Tropical Cirrus Are Highly Sensitive to Ice Microphysics Within a Nudged Global Storm-Resolving Model

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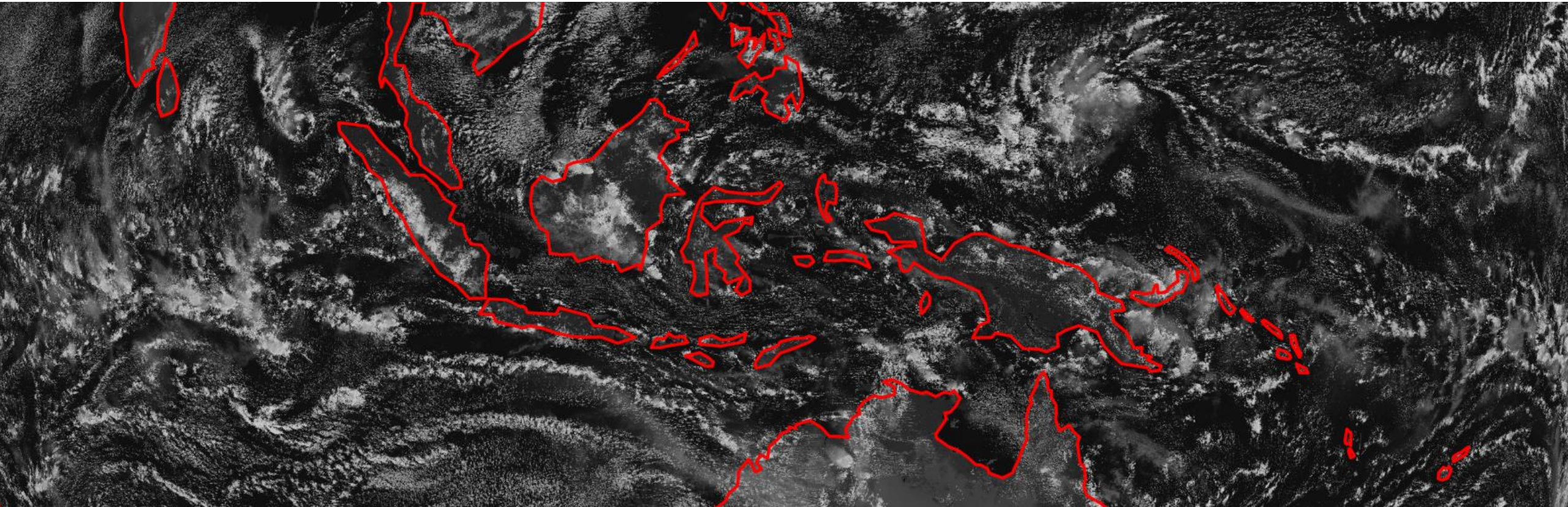
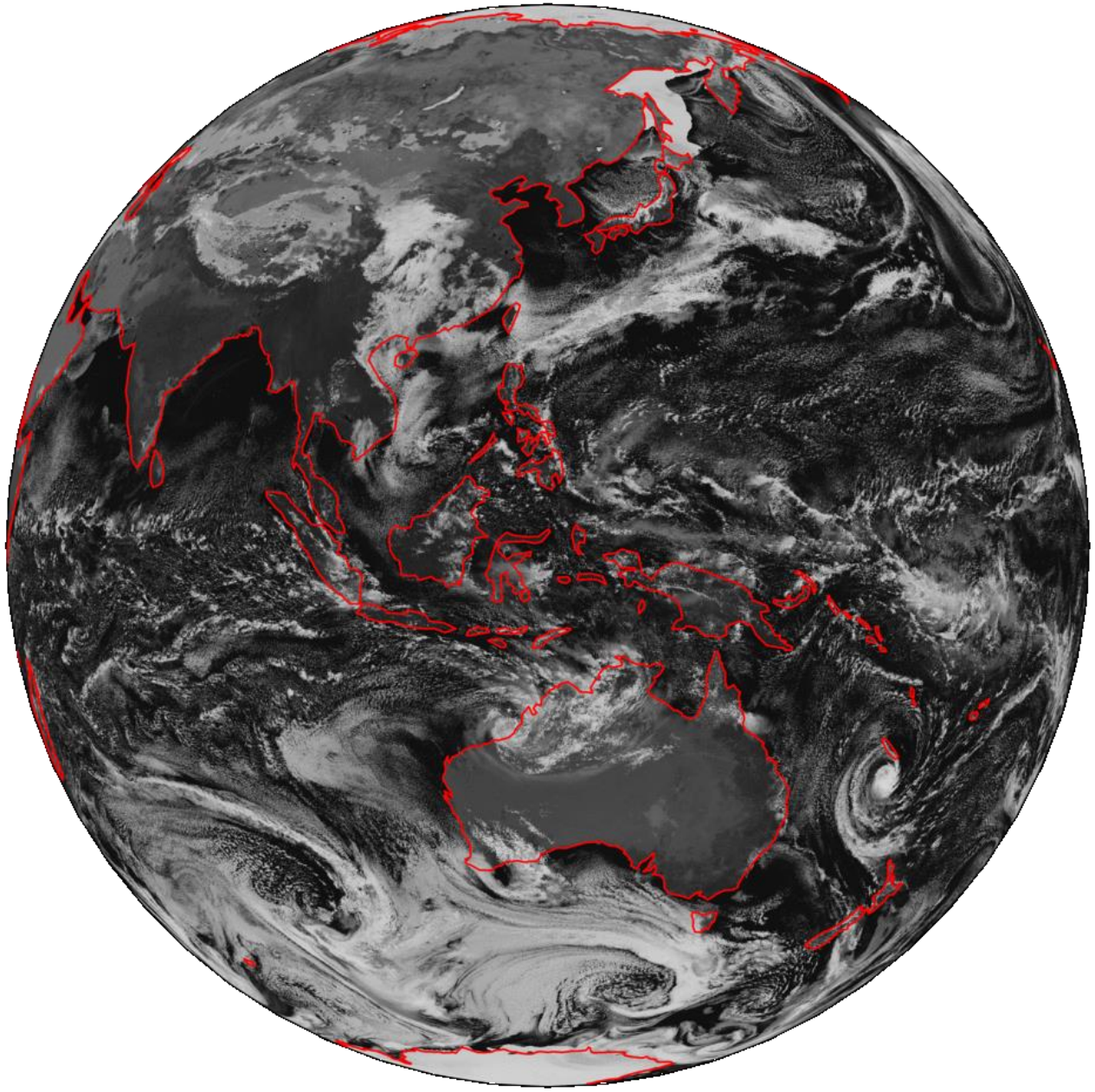


Study Ingredients: Global storm-resolving simulations

Why Nudge?

- Shuts down microphysics-dynamics feedbacks
  Allows us to isolate the direct/instantaneous impacts of microphysics on cirrus properties

- Reduces advective errors compared to ERA5/real atmosphere
  Allows us to evaluate the simulations with coincident observations



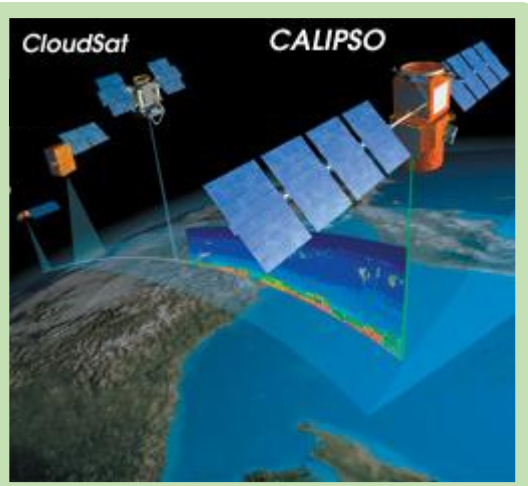
Study Ingredients: Observational Datasets for evaluation

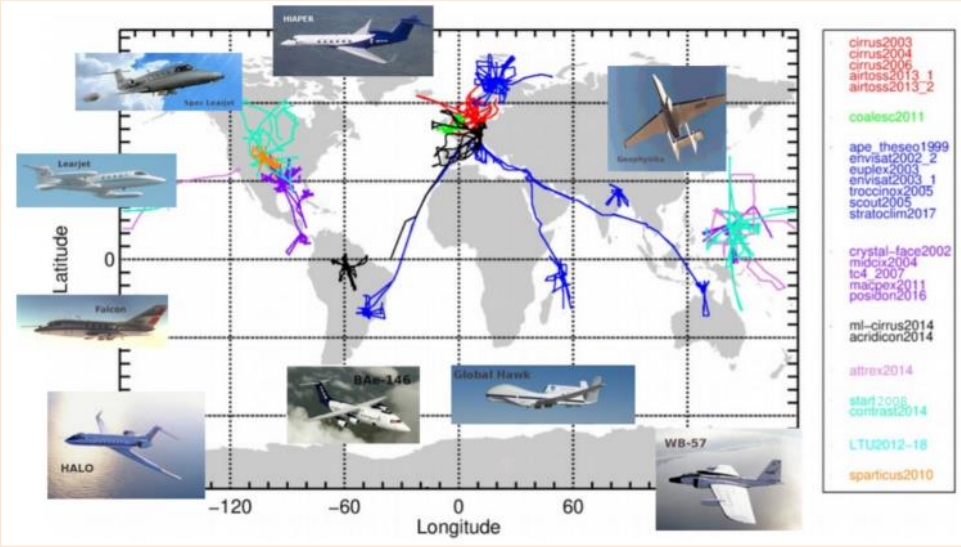
CERES SYN1DEG [cloud radiative effects]

- Coincident gridded radiative fluxes (1°x1°)
- Variables: Shortwave and longwave cloud radiative effects (SWCRE and LWCRE)

CALIPSO-CloudSat retrievals [cloud macrophysics]

- DARDAR-CLOUD (V2.1.1 and V3.1) and 2C-ICE Version RF05
- Climatology for February (2007-2012)
- Variable: frozen water content

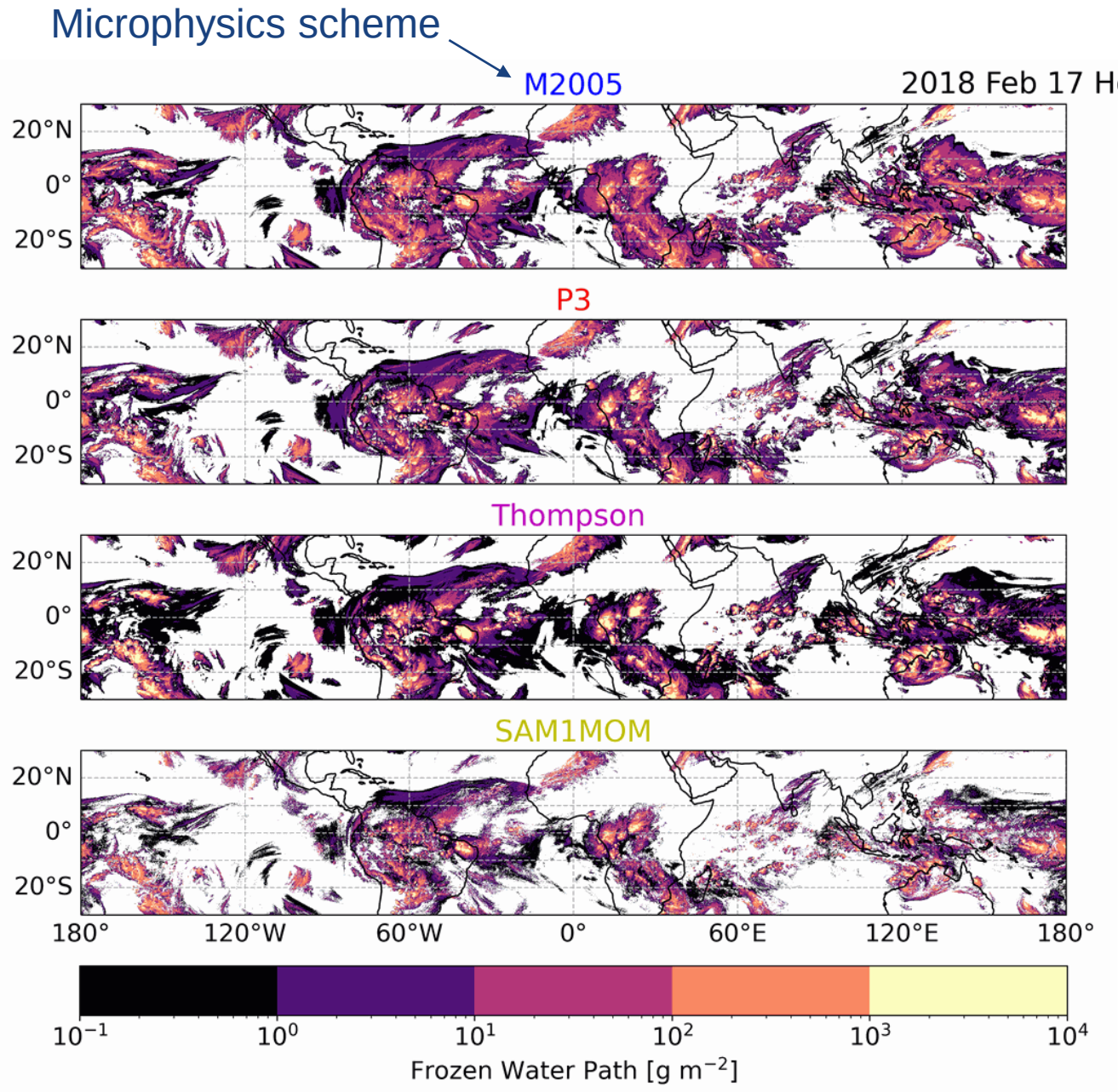




Microphysics guide to cirrus II (Krämer et al. 2020) [cloud microphysics]

- Five tropical field campaigns
- Variables: frozen water content, frozen hydrometeor number concentration

Cirrus cloud properties vary widely across the four simulations



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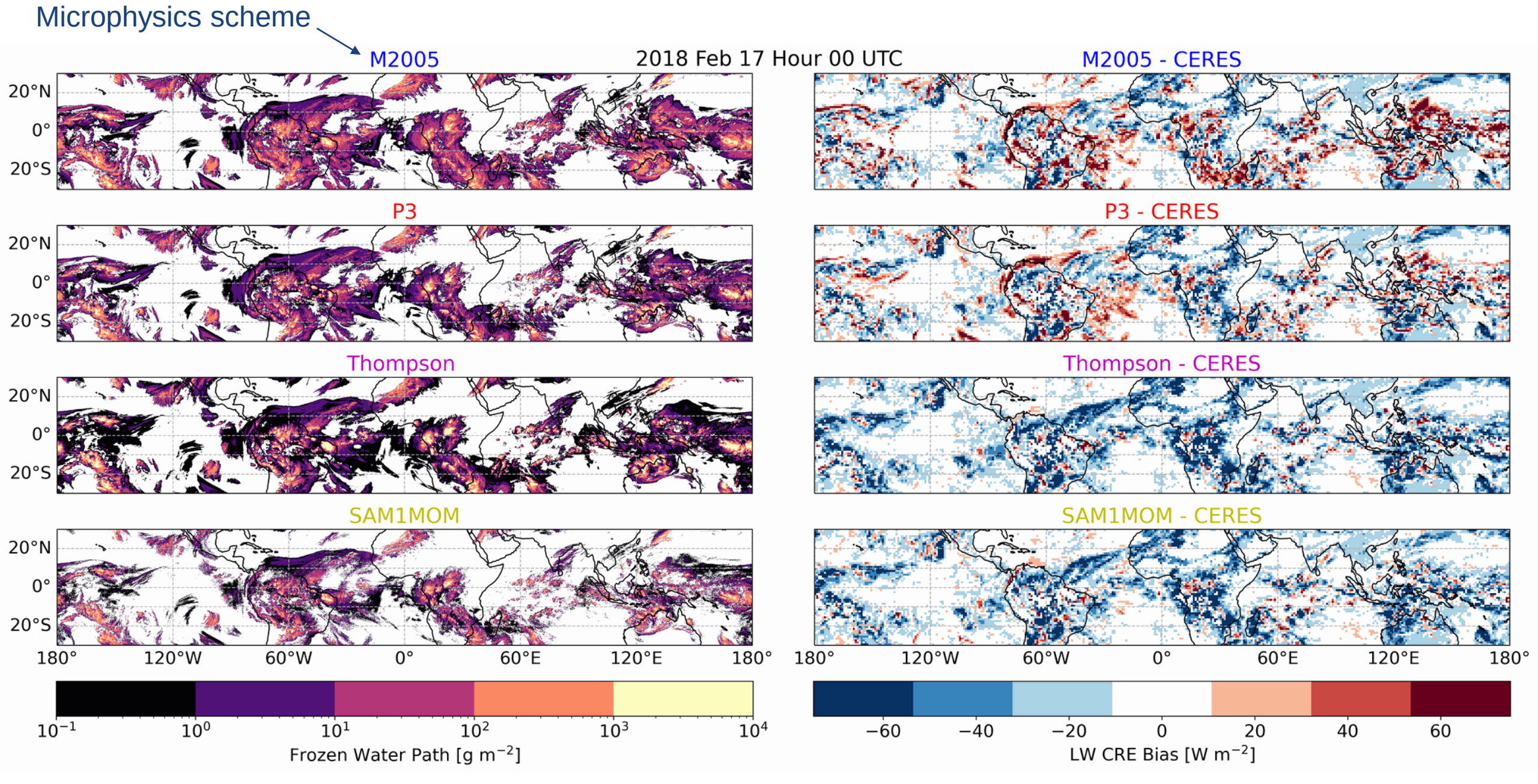
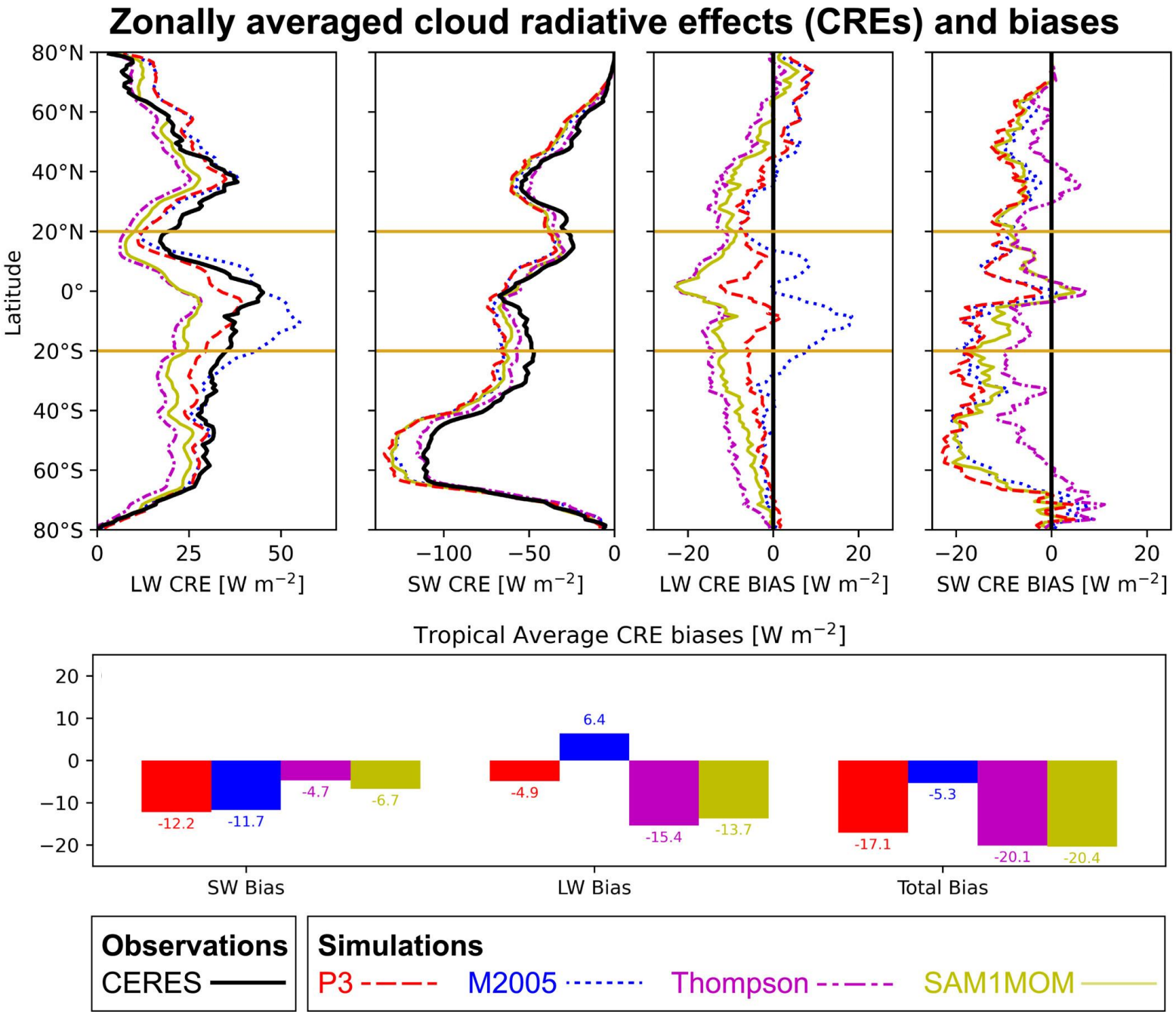
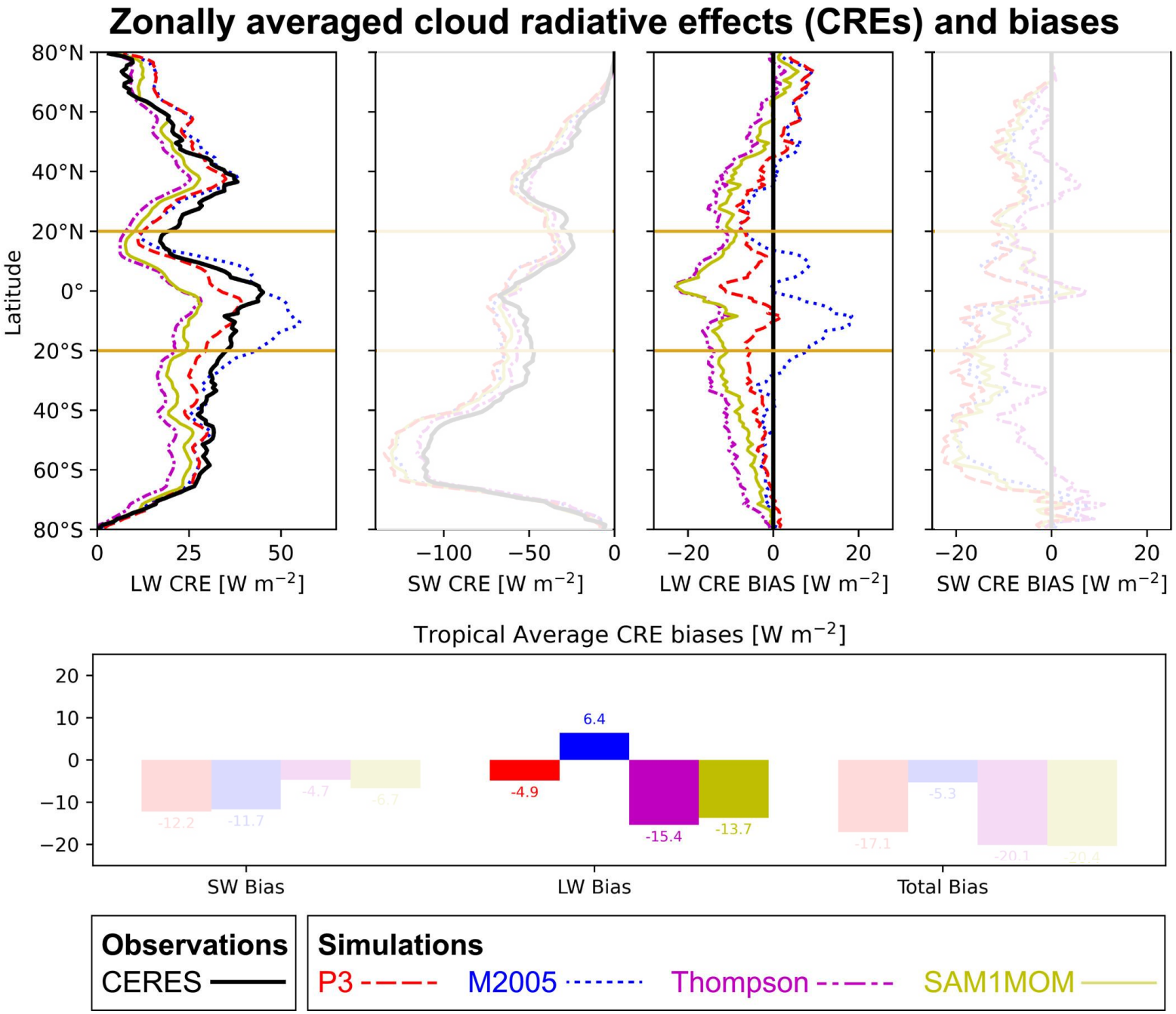



Zonally averaged cloud radiative effects (CREs) and biases
Latitude
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
0
25
50
LW CRE [W m^{-2}]
−100
−50
0
SW CRE [W m^{-2}]
−20
0
20
LW CRE BIAS [W m^{-2}]
−20
0
20
SW CRE BIAS [W m^{-2}]
Tropical Average CRE biases [W m^{-2}]
20
10
0
−10
−20
-12.2
-11.7
-4.7
-6.7
-4.9
6.4
-15.4
-13.7
-17.1
-5.3
-20.1
-20.4
SW Bias
LW Bias
Total Bias
Observations
CERES
Simulations
P3
M2005
Thompson
SAM1MOM



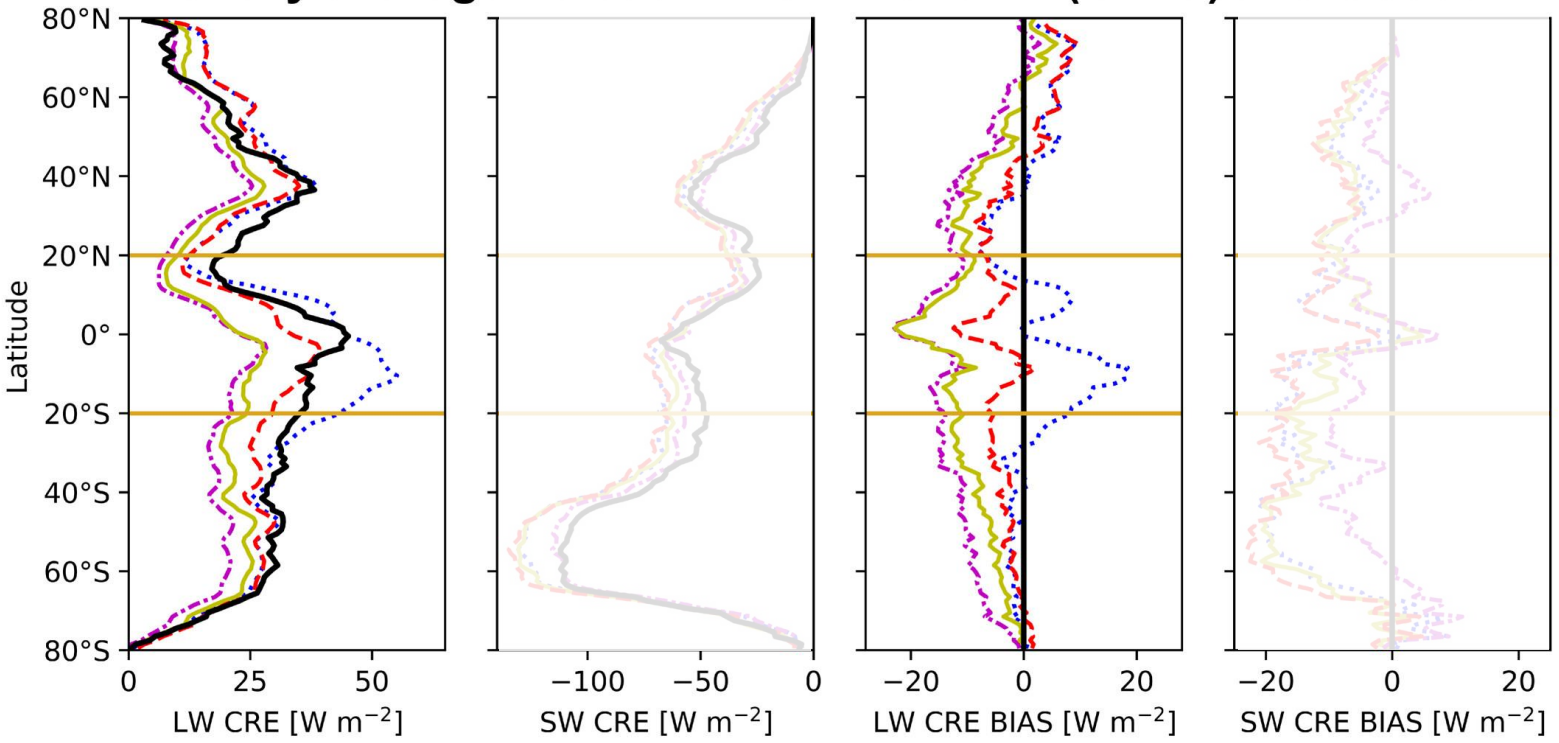
Tropical average longwave cloud radiative effects vary over 22 W m^{-2} depending on microphysics

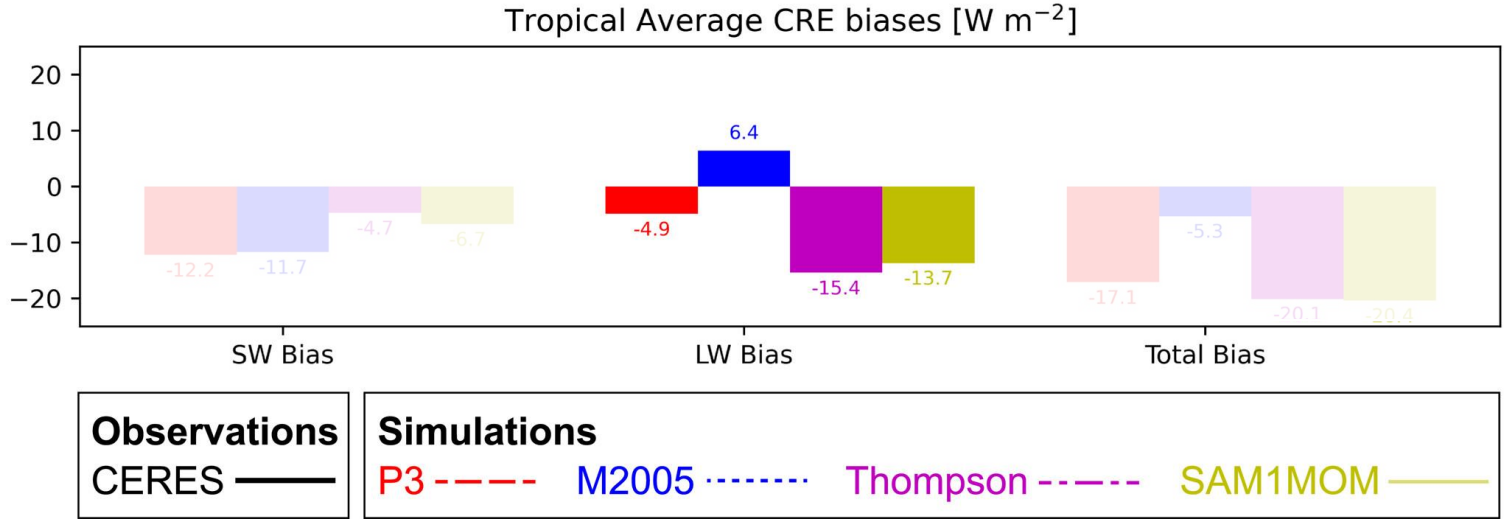
M2005 is the only simulation with a positive bias (implying too much and/or too thick high cloud), which is +6.4 W m^{-2}

P3 has the smallest bias of -4.9 W m^{-2}

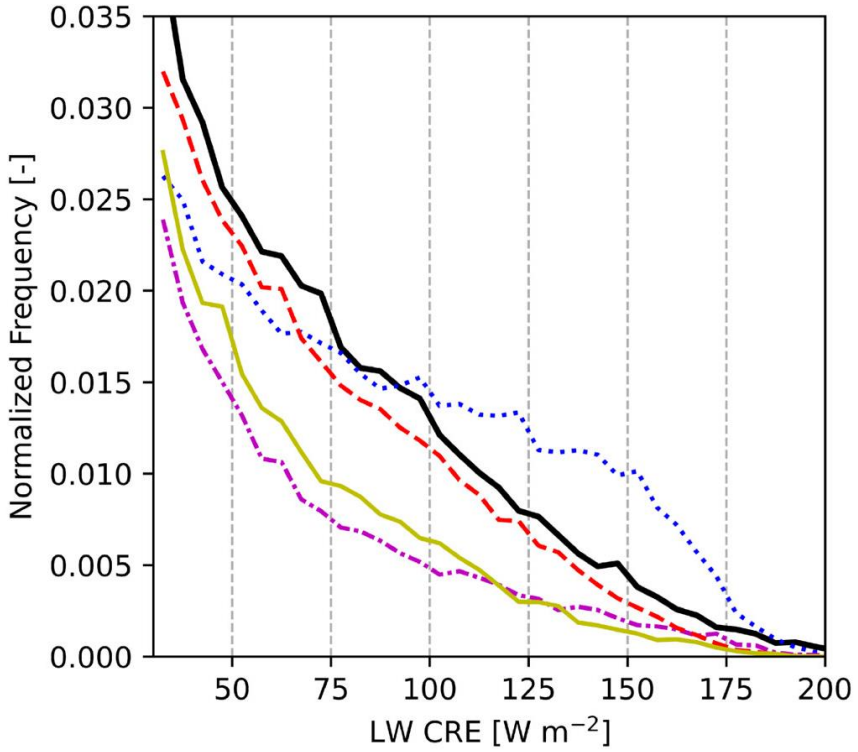
Thompson and SAM1MOM have large negative biases of -15.4 W m^{-2} and -13.7 W m^{-2}, respectively

Zonally averaged cloud radiative effects (CREs) and biases



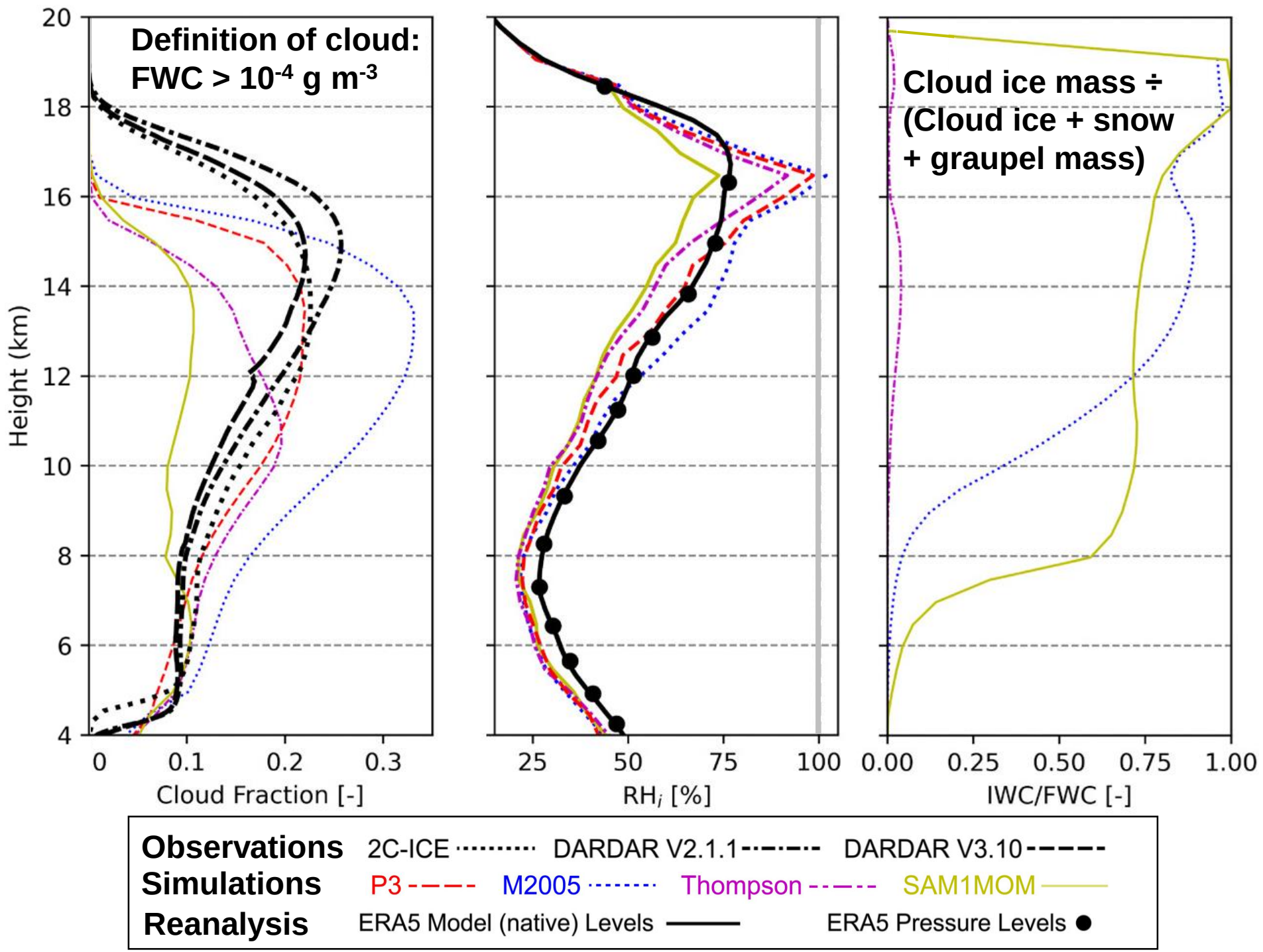


Tail of the distribution of **LW CRE** [gridded to 1°x1°]



Next step: Use a broader set of observations to identify probable causes of differences across the simulations and of longwave biases

distribution shape



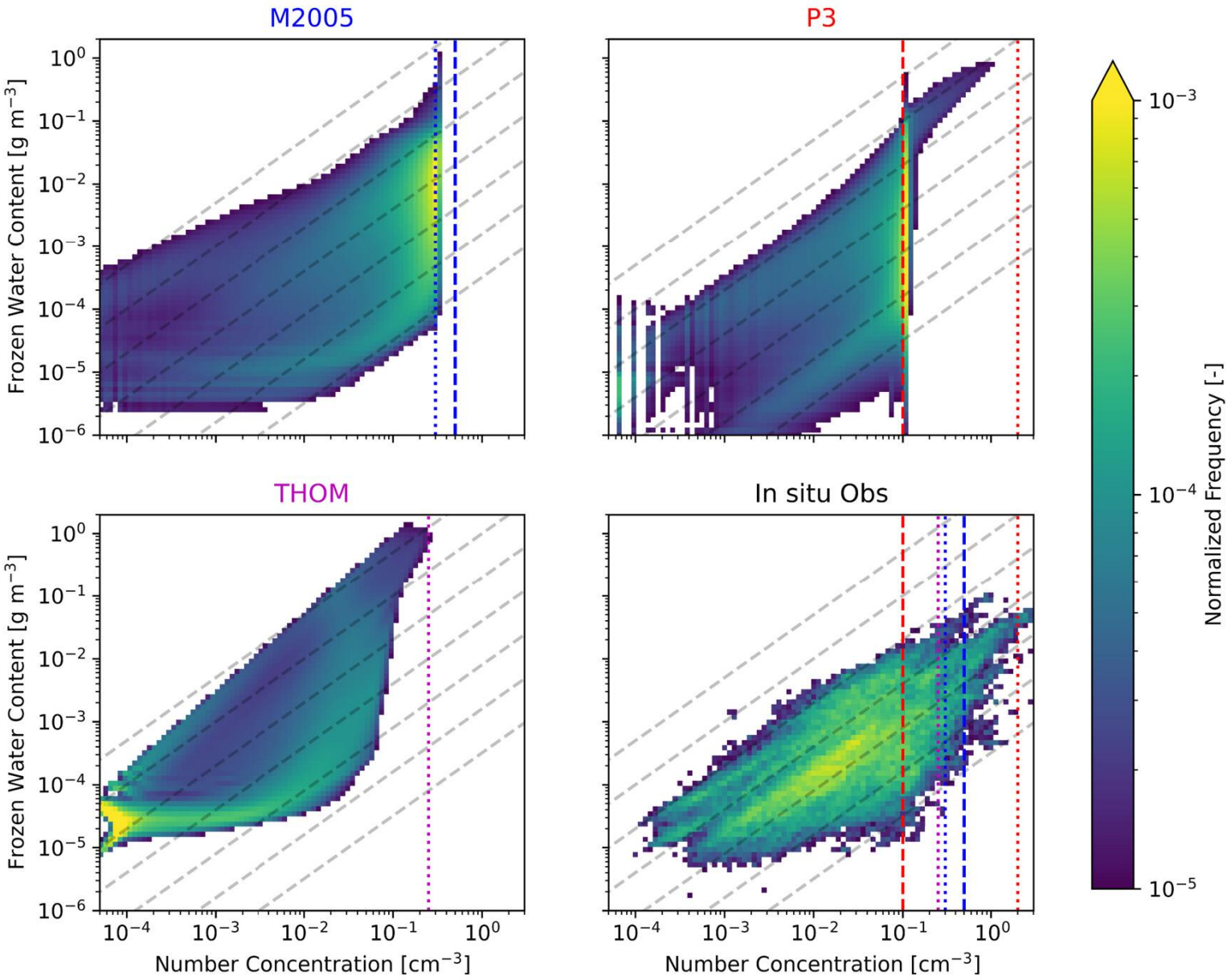
P3 is the most realistic

SAM1MOM has too little cloud everywhere in the profile…
and is too dry in the upper troposphere due to the use of ***saturation adjustment***

Thompson has a peak in cloud fraction too low in the atmosphere…
and its frozen hydrometeor mass is mostly precipitation due to ***overestimated autoconversion of cloud ice to snow***

M2005 has too much cloud everywhere

Microphysics comparison with aircraft measurements



Grid cells in Thompson with tiny amounts of ice are likely remnants of cloud after sedimentation

Ice crystal number concentrations in M2005 and P3 are strongly constrained by limits (0.3 cm^{-3} and 0.1 cm^{-3}), which is unphysical

Frozen hydrometeor number concentrations strongly affect sedimentation and cloud lifetime…

Do the different limits in M2005 and P3 explain most of the differences in simulated cirrus between the two simulations?

Summary:

Microphysics ⇨ Cirrus ⇨ Tropical longwave cloud radiative effects

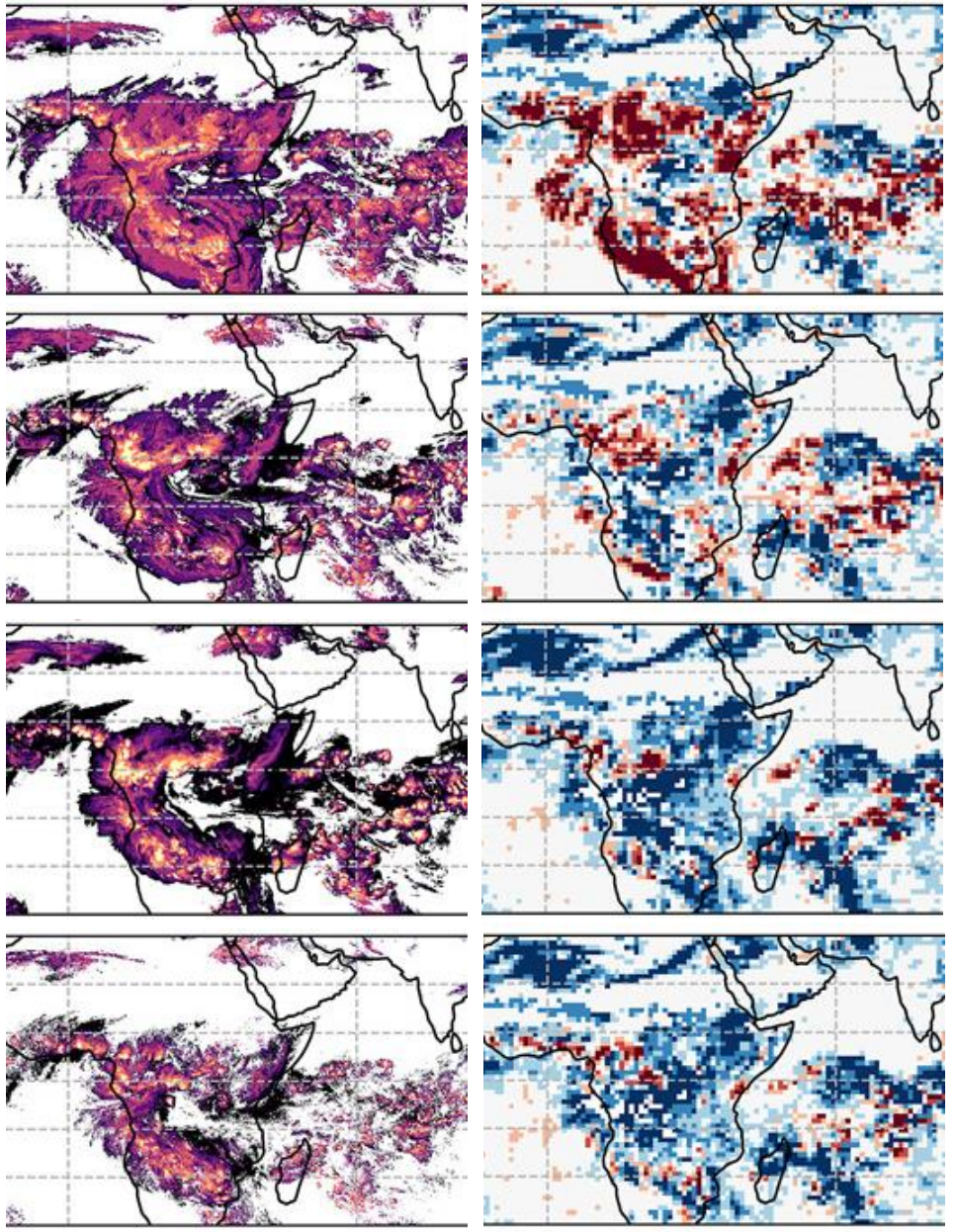
- Tropical cirrus and the tropical longwave radiative budget are highly sensitive to microphysics even when microphysics-dynamics feedbacks are shut down
- Nudging helps make the best use of observations (e.g. allows for the use of coincident observations)

M2005: Large ice crystal number concentrations (0.3 cm^{-3}), weak sedimentation

P3: Less large Ice crystal number concentrations (0.1 cm^{-3}), less weak sedimentation

Thompson: Overly efficient autoconversion of cloud ice to snow

SAM1MOM: No ice supersaturation



Future steps:

Microphysics ⇨ Cirrus ⇨ Tropical longwave cloud radiative effects

- Understand why ice crystal number concentrations ubiquitously hit limits (e.g. biases in microphysics vs dynamics)
- Remove or raise limits (*Gasparini et al. 2022, Gasparini et al. 2025 in review at ACP*)
- Constrain sedimentation and understand its impact on cirrus properties and cloud radiative effects

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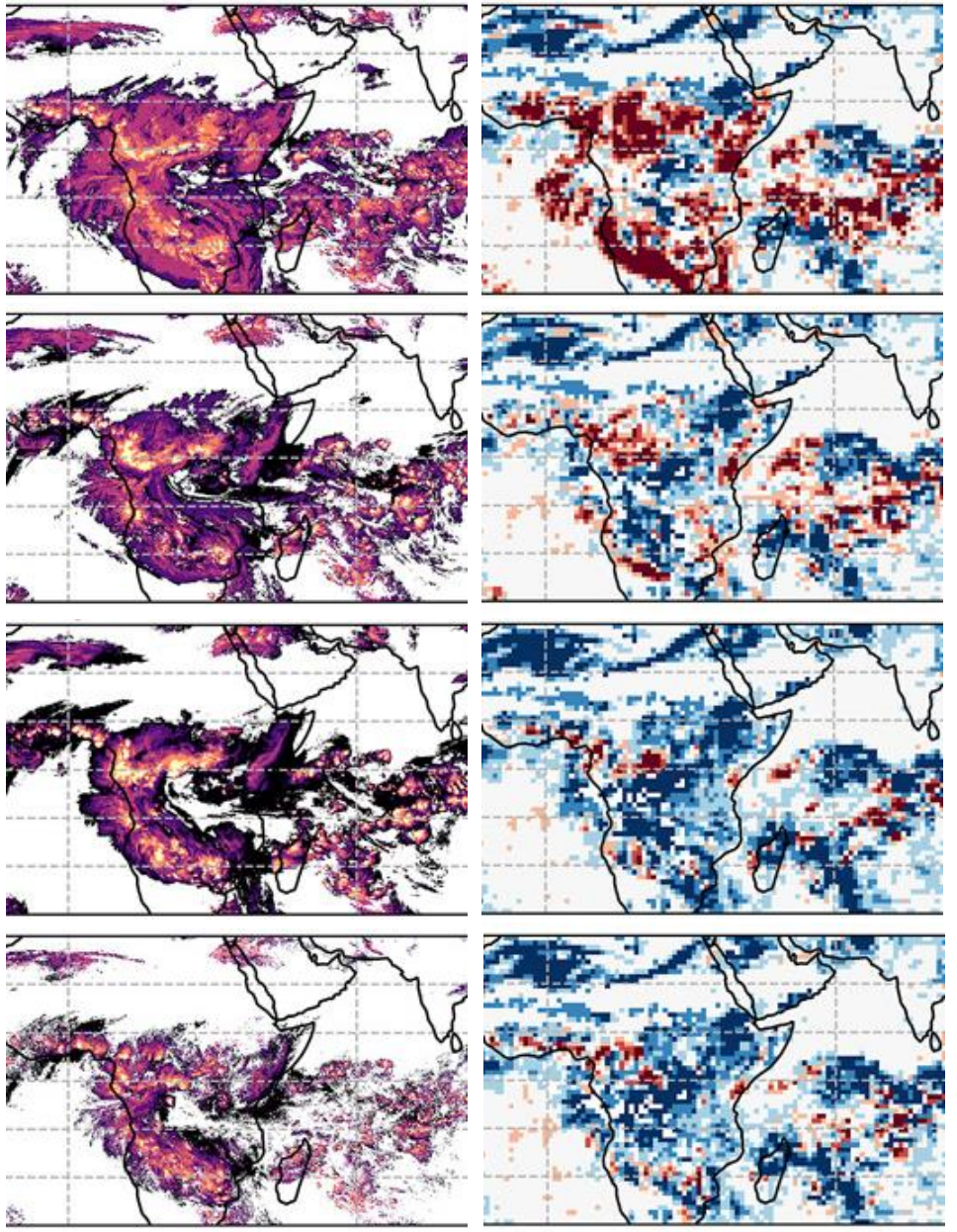
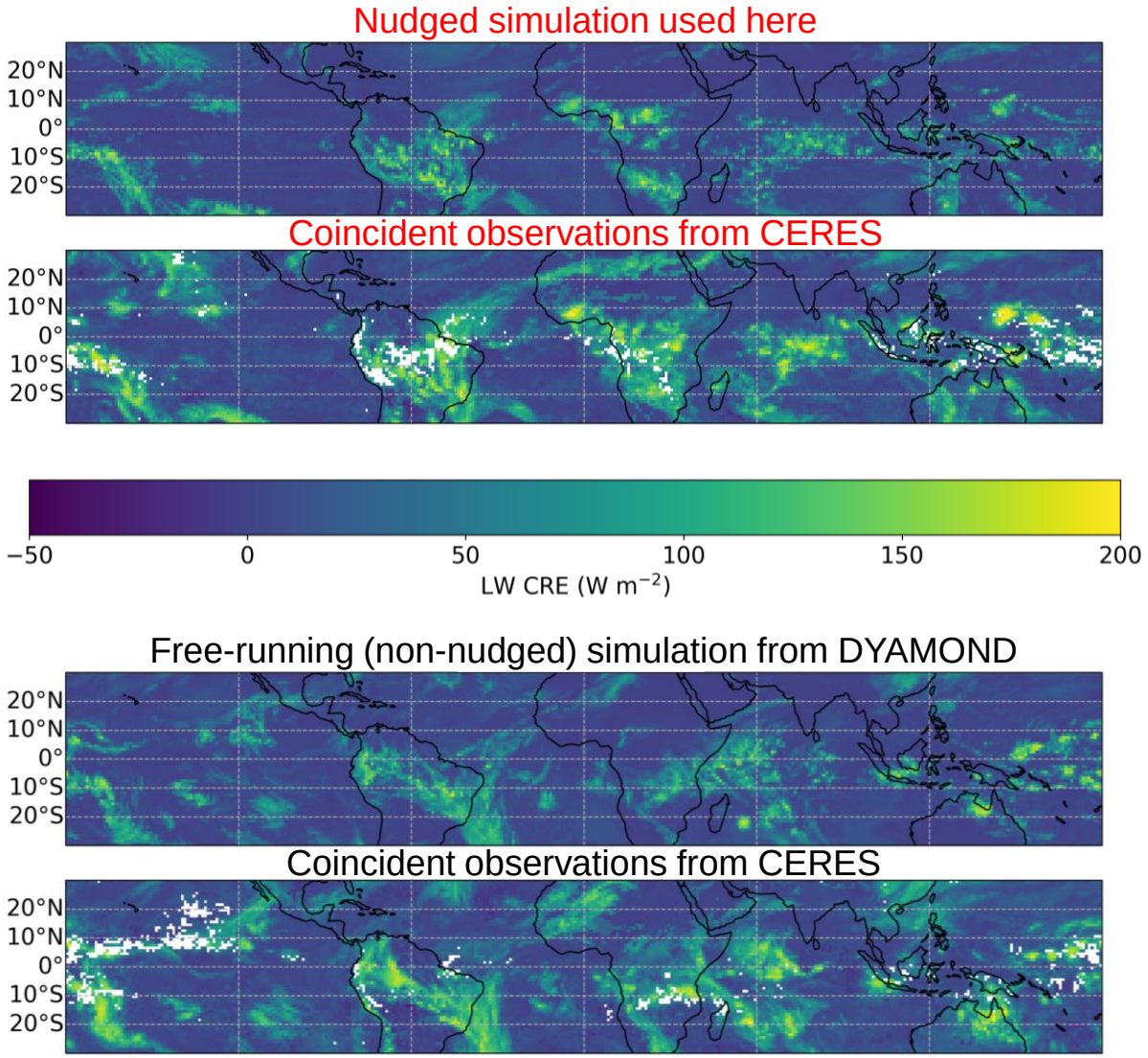


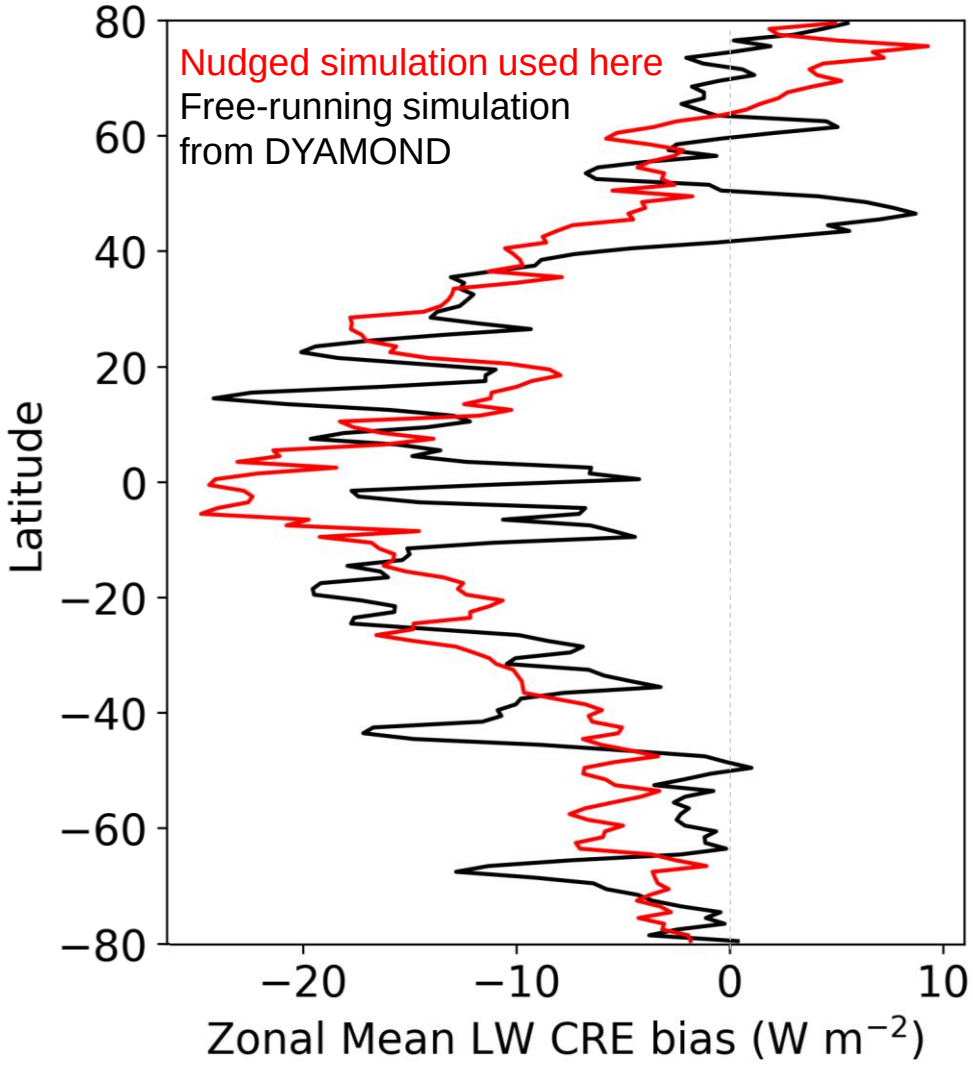
Extra Slides

LW CRE from CERES and simulations after five days



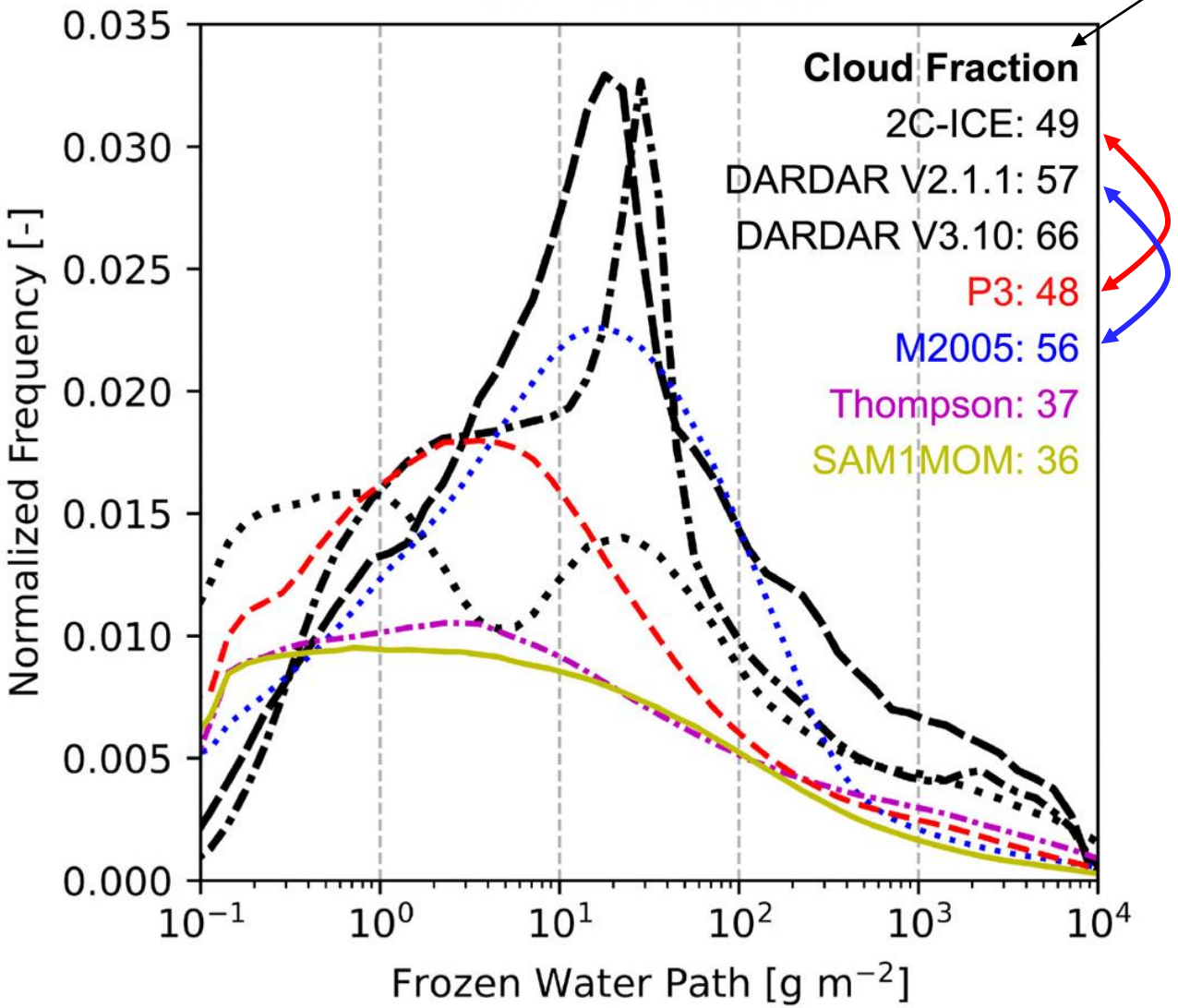
The large-scale patterns of clouds in a free-running SAM simulation agree well with CERES

LW CRE bias compared to CERES after five days



However, the profile of LW CRE bias from the free-running simulation is spiky due to advective errors

Distribution of Frozen Water Path



Definition of cloud: FWP > 0.1 g m^{-2}

P3 has a similar fraction of cloudy columns as 2C-ICE

M2005 has a similar number of cloudy columns as DARDAR V2.1.1

Thompson and SAM1MOM have too little cloud compared to all retrievals

Large variability across different retrievals products makes this a weak constraint

Observations 2C-ICE ····· DARDAR V2.1.1 -·-·-· DARDAR V3.10 – – – –

Simulations P3 – – – M2005 ····· Thompson – · – · – SAM1MOM ——