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Evaluation of the Predicted Particles Properties (P3) microphysical scheme in E3SM

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E3SM Energy Exascale Earth System Model

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Motivation

- E3SM's current cloud microphysics (MG2, Morrison and Gettelman, 2015) artificially converts ice to snow – it neglects the physical evolution of hydrometeor riming, which is important for simulation of deep convection
- The Predicted Particle Properties (P3) scheme allows for physical evolution of ice particles at local grids by predicting rimed mass and volume

Driving question:

- What is the impact of changing MG2 with P3 microphysical scheme on the climate and precipitation ?

Simulation setup - E3SMv2 candidate at 'ne30'

Physics: MG2/P3 + CLUBB + RRTMG
Chem: Linoz-mam4-resus_mom_soag
Compset: F2010SC5-CMIP6
Resolution: 'ne30' (1 deg x 1 deg)
Simulation: 3 years (1 yr spin-up, 2 yr analysis)

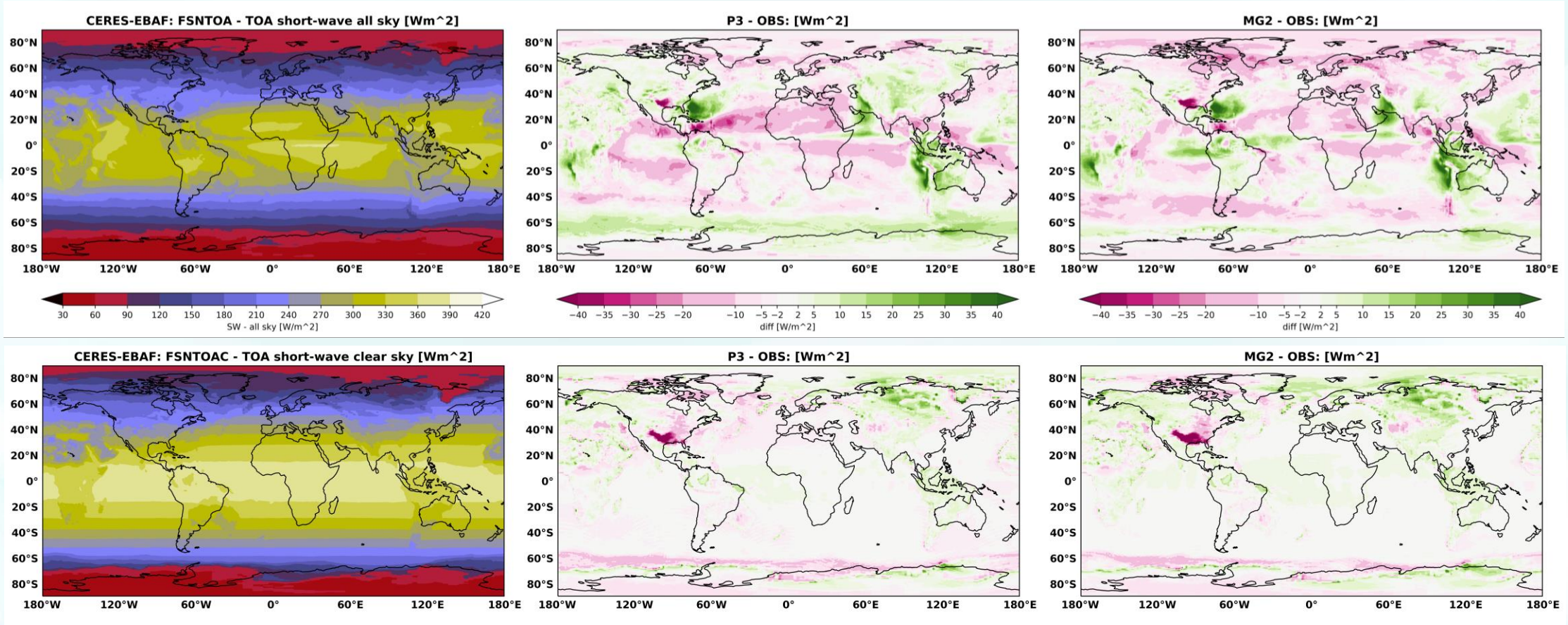
Differences in microphysical treatment P3 / MG2

MG2	P3
• **Prognostic**: Droplets, rain, ice, snow	• **Prognostic**: Droplets, rain, densified ice (represents ice, snow, graupel,hail), rimed mass & volume
• **Hydrometeros Density**: constant	• **Hydrometeors Density**: changes according to rimed mass/volume
• **Particle size**: Mass-size / mass-area / mass-terminal velocity relations based on non-rimed spherical	• **Particle size**: Mass-size / mass-area / mass-terminal velocity relations based on non-spherical rimed/non-rimed
• **Radiation:** spherical non-rimed relations	• **Radiation:** non-spherical rimed relations (may radiate stronger)

SCREAM-P3 used here was extensively debugged to incorporate important bug fixes

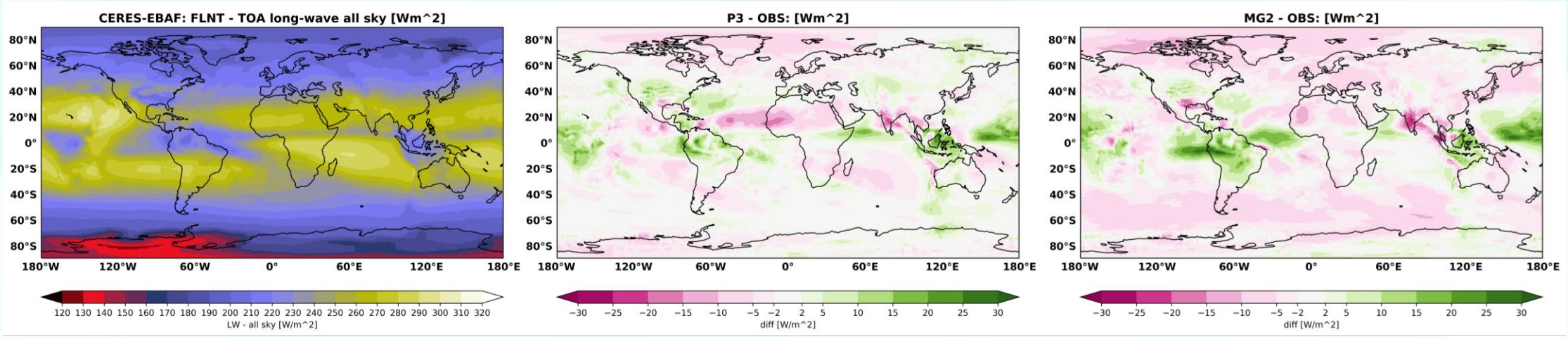
Shortwave Radiative Fluxes

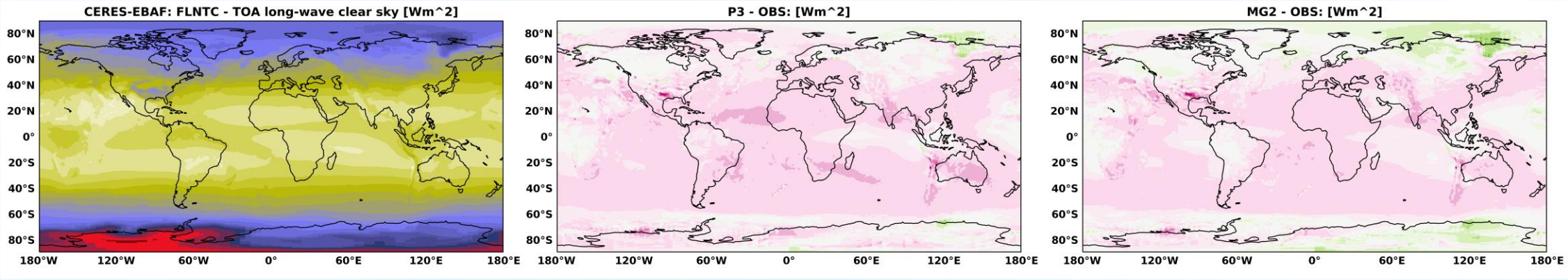
- With P3 lower bias in SWRF (all-sky) is seen in the Southern Ocean, Arctic, central/eastern Asia
- However, larger biases in SWRF in the Atlantic and eastern-Pacific tropical area
- There are common biases between P3 has MG2, with different magnitudes



Longwave Radiative Fluxes

- P3 has lower LWRF bias in the Southern Ocean, Arctic region, west coast of South-America, central/eastern Asia
- The clear-sky LW flux introduces large homogenous biases mainly through water vapor



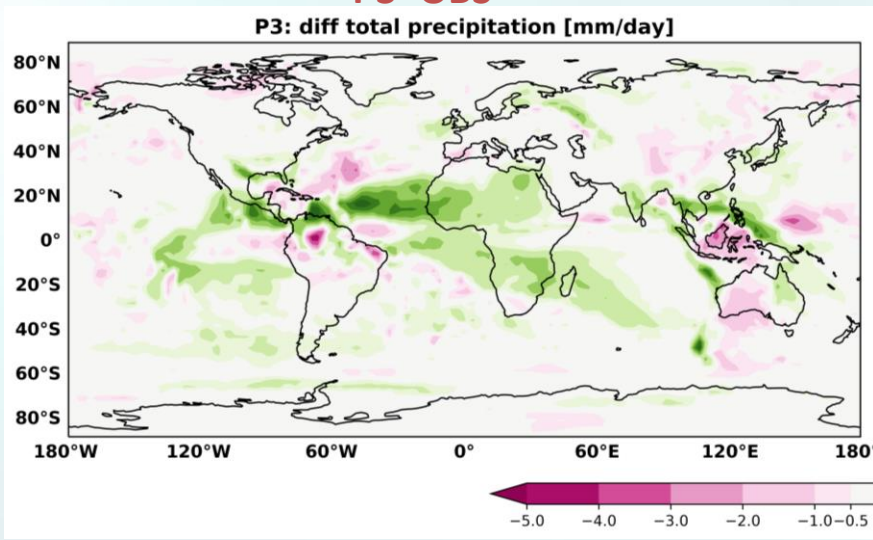


Total Precipitation

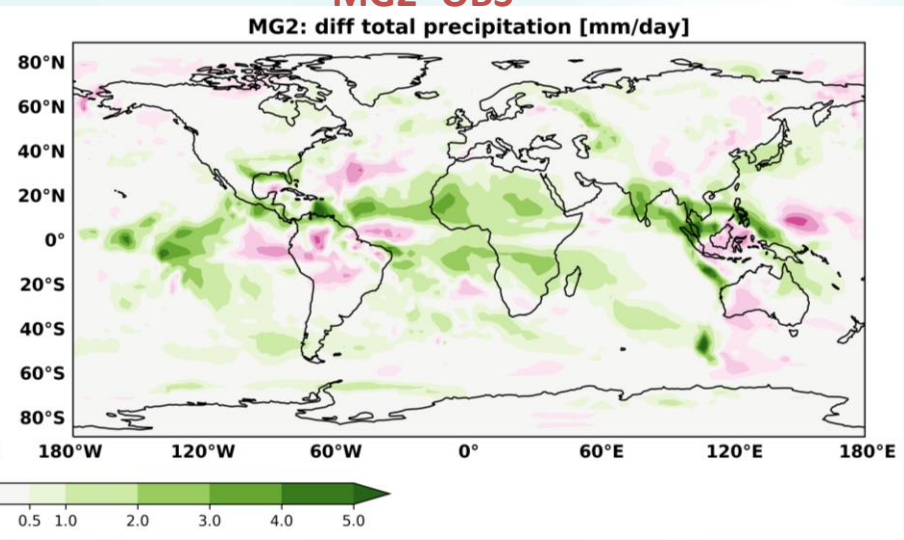
Mean state – comparison between P3 / MG2 and Obs:

- P3 shows lower bias in: tropical Eastern Pacific ocean, south-America, and TWP
- There are common biases in P3 and MG2, which might be contributed by other components of the model

P3- OBS



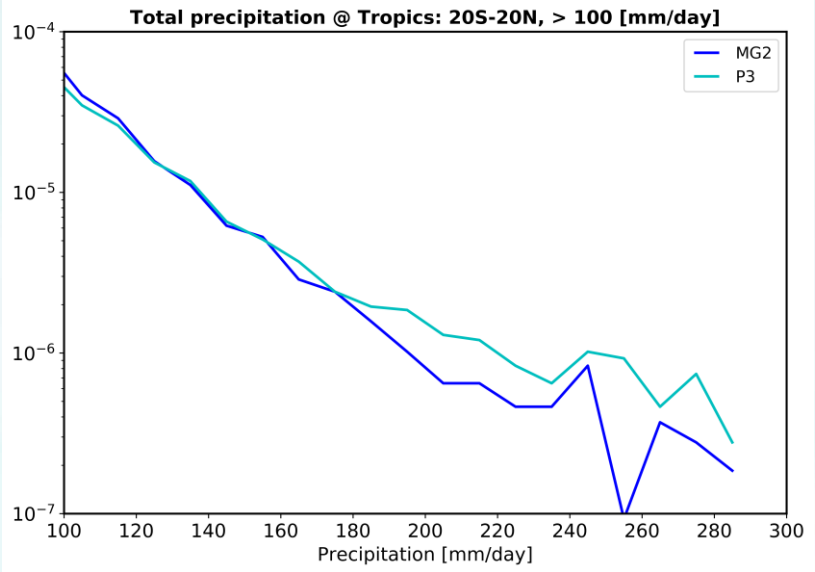
MG2- OBS



Precipitation – compare MG2 to P3:

- 24h averaged **tropical precipitation** shows P3 increases mainly strong stratiform rain > ~ 6 mm/h

P3 vs MG2

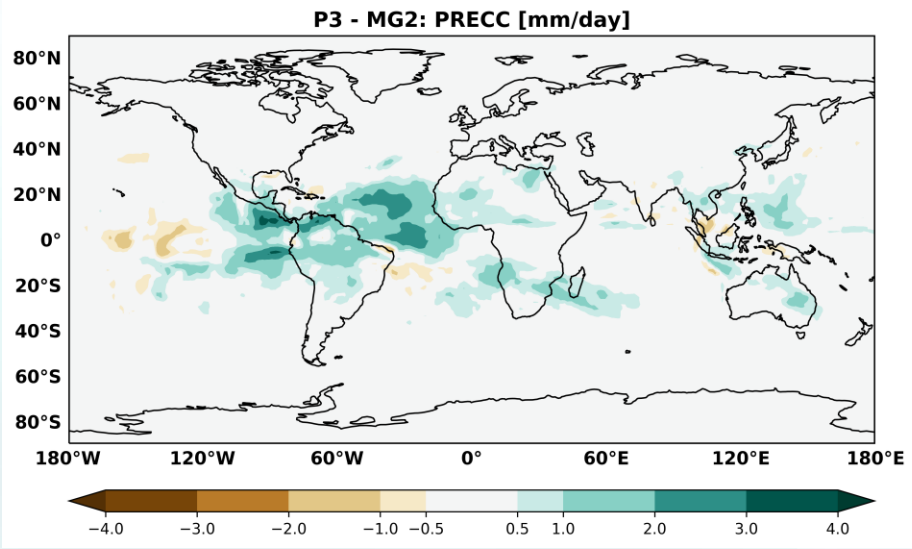


Precipitation components

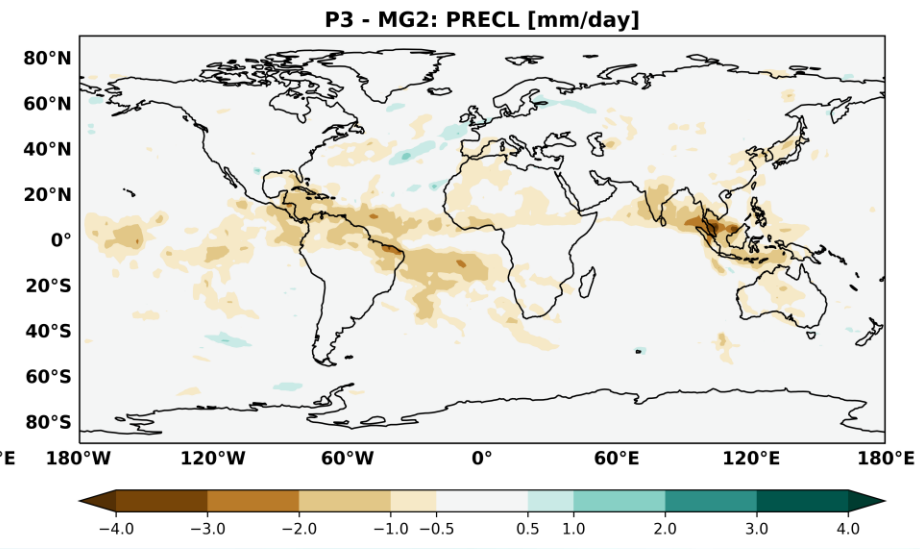
Differences in convective and large-scale precipitation between P3 and MG2:

- With P3, the model predicts more convective but less large-scale precipitation than MG2 over the tropical Atlantic and eastern Pacific Ocean

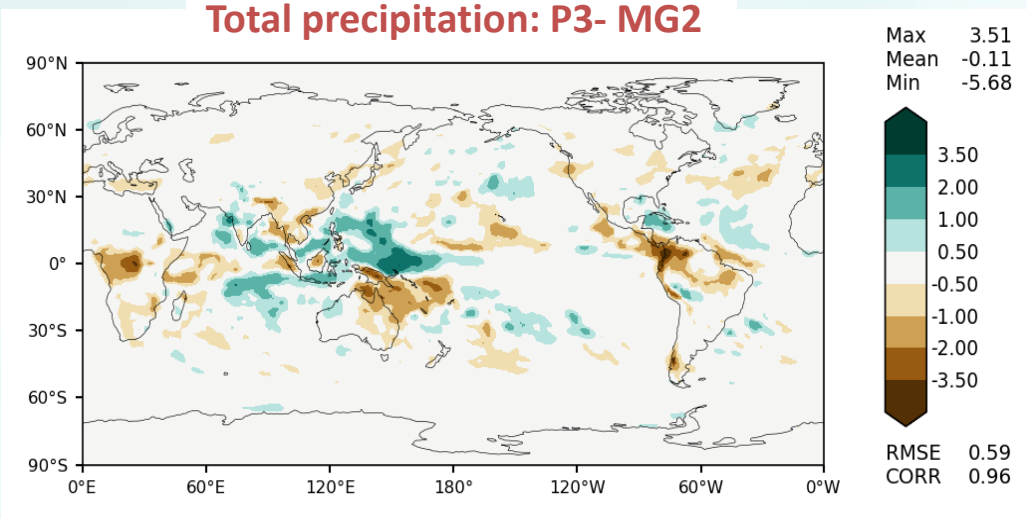
Convective: P3- MG2



Large-scale: P3- MG2



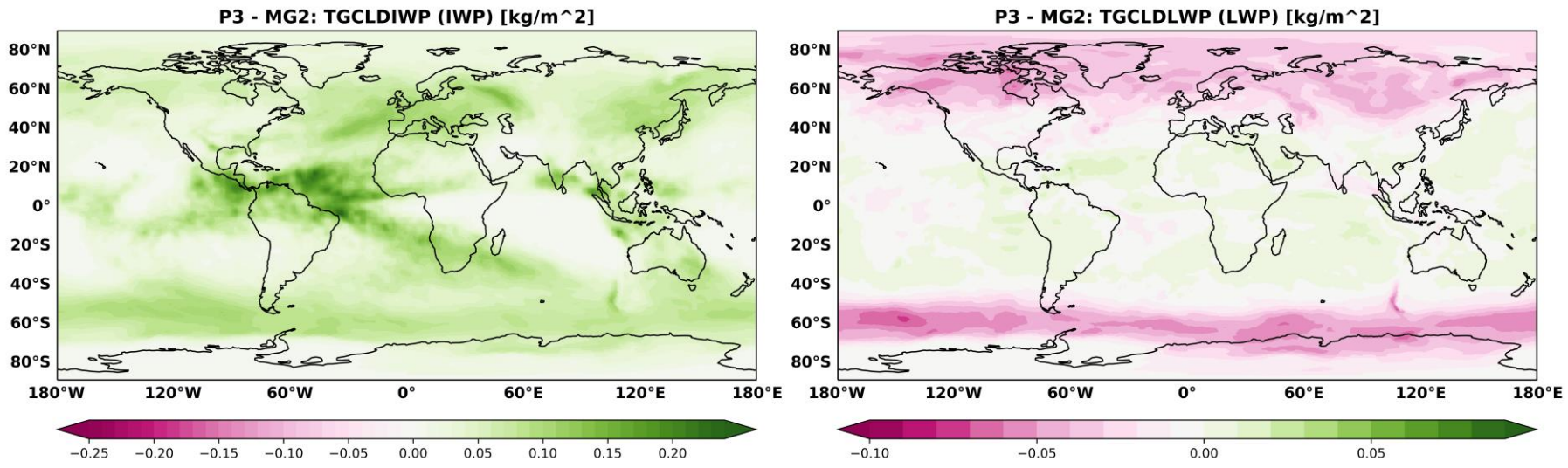
Total precipitation: P3- MG2

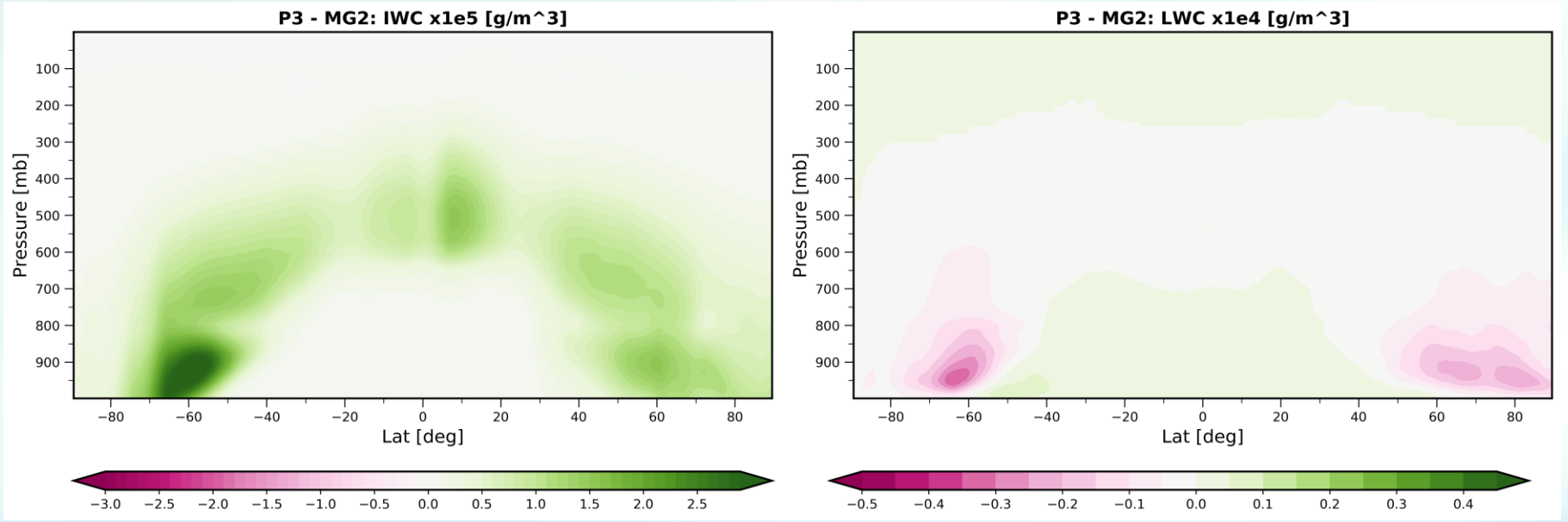


Ice / Liquid Water Path and mass content

IWP and LWP – compare MG2 to P3:

- P3 has thicker ice clouds and comparable amount of liquid clouds in the tropics
- P3 has lower LWP over the high-altitudes than MG2, and temperature-dependent ice nucleation in mixed-phase clouds might contribute to it.





Sensitivity to ice nucleation parameterization in mixed-phase clouds

- In the original P3, ice nucleation and droplet freezing in mixed-phase clouds are temperature-dependent only, which are commonly used in the weather models
- MG2 employed the Classical (ice) Nucleation Theory (CNT) for ice nucleation and droplet freezing in mixed-phase clouds, which is aerosol-dependent

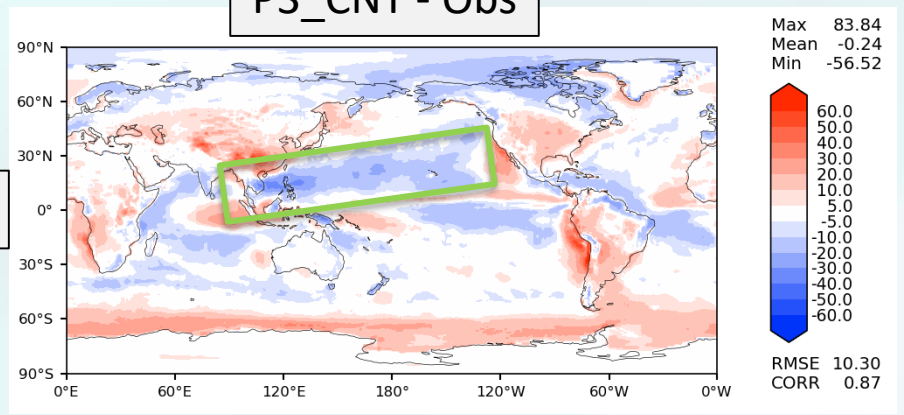
P3_CNT – switched to CNT for the ice nucleation and droplet freezing in mixed-phase clouds

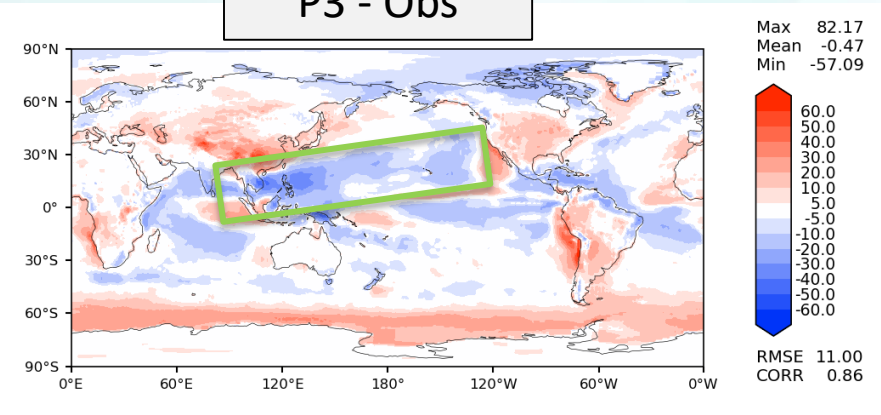
- P3_CNT reduces the western-Pacific SWCF bias, and southern ocean
- The LWCF bias is reduced in the tropical pacific and Arctic, but is increased over the Eastern India Ocean

P3_CNT - Obs

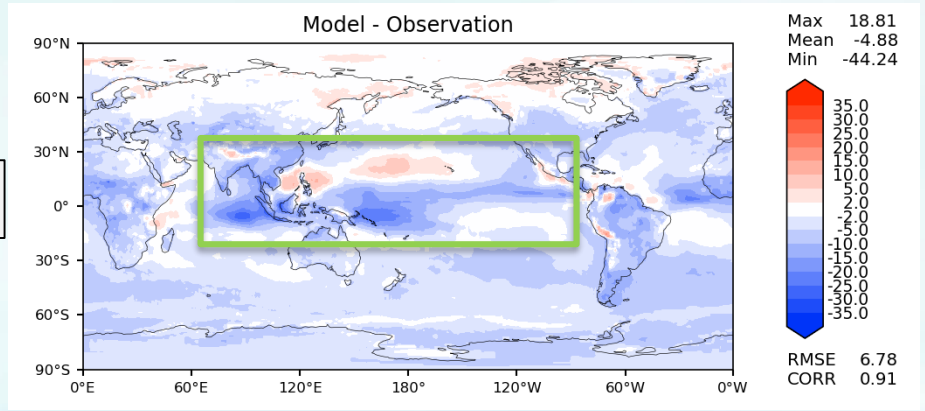
P3 - Obs

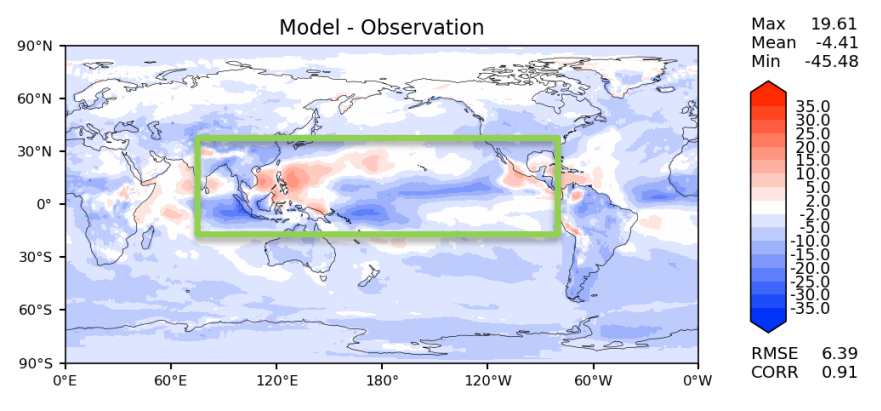
SWCF





LWCF





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Summary

- In ‘ne30’ simulations P3 was shown to reduce significantly the LWCF compared to MG2 in large areas of the globe
- The SWCF bias is seen to be reduced in specific areas (Southern Ocean, Arctic, central/eastern Asia), but increased in magnitude within the common biased areas P3 shares with MG2; This is likely due to the excessive ice in high clouds
- Total precipitation simulated with P3 shows to reduce the bias in: tropical Eastern Pacific ocean, south-America, and TWP. However, several other large precipitation biases are common with MG2; In the tropical region (Atlantic/Pacific), the large bias in convective precipitation (PRECC) is likely caused from P3 interaction with the convective parameterization (ZM) through latent / sensible heat. This should be further tested and clarified
- Preliminary sensitivity test showed that linking ice nucleation and droplet freezing with aerosols/dust/soot may be important compared to traditional temperature-dependent parameterization scheme

Further plans

- P3 rain microphysics has been recently developed into a 3-moment scheme (added prognostic radar reflectivity) and will be tested in E3SM. It expects to relieve the excessive raindrop size sorting
- P3 ice microphysics has been recently developed into a 3-moment scheme and will be tested in E3SM