Developments of Cloud Microphysics and Deep Convective Wet Removal for E3SM v3 – Improving Simulations of Clouds, Aerosols, and Aerosol-Cloud Interactions

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1. Introduction

- E3SM version 2 has overly strong aerosol effective radiative forcing due to biases in cloud and aerosol simulations, a main reason leading to the model failure in reproducing the temperature trends over the industrial period.
- The limitations of cloud microphysics scheme (MG2) include artificially partitioning frozen particles into cloud ice and snow, and lacking rimed ice particles. Insufficient wet removal is a main reason for the overestimation of aerosol burden and lifetime.
- Here we improve cloud and aerosol simulations and reduce the overly strong aerosol forcings by replacing MG2 with the Predicted Particle Properties (P3) and improving the aerosol wet removal treatments. These developments are incorporated in E3SM v3.

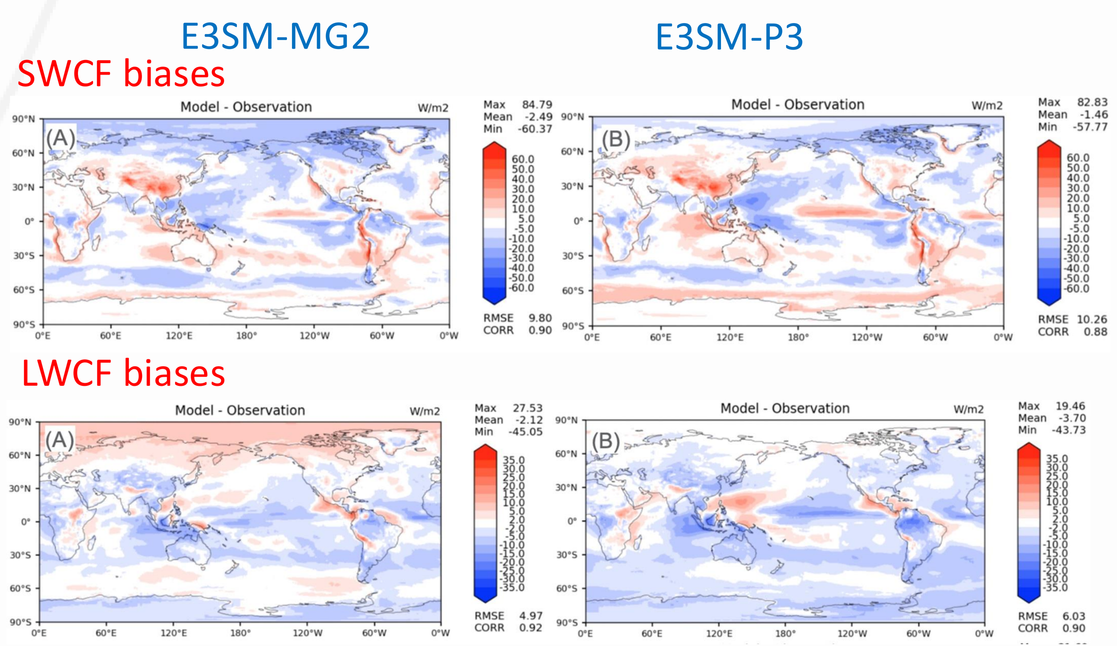
2. Experiment setup

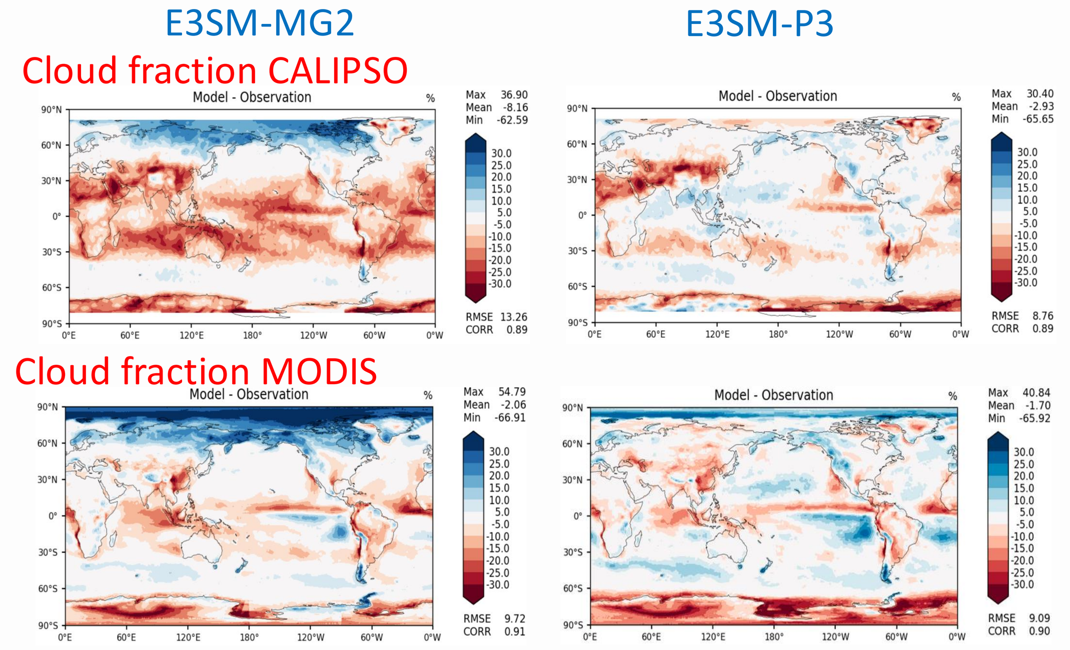
Experiment	Cloud schemes	Wet removal scheme changes
E3SM-MG2	E3SMv2, MG2 + ZM	Default in E3SM v2
E3SM-P3	Based on E3SM-MG2, replace MG2 with P3	Default in E3SM v2
Newcloud	Based on E3SM-P3, add ZM convective microphysics, mesoscale heating, and further adjustments	Default in E3SM v2
Newcloud+WetR3	Same as Newcloud	○ Couple vertical velocity in deep convection with deep convection wet removal ○ Consider cloud-borne aerosol detrainment from deep convection ○ Reorder deep convection wet removal and stratiform wet removal

15-month wind-nudged runs and 5-year free runs

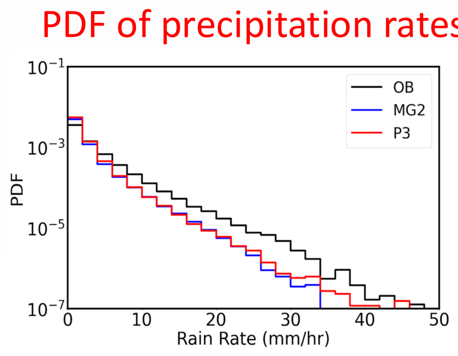
3. Results

3.1 P3 reduces biases in cloud radiative forcing, cloud fraction, heavy precipitation rate, and aerosol radiative forcing

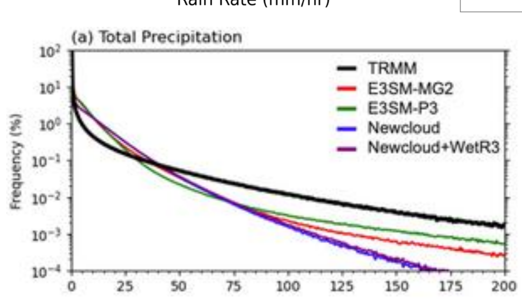




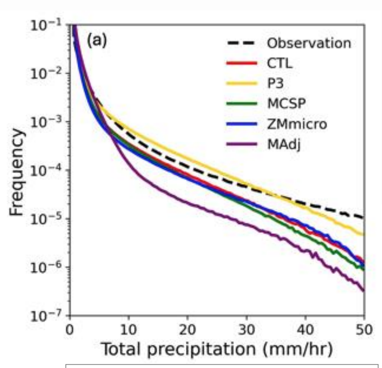
PDF of precipitation rates



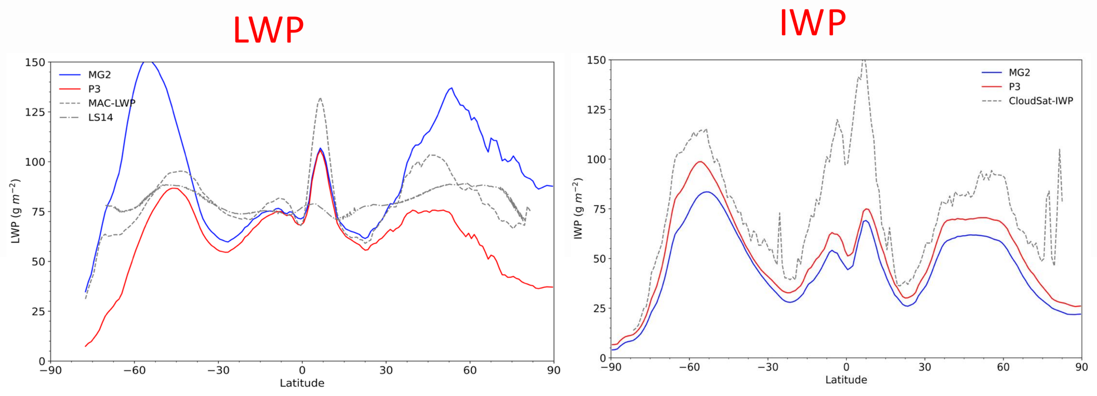
CONUS, 0.25-deg (*Wang, Fan, et al. 2021, JAMES*)



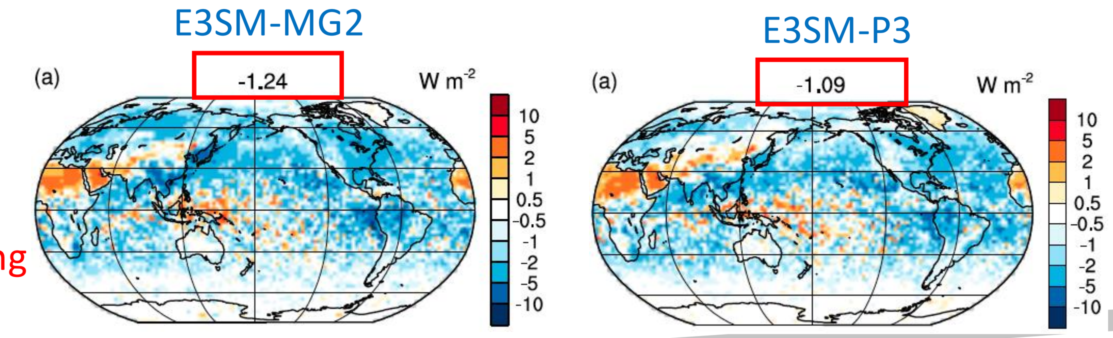
Tropics, 1-deg (*Shan, Fan, et al. 2024, JAMES*)



West pacific, 0.25-deg (*Zhang, et al. 2024, JGR*)



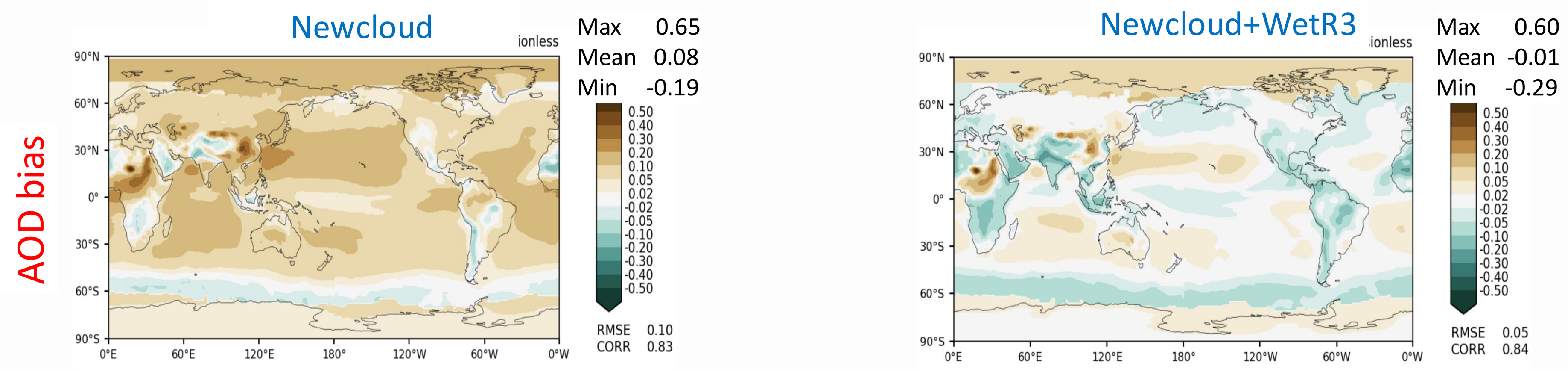
Compared with CloudSAT



Total aerosol radiative forcing

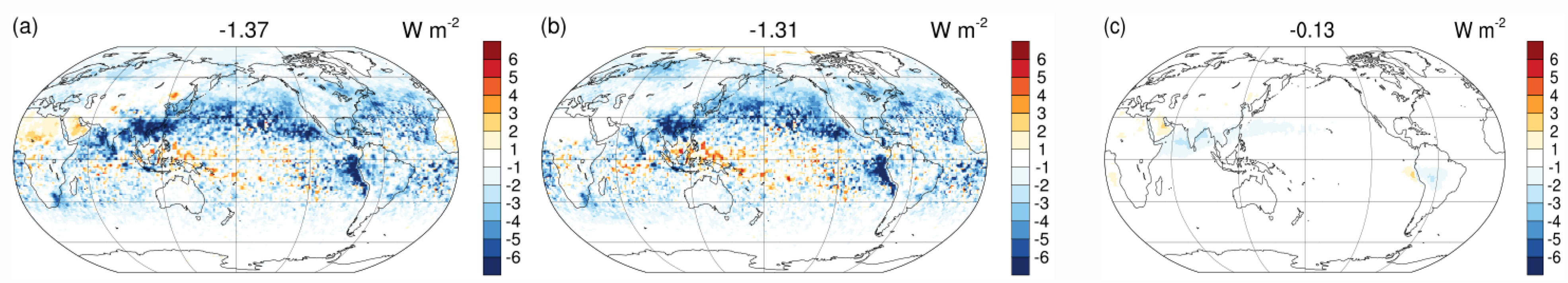
3.2 Aerosols and aerosol forcing from the improved wet removal treatments

	ERF_{aer} ($W\ m^{-2}$)	ERF_{aci} ($W\ m^{-2}$)	ERF_{ari} ($W\ m^{-2}$)	SO_4 burden (TgS)	BC burden (Tg)
Reference	(-1.49, -0.73)	(-1.43, -0.29)	(-0.65, 0.15)	(0.37, 0.83)	(0.081, 0.181)
E3SM-MG2	-1.24	-1.45	0.10	6.73	0.21
E3SM-P3	-1.09	-1.38	0.20	9.91	0.26
Newcloud	-1.36	-1.79	0.31	11.12	0.29
Newcloud +WetR3	-1.34	-1.52	0.09	6.70	0.19
Newcloud +WetR3-k_{POM}	-1.37	-1.31	-0.13	6.62	0.13



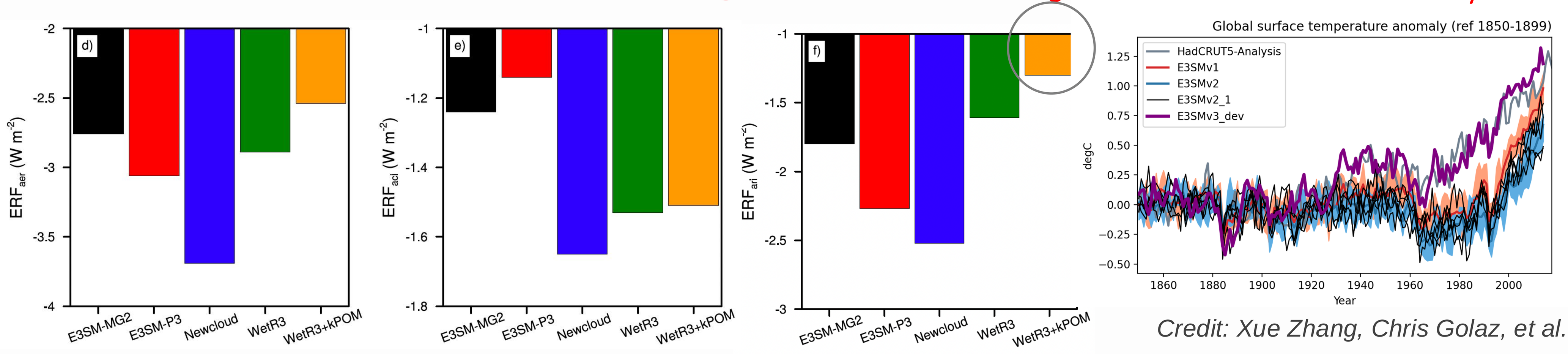
3.3 Tuning hygroscopicity of primary organic matters (k_{POM})

- Although the wet removal treatments improve aerosol properties and aerosol forcing significantly, ERF_{aci} is still too large, and BC burden and lifetime are too long.
- E3SM assumes hydrophobic POM with k_{POM} of 10^{-10}, which does not account for hydrophilic ones. We adjust the value to a median value 0.07 (note 0.04 was used in the public version of E3SMv3)



- Increasing k_{POM} mitigates BC overestimation, qualitatively changing aerosol direct forcing from position to negative, agreeing with IPCC estimates. Aerosol indirect forcing is also reduced

3.4 Contribute to reducing surface radiative forcing and reproducing surface T trend



Credit: Xue Zhang, Chris Golaz, et al.

4. Conclusions

- The new cloud microphysics scheme P3 reduces biases in cloud radiative forcing, cloud fraction, heavy precipitation rate, and aerosol direct radiative forcing.
- The improved treatments for aerosol wet removal, particularly by deep convection effectively mitigate aerosol overestimations and reduce aerosol forcing. By further adjusting k_{POM}, aerosol direct and indirect forcing agree with the IPCC AR6 assessment. All these developments contribute to the reproduction of surface temperature trends during the industrial period by E3SM v3.

More details: Shan, Y., J. Fan, K. Zhang, et al., (2024), *JAMES*, https://doi.org/10.1029/2023MS004059.

E3SM Energy Exascale Earth System Model

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