Understanding Biases in E3SMv2 Simulated Cloud Droplet Number & Aerosol Concentrations over the Southern Ocean

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Key points

- The default E3SMv2 underestimates cloud droplet number and aerosol concentrations when compared with observations
- Improving DMS emission and chemistry enhances model-observation agreement for cloud droplet number and boundary layer aerosols
- Biases persist in the free troposphere aerosols likely due to insufficient growth of Aitken particles

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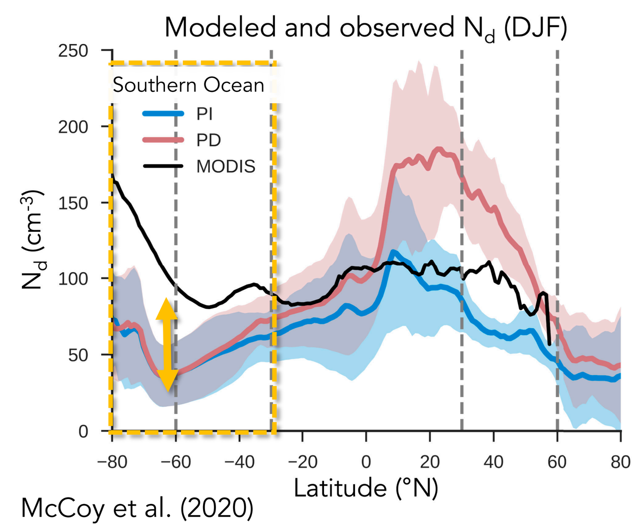
Image credit: NASA Ocean Color Image Gallery

Motivation & Background

Cloud droplet number (N_d) is largely controlled by the balance between sources and sinks of aerosols, and its accurate representation in climate model is crucial for predicting future climate.



McCoy et al. (2020)

However, models often underestimate N_d over the Southern Ocean (SO), where natural sources dominate, and aerosols are composed primarily of marine biogenic sulfate and sea spray.

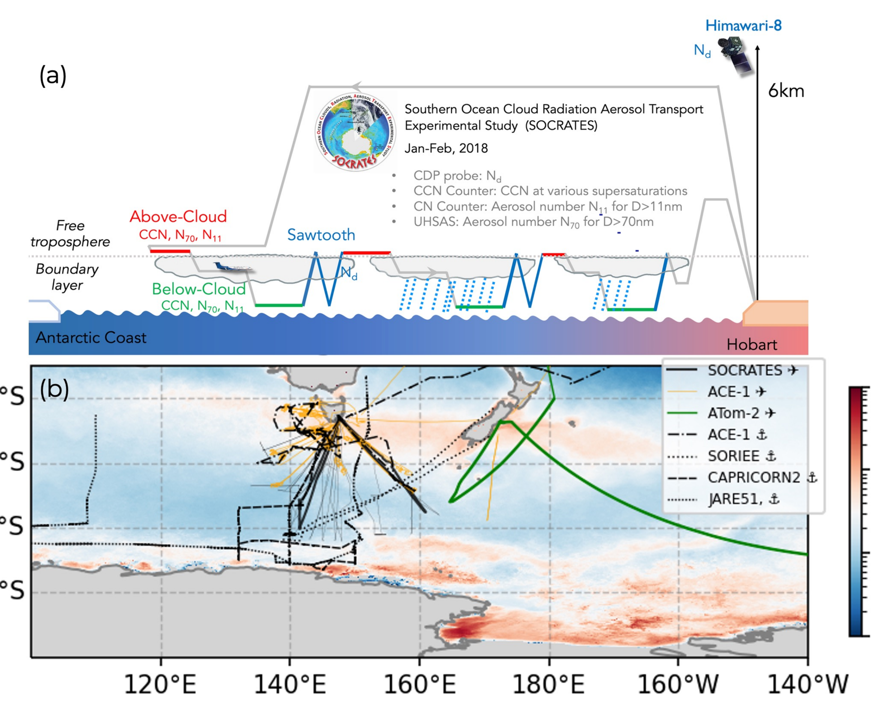
In this study, we use a range of diverse observations to untangle biases in the Energy Exascale Earth System Model version 2 (E3SMv2) simulated clouds, aerosols, and sulfur species over the SO.

Data & Model

To evaluate E3SMv2 simulated N_d and aerosols, we mainly rely on aircraft data from SOCRATES. (Fig.1a)

To evaluate simulated sulfur species, we use data from other campaigns conducted over the SO during the austral summer. (Fig.1b)

Figure 1. (a) Schematic shows how SOCRATES aircraft data are used; (b) a map showing the tracks of all campaigns included in this study.



We conduct sensitivity tests, focusing on updating the DMS emission and chemistry in E3SMv2.

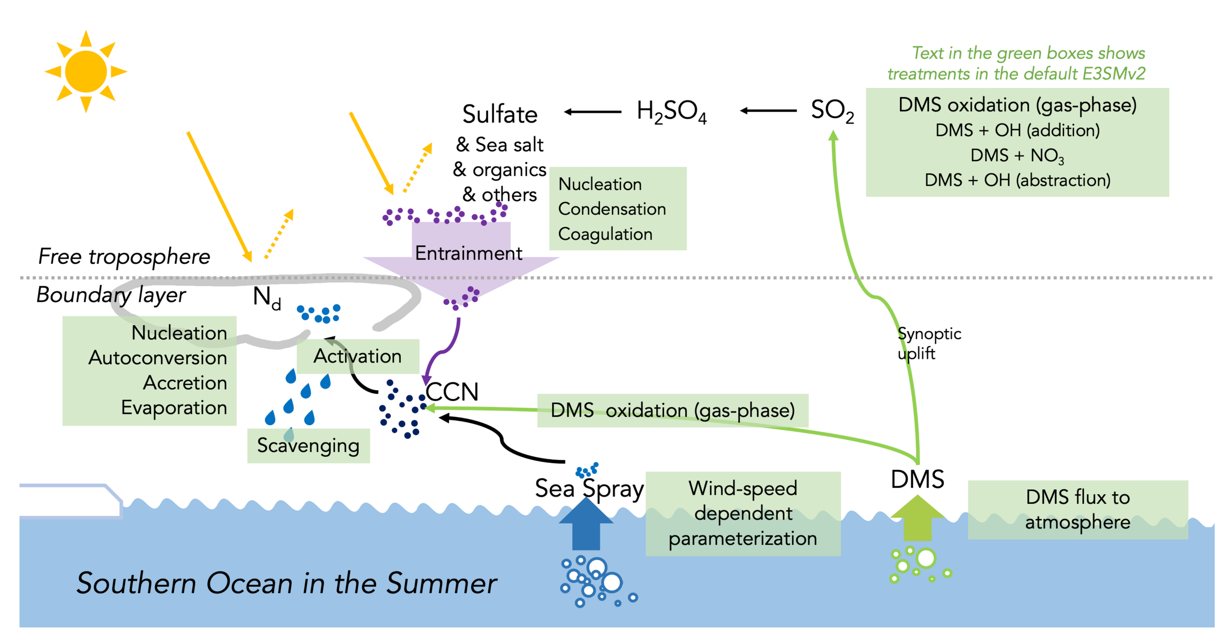


Figure 5. Schematic for the E3SMv2's relevant processes

Update DMS emission

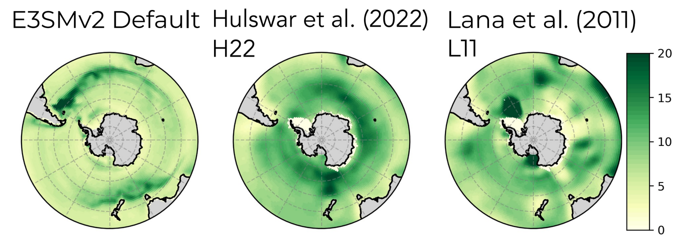


Figure 6. DMS flux in Feb [μmol m^{-2} d^{-1}].

Update DMS chemistry

- Update the oxidants file with new CAM-Chem results
- Modify the reaction rates for DMS+OH and DMS + NO_3 using Burkholder et al. (2015)
- Add DMS+O_3 (gas) pathway
- update DMS + OH addition reaction to conserve sulfur

How well does the default E3SMv2 perform?

The default E3SMv2 underestimates N_d and aerosols in both boundary layer (BL) and free troposphere (FT) over the SO when compared to observations.

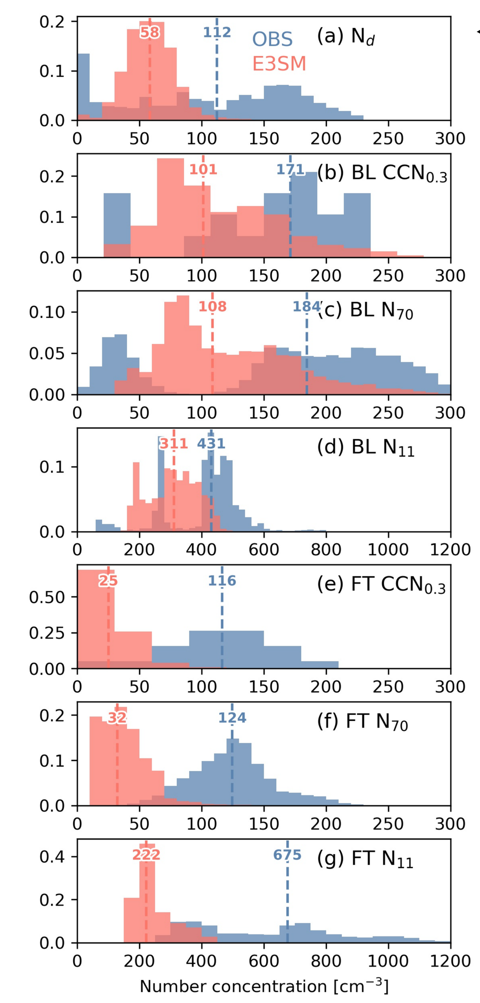


Figure 2. E3SMv2 3km Regionally Refined Mesh (RRM) simulated and observed N_d, CCN, N_{70} and N_{11} for collocated samples.

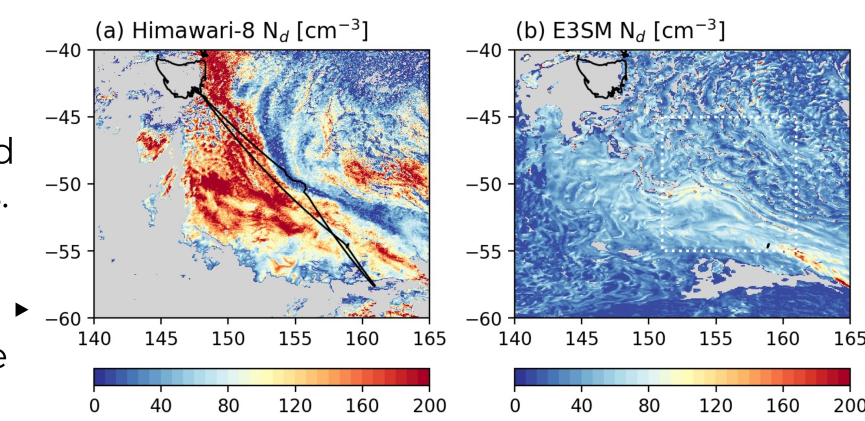


Figure 3. E3SMv2 simulated N_d and Satellite retrieval of N_d on Feb 20, 2018 at 00 UTC.

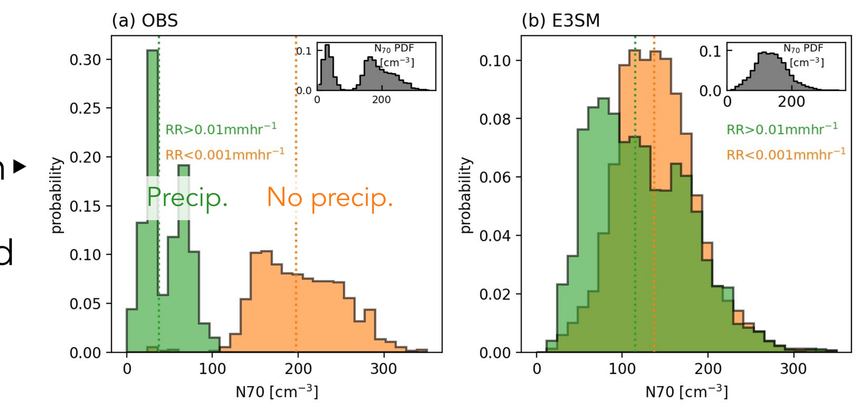
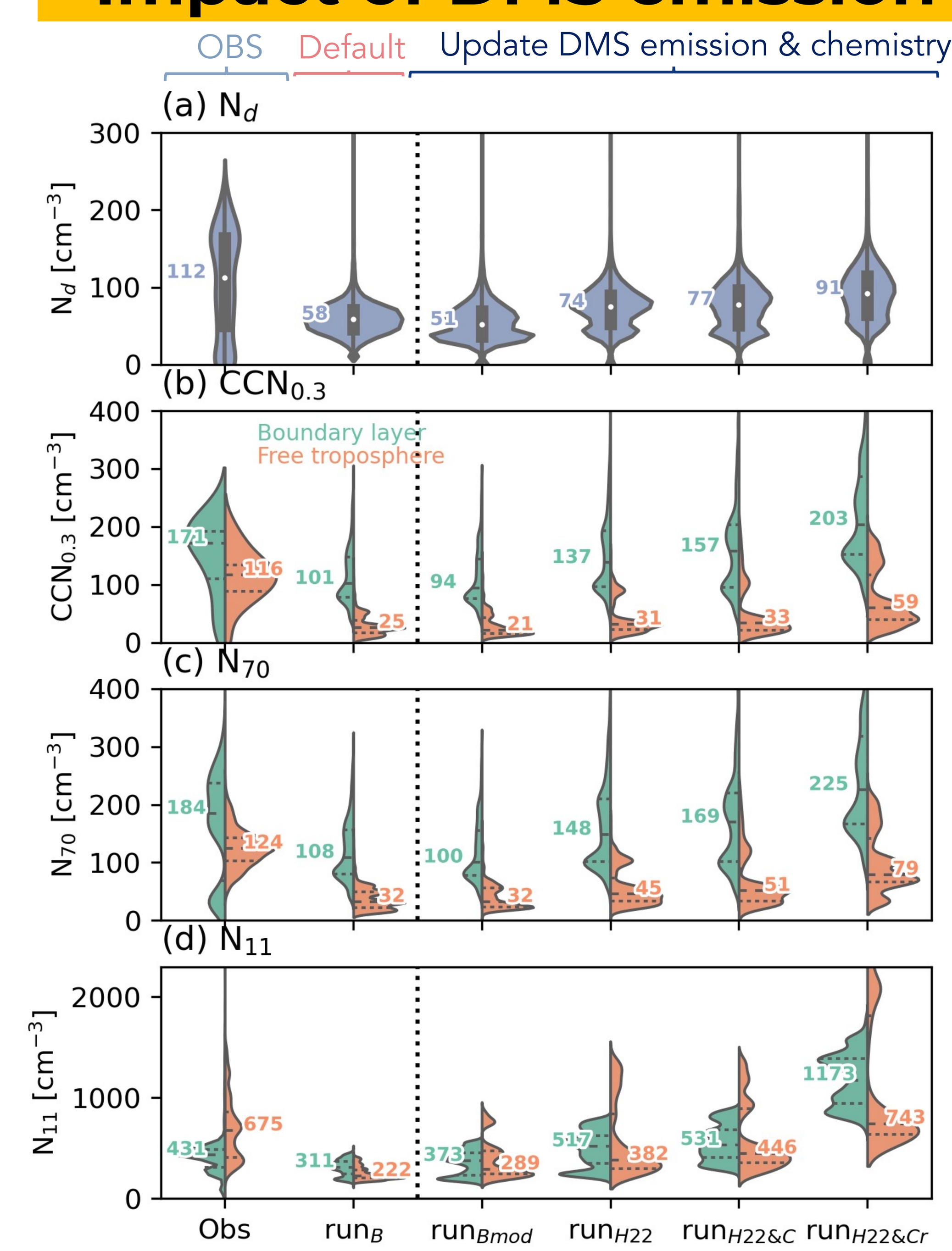


Figure 4. The comparison of the probability density function of N_{70} partitioned based on rain rate.

The model's below-cloud scavenging is likely too weak and fails to capture the distinct N_{70} modes observed for precipitating and non-precipitating areas.

Impact of DMS emission & chemistry updates



Updating DMS emission and chemistry improves agreement between model and observation in N_d and boundary layer aerosols.

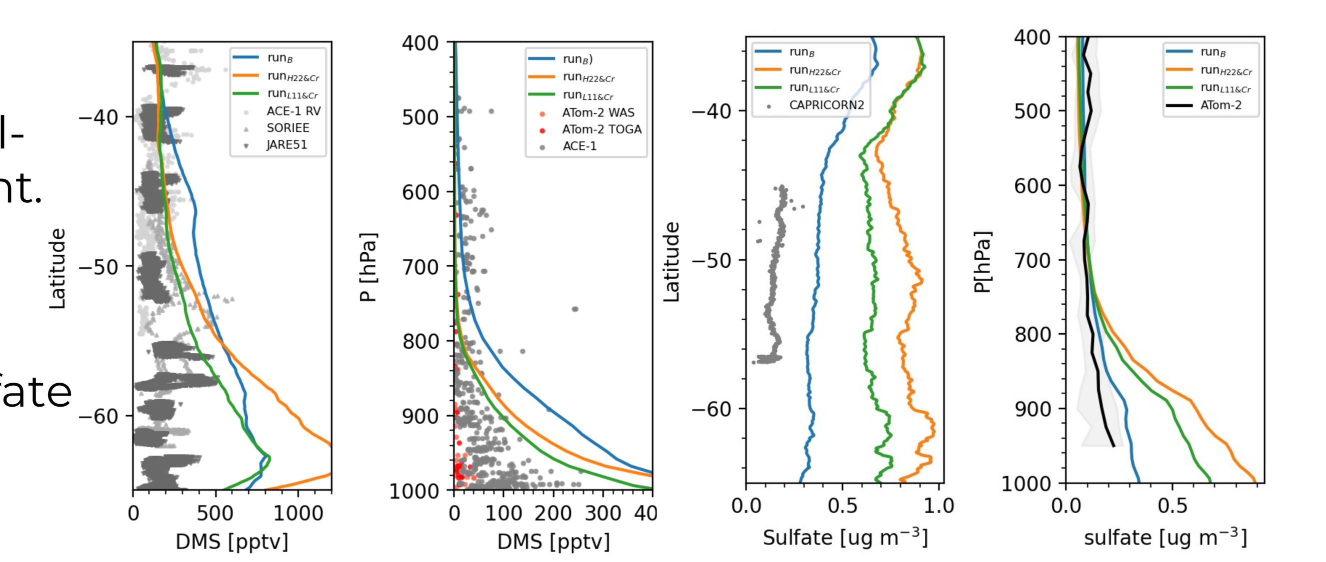
Despite reasonable N_{11}, model still underestimates $CCN_{0.3}$ and N_{70} in the free troposphere, likely due to insufficient growth of Aitken particles.

Figure 7. Violin plots for aircraft observed and E3SMv2 simulated N_d, $CCN_{0.3}$, N_{70}, and N_{11} in 3km runs for collocated samples. Panels b,c,d. depict results in both the boundary layer and the free troposphere.

Figure 8. Comparison between observed and simulated DMS and sulfate, which are plotted against latitude and against pressure.

The updates reduce DMS vertically and improve overall model-observation agreement.

The model still overestimates DMS at high latitudes and sulfate mass concentration.



Future work

- Our study underscores the need for further model development to improve DMS-related processes in E3SMv2 and other climate models.
- Future work is needed to address aerosol biases in the free troposphere and to improve below-cloud scavenging.
- More measurements of sulfur species and oxidants would be valuable, preferably alongside observations of aerosols, clouds, and precipitation.

Reference

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