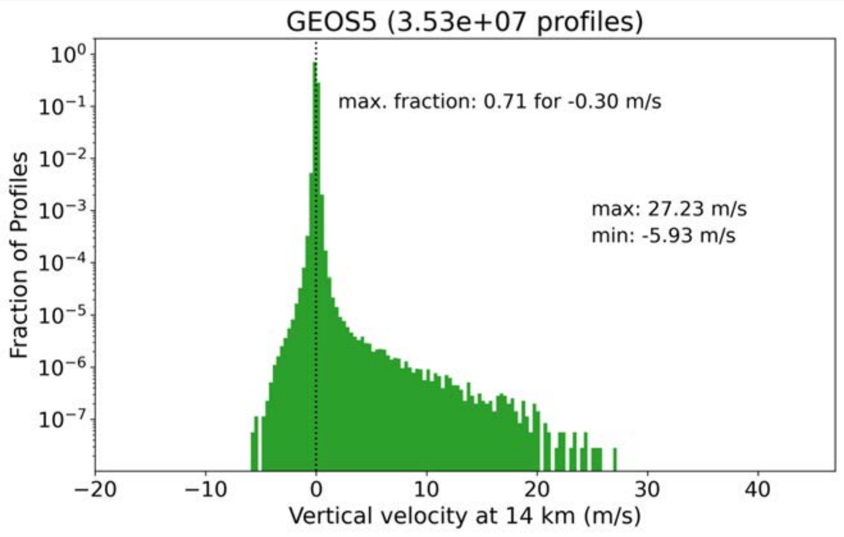
DARDAR: August 2009 combined radar/lidar retrievals

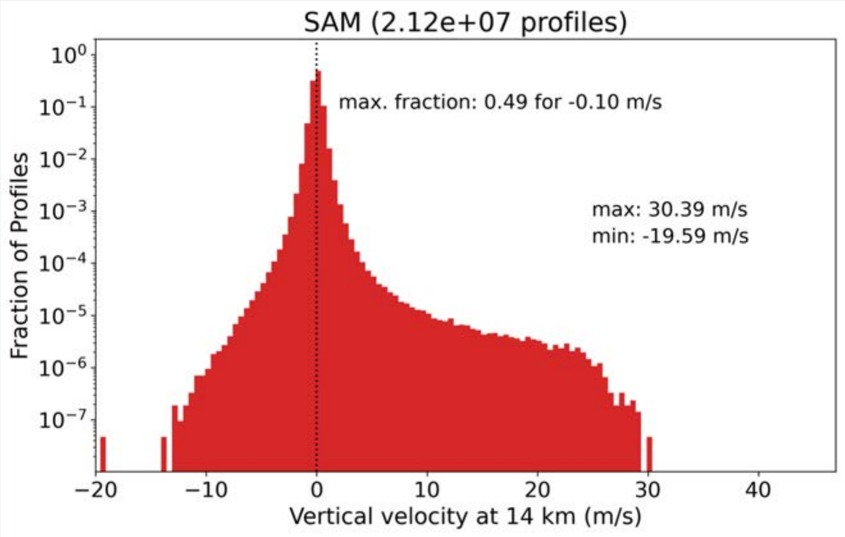
Large disagreement in max. 14km vertical velocity

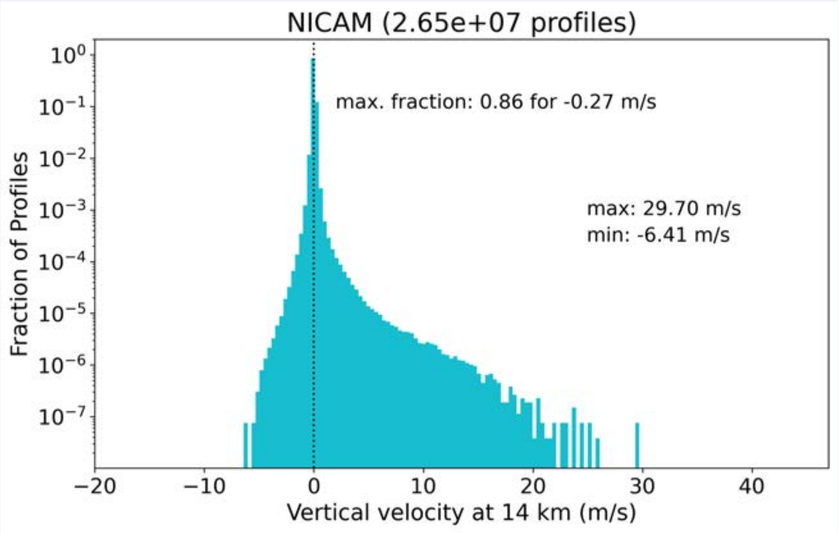
10°x10° box, native grid









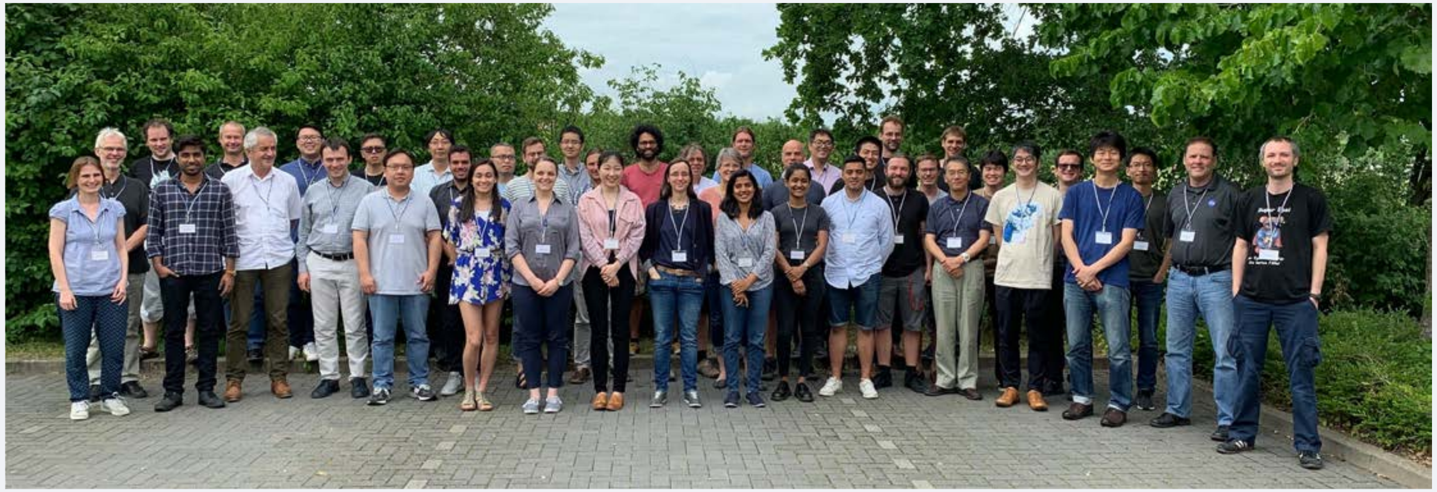


Summary and Conclusions

- Overall, FV3 and ICON realistically simulate the structure and qualitative texture of deep convection
  - FV3: deeper convection, more stratiform precipitation, more cloud ice
  - SAM, NICAM and GEOS not quite as similar
- There are large differences in the distribution of ice and vertical velocity between models
  - Differences in model dynamics and microphysics
  - Amount and extent of ice in TTL especially is very different
- Further refinements in vertical resolution (esp. at high altitudes) and model microphysics are needed to improve simulation of TTL cirrus

Acknowledgements

https://www.pire-cirrus.org/



2nd DYAMOND-ESiWACE Hackathon, 19-21 June 2019