Evaluating Size-Resolved Dust Concentrations in the Mixed-Phase Cloud Regime

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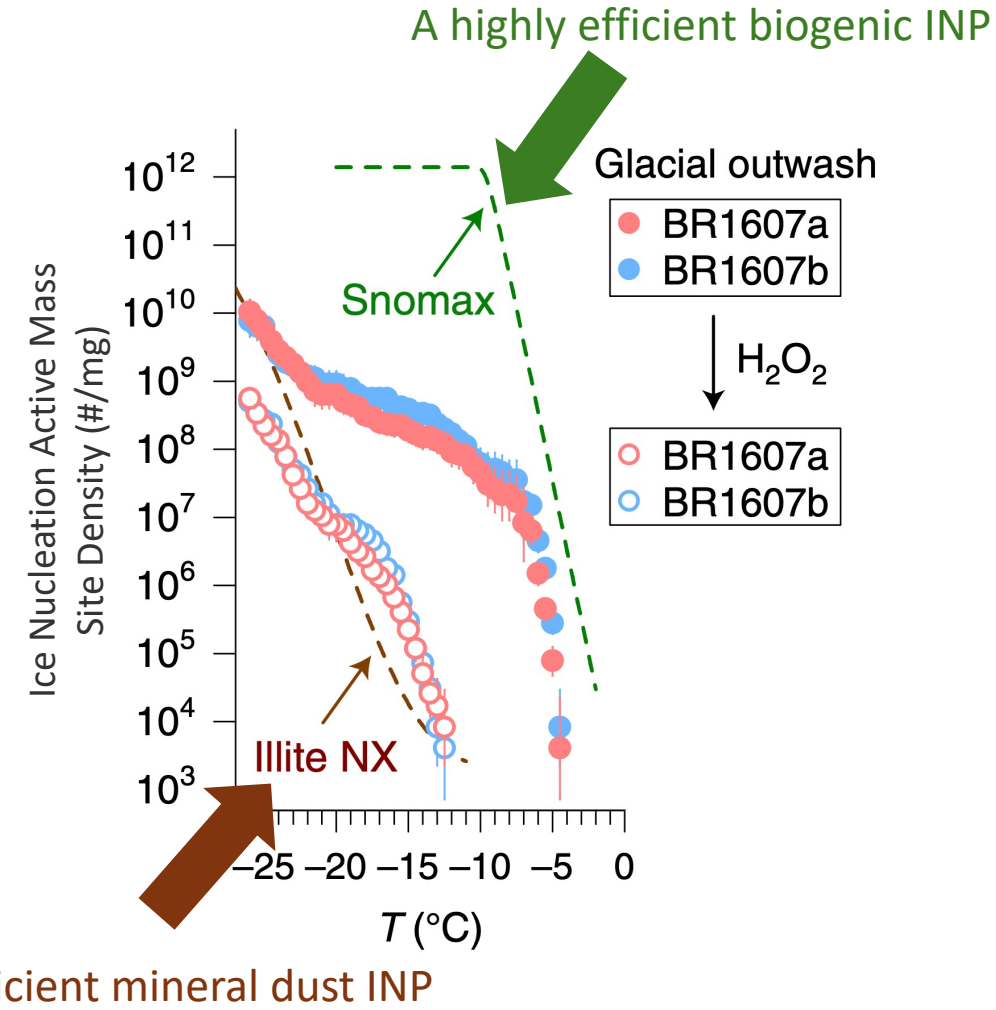


Context and Motivations

- **Aerosols** play a crucial role in cloud formation, and **clouds** are significant modulators of Earth's radiation budget.
  - But models still **poorly** represent both clouds and aerosols due to their controlling processes ranging across spatial and temporal scales.
- **Dust** is a key **ice-nucleating particle** (INP) that influences the formation of **mixed-phase clouds** (MPC).
  - Thus, quantifying the background dust concentration at these altitudes is essential for developing a size-resolved dust climatology, which could improve model projections by **increasing** accuracy and **reducing** computational costs.

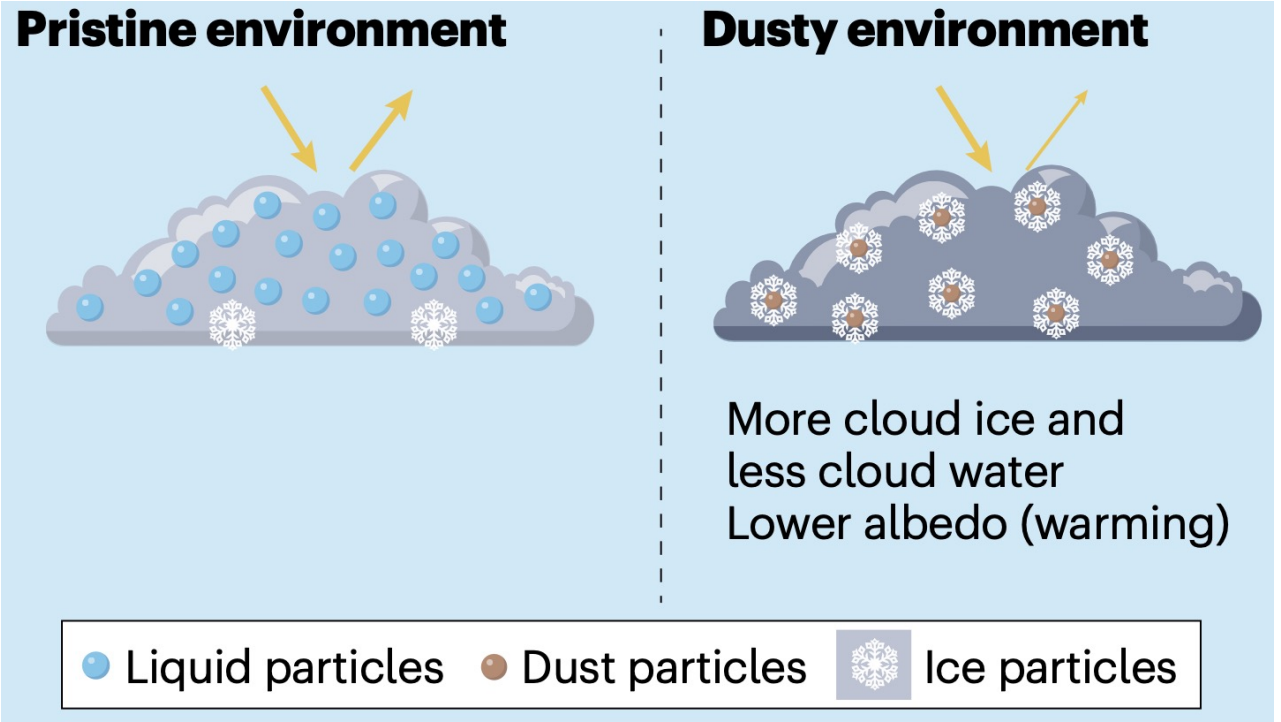
Dust can Serve as Ice Nucleating Particles and is Highly Efficient at Temperatures Below -20°C

- Dust can **transported** long distances to contribute to cloud microphysics in remote areas or be emitted from **local** sources.
  - **Larger** particles or those coated with **organic** material may have **enhanced** ice nucleating abilities.
- Dust's ice nucleation efficiency increases with **decreasing** temperature, making it a dominant INP in colder conditions.
- MPCs are not only highly sensitive to the temperature but also to the **concentration of dust**.



Tobo et al. (2022)

The Glaciation State of Mixed-Phase Clouds has an Impact on its Radiative Interactions



Adapted from Kok et al. (2023)

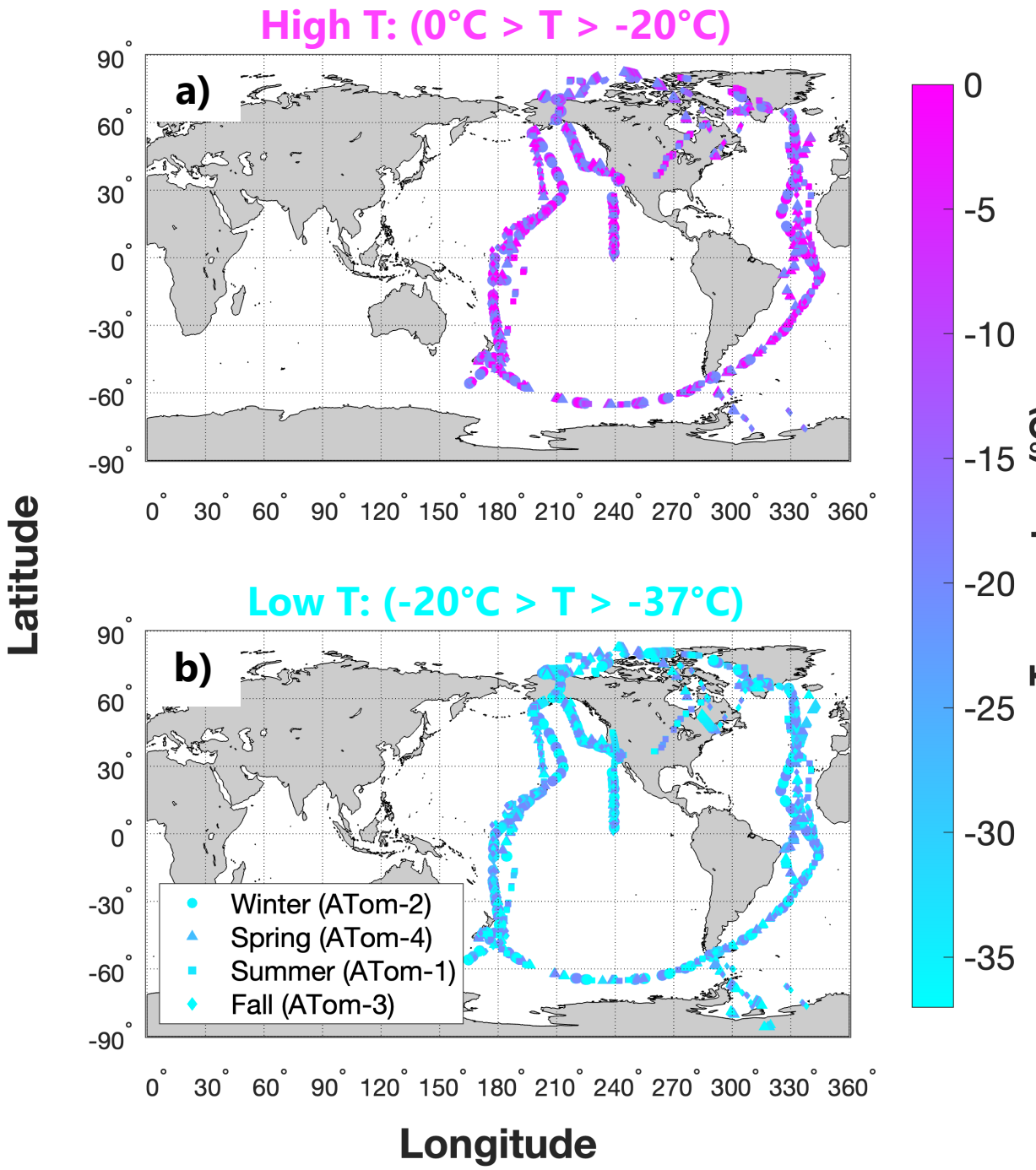
- Depending on the **glaciation state**, MPCs can **cool** the Earth by reflecting incoming shortwave radiation or **warm** it by interacting with longwave radiation.
- The ratio of INPs to cloud condensation nuclei (CCN) ranges from 1 in 100 to 1 in 10^8, depending on temperature.
  - As a result, the **dust concentration** plays a crucial role by controlling the progression of the **Wegener–Bergeron–Findeisen** (WBF) process, which in turn affects the MPC lifetime.

Research Questions

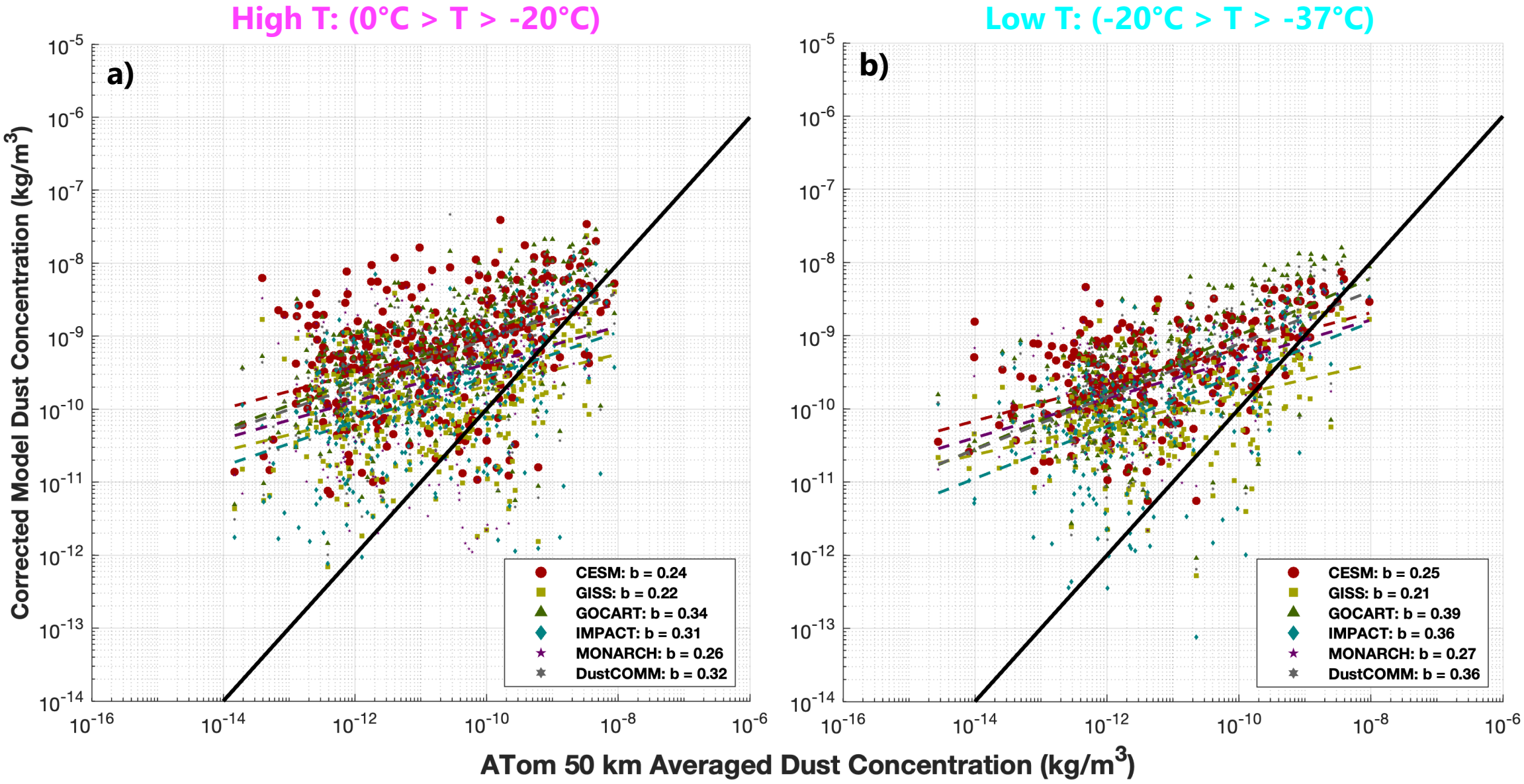
1. What are the observed size-resolved dust concentrations in the **MPC regime**?
2. How do observed size-resolved dust concentrations in the MPC regime **compare** with those from 5 global climate models and a dust reanalysis product?
3. How well do these global climate models capture the variability in size-resolved dust concentrations within the **low (-37°C to -20°C)** and **high (-20°C to 0°C)** temperature ranges of the MPC regime?

ATom Observations and Model Framework

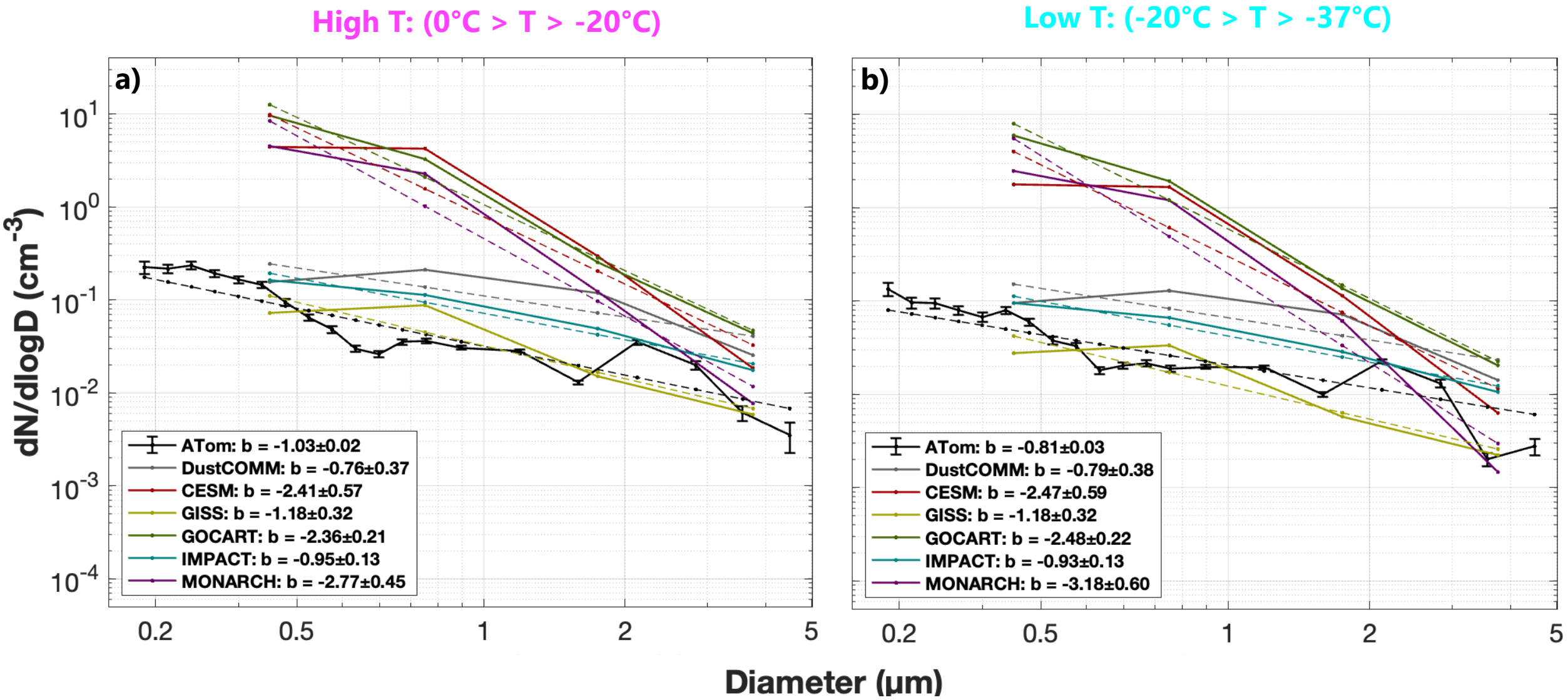
- We used size-resolved dust concentrations from the **Atmospheric Tomography Mission** (ATom).
  - There are **4** missions in this campaign, covering each season during the years 2016 - 2018.
- We compared these observations to **5 global climate models**, (CESM, GISS, GOCART, IMPACT, & MONARCH) and **DustCOMM**, a dust climatology reanalysis product.
  - The ATom measurements were **downsampled** by averaging over a few minutes to match the coarser resolution of the models and DustCOMM.
  - We then used a **correction factor** derived from **MERRA-2** dust reanalysis data to adjust the models and DustCOMM dust concentrations to the specific meteorology of the ATom measurements.



Models Overestimate the Dust Mass Concentration in the MPC regime

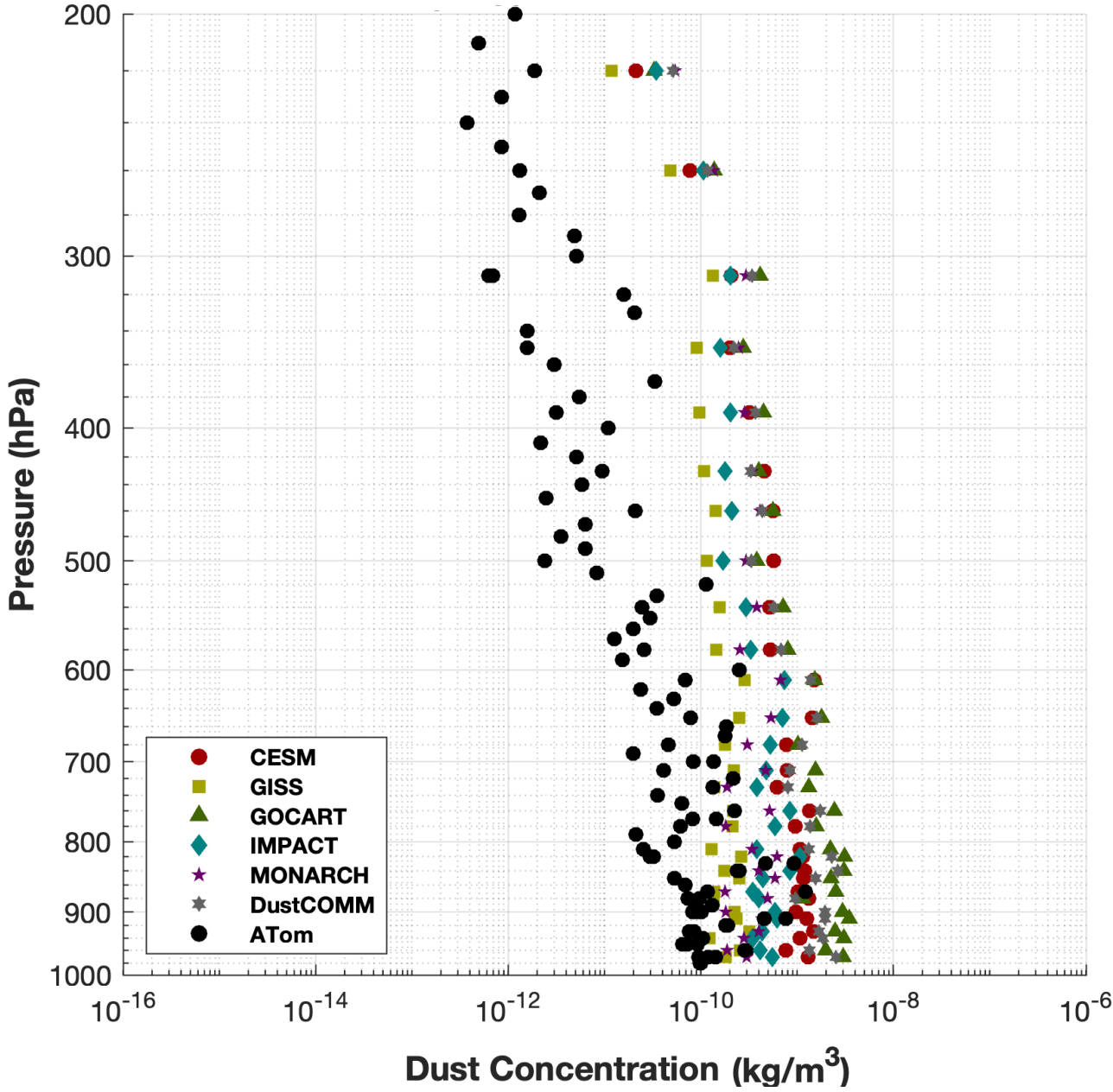


Models Overestimate Dust at Fine Sizes More so than at Coarse Sizes in the MPC Regime



Models Show Greater Discrepancies at Higher Altitudes

- One potential reason for the **overestimation** of dust in the MPC regime by global models is the challenge of parameterizing aerosol losses during **convective transport** and **cloud processes**.
  - Therefore, fine dust may not be removed as **effectively** as coarse dust.



Shi et al. (2022)

Final Remarks & Future Directions



Models **overestimate** dust mass concentrations in the MPC regime.



Overestimation is more pronounced for **fine** dust compared to coarse dust.



There may be an **underestimation** of aerosol losses during **convective transport** and **cloud processes**, particularly for fine dust.



We plan to compile **more** observational background dust concentration data along with INP measurements.



Ultimately, we aim to further improve **DustCOMM** to enhance model accuracy in representing dust size distributions at the **MPC regime**.

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Thank you!
Any questions?



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Accounting for Representation Error

$$C_{\text{model}}(year_i, day_i, time_i, \theta_i, \phi_i, p_i) = \bar{C}_{\text{model}}\left(season, \breve{\theta}_i, \breve{\phi}_i, \breve{p}_i\right) T(year_i, day_i, time_i, \theta_i, \phi_i, p_i),$$

$$T(year_i, day_i, time_i, \theta_i, \phi_i, p_i) = \frac{C_{\text{reanalysis}}(year, day, time, \breve{\theta}_i, \breve{\phi}_i, \breve{p}_i)}{\overline{C_{\text{reanalysis}}}(season, \breve{\theta}_i, \breve{\phi}_i, \breve{p}_i)}$$

- The ATom data has much finer spatial and temporal resolution compared to the coarser model or DustCOMM data.
  - This mismatch leads to **representation errors** when comparing the datasets.
- To correct for these errors, we use a **correction factor (T)**, which adjusts the model or DustCOMM climatology to match the exact time and location of the ATom measurements.
  - The correction factor is based on **high-resolution reanalysis data** (MERRA-2) that translates the model climatology to the specific meteorology during the ATom missions.
- This correction ensures that the model output is aligned with the **meteorological conditions** at the time of the measurements.