Desert Research Institute

Improving Simulations of Cirrus Cloud Thinning by Utilizing Satellite Retrievals

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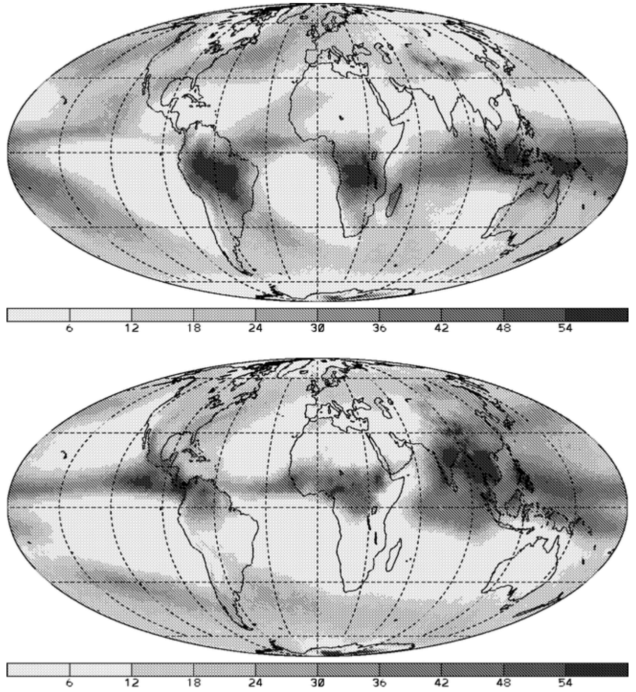
https://worldview.earthdata.nasa.gov/

Cirrus Clouds

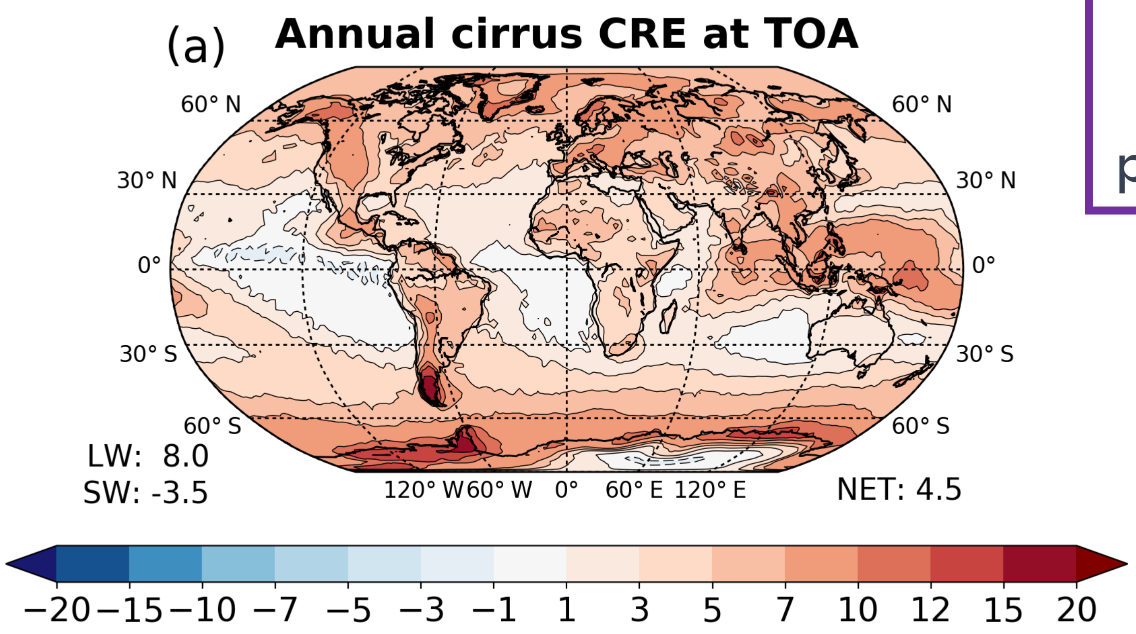
- Cirrus clouds cover about **20-25%** of the earth's surface on global annual averages and about **60-80%** in the tropics.



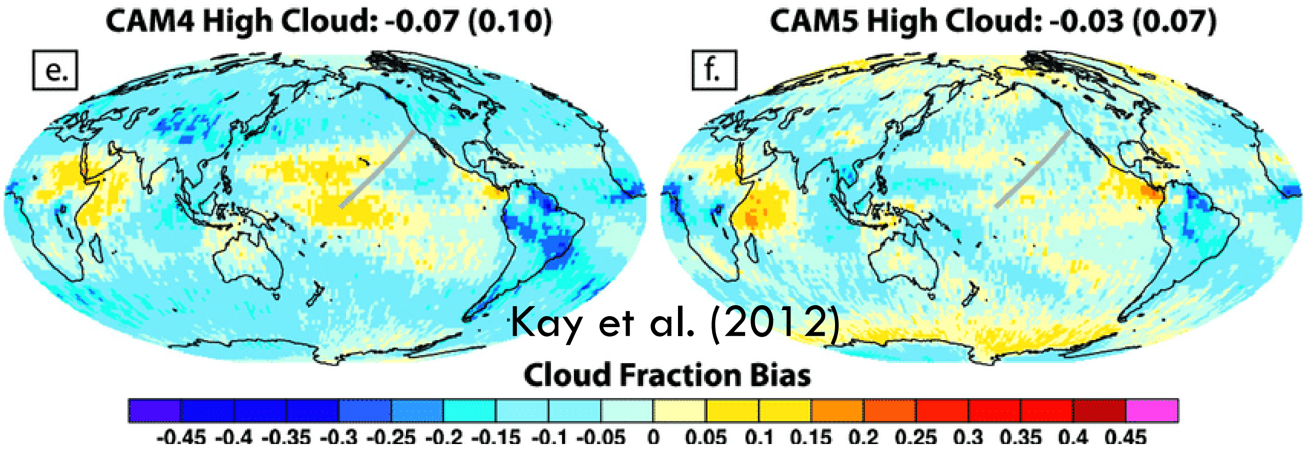
High cloud amount (%) for DJF and JJA (Stubenrauch, et al., 2006)

- A net **warming** effect of ~ **5 W m^{-2}**

Gasparini et al., (2016)



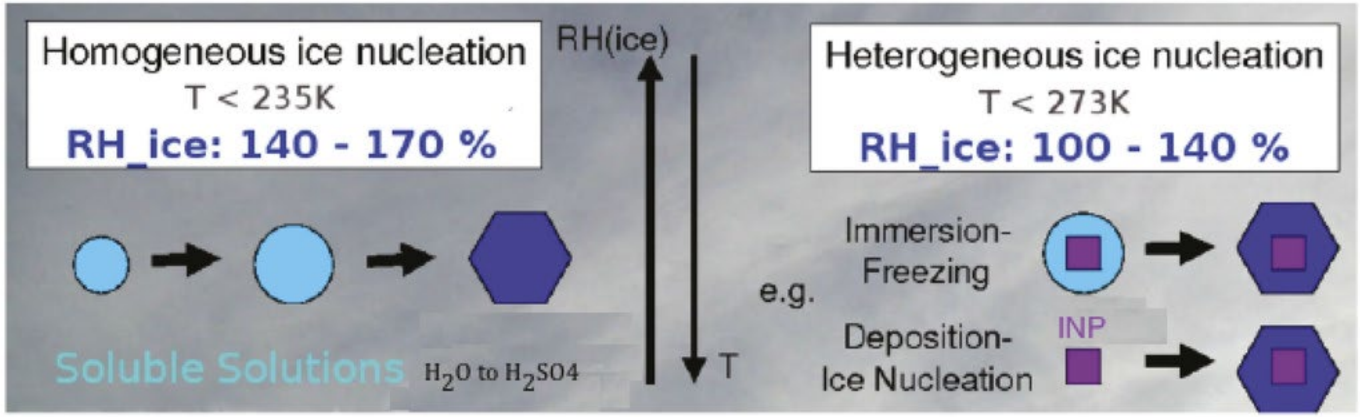
Simulating cirrus clouds in GCMs poses challenges due to the complex cirrus processes (Karcher, 2017).



Kay et al. (2012)

Homogeneous vs. Heterogeneous

- Among **Challenges** in modeling cirrus cloud.
- Identifying the **relative importance of hom vs. het nucleation** in cirrus clouds will result in a more accurate simulation of **cirrus clouds in GCMs** (Heymsfield et al., 2017)

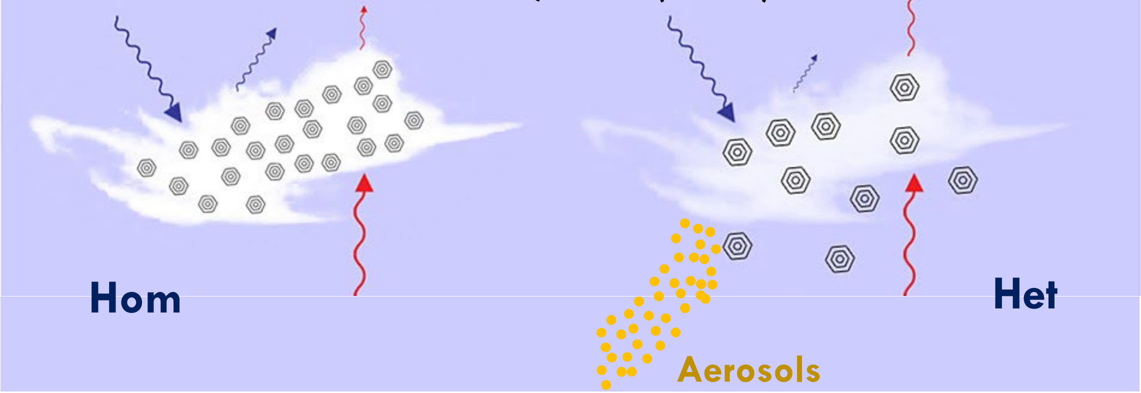


Heymsfield, et al. (2017)

Ice Nucleating Particle (INP) compositon

Bad INP	Good INP
Organics	Mineral dust
Soot	Biological particles

Storelvmo, et al. (2013)



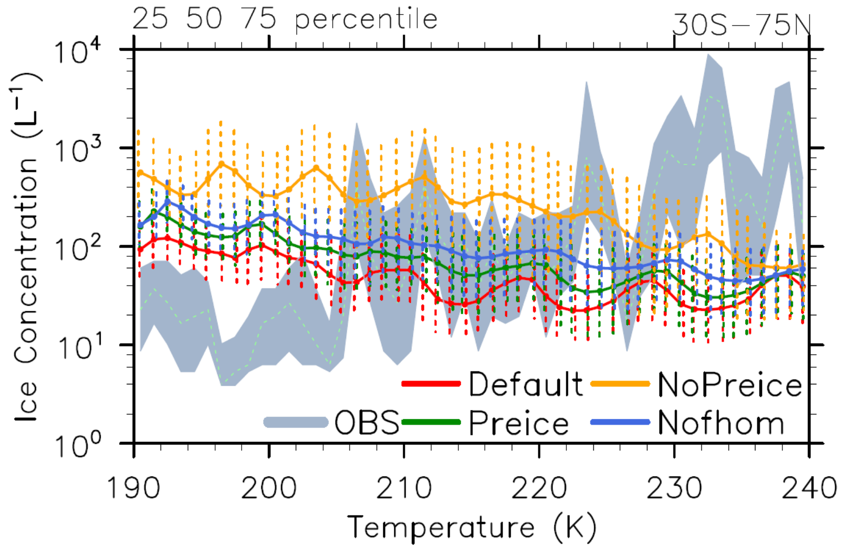
Hom cirrus:

- ➢ occurs when liquid droplets freeze, with no involvement of aerosols.
- ➢ Higher ice particle number concentration (*Ni*)
- ➢ Smaller ice particles
- ➢ Optically thicker

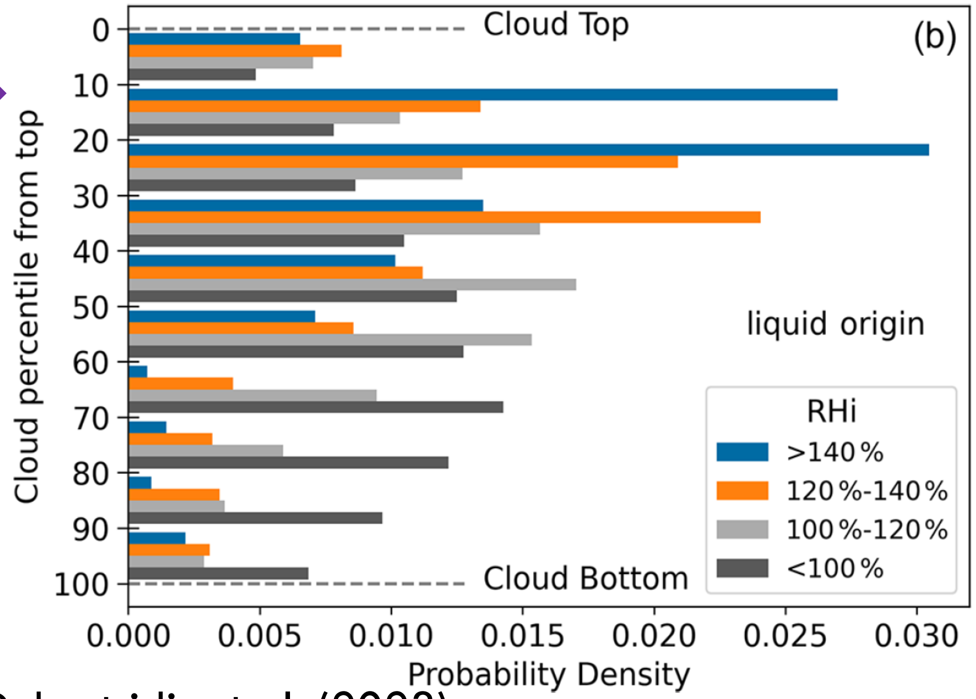
"Pre-existing Ice" in GCMs

- **Modeling of pre-existing ice:**
  1. Implementation in a **GCM** yielded a significant (10x) **reduction** in cirrus cloud **ice number concentration** (N_i).
  2. Increase in ice mixing ratio (q_i) results in a stronger **pre-existing ice** influence.
- **Remote Sensing Insights:**
  1. High relative humidity with respect to ice (RH_i) exists near **cloud tops.**
  2. Dominance of **hom process** leads to small q_i, small particle size, and high N_i at cloud tops.
- **Vertical Resolution Challenge:**
  1. GCMs have coarse vertical resolution (+500m) and **overestimate** pre-existing ice due to **layer-mean q_i:**

- Layer-mean q_i is likely **much greater** than **actual q_i** at the **top of layer** in GCMs.



Shi et al. (2015)

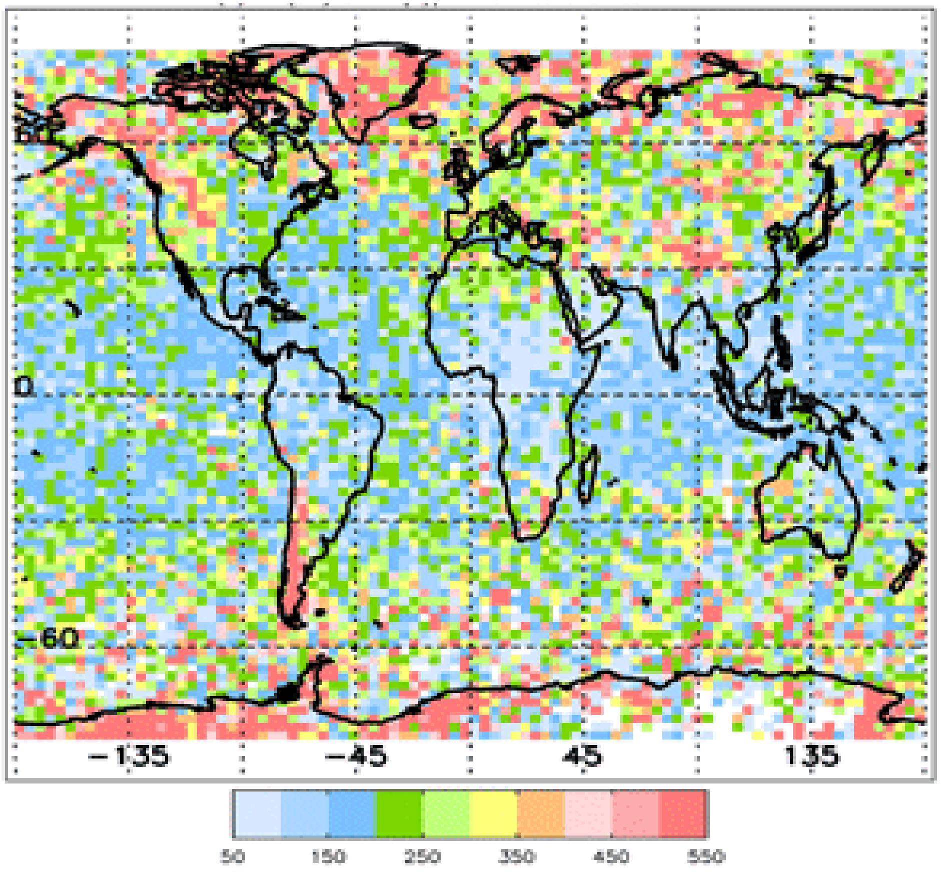


Dekoutsidis et al. (2023)

Cirrus Cloud Thinning (CCT)

- **CCT: transition from hom to het cirrus.**
- **Het:**
  - regarded as the main ice production process
  - garnered substantial attention through both field campaigns and GCM simulations (e.g., Cziczo, et al., 2013).
- New **global-scale satellite retrievals** from CALIPSO by Mitchell et al. (2018): **hom process is far more important than previously recognized.**
- What does this imply?
  The **effectiveness of CCT might surpass previous estimates,** considering that the cooling efficacy of CCT depends on the fraction of hom cirrus.

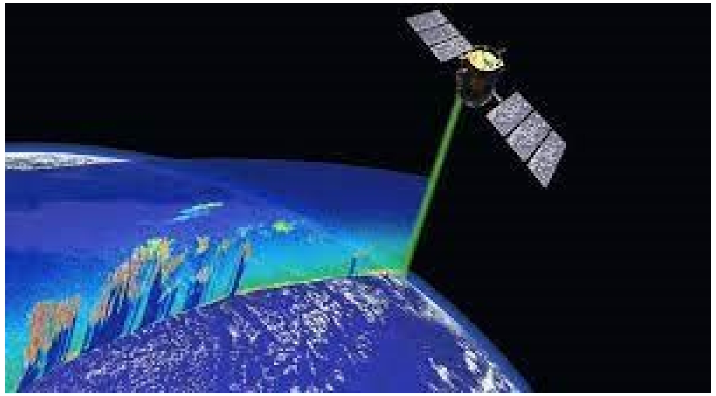
Ice particle number concentration N_i (L^{-1})



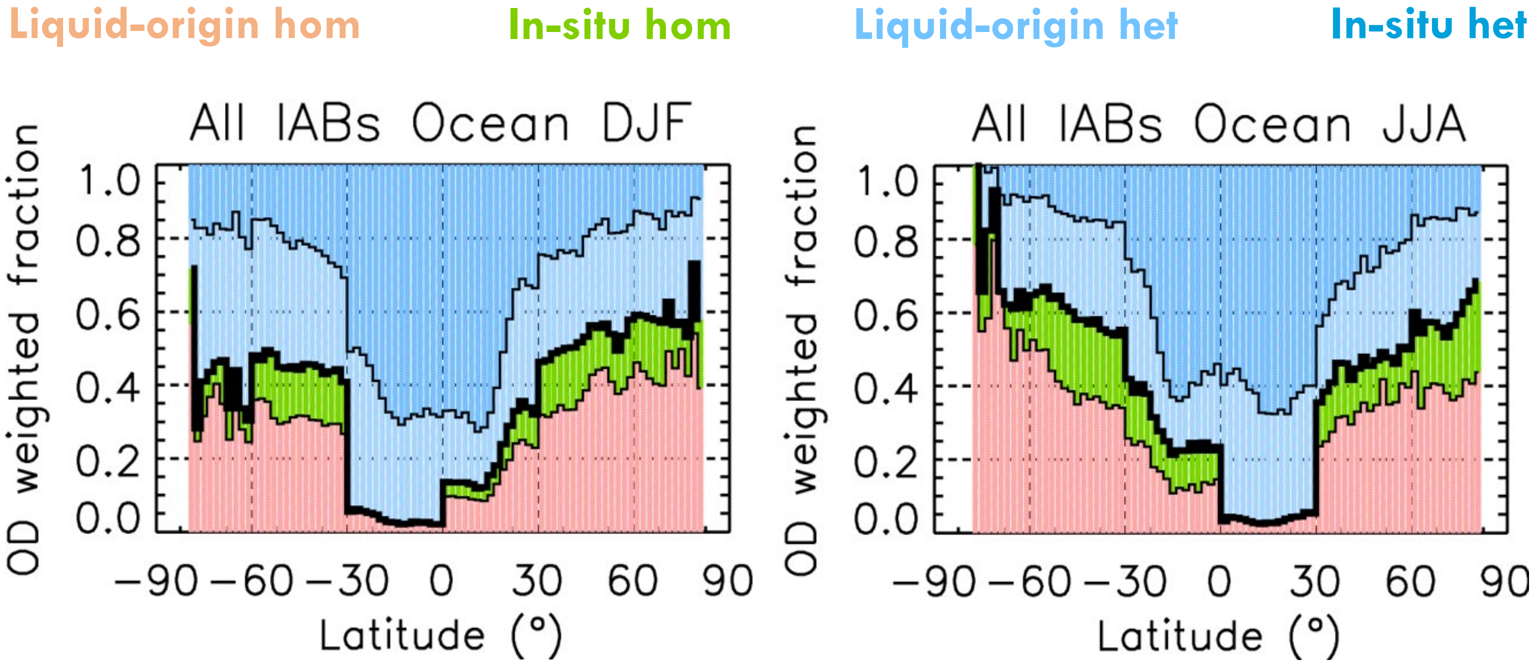
Mitchell et al. (2018)

New CALIPSO Cirrus Retrieval

- Building on the work of Mitchell et al. (2018), we have developed a **CALIPSO** satellite retrieval to **quantify hom and het cirrus** clouds on a **global scale.**
- Ice microphysical variables are retrieved using equations based on Erfani and Mitchell (2016).



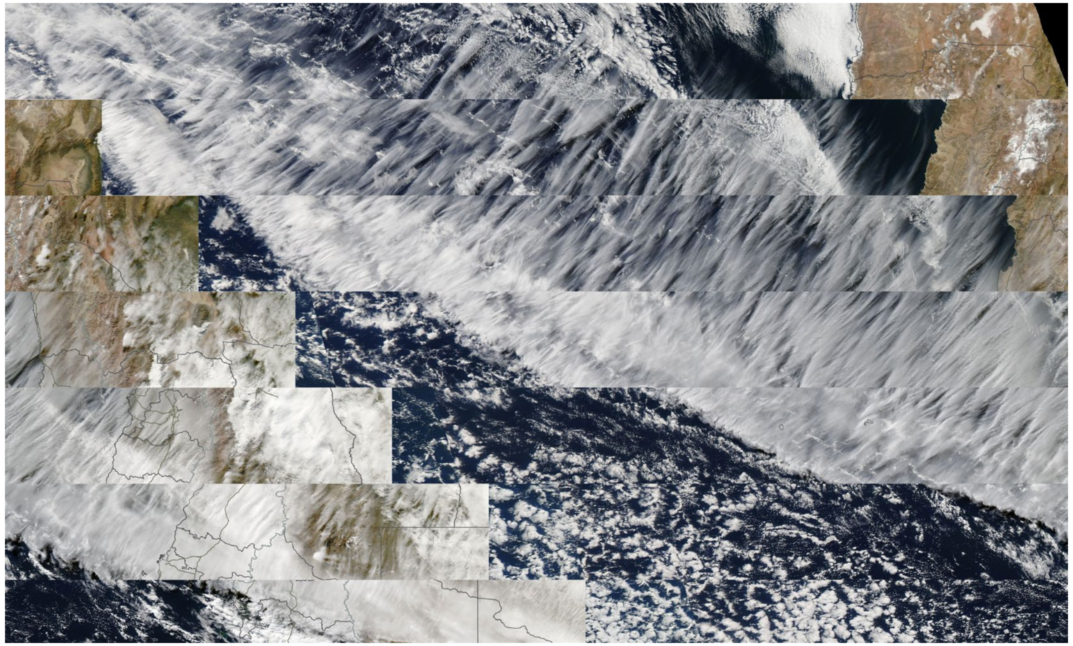
- Outside the tropics during winter (CCT is most effective), **Cloud optical depth (OD)-weighted hom fraction** tends to be **> 50%.**
- This indicates that **hom** cirrus clouds contribute **substantially** to the earth's **radiation budget.**



Objectives

Using CALIPSO satellite retrievals

- to estimate cirrus cloud radiative effect (**CRE**) at the TOA, at the surface, and within the atmosphere in a radiative transfer model (**RTM**)
- to improve the representation of cirrus cloud processes particularly those related to **CCT** in a **GCM**

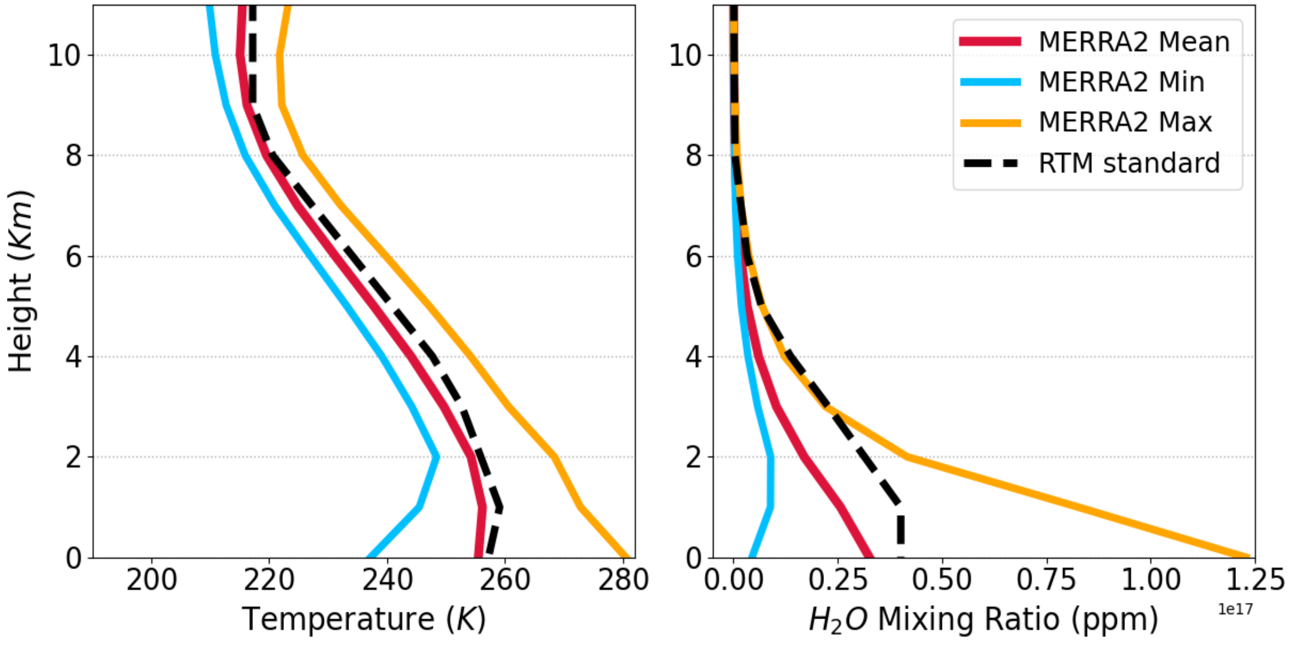


SE Pacific
Aqua/MODIS

Radiative Transfer Model (RTM)

Model setup

- library for Radiative transfer (**libRadtran**; Emde et al., 2016)
- Solver: one-dimensional Discrete Ordinate Radiative Transfer model (**DISORT**) with **6 streams.**
- The spectral wavelength range: **longwave (LW):** from 3.1 µm to 100 µm
- **Meteorological** profiles: **MERRA2** data averaged for **Arctic night.**
- The RTM location and time: latitude 70°N and Arctic night (LW only).

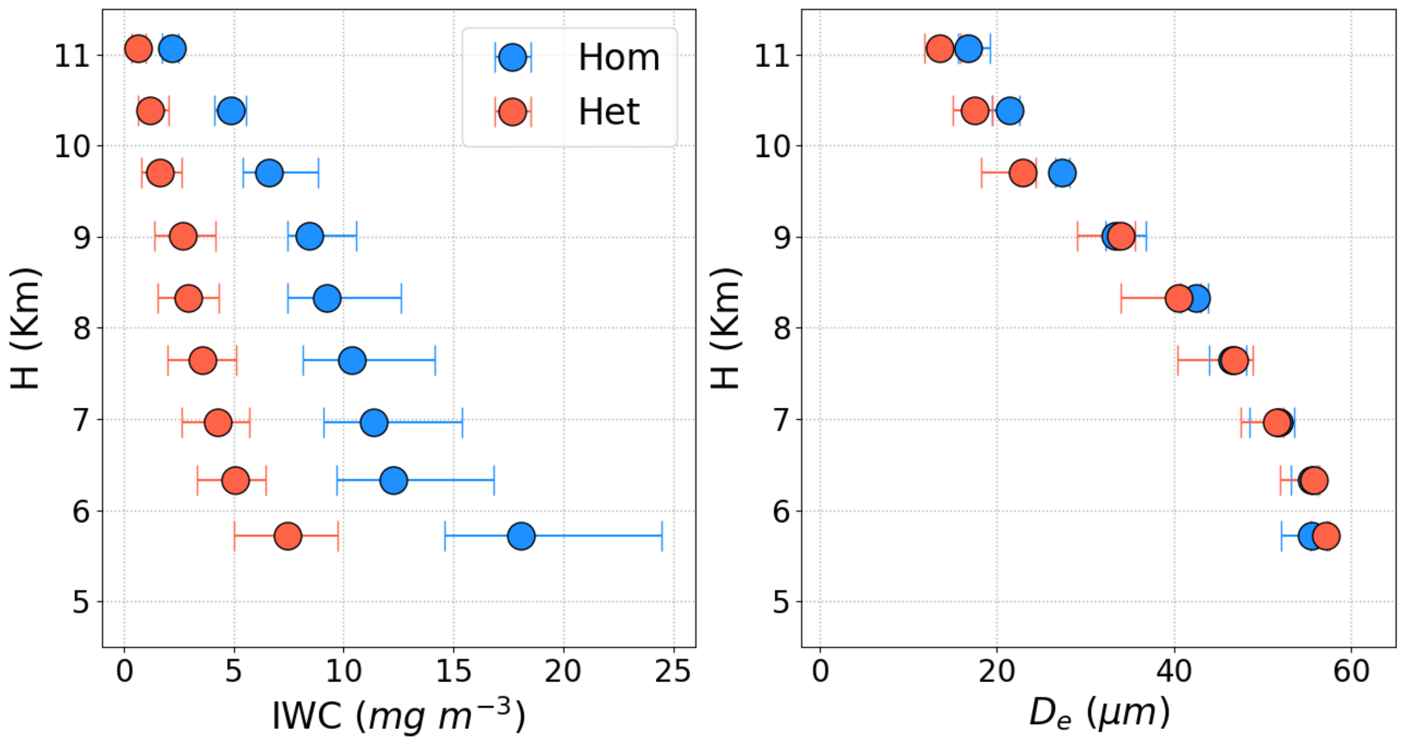


Creating cloud profiles as RTM inputs

- **CALIPSO retrievals** of **hom** and **het IWC** and ***D*$_e$** are used as **inputs of RTM** to simulate radiative properties of cirrus clouds.
- For each hom and het, the IWC and *D*$_e$ **"profiles"** from ~ 5.7 km to 11.1 km is **divided into 4 clouds each** having a thickness of ~ 1.3 km (representative for cirrus) but with different cloud base and top heights.

CALIPSO retrievals over Arctic land during winter

Markers: median values; Error bars: 25th and 75th percentiles

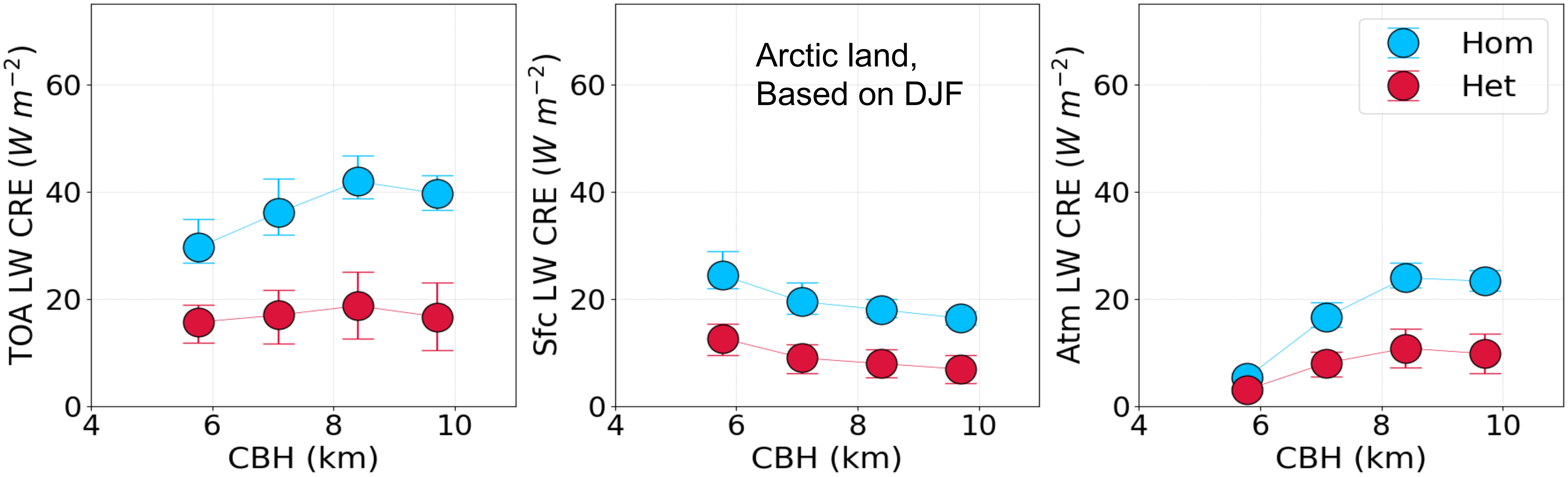


ice water content **effective diameter**

RTM Results

- Under cirrus **overcast** conditions **without low clouds**, a transition from all-hom to all-het cirrus clouds during "**Arctic night**" (i.e., no SW radiation) could result in a **significant surface cooling** with a change in cloud radiative effect (ΔCRE) of ~ **-10 W m^{-2}**.
- Considering the fraction of hom cirrus (e.g., **0.3**) for the Arctic night, the **overall surface cooling is: ΔCRE ≈ -3 W m^{-2}.**
- **Similar** results are achieved for **Antarctic night.**

CBH: cloud base height



Using CALIPSO Retrievals in a GCM

- Community Atmosphere Model, Version 6 (**CAM6**)
- Resolution: ~**1 deg.**
- Cloud microphysics scheme: Morrison-Gettelman version 2 (**MG2**)

#	Experiment name	Run period (years)	Description
1	baseline	20	Baseline CAM6 simulation
2	nopreice	20	Removing the pre-existing ice from CAM6
3	het	20	Implementation of het cirrus based on CALIPSO retrievals
4	natural	20	Implementation of both het and hom cirrus based on CALIPSO retrievals

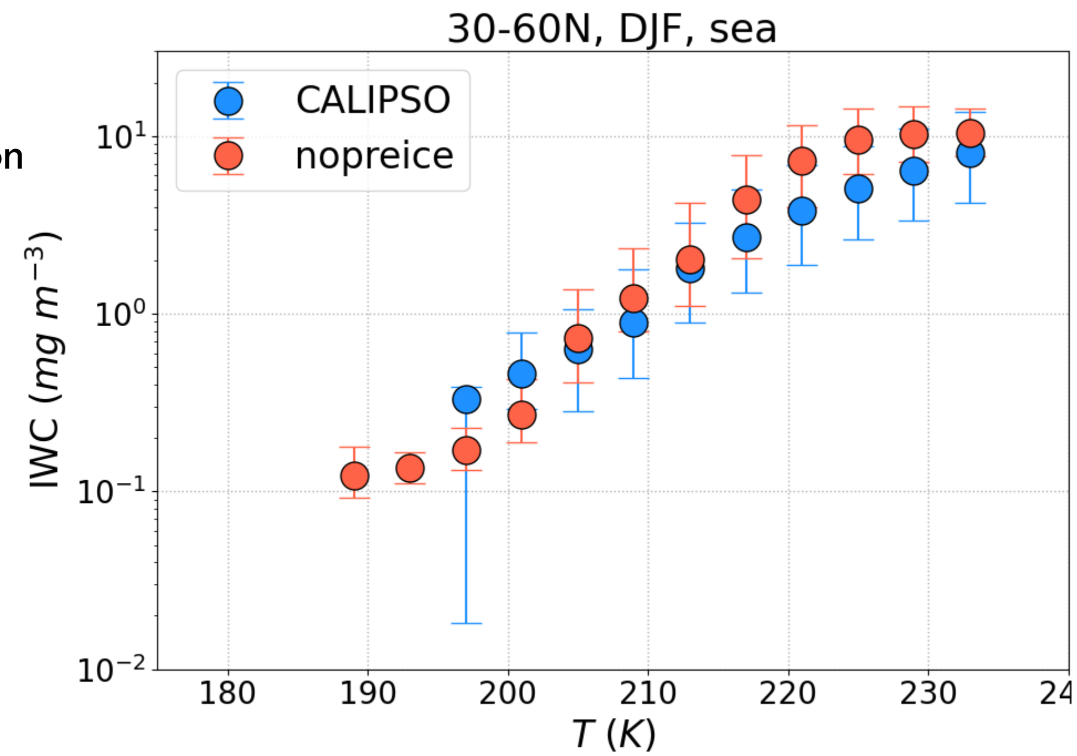
Removing the Pre-existing Ice

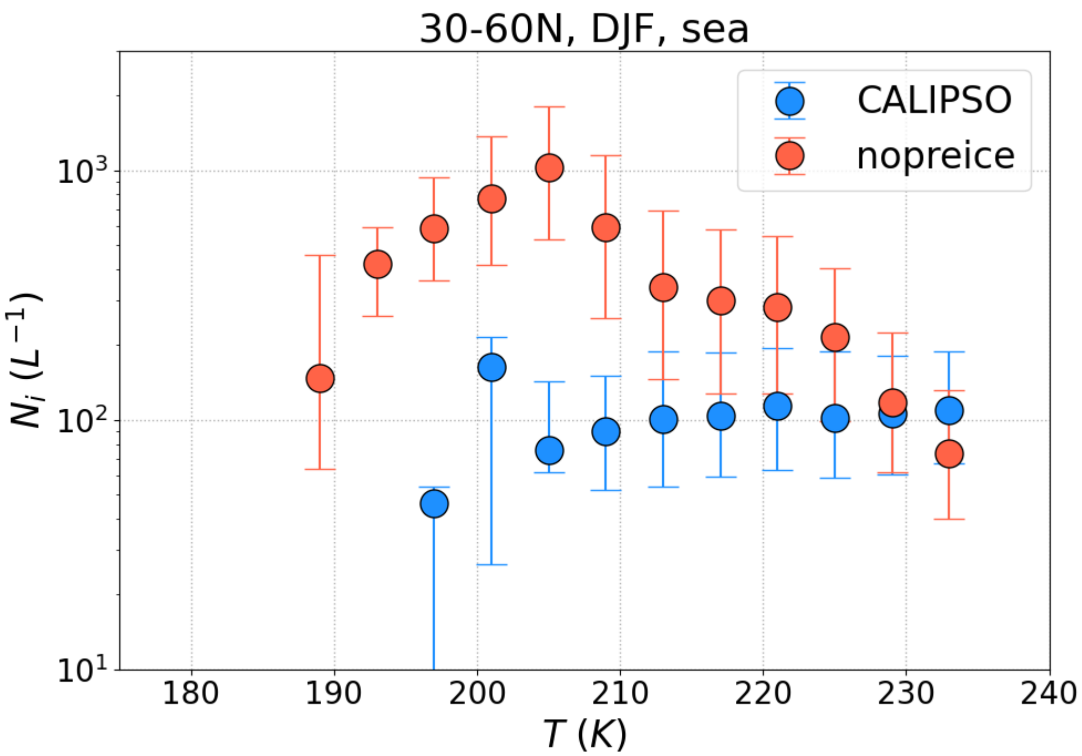
- Good agreement between simulated and observed IWC
- Similar results for different regions and seasons.

20-year simulation

Markers:
median values;

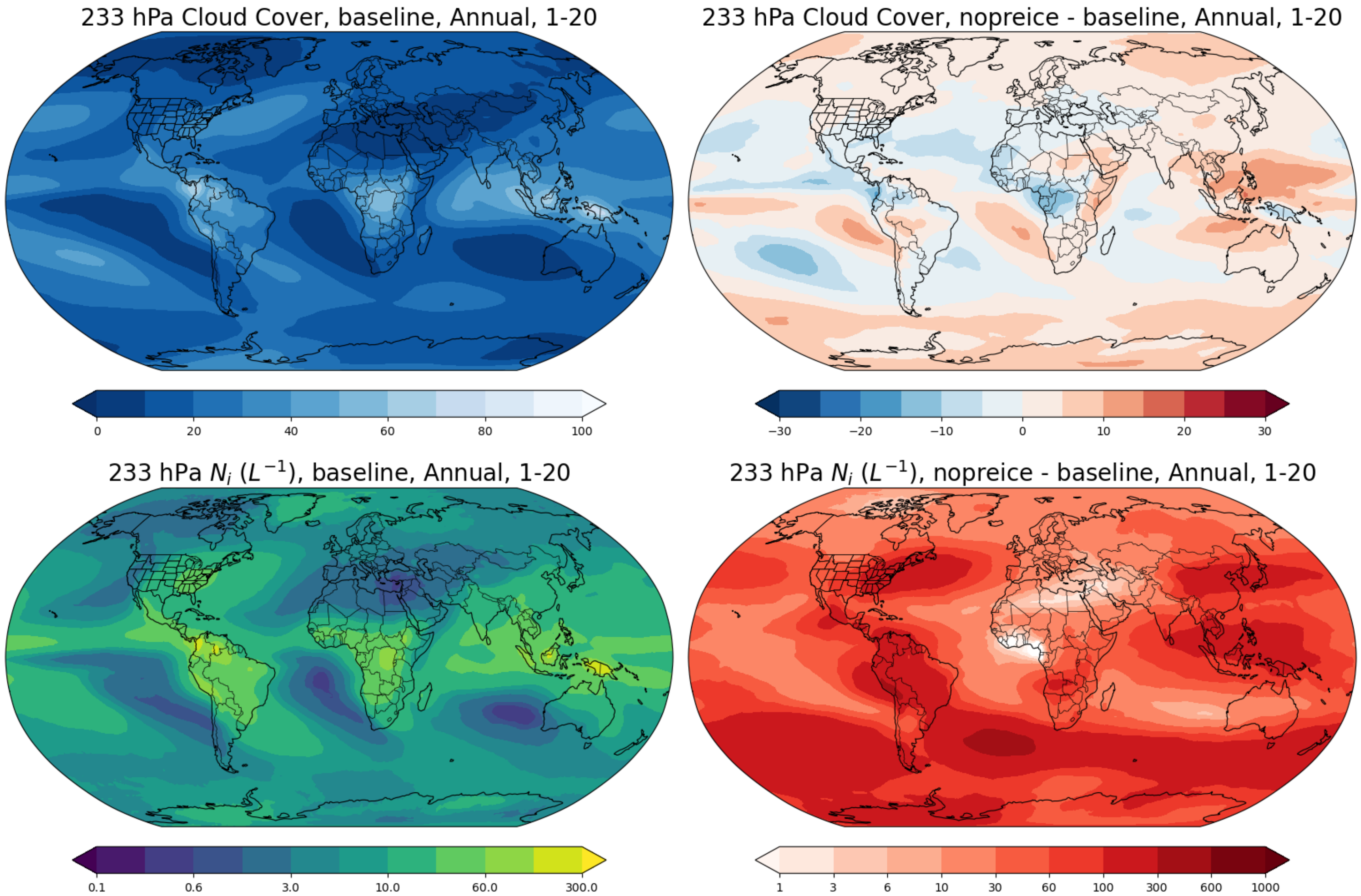
Error bars:
25th and 75th
percentiles





Removing the Pre-existing Ice

- Turning off pre-existing ice in CAM6 facilitates conditions favoring "hom" process.
- **Significantly enhances $\boldsymbol{N_i}$** with minimal impact on IWC, cloud fraction (CF), etc.

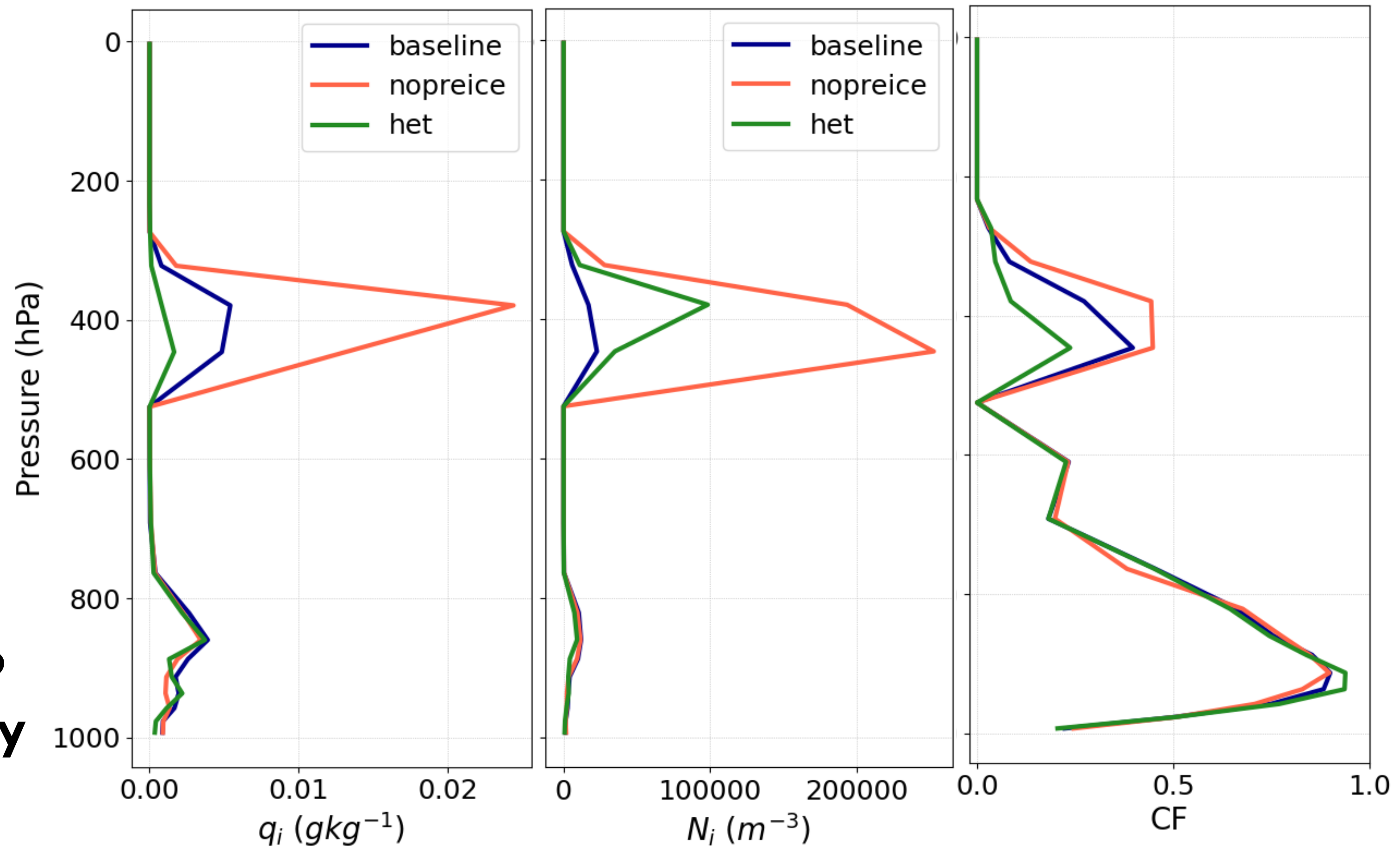


“het” Implementation

- From **Single**-column CAM6 (**SCAM**) for an Arctic campaign (MPACE)
- With our parameterization for “het” conditions, **faster fallspeed** and consequently, **lower IWC, N_i, and cloud cover** is achieved.

Next step:

Conducting “het” and “natural” CAM6 on a **global scale** to **comprehensively** assess the impact of CCT within a complex atmospheric system.



Summary

- Our group focused on developing a new CALIPSO retrieval to **identify the relative contribution of hom and het cirrus clouds**. Notably, it is revealed that over 50% of the cirrus radiative effect in the extratropical regions during winter originates from hom cirrus.
- Using an RTM, libRadtran, we determine the radiative effects of CALIPSO's hom and het cirrus clouds. The results indicate that **a transition from hom to het cirrus clouds,** whether due to natural causes or CCT, could lead to significant cooling during the Arctic/Antarctic night (absence of SW) with a **ΔCRE of ~ -3 W m^{-2}** at the surface for cirrus overcast conditions and in the absence of low clouds.
- Currently, we are **implementing the CALIPSO retrievals into a GCM**, CAM6. This implementation aims to enhance the representation of both hom and het cirrus processes, providing a more accurate simulation of climate and **CCT**.

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Thank you very much!

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