Processes Influencing Cloud Droplet Number in High Latitude Southern Ocean Low Clouds

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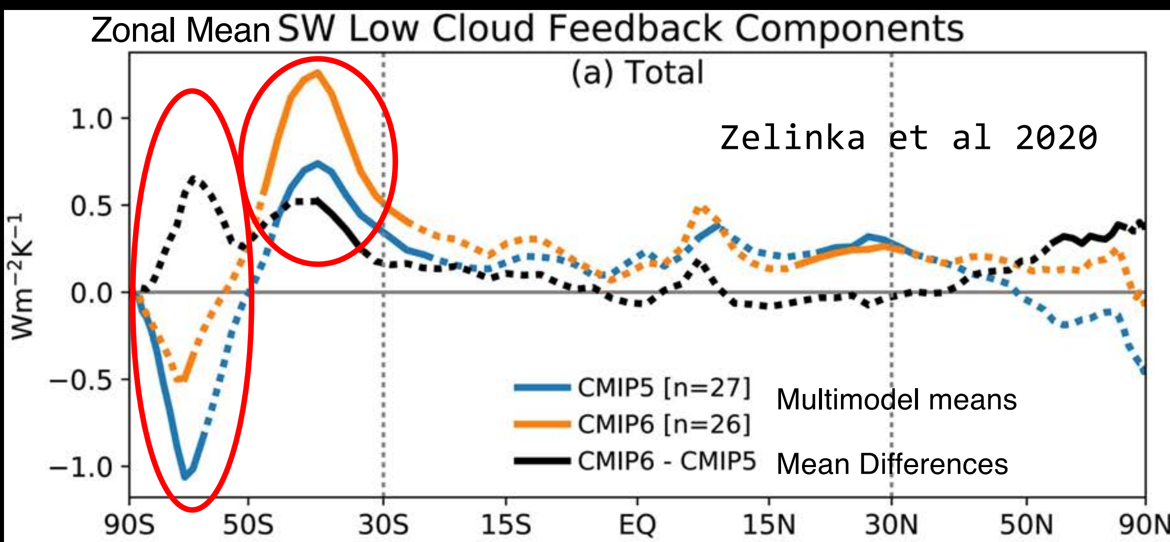
- Southern Ocean Marine Low Clouds
  - Mostly geometrically thin
  - Within 3 km of the surface, compose 89% of the cloud cover over the Southern Ocean
  - (doi:. 10.1029/2021JD034569) – Source CloudSat and CALIPSO
  - ~80% composed of supercooled liquid and non precipitating
  - Responding to mostly natural processes in a uniquely pristine atmosphere (McCoy et al., 2020)

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., et al. (2020).

Causes of higher climate sensitivity in CMIP6 models.

Geophysical Research Letters, 47, e2019GL085782. https://doi.org/10.1029/2019GL085782

Coupled Model Intercomparison Project (CMIP) 6 to determine the sensitivity of Earth's climate to changes in atmospheric CO2.

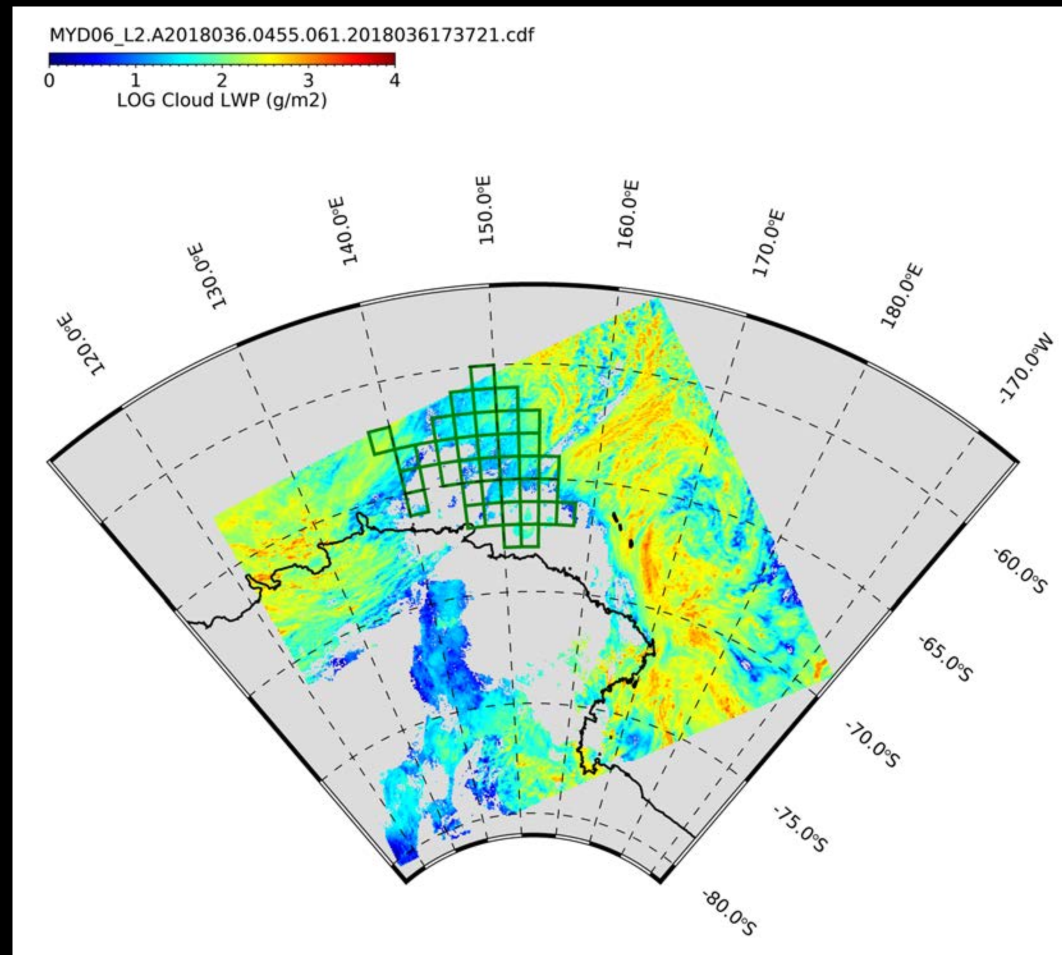


Southern Ocean cloud feedbacks are responsible for the higher Effective Climate Sensitivity (ECS) in CMIP 6

60S: Changes (decreasing negative feedback) due to microphysics and phase partitioning

40S: Changes (increasing positive feedback) due to greater sensitivity to mixing and decreasing cloud cover with warming

- Modis L2 Cloud Product
- Cloud scene as 1x2 box
- Extract cloud property statistics from "scenes"
- Liquid, non-precipitating marine low clouds



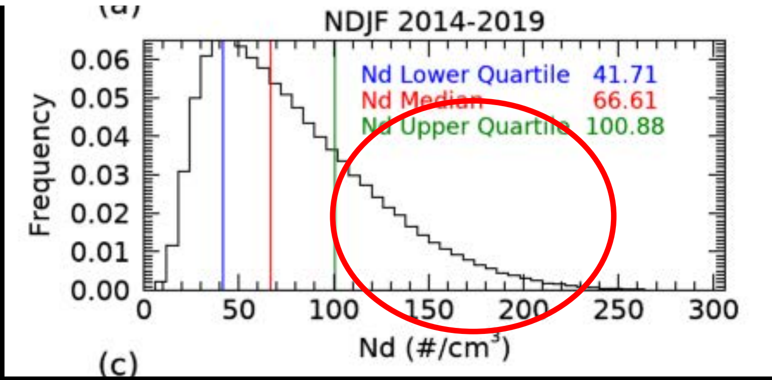
Findings from Recent Paper in ACP Letters: (*https://doi.org/10.5194/acp-23-1677-2023*)

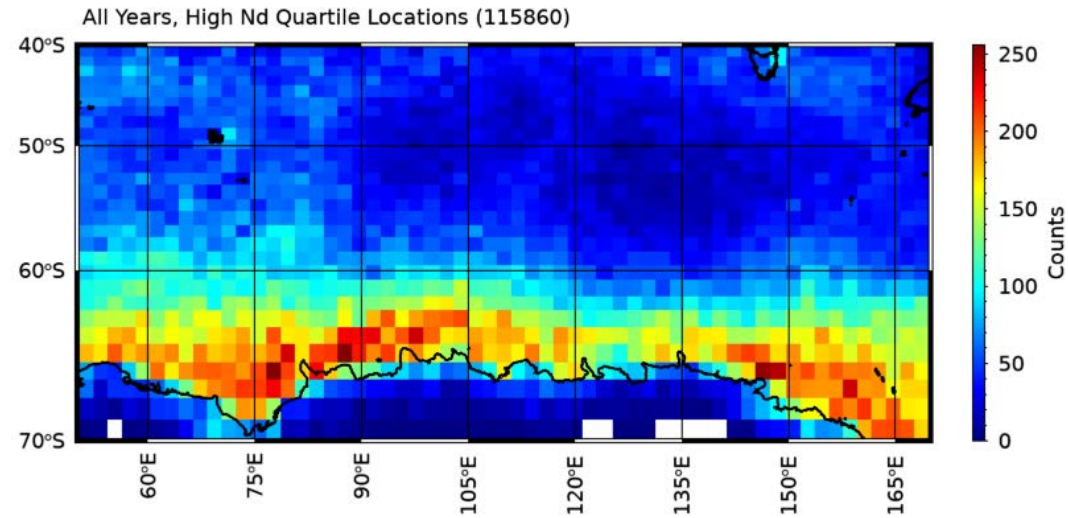
Analyzed 5 Summers of MODIS L2 and CERES data focusing on non precipitating low cloud scenes:

Where are the upper N_d quartile clouds scenes found?

Strong gradient near 60S with highest occurrences south toward coastal Antarctica

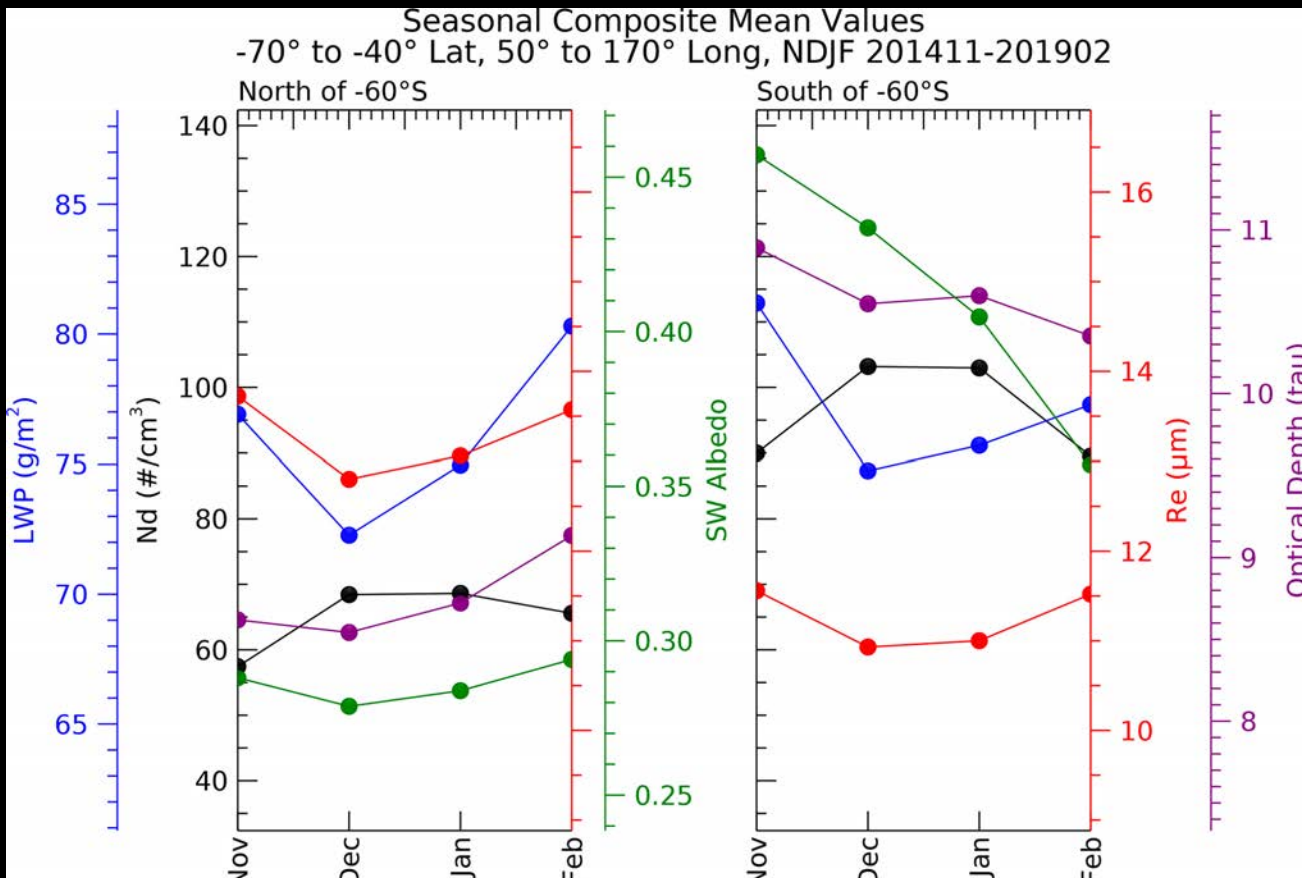
- *Modal values near 50 cm^{-3} with long tail to beyond 150 cm^{-3}*

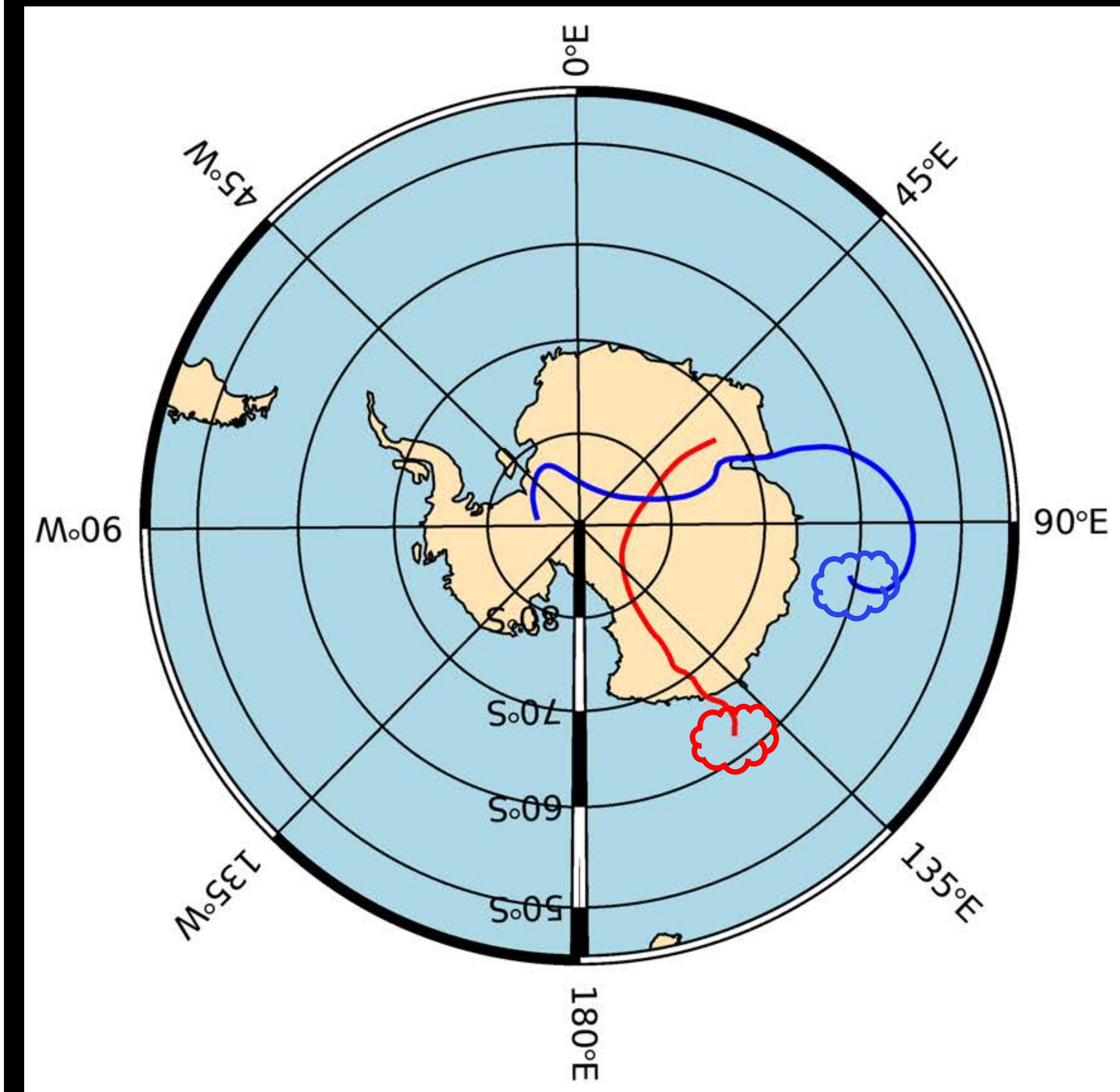




Findings from Recent Paper in ACP Letters: (*https://doi.org/10.5194/acp-23-1677-2023*)

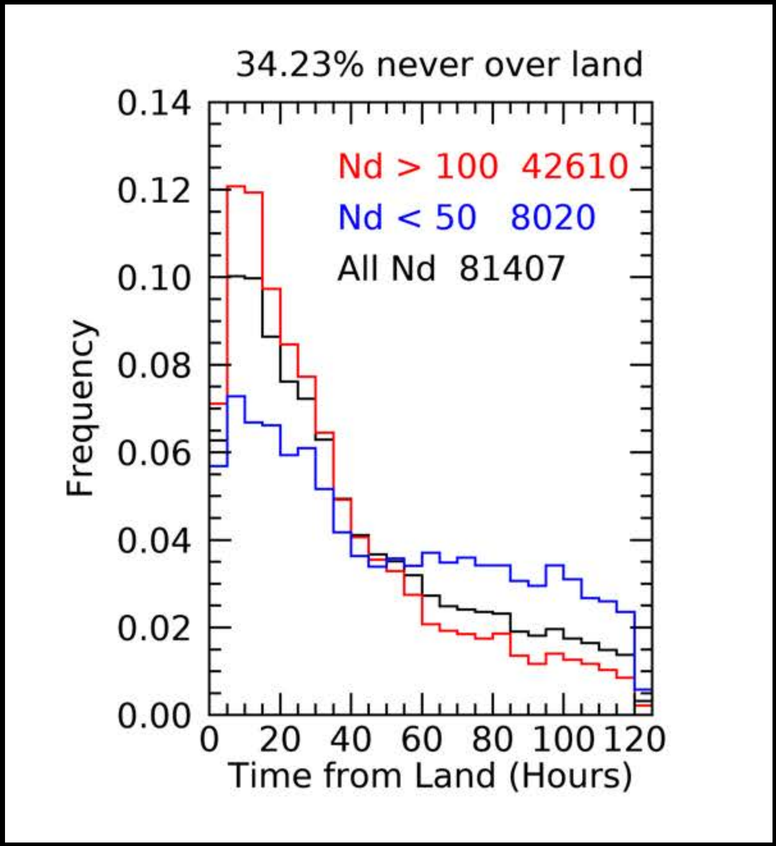
The gradient in microphysics results in measurably brighter clouds south of -60 versus north even though LWP is similar.





Air Mass History

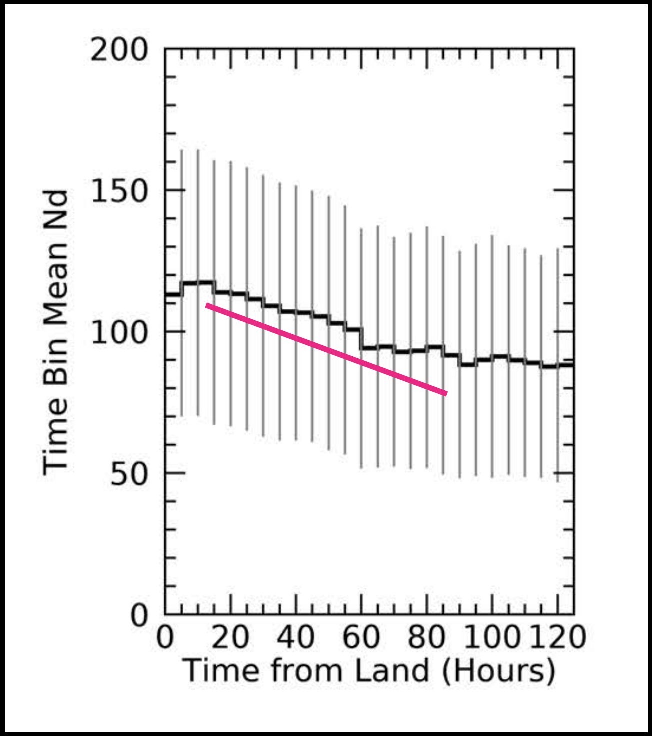
- Hysplit 5-day standard back trajectory
- Amount of time since the cloud last left the land
- “Time from Land” not “Distance from Land”



- “Time from Land” in hourly bins
- All clouds sampled over water
- 34% clouds never over land
- Black=All clouds that spend some time over land
- Red=Clouds with Nd > 100 /cm3
- Blue=Clouds with Nd < 50 /cm3

High Nd values found where cloud has been away from land for a shorter time.

If the cloud was sampled a long time from leaving the land, low Nd values.



Find the mean and standard deviation of the cloud Nd values in each hourly time bin.

Nd becomes systematically lower with time from last land influence

Anecdotal Impression:

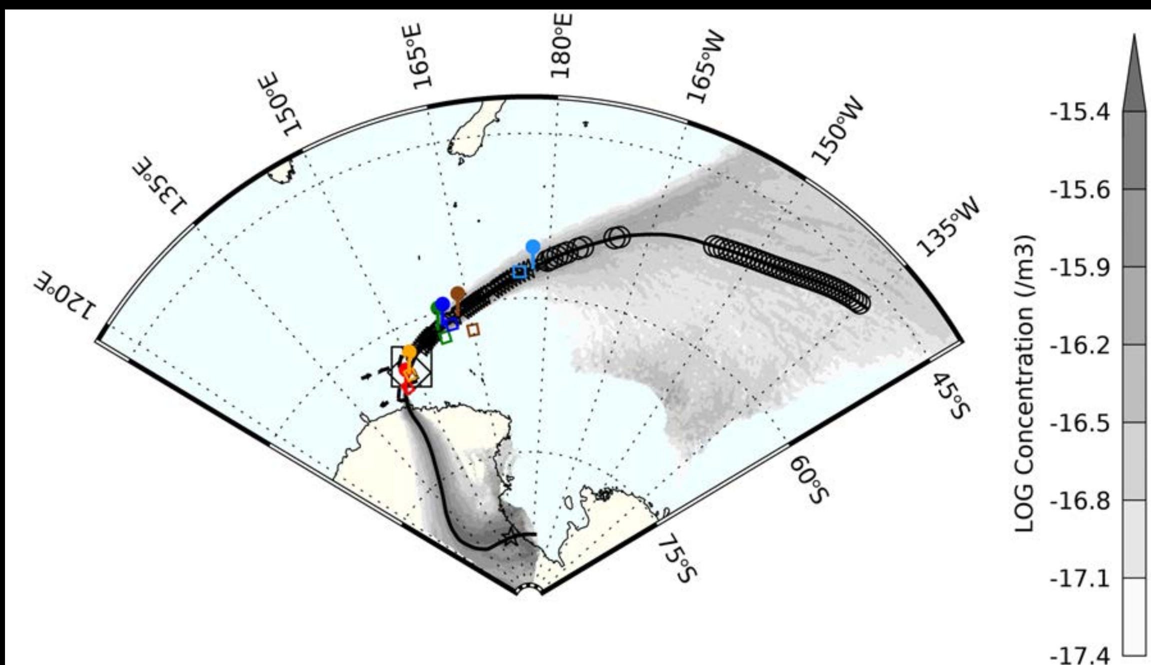
1. Proximity to air mass trajectories over continental Antarctica seems to be an important predictor of high Nd.
2. Long tracks over open water seem to result in decay in Nd as precipitation processes consume CCN….

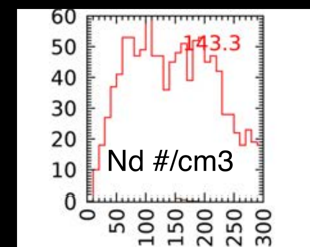
Testing this with MODIS data along trajectories (Stilt/Hysplit)

Next Step: Why? While biogenic aerosol is higher in the high latitudes resulting in brighter clouds, 1) Where are the new CCN formed? 2) What are the processes that control the observed gradient?

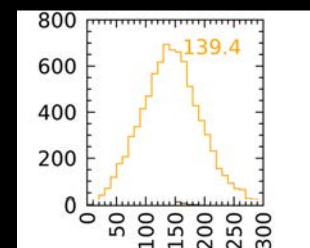
Approach: Follow air mass trajectories (STILT/HySplit) and sample MODIS L2 along these trajectories to see how cloud systems evolve with time along trajectory

Example: 20180205 centered on Ship (red) after long trajectory over ice sheet…





Aqua
0455UTC
2018/02/05



Terra
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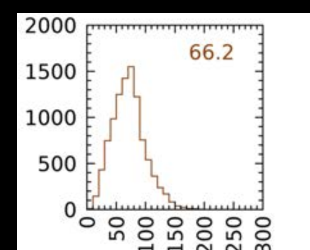

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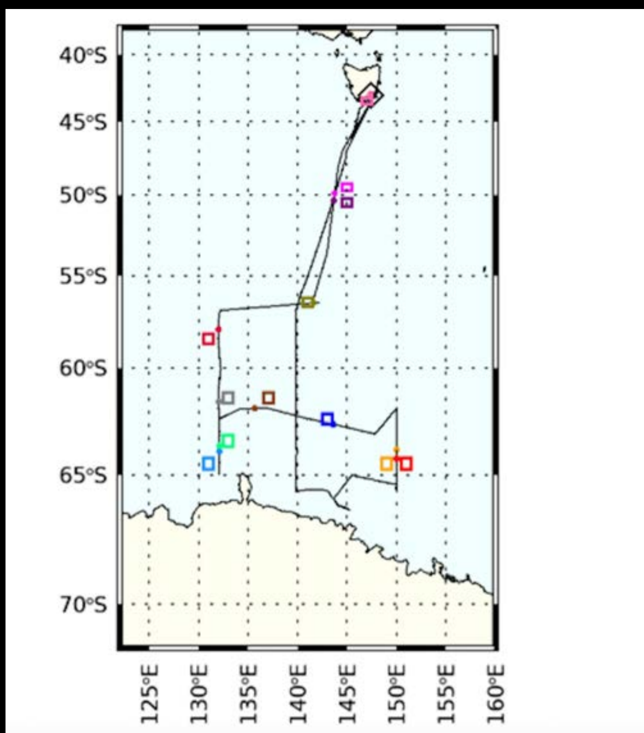
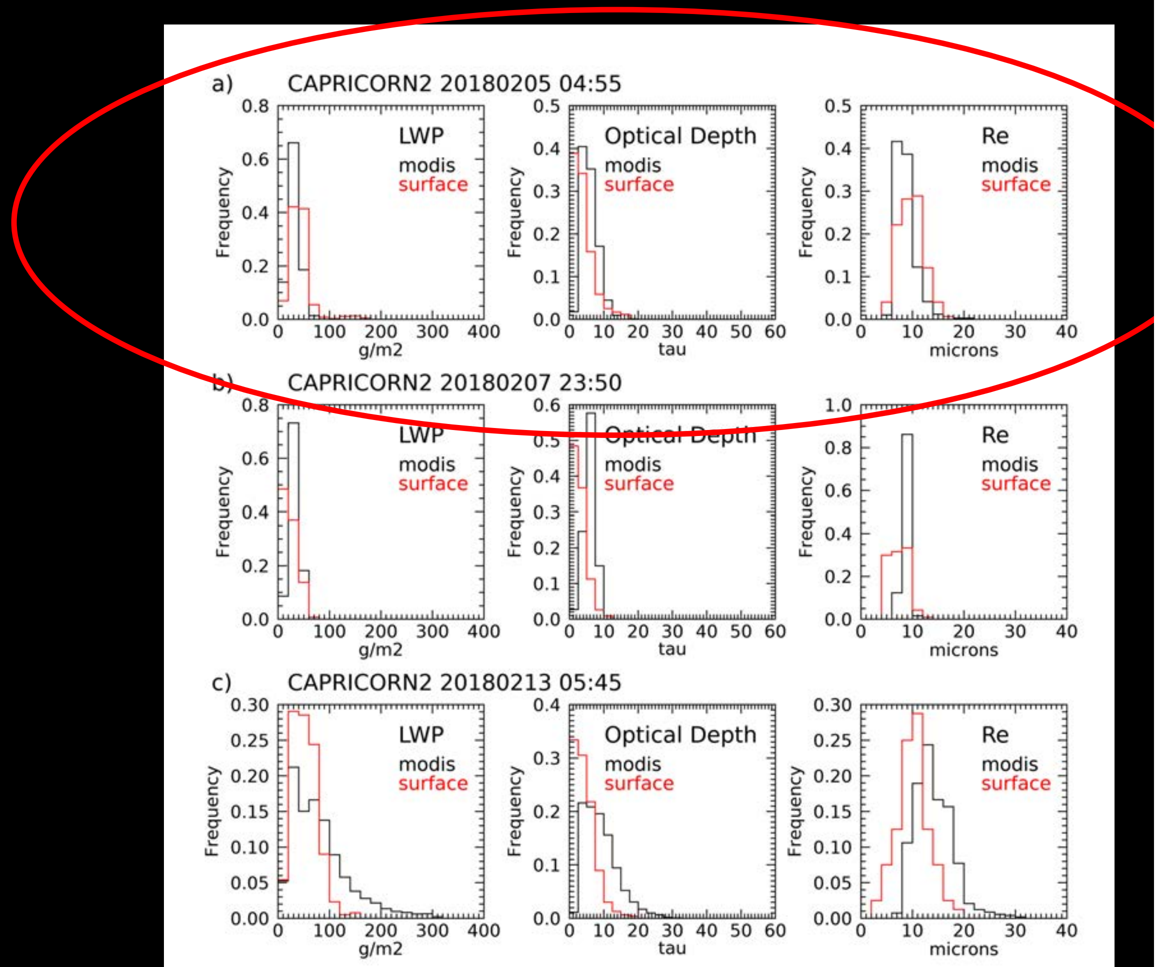
2018/02/07

Systematically Comparing MODIS L2 Cloud Properties with ship-based remote sensing (several dozen overpasses)…



A sample of case study comparisons we are developing



Conclusions:

- Understanding marine low clouds over the Southern Ocean is critical to understanding Earth's Climate Sensitivity

- Very strong gradients in marine low cloud properties near 60S result in higher albedo clouds for a similar LWP.
  - cloud brightening associated with the natural cycle in seasonal biogenic aerosol is a distinct feature of this region and offers a natural laboratory for studying aerosol-cloud interaction.

Where are the new aerosol particles formed? NPF that grows to sulfate CCN have not been observed!

Hypothesis: Trajectories over high actinic flux regions of the Antarctic Free Troposphere with sufficient biogenic sulfate and oxidants enable new particle formation that result in marine boundary layer CCN from katabatic flows.

Preliminary testing seems to support this idea….

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