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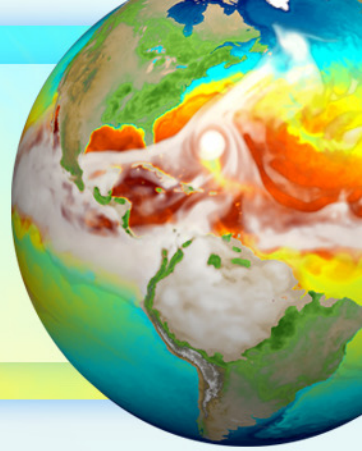

Evaluation of the P3 Microphysics in E3SMv2

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P3 microphysics – why?

- **Limitations of the cloud microphysics parameterization in E3SM:**
  - Artificial partitioning of frozen particles into cloud ice and snow
  - Physical properties like Vt, density, projected area are fixed within a category (ice/snow)
  - In ascending mixed-phase air volume, graupel/hail are not considered, which is an important component of convective microphysics

- **P3 (predicated particle properties) :**
  - Physical representation of ice microphysics is more consistent
  - Variety of ice-phase particle: unrimed ice, dry snow, rimed snow, graupel/hail -- thus, removing the artificial conversion between particles
  - Rimed volume is prognosed (e.g., particles density) -- implications for transition between small- / medium- / strong- 'stratiform' precipitation in high-res simulations
  - A 3-moment P3 scheme / multi-Cat are available for further improvement

Simulation configuration

- **E3SMv2 candidate**
  - Recent master (10th March 2021; #3b539942df)
  - F2010SC5 with recent v2 tuning parameters
  - Duration: 6yrs, with analysis applied for 5yrs (or 2yrs for simplicity)
  - Simulation's period is 2010-2016 (or 2010-2012)
  - Grid: ne30pg2_r05_oECv3; BC/IC: repetitive from 2010
  - Timestep: 30 min / microphysics 5min

- **Major changes in the P3 microphysics (after a debugging period) :**
  - Subgrid variation of cloud liquid is considered for auto-conversion and accretion
  - Apply the MG2 auto-conversion, accretion and WBF tunning params
  - Adding immediate melting after sedimentation
  - Including the Classical Nucleation Theory (CNT) scheme as an option to replace the immersion freezing and heterogenous ice nucleation in P3

Climatology

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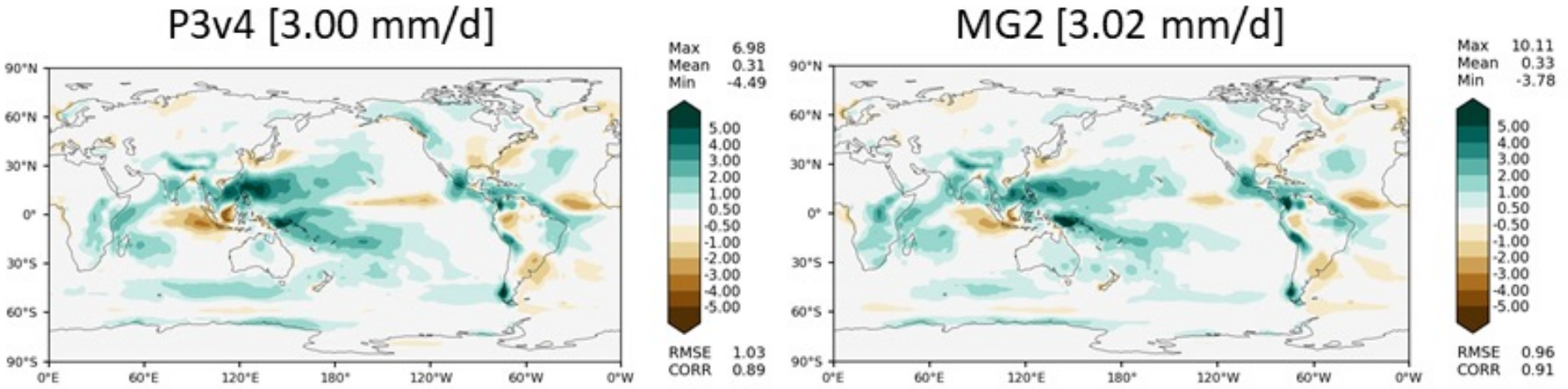
Surface precipitation



- P3v4 shows a notable resemblance to MG2
- In some specific areas like the south Africa, Middle America, and northern South America, wet biases are reduced in P3v4
- TWP wet bias and the eastern Indian ocean dry bias increase compared with MG2

Precipitation (3hr avg)

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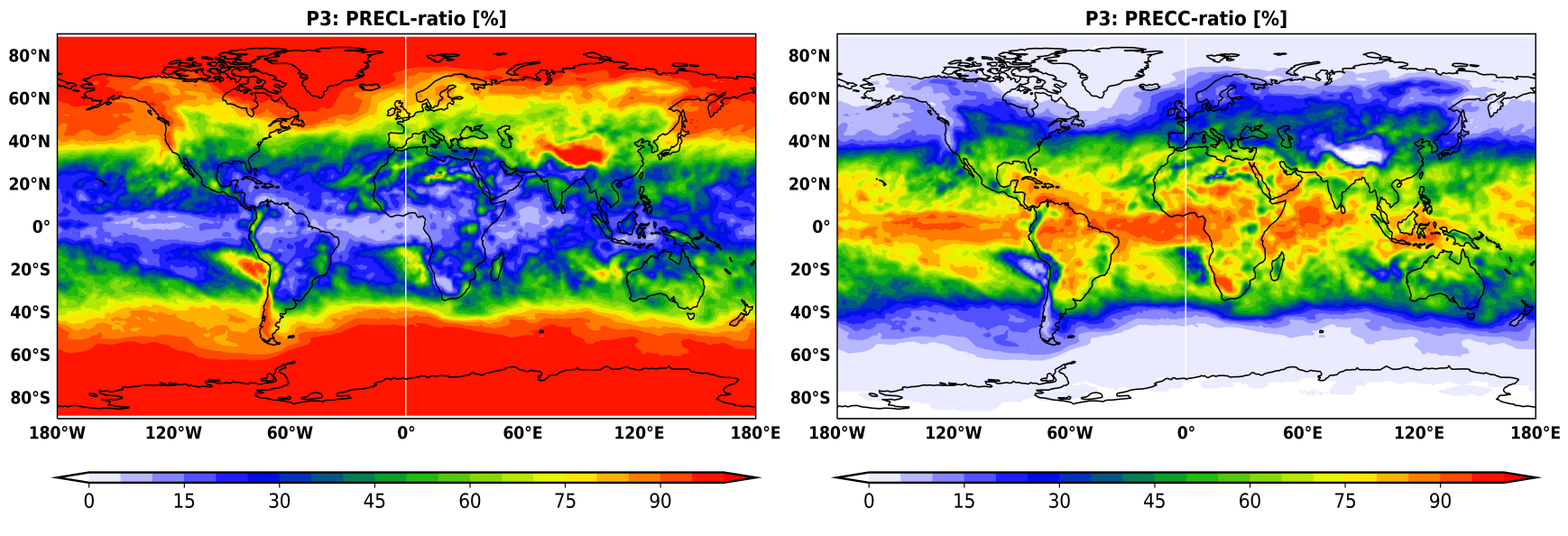
accum PRECL ('stratiform')

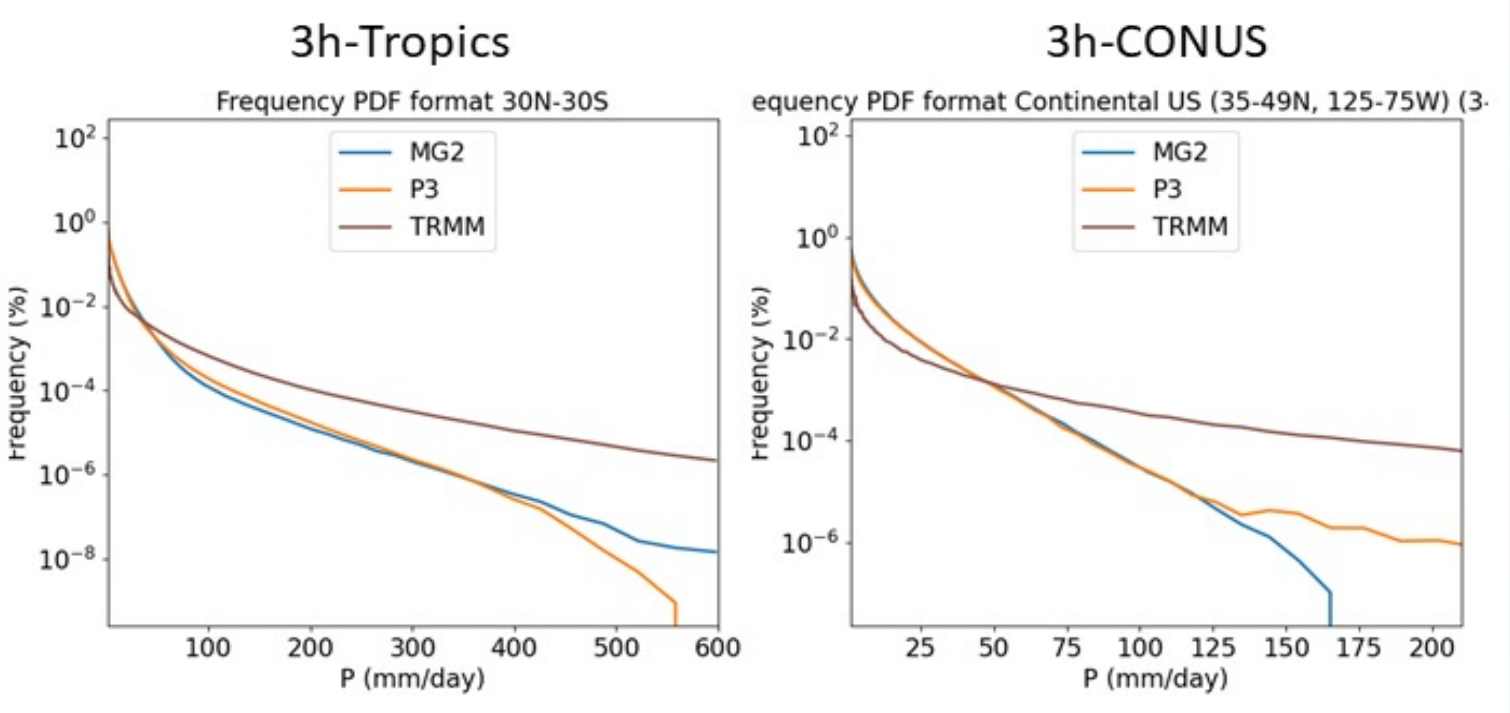
accum PRECC ('convective')



- In the Tropics (30N-30S), >65% is precipitation from Cumulus parameterization over a wide area, which hinders the P3 microphysical contribution to precipitation
- Over Continental US, > 60% is associated with large-scale precipitation

Precipitation (3hr avg)

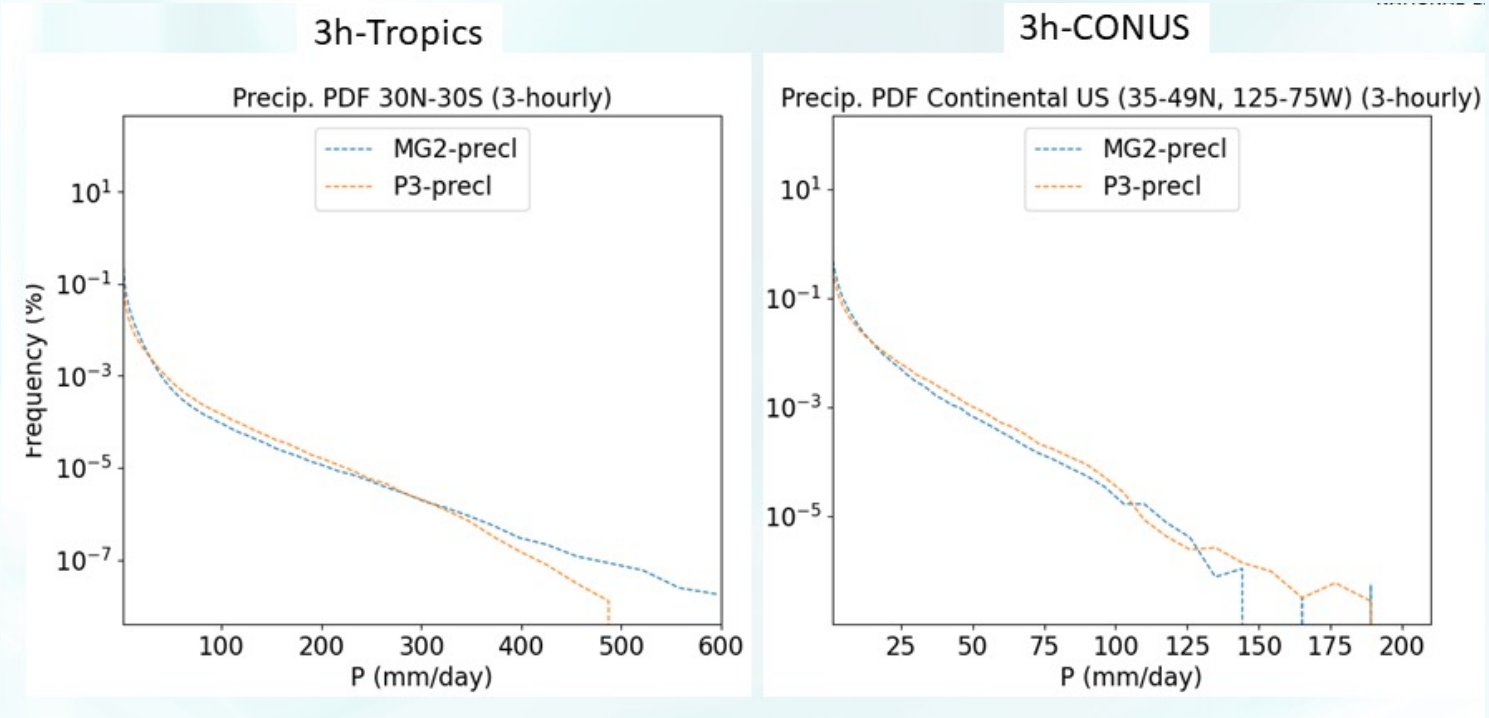
Total Precipitation (PRECT) PDF



- In CONUS the P3 simulation has more intense precipitation rates, which is expected since rimed particles in P3 gives larger rates in large-scale stratiform clouds
- However, in the Tropics the frequencies of very large precipitation rates are reduced in P3 compared with MG2

Precipitation (3hr avg)

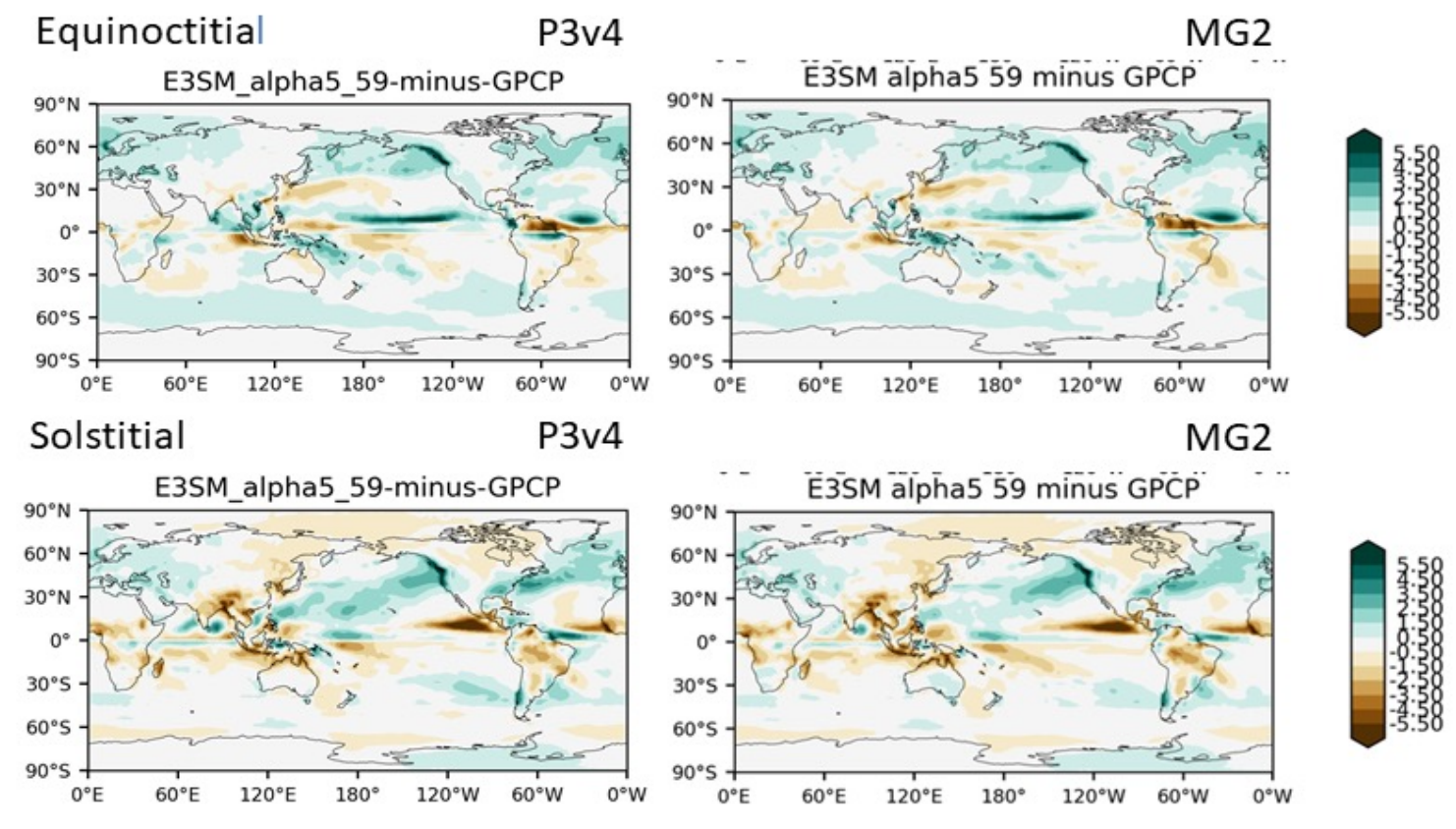
Large scale precipitation (PRECL-'stratiform') PDF



- P3 dominates the stratiform precipitation up to ~185 [mm/hr] / ~280 [mm/hr] for the CONUS / Tropical precipitation

Climatology

Monsoon



- Annual average Monsoon analysis in the Equinoctial (top) and Solstitial (bottom) modes shows comparable performance.

Climatology

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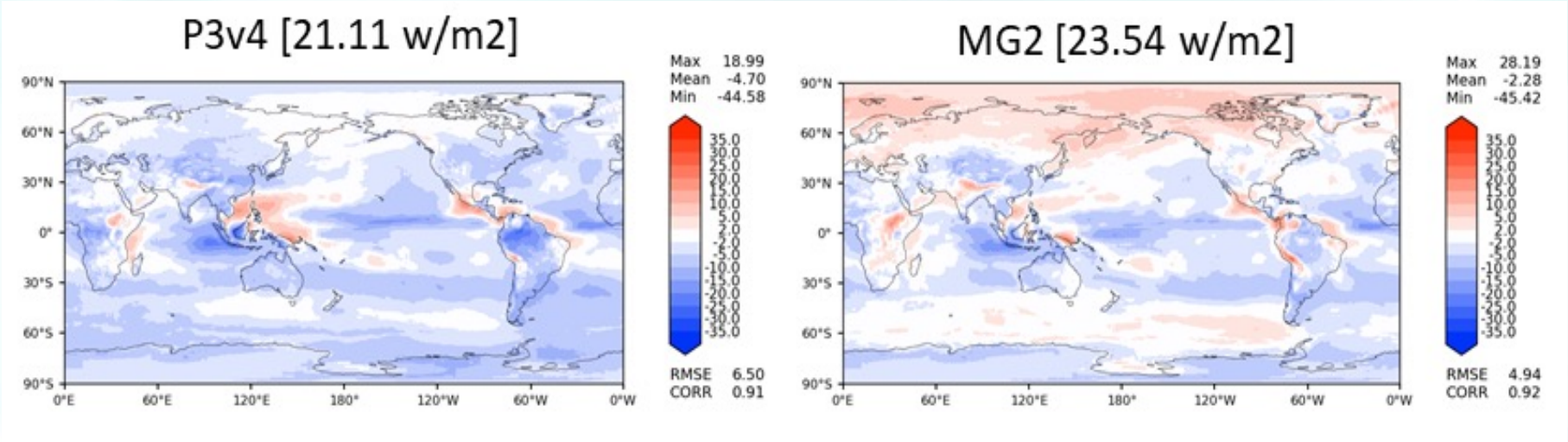
LWCF



- P3v4 removes the large positive bias existing in MG2 over the arctic region
- However, P3v4 down performed in the Southern Hemisphere (~30 S, and 30-60 S), corresponding to less low clouds compared with MG2
- Over the Tropics the performance is fairly comparable, with larger negative bias around the Amazonian region

Climatology

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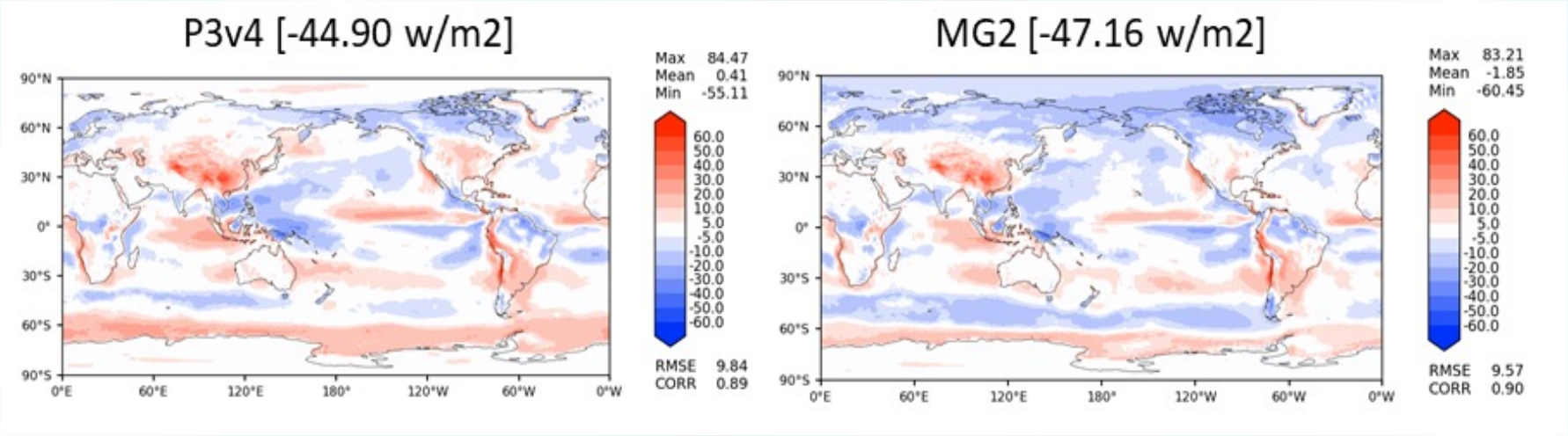
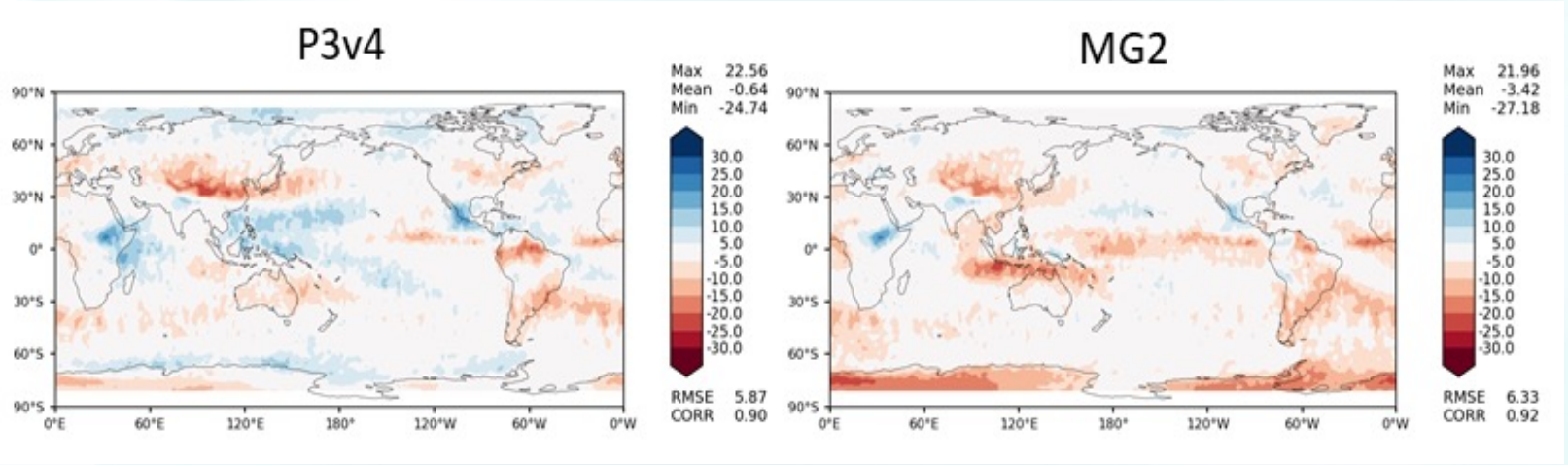
SWCF



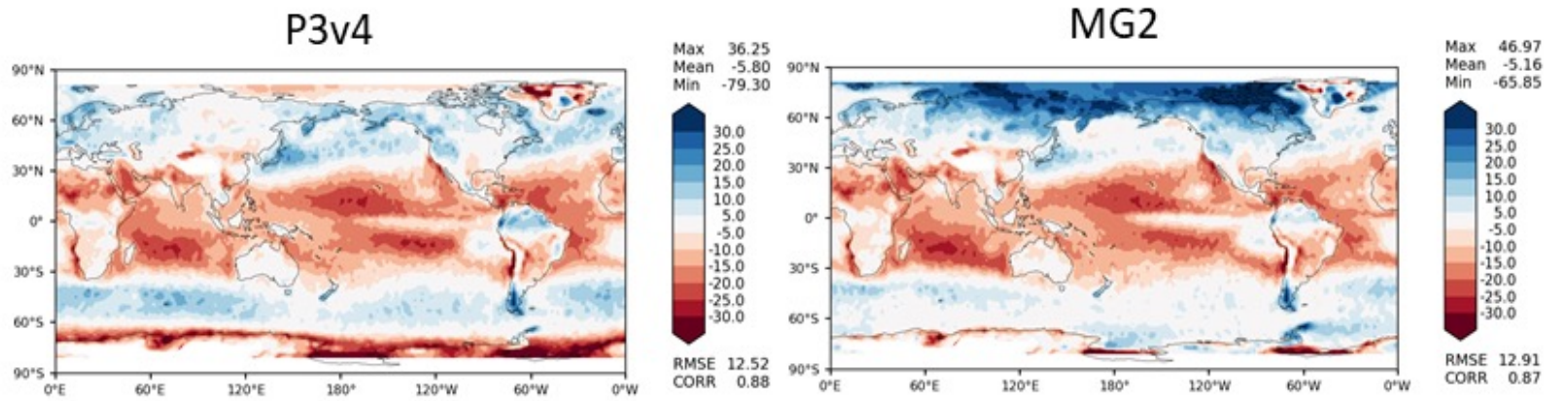
- Notable improvement in P3v4 compared to MG2 for the mid and high latitudes of NA (40-90 N) as well as the Southern Ocean (warm sector, 30-60 S) biases

- P3v4 increases the positive biases over the cold sector of the SO (60-75 S). The domain mean value in P3v4 is also closer to observation (-45.31 W/m2)

Cloud Faction

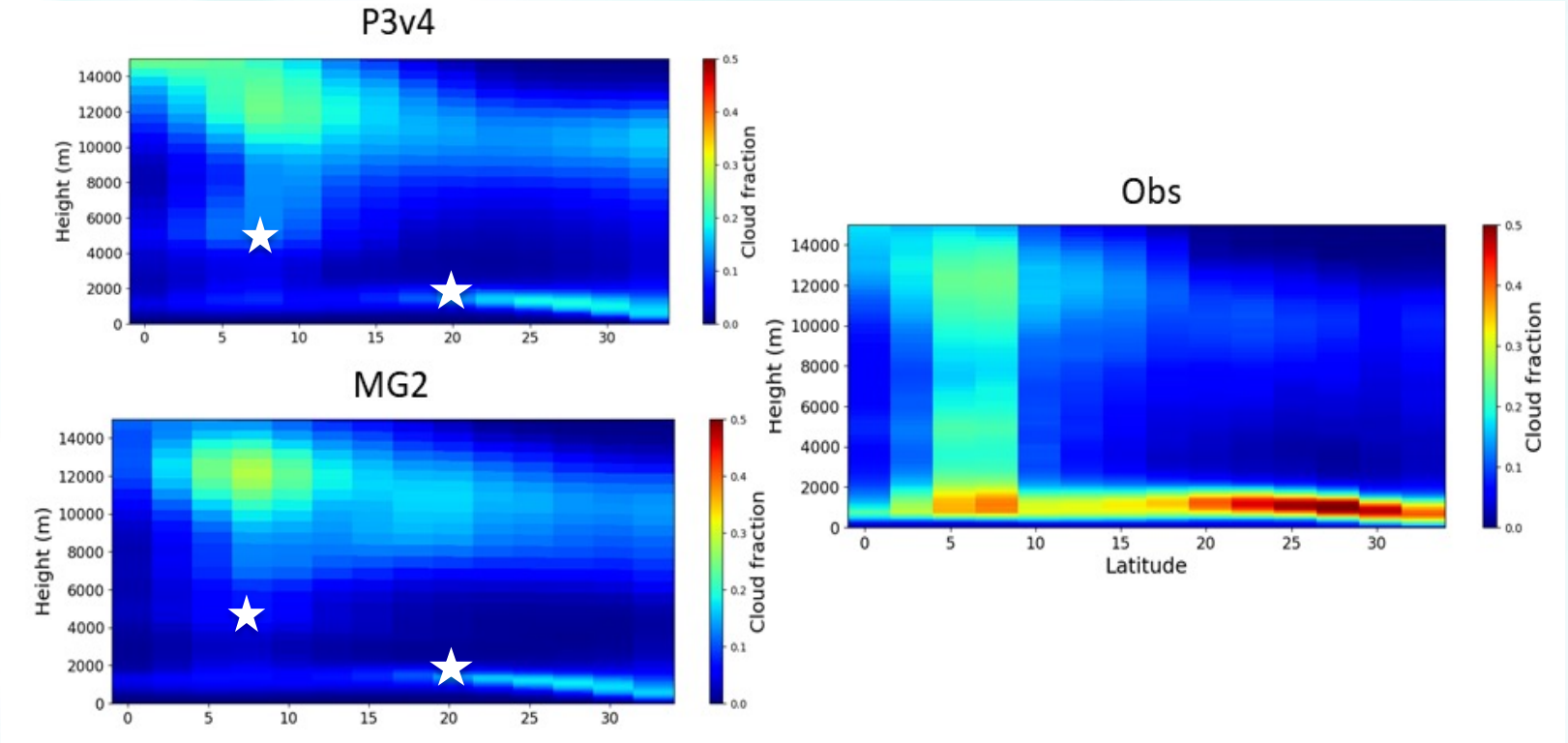


HGH



LOW

Cloud Faction (total) along the GPCI transect



- The total cloud fraction in P3v4 is comparable to MG2, with a slightly better simulation of the middle clouds and low clouds

Microphysics (ANN avg)

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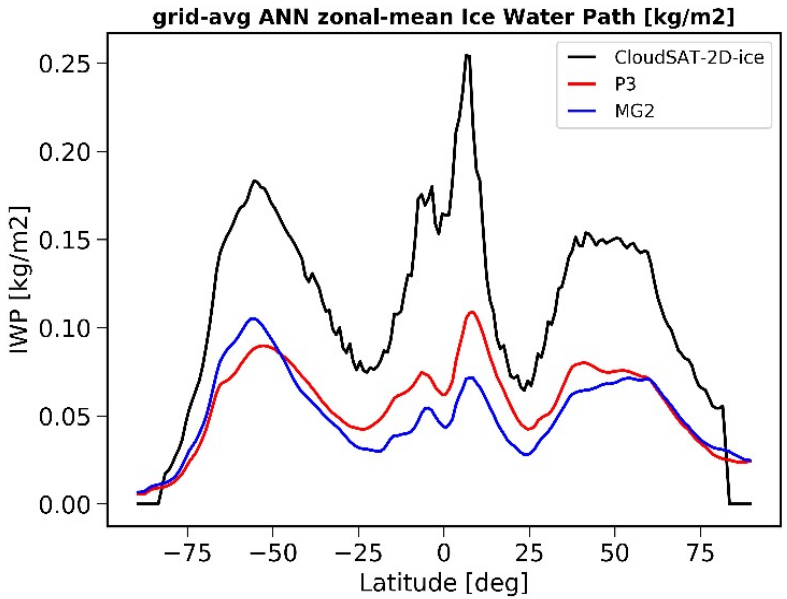
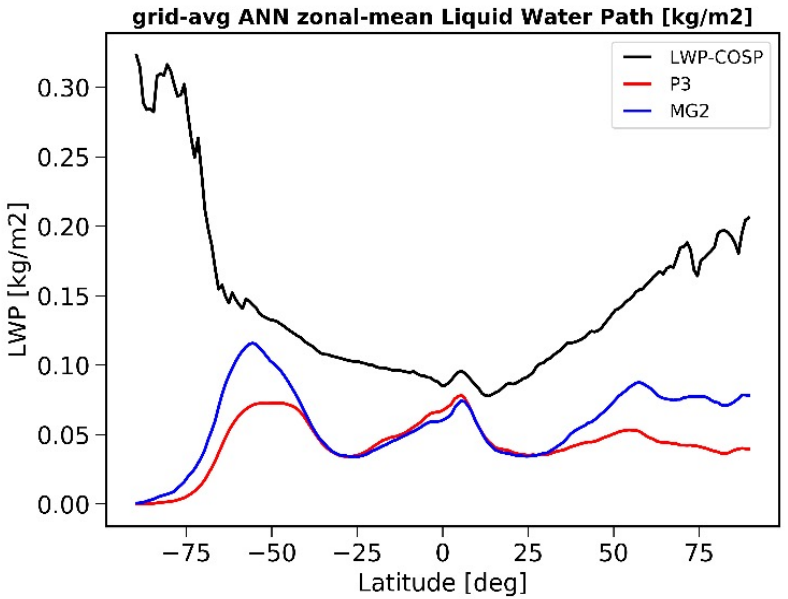
IWP



LWP



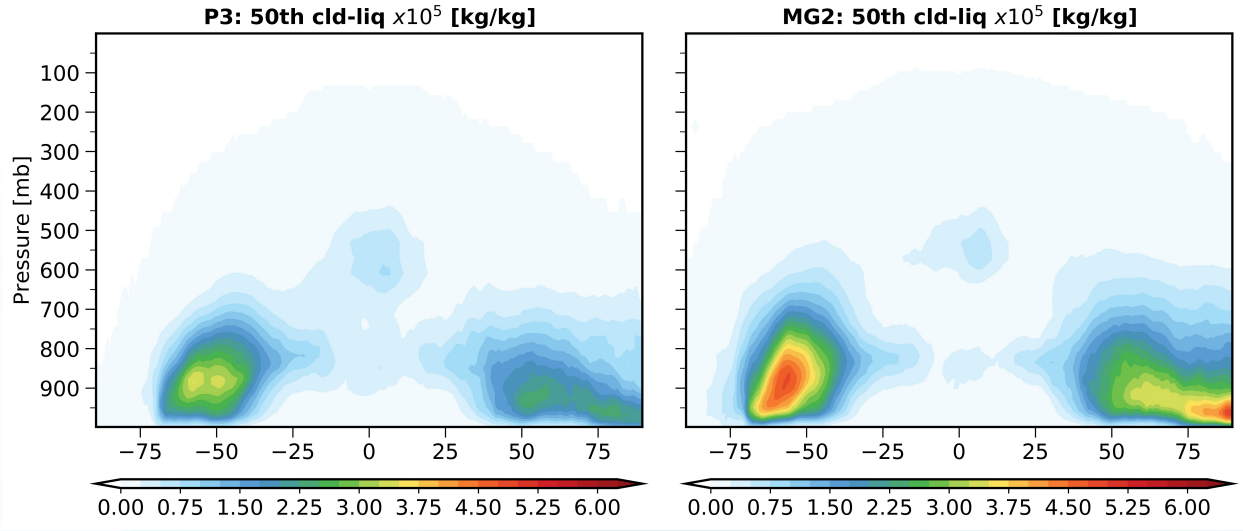
* for MG2, IWP includes both ice + snow

- P3v4 increases significantly the IWC except around the cold-sector of the SO
- The LWC increases in the tropics, but decreases substantially at midlatitudes compared to MG2
- The lower LWP at the expense of IWC in the NH high-latitudes clouds is consistent with lower SWCF/LWCF bias, whereas in the SH larger IWC (low LWP) decreases low clouds

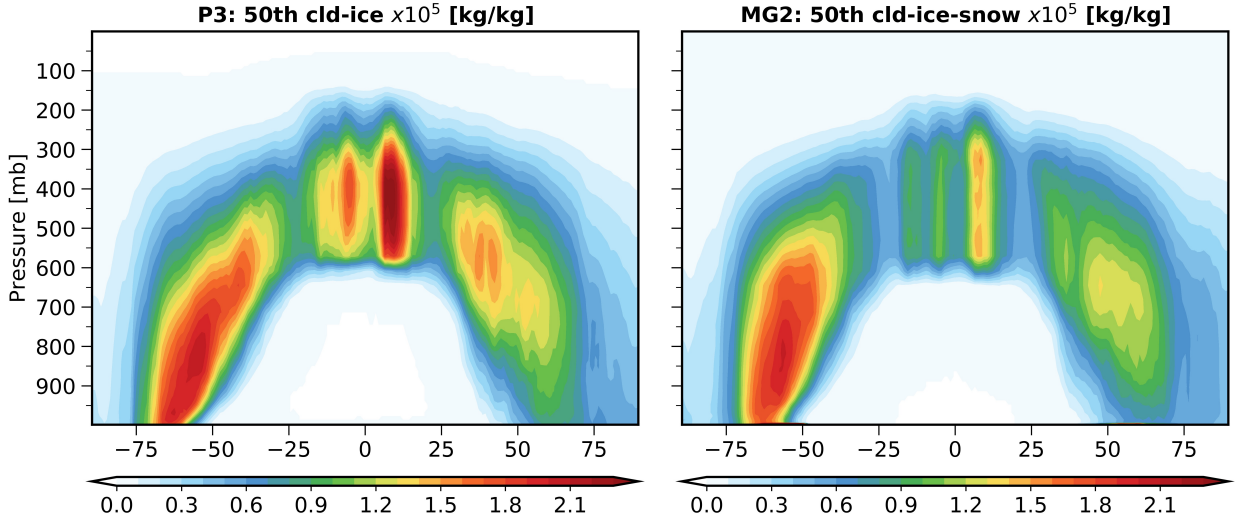
Microphysics (ANN avg)

Cloud mass content

Zonal median



Ice mass content



- MG2 predicts excessive cld-liq over the Arctic – implications on LWCF
- P3v4 has less liquid (low clouds) south of 30S; Interestingly, the less liquid north of 50S provides better radiative forcing
- Increased in IWC mainly associates with Tropical convection, and Northern mid-latitude clouds

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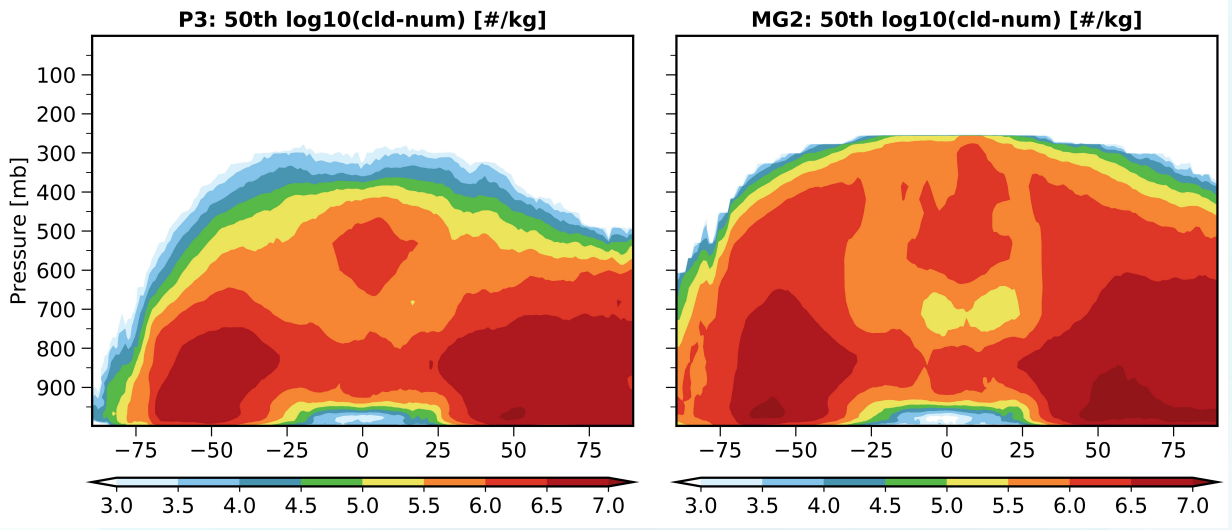
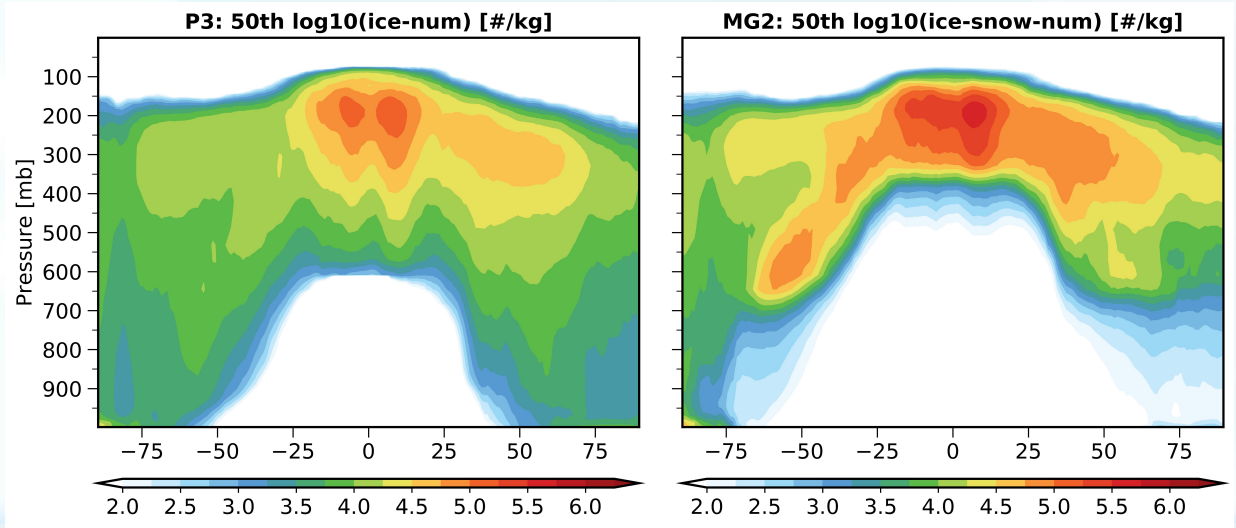
Microphysics (ANN avg)

Cloud droplet number

Zonal median (log10)



Ice number

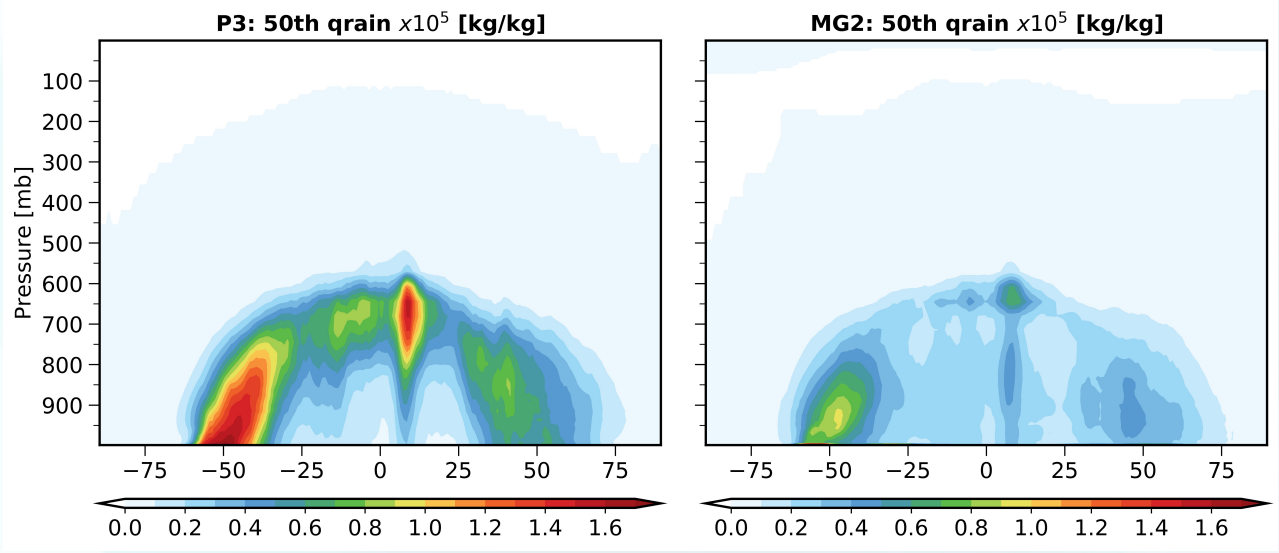


- Vertical change of droplet number with altitude is more realistically
- P3v4 has significantly more ice-num between 400-600 mb; wet scavenging?
- Ice nucleation is the same between P3 and MG2, those differences could be mainly from sink processes (sublim, melting, selfcoll, rainfrz)

Microphysics (ANN avg)

Rain mass content

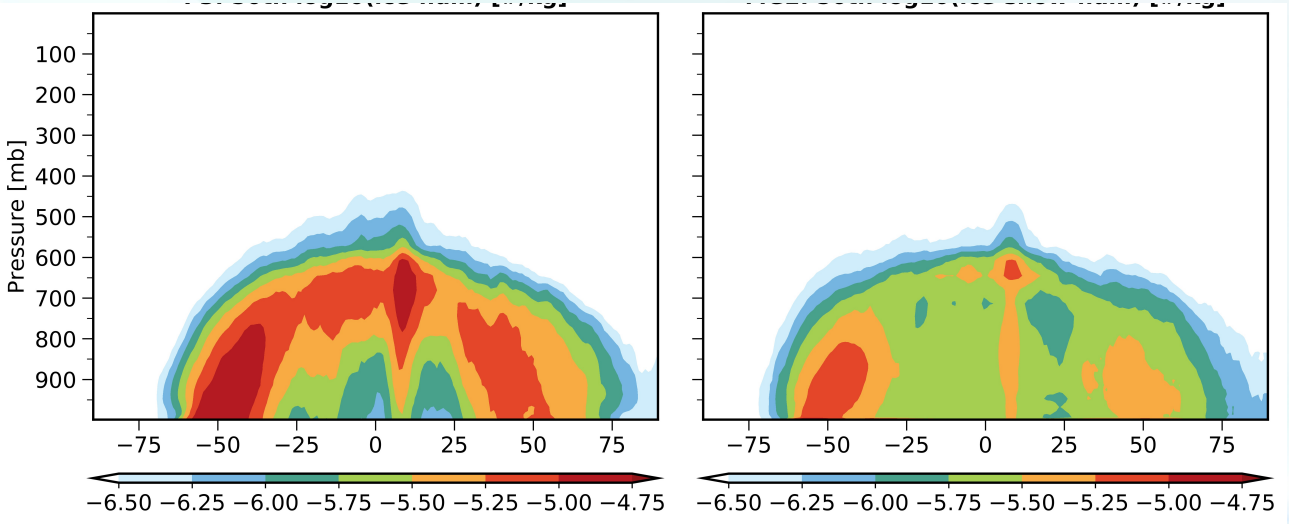
Zonal median



- Significantly more rain mass and number
- Mainly from ice melting

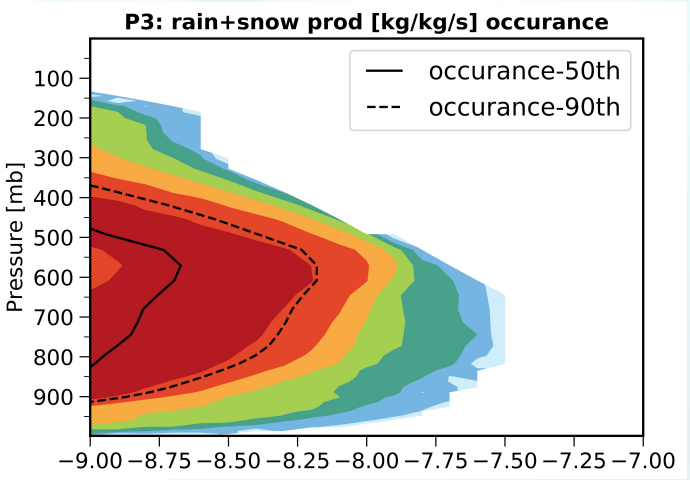
Rain number conc

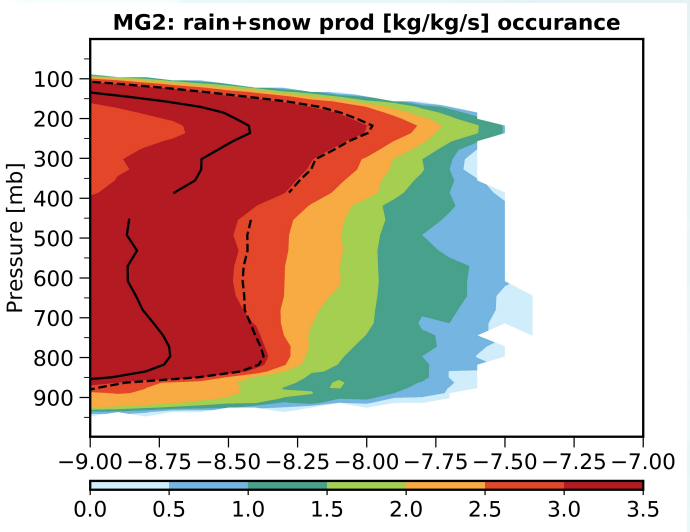
Zonal median (log10)



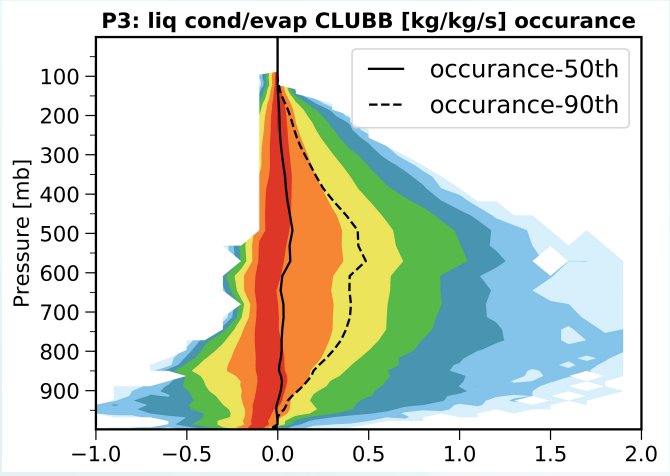
Microphysics-E3SM interaction (ANN avg)

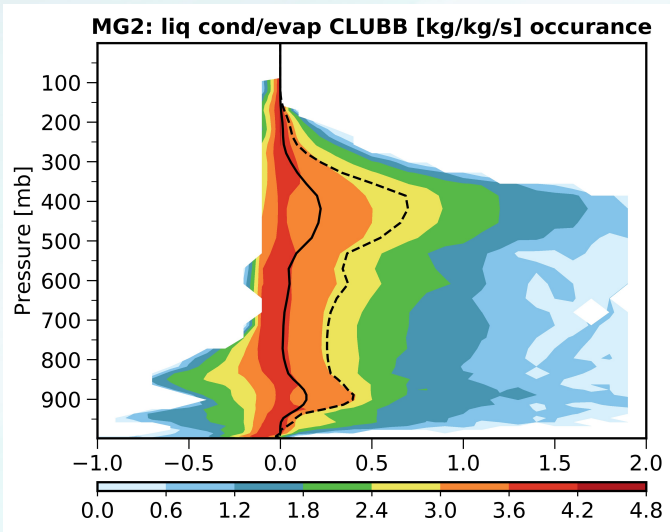
CFADs – wet scavenging





CFADs – MP-clubb





- Wet scavenging of aerosols in P3 is lower at high-level since the scavenging by precipitating ice particles is not representative
- P3 doesn't have the low-level condensation pick from CLUBB

Summary

- Overall, the P3 microphysics shows a comparable climatology to MG2
- P3 improves both the cloud shortwave and longwave radiative forcing in the Northern Hemisphere and the high cloud fraction in the Tropics
- The ice water path increases with P3 compared with MG2, and the frequency of heavy precipitation rates over the continental US is larger with P3, both of which are more consistent with observations
- There are specific areas needed further improvements such as:
  - relatively low liquid water content at midlatitudes
  - low-cloud fractions over the cold sector of Southern Hemisphere
  - Consider aerosol wet-scavenging by precipitating ice particles to improve simulated aerosol loading
- Further understanding of the P3 coupling with other physical modules in E3SMv2
- Further development

Supplementary figures

Surface precipitation - sensitivity

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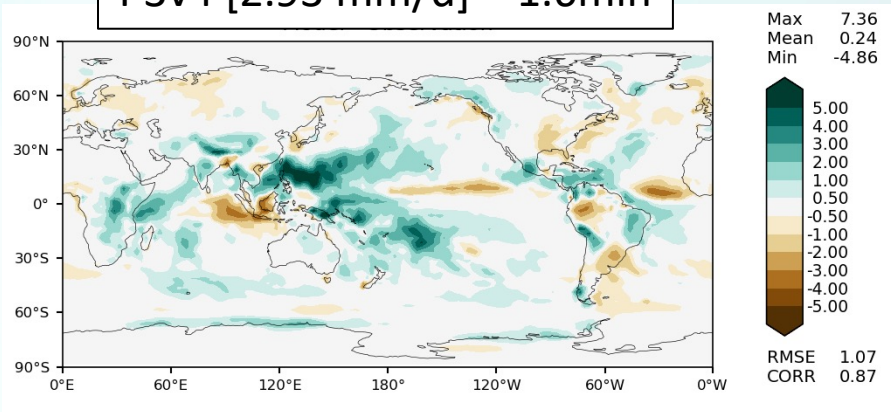
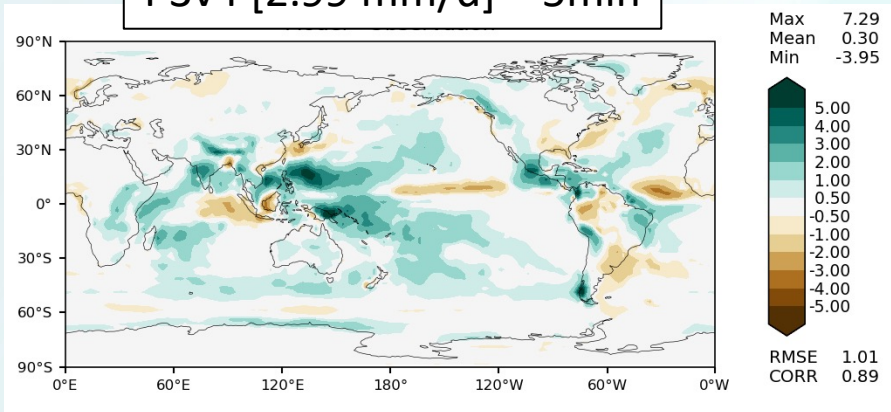
P3v4 [2.93 mm/d] – 1.6min



P3v4 [2.99 mm/d] – 5min



2 yrs

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Supplementary figures

Surface precipitation
– diff in [%]

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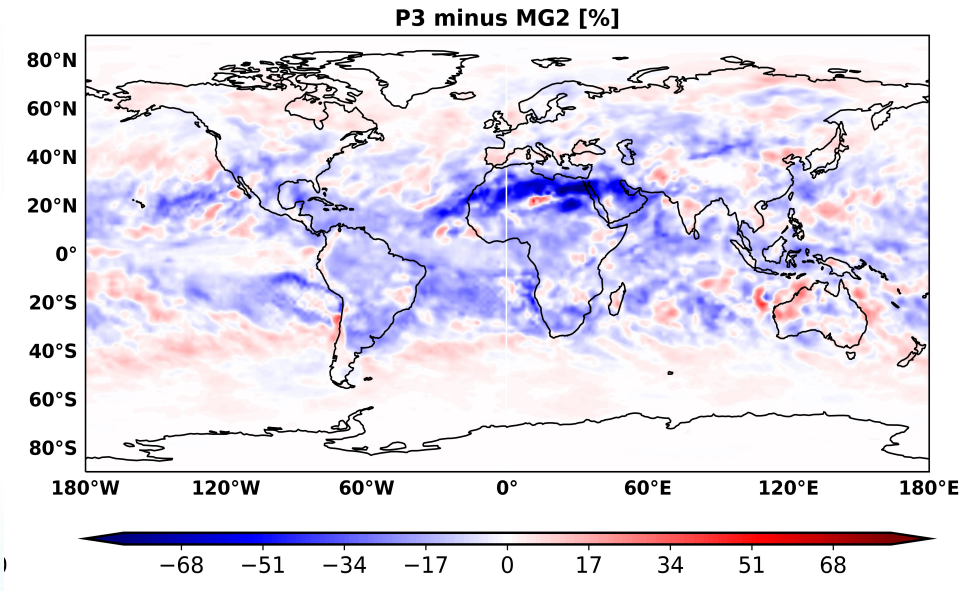

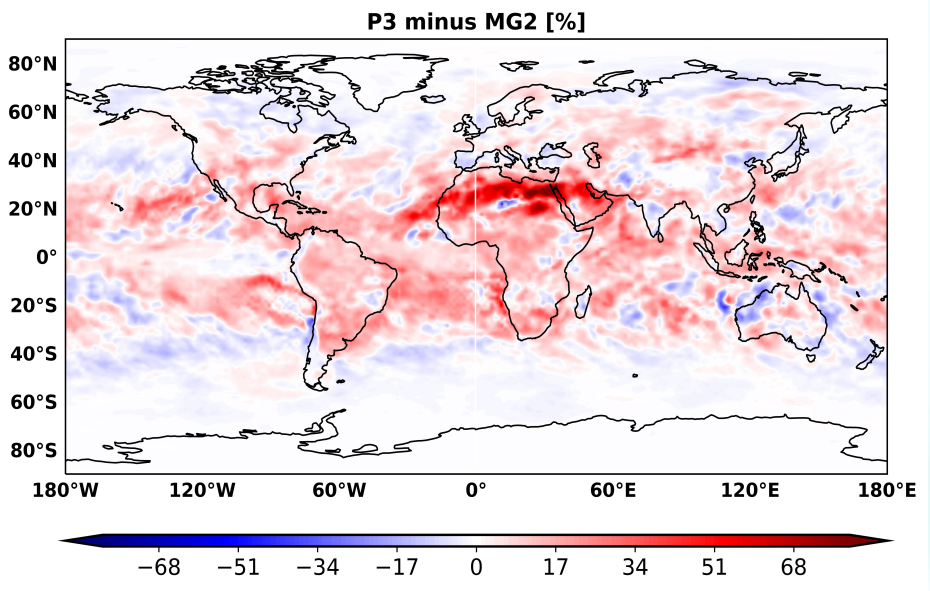

2 yrs

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