Evaluation of Himawari cloud properties using ship-based and aircraft measurements over Southern Ocean

Baike Xi, University of Arizona

Xiquan Dong, Xingyu Zhang, Xiaojian Zheng, University of Arizona

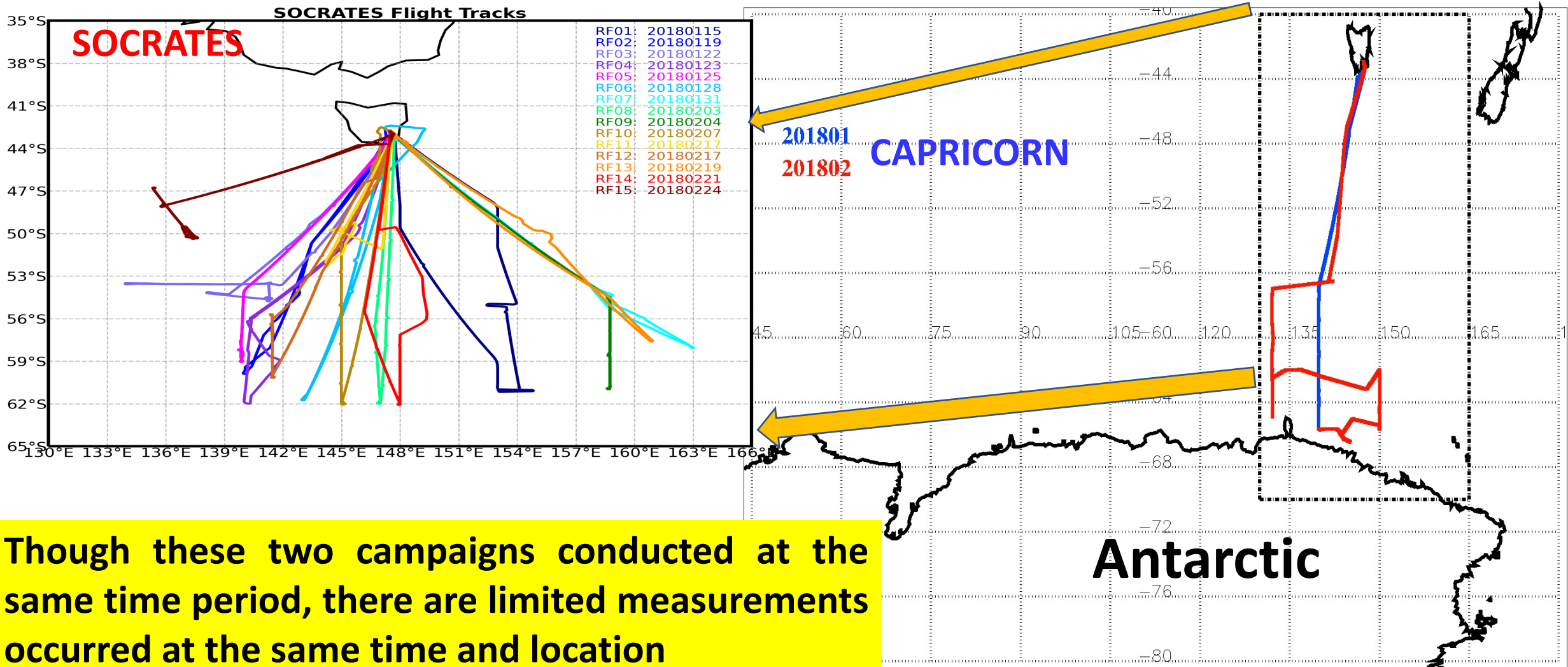CERES Cloud working group

Special thanks for Dr. Alain Protat (BOM of Australia)

THE UNIVERSITY OF ARIZONA

Overview of SOCRATES and CAPRICORN field Campaigns

SOCRATES and CAPRICORN were conducted during January and February of 2018

SOCRATES

SOCRATES Flight Tracks

RF01: 20180115
RF02: 20180119
RF03: 20180122
RF04: 20180123
RF05: 20180125
RF06: 20180128
RF07: 20180131
RF08: 20180203
RF09: 20180204
RF10: 20180207
RF11: 20180217
RF12: 20180217
RF13: 20180219
RF14: 20180221
RF15: 20180224

CAPRICORN

201801
201802

Antarctic

Though these two campaigns conducted at the same time period, there are limited measurements occurred at the same time and location

Data sets from Ship-based and Aircraft

The Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES) from January to February 2018
- CPC → CN size > 10 nm
- UHSAS → CN size > 70 nm
- CCN

The instruments on the ship during CAPRICORN are
1) Cloud radar (94 GHz)
2) Microrain Radar (MRR, 24 GHz)→rain frequency.
3) Microwave radiometer (MWR)→LWP
4) Micropulse Lidar (MPL)→Cloud phase near the cloud base

Himawari cloud properties:
➢ Matched with ship-based time and location
➢ Matched with aircraft trajectory

Goals:
1) Evaluate Himawari cloud retrievals using ship-based measurements
2) Investigate the impact of aerosols on satellite retrieved cloud properties and TOA albedo

Comparisons of CF and cloud heights between ship-based and H08 (1/11 – 2/21, 2018)

(a) CF — CAPRICORN (76.5%), H08 (75.1%)

(b) H_{base}

(c) H_{top}

LOW MID MOL HGH HOM HML HOL
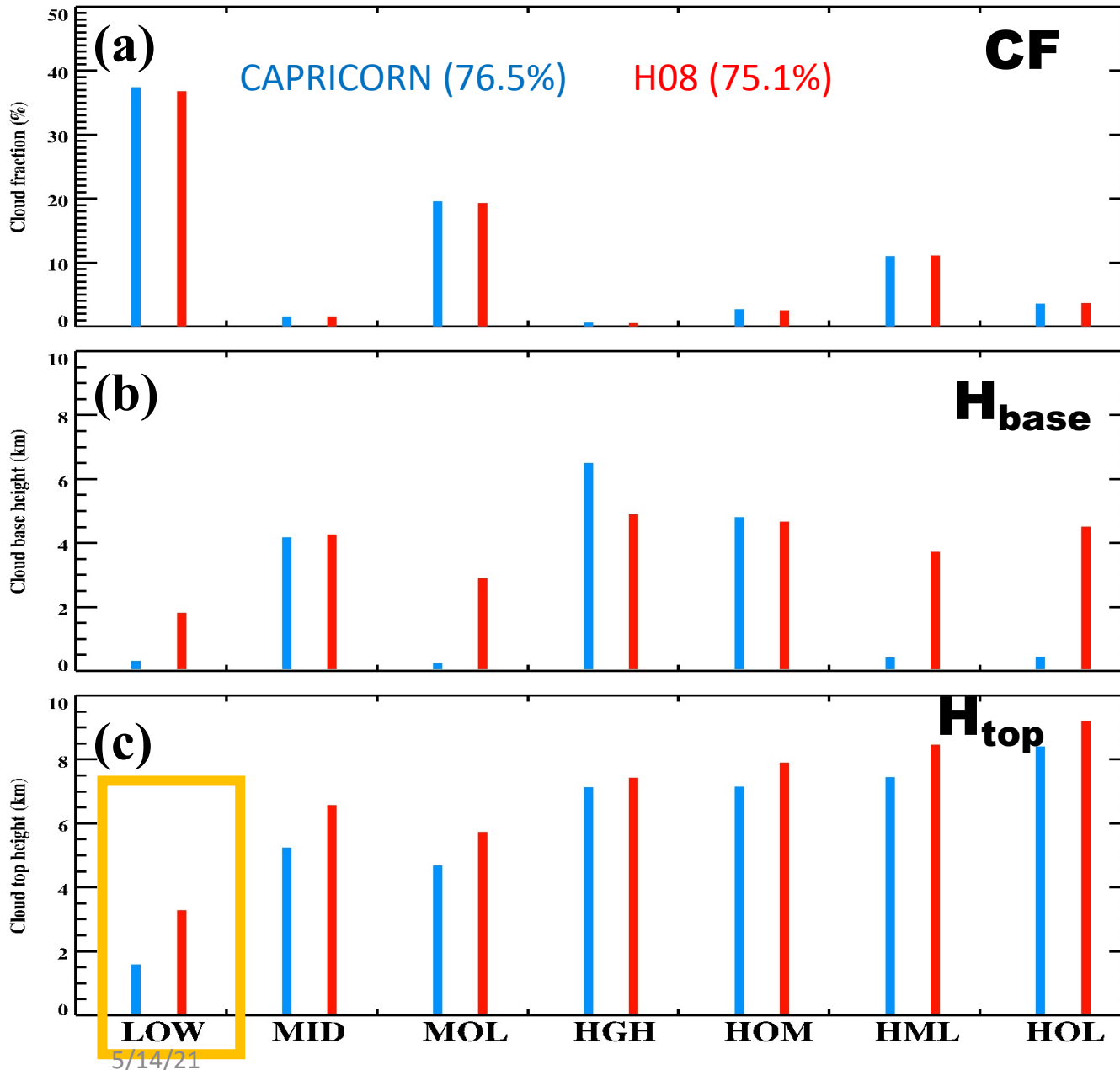
(a) Cloud fraction (CF):
Excellent agreement in both total CF and each type of CFs.

(b) Cloud base height (H_{base})
Good agreement for MID and HOM, But H08 estimated H_{base} are higher than ship-based measurements LOW, MOL, HML and HOL (all include 'L')

(b) Cloud top height (H_{top})
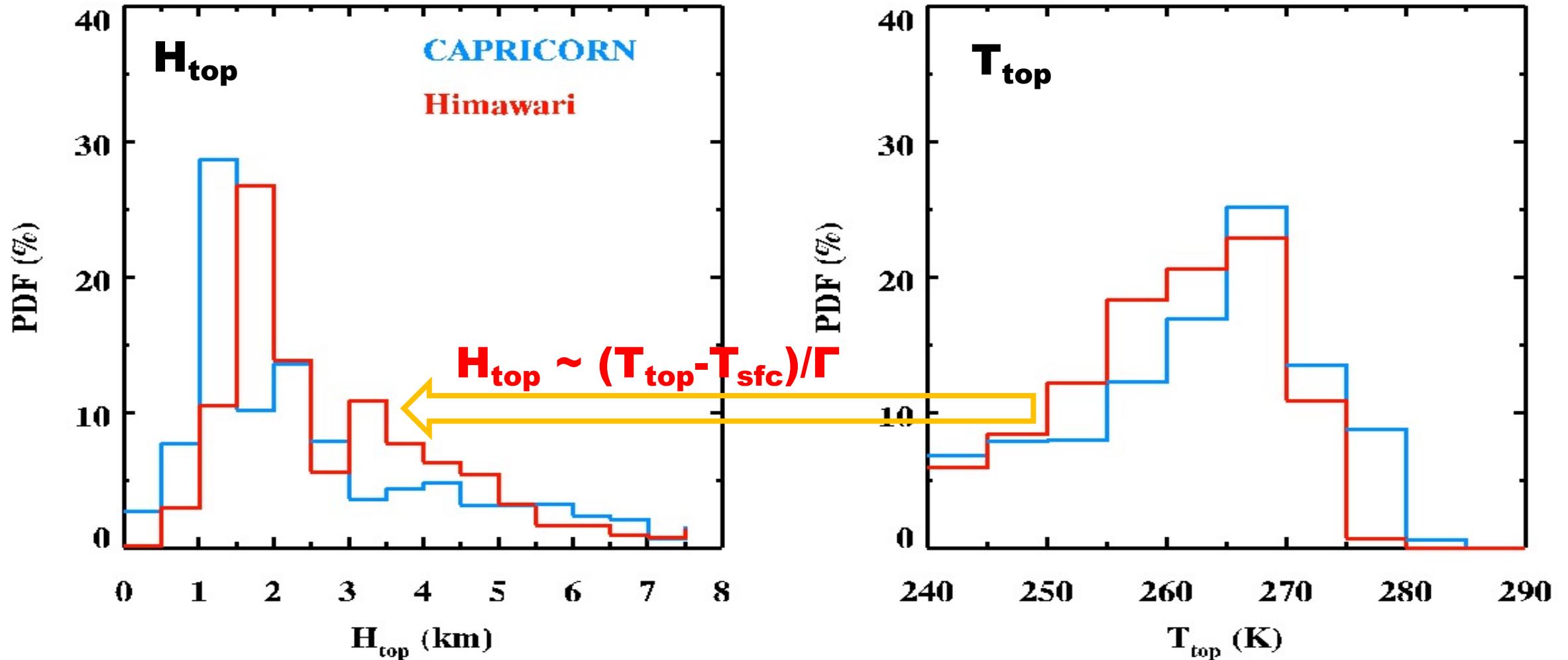H08 estimated H_{top} are slightly higher, but the mean LOW H_{top} is doubled that of ship-based.

5/14/21

Pixel-level cloud samples are identified as liquid by Himawari
Including LOW, MOL, HML and HOL (all have 'L')

Pixel-level cloud samples are identified as liquid by Himawari

Including LOW, MOL, HML and HOL (all have L)

$$H_{top} \sim (T_{top}-T_{sfc})/\Gamma$$

CAPRICORN
Himawari
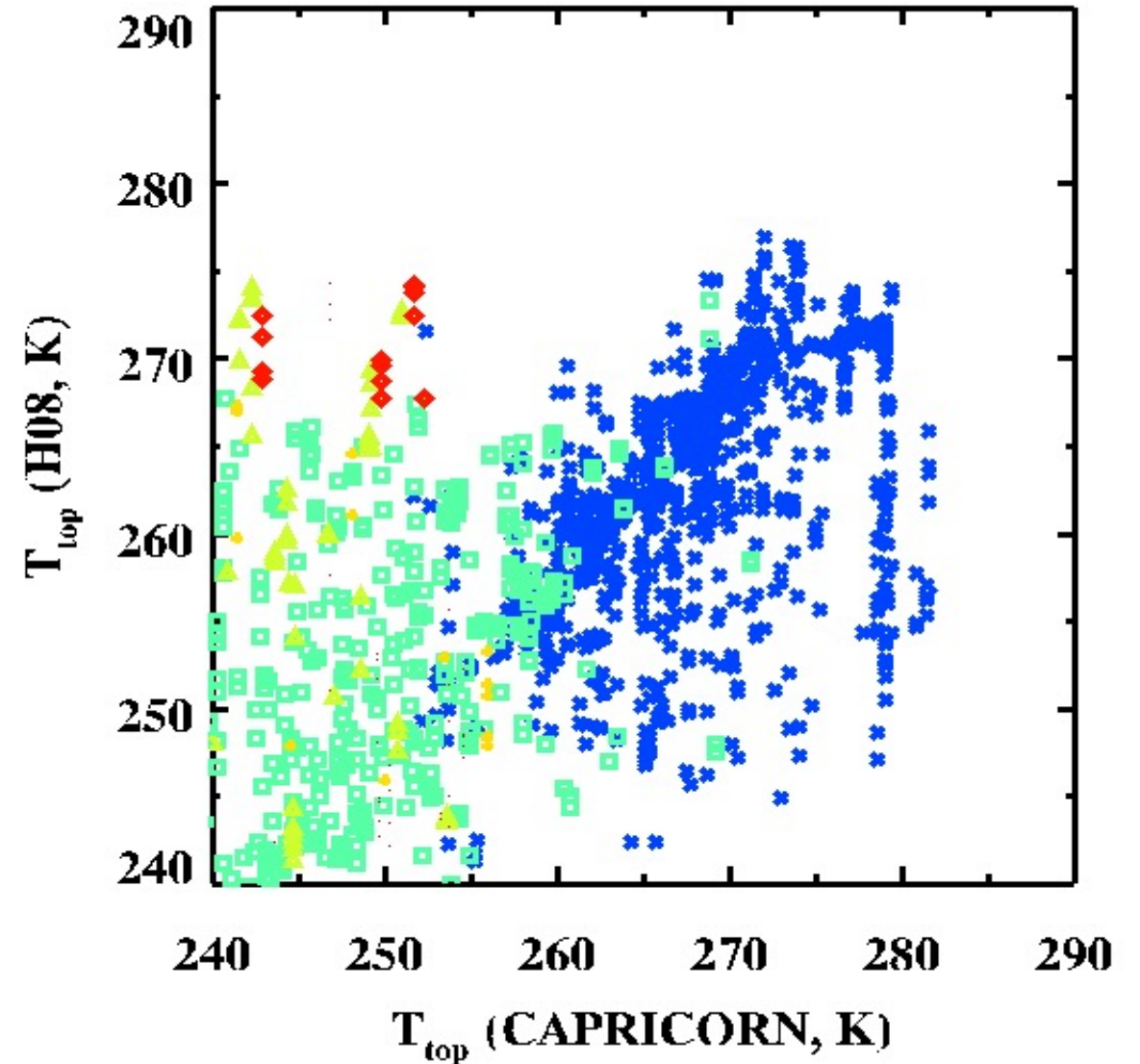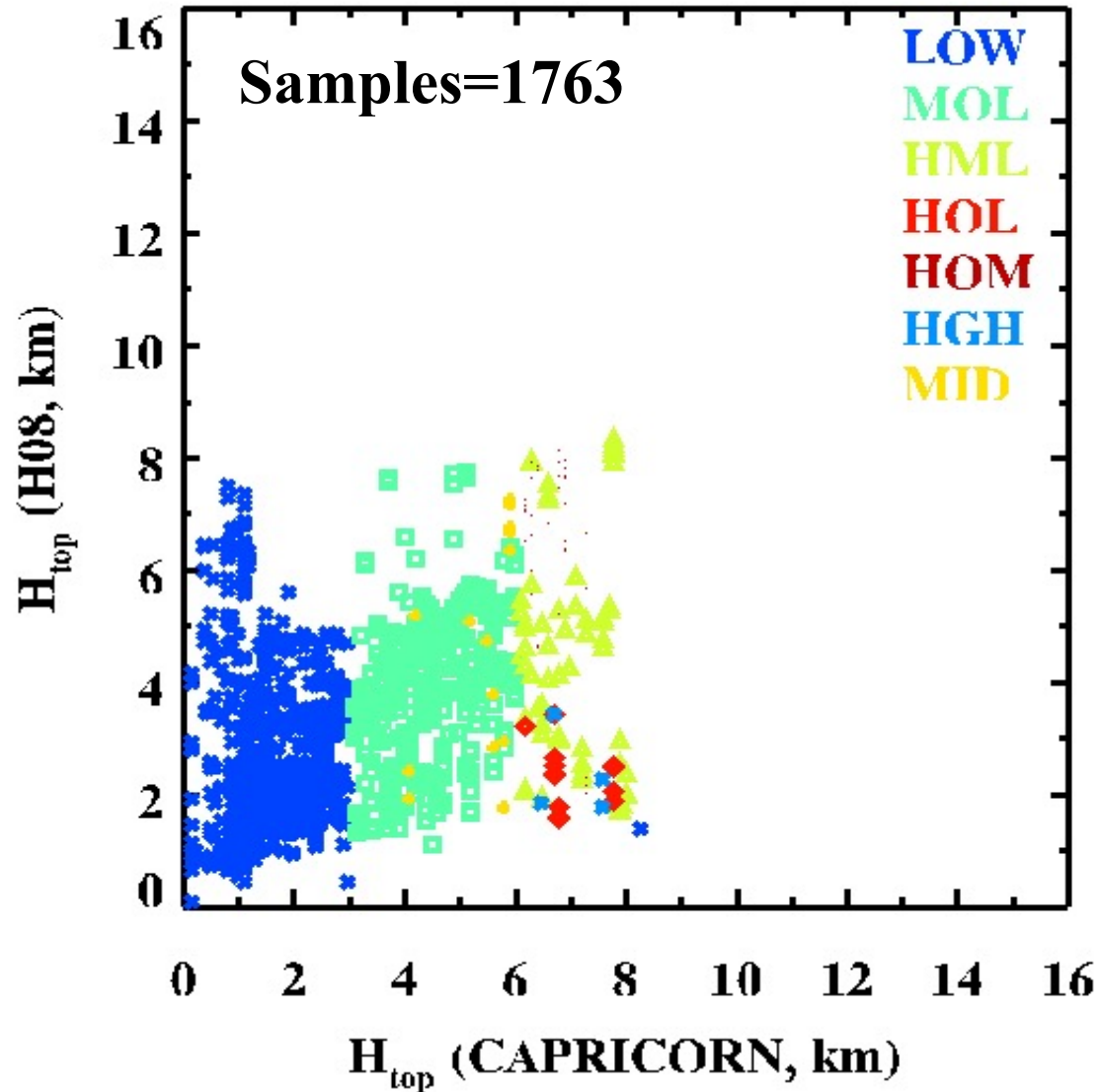
The co-located samples between ship-based and H08 show that H08 T_{top} are slightly lower than those from ship-based, which lead to higher H_{top} from H08, but why?.

Motivation

- **From the co-located samples during CAPRICORN: Why CFs are closer to each other, while H08 derived H_{top} associated with boundary layer, especially for LOW clouds, are much higher?**

- **A recent publication draws our attention that the CN number concentrations during SOCRATES were very high, especially for small particles (10 to 70 nm). These small particle cannot be easily activated to CCN, but may have strong scattering properties, which may impact satellite retrievals.**
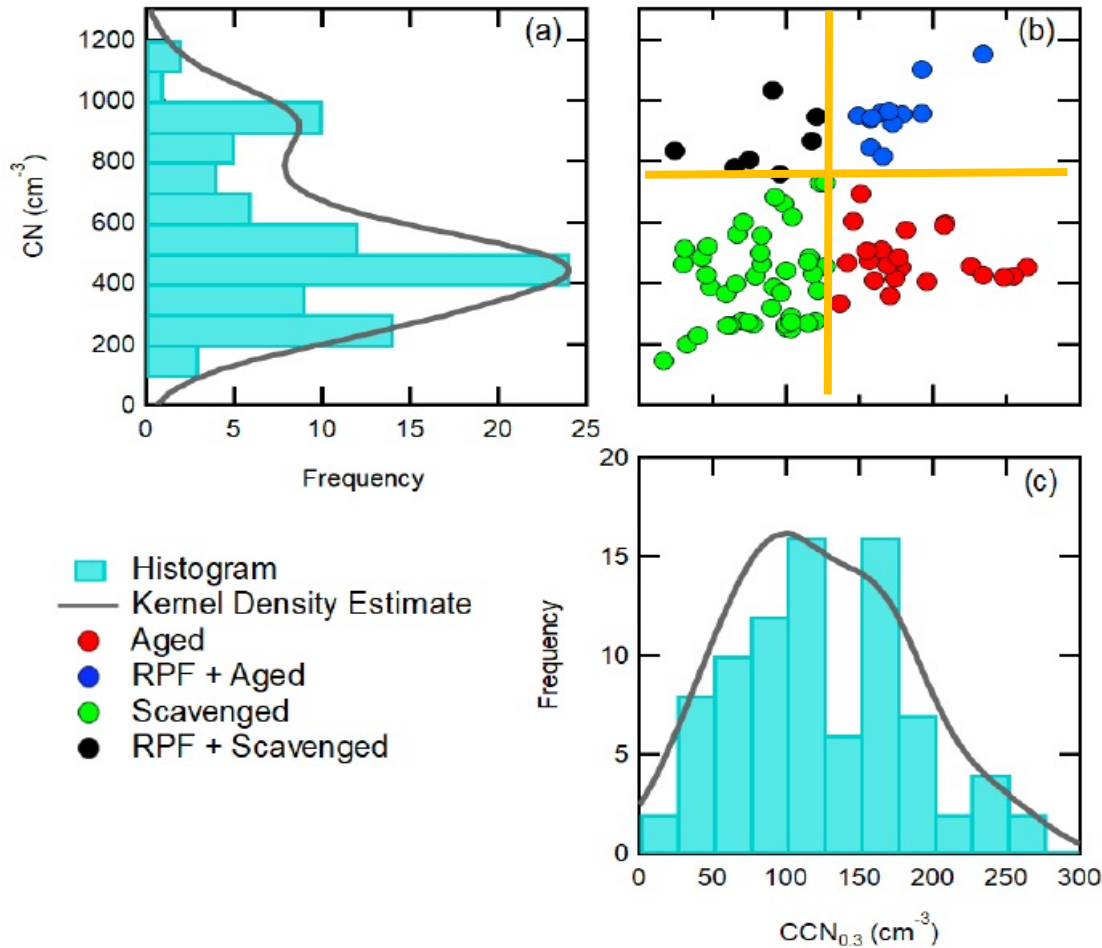
Sanchez et al., 2021, ACP

Four types of aerosols:

1) CN >750 and CCN >125 cm $^{-3}$ →RPF+Aged
2) CN ≤750 and CCN ≤ 125 cm $^{-3}$ → Scavenged
3) CN ≤ 750 and CCN >125 cm $^{-3}$ → Aged
4) CN >750 and CCN ≤ 125 cm $^{-3}$ → RPF+Scavenged

Figure 1. Histograms and kernel density estimates of (a) CN concentrations and (c) MBL $CCN_{0.3}$ (CCN concentration at 0.3% supersaturation). (b) MBL CN and $CCN_{0.3}$. Measurements are divided into four particle regimes based on the observed bimodal distributions of both CN and $CCN_{0.3}$.
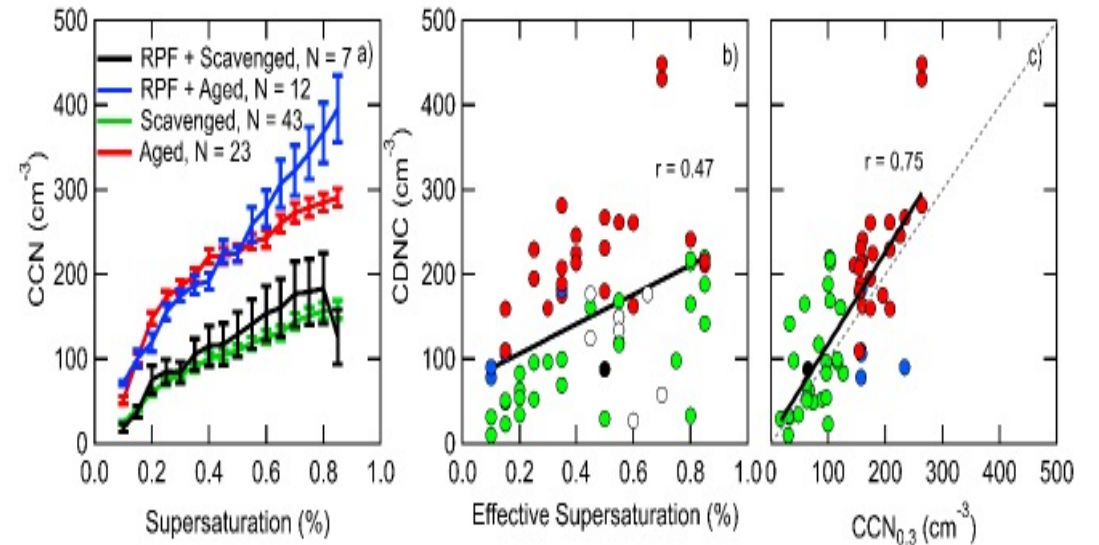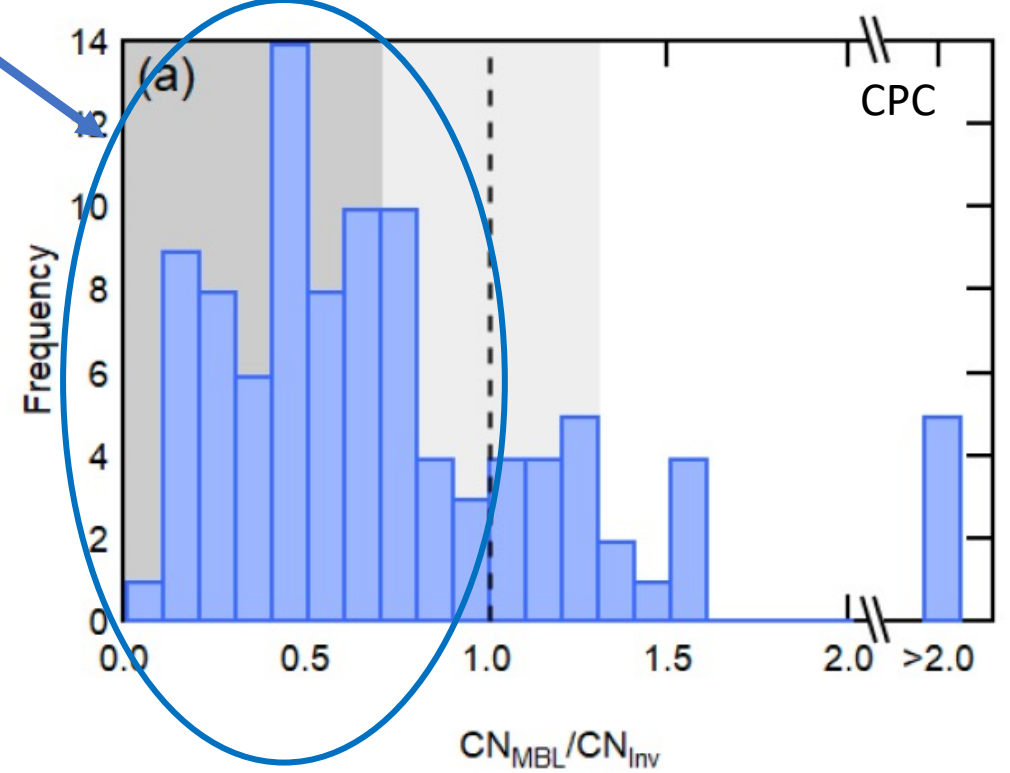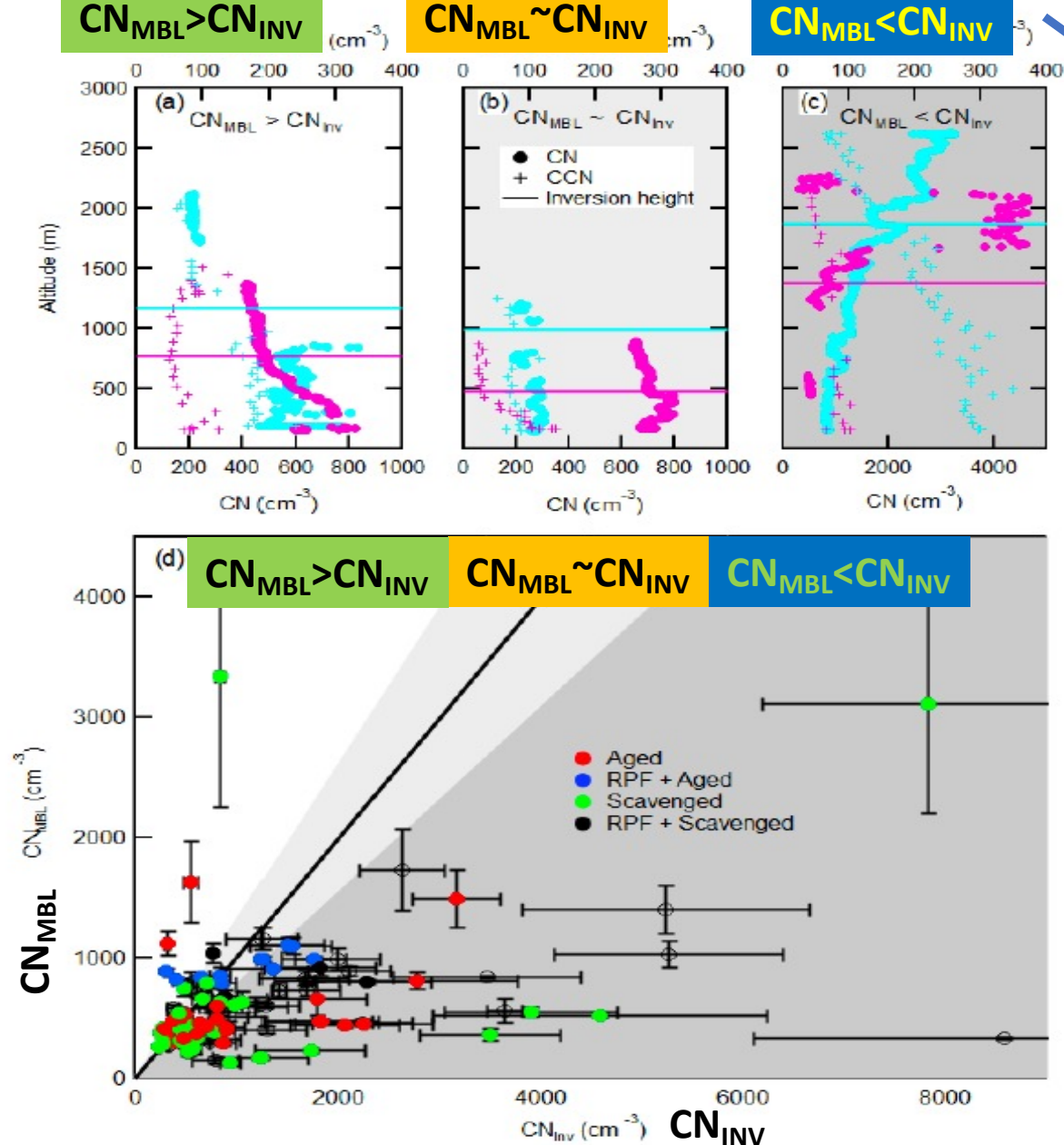
Figure 2. (a) Mean MBL CCN spectra for each regime. The number of samples (N) at each supersaturation of the CCN spectra varied from the number of samples in the legend because occasionally CCN spectra scans were not fully completed by the end of the MBL leg. Error bars represent the standard error ($\sigma/\sqrt{N}$). Correlations of measured CDNC with (b) calculated effective supersaturation and (c) measured MBL $CCN_{0.3}$. Empty points did not have a corresponding $CCN_{0.3}$ or CN measurement. Solid lines in (b) and (c) represent linear fits and the dashed line in (c) represents the 1:1 line.

CN_MBL>CN_INV (cm⁻³)   CN_MBL~CN_INV (cm⁻³)   CN_MBL<CN_INV (cm⁻³)

CPC

CN_MBL>CN_INV   CN_MBL~CN_INV   CN_MBL<CN_INV
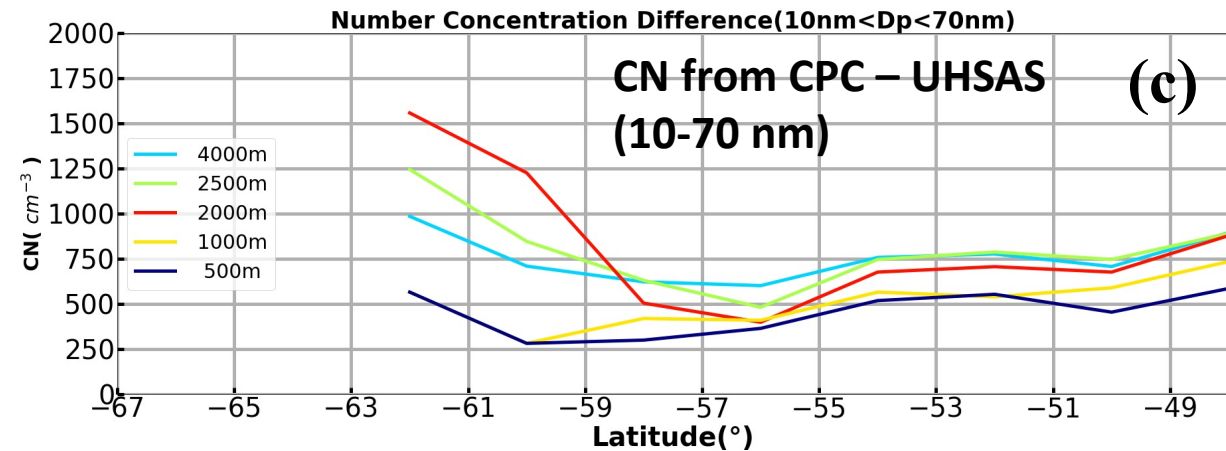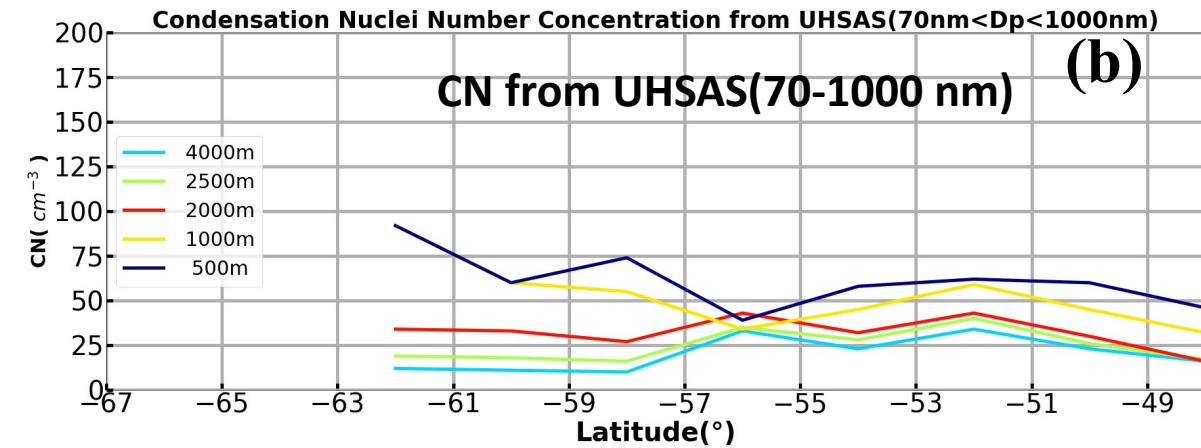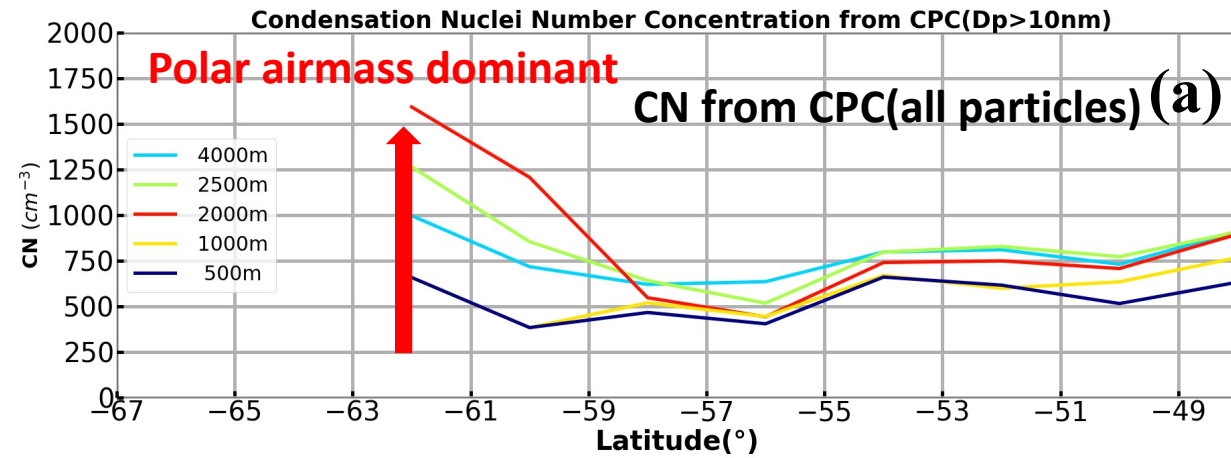
Sanchez et al., 2021, ACP

Our *hypothesis* is that the high CN concentration and low CCN concentration in the free troposphere should have significantly impacts on the satellite retrieved cloud optical properties.
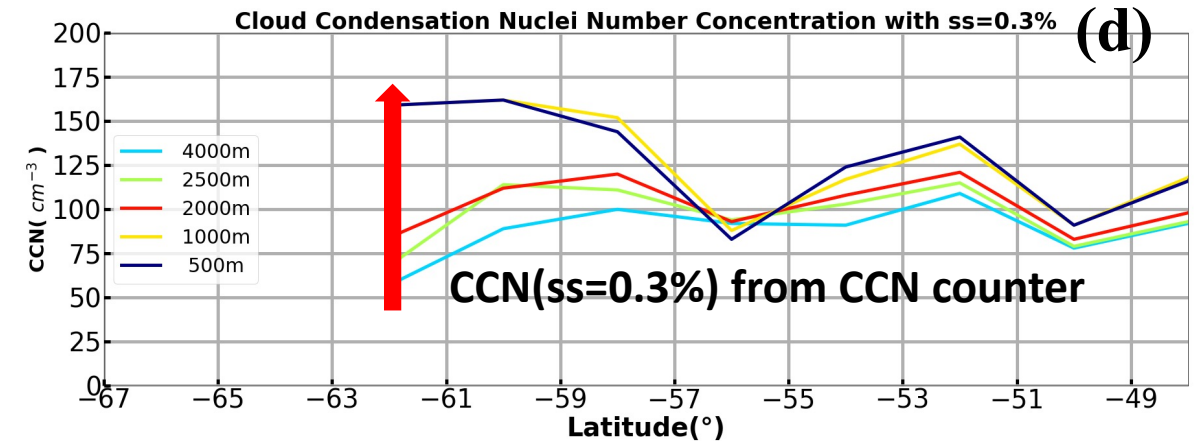
Figure Partial profile of CN and CCN at 0.43% supersaturation corresponding to (a) elevated CN concentration (b) well-mixed CN profiles and (c) elevated CN concentrations aloft. The cyan and magenta points in (a-c) represent vertical profiles. (d) Comparison of CN measured in the surface coupled MBL and decoupled layer or FT. Error bars standard error. Empty markers do not have a corresponding CCN_{0.3} measurement.

5/14/21

Aircraft in-situ measurements of CN and CCN

Condensation Nuclei Number Concentration from CPC(Dp>10nm)

Polar airmass dominant

CN from CPC(all particles) (a)

Condensation Nuclei Number Concentration from UHSAS(70nm<Dp<1000nm)

(b)

CN from UHSAS(70-1000 nm)

Number Concentration Difference(10nm<Dp<70nm)

CN from CPC – UHSAS (10-70 nm) (c)

Cloud Condensation Nuclei Number Concentration with ss=0.3%

(d)

CCN(ss=0.3%) from CCN counter

CPC can measure the particle size down to 10 nm;

UHSAS can measure the size down to 70 nm;

➤ At 62 °S, elevated CN measured by CPC are small particles shown in (c);
➤ At 50 °S, there are also quite large CN number concentration at 2000, 2500 and 4000 m.

➤ At 62 °S, CCN >CN (UHSAS) at each height, indicating that some of smaller particles (D_P < 70 nm) have been activated into CCN at SS of 0.3%;
➤ The lowest height bin has most activated CCN from 62 to 50 °S

Latitudinal variations of cloud properties derived from H08
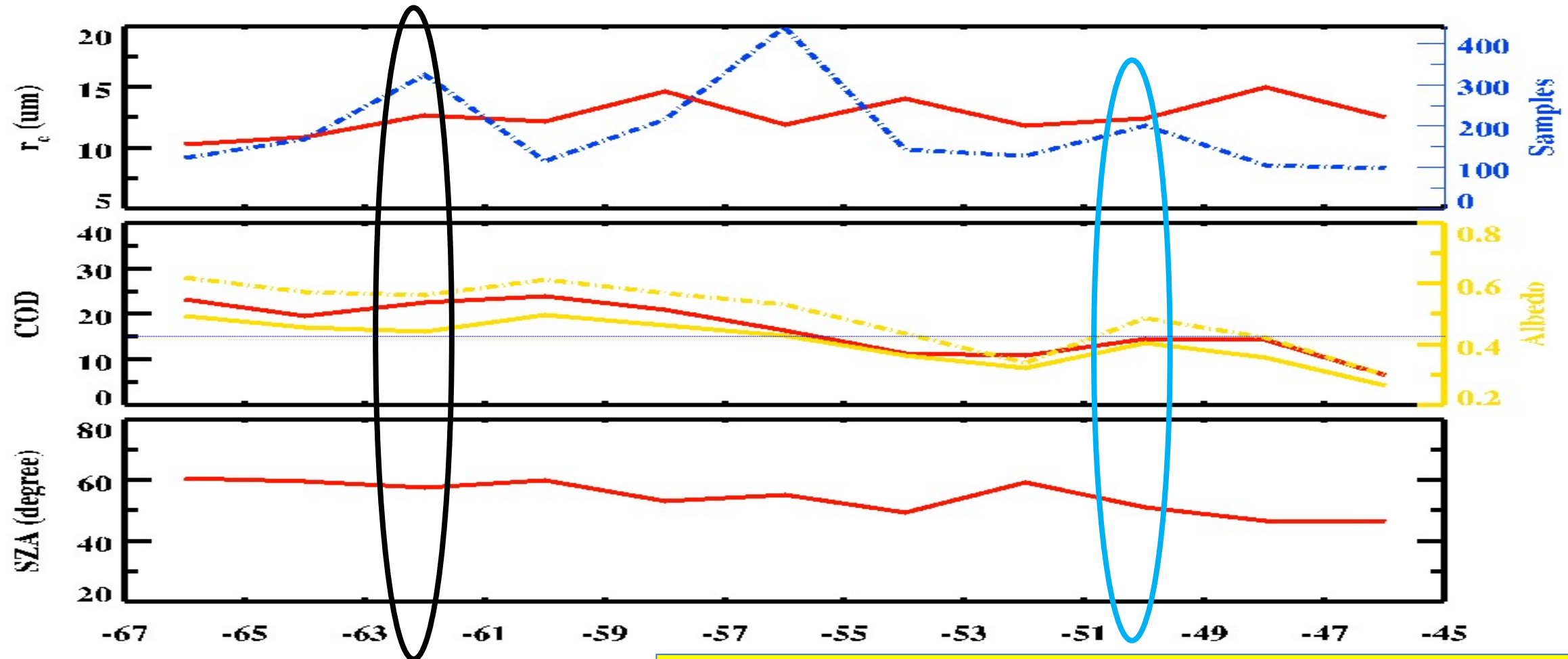
Hypothesis: With more CN above MBL clouds, it will significantly impact cloud COD and Albedo, but not for r_e at 62 °S (black oval).
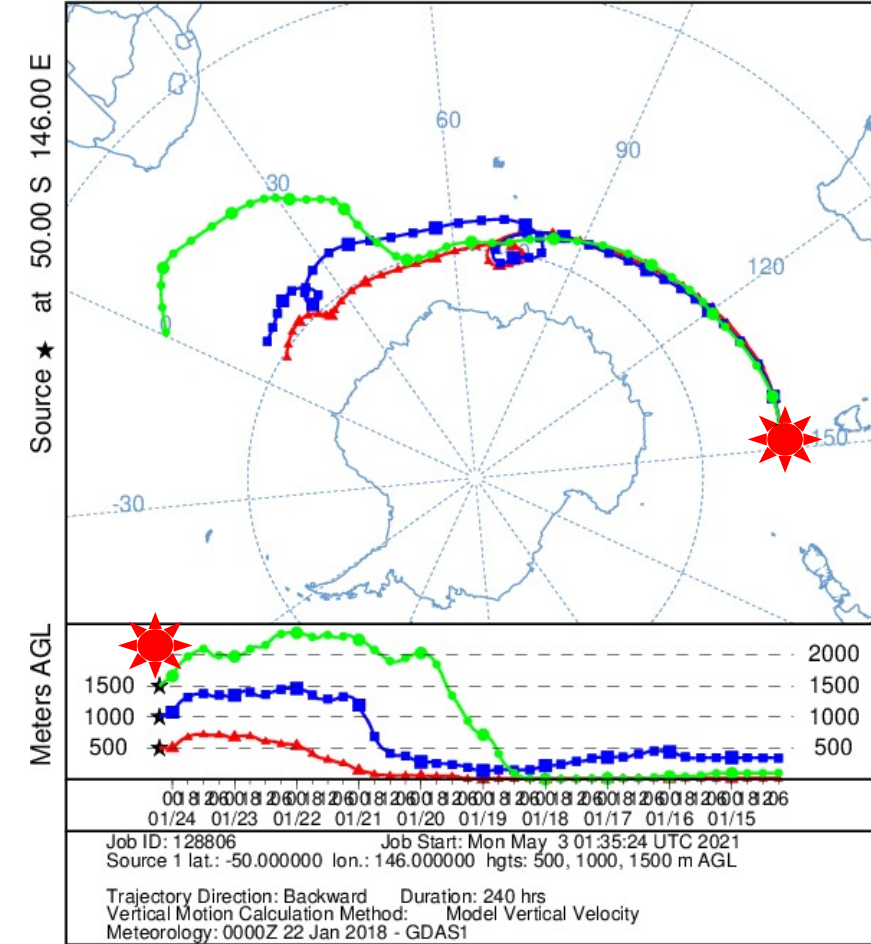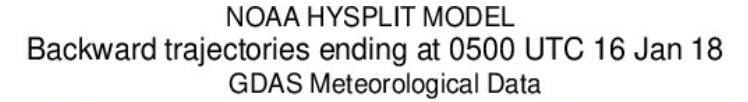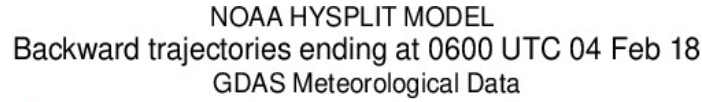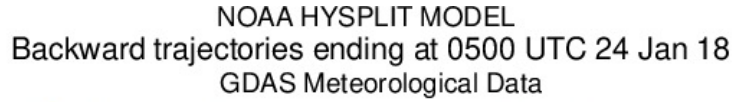
- r_e doesn't show impact by polar air mass;
- COD and SZA at 62 °S are higher than those at 50 °S, which result in visible reflectance at 62 °S 10% higher

How does aerosol layer above cloud layer affect the cloud height retrievals
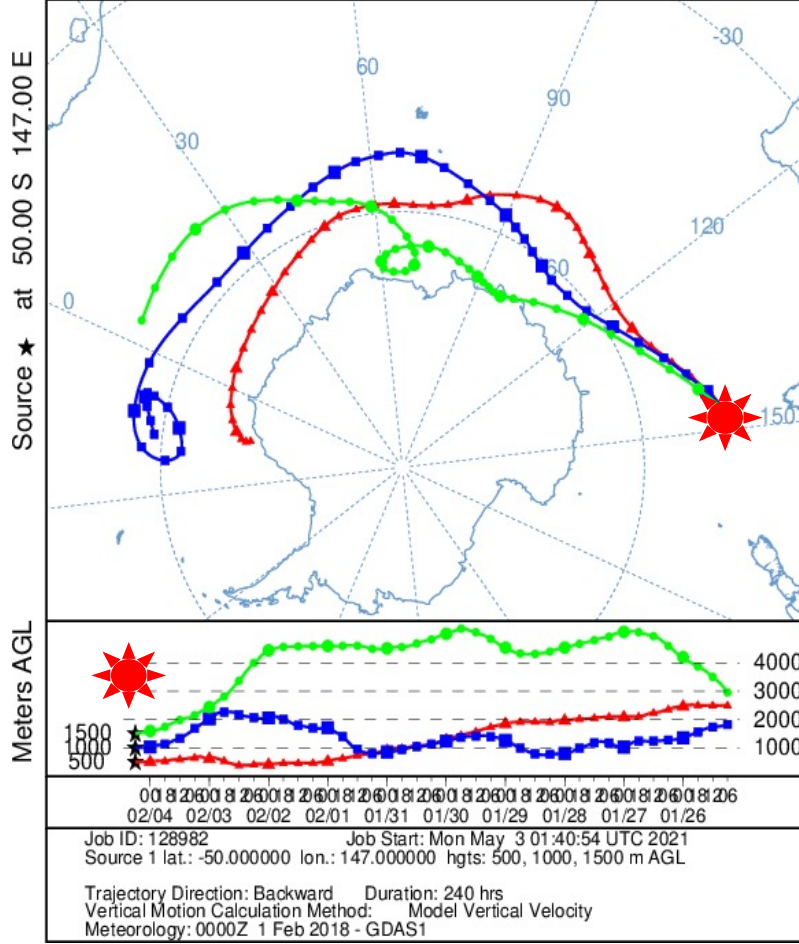
- Cloud emmsivity $\varepsilon = 1 - e^{-COD_{IR}}$
- When $COD_{IR} \sim 5 \ (COD_{vis} \sim 10), \varepsilon \sim 1$
- When CN above cloud layer: $COD > COD_{ture}$
  - ➔ higher cloud emissivity ε
  - ➔ lower T_{top} ($\sim T_b/\varepsilon$) than true cloud-top temperature
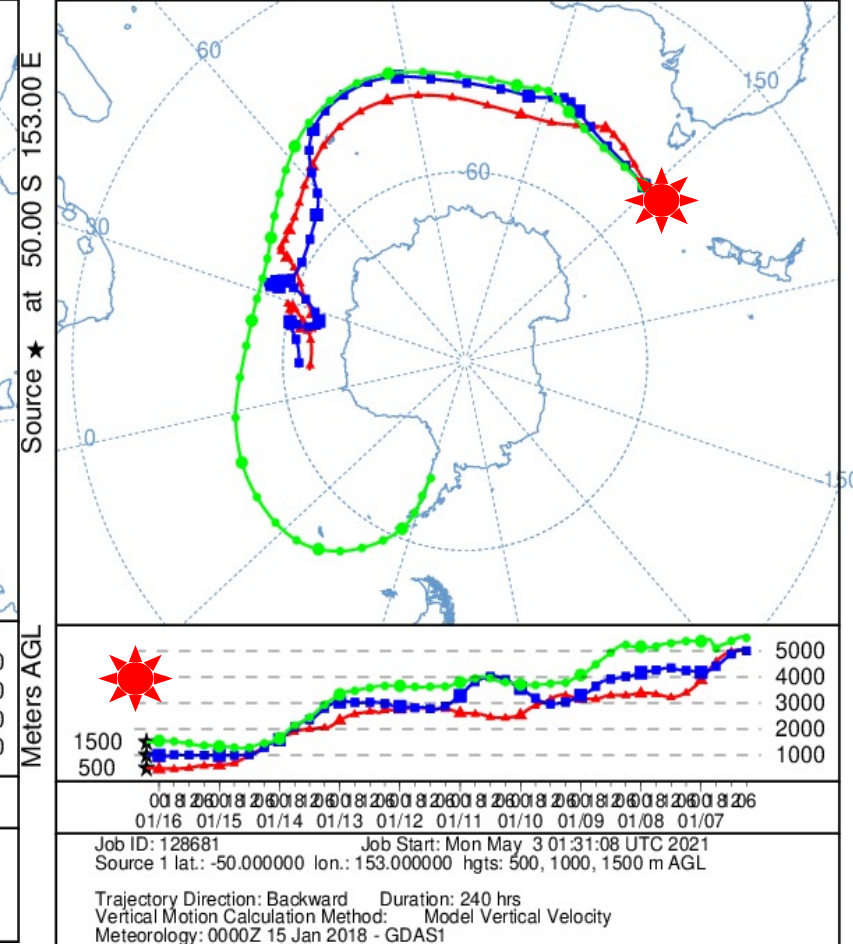 - ➔ colder T_{top} result in higher cloud-top height than it should be H_{top} [$\sim(T_{top}-T_{sfc})/\Gamma$]

NOAA HYSPLIT Back trajectories of Air masses over SO

NOAA HYSPLIT MODEL
Backward trajectories ending at 0500 UTC 24 Jan 18
GDAS Meteorological Data

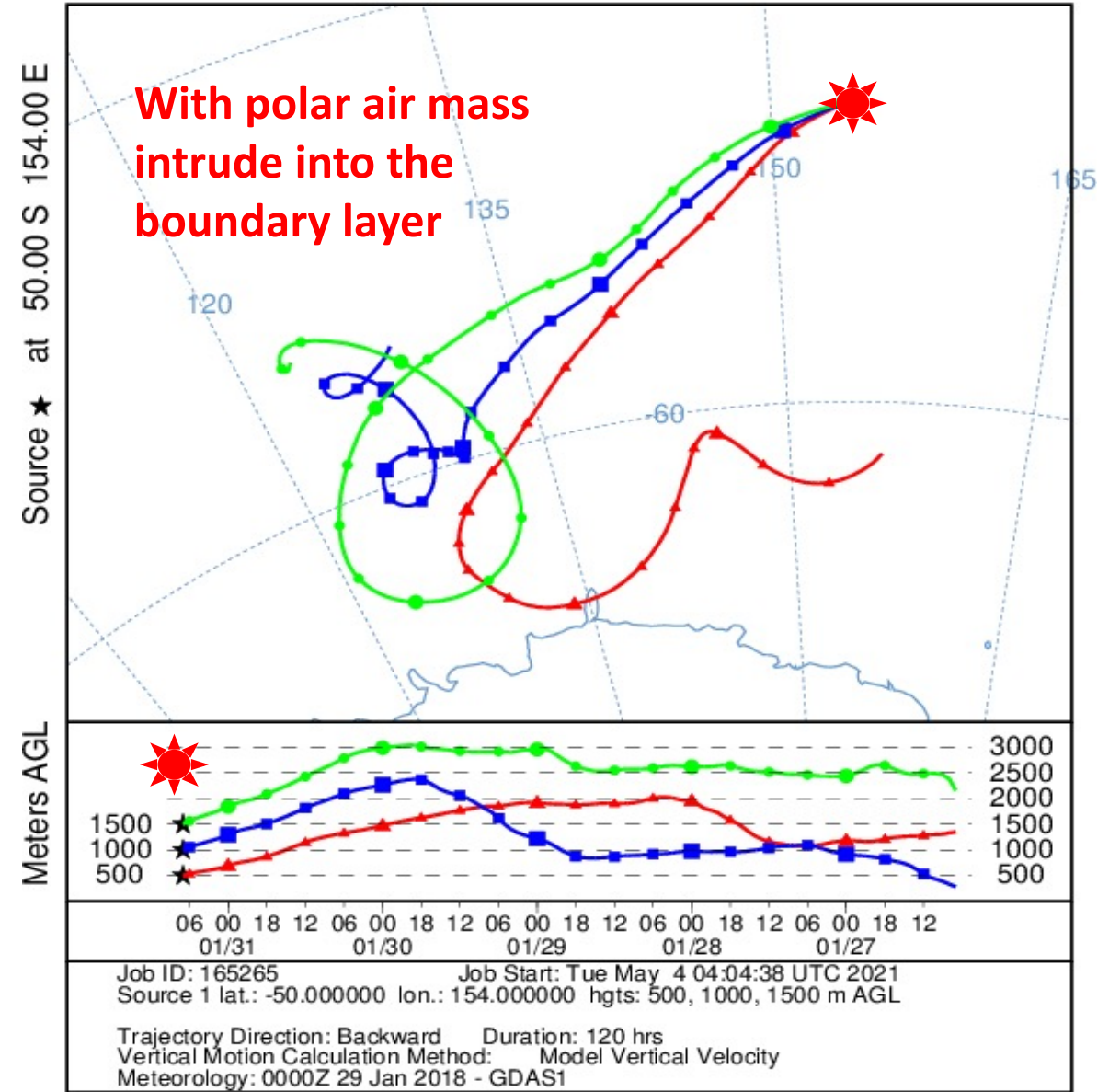NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 04 Feb 18
GDAS Meteorological Data

NOAA HYSPLIT MODEL
Backward trajectories ending at 0500 UTC 16 Jan 18
GDAS Meteorological Data

Most aloft CN may come from MBL

Most aloft CN may come from both MBL and FT

Most aloft CN may come from Free Troposphere

NOAA HYSPLIT Back trajectories of Air masses over SO

Selected cases: Pixel-level liquid-phase clouds defined by H08 at 50 °S
H_{top} and T_{top} with (and without) polar air masses

(W/O) samples = 33602
(With) samples = 21491

$H_{top} > H_{top}$

$T_{top} < T_{top}$
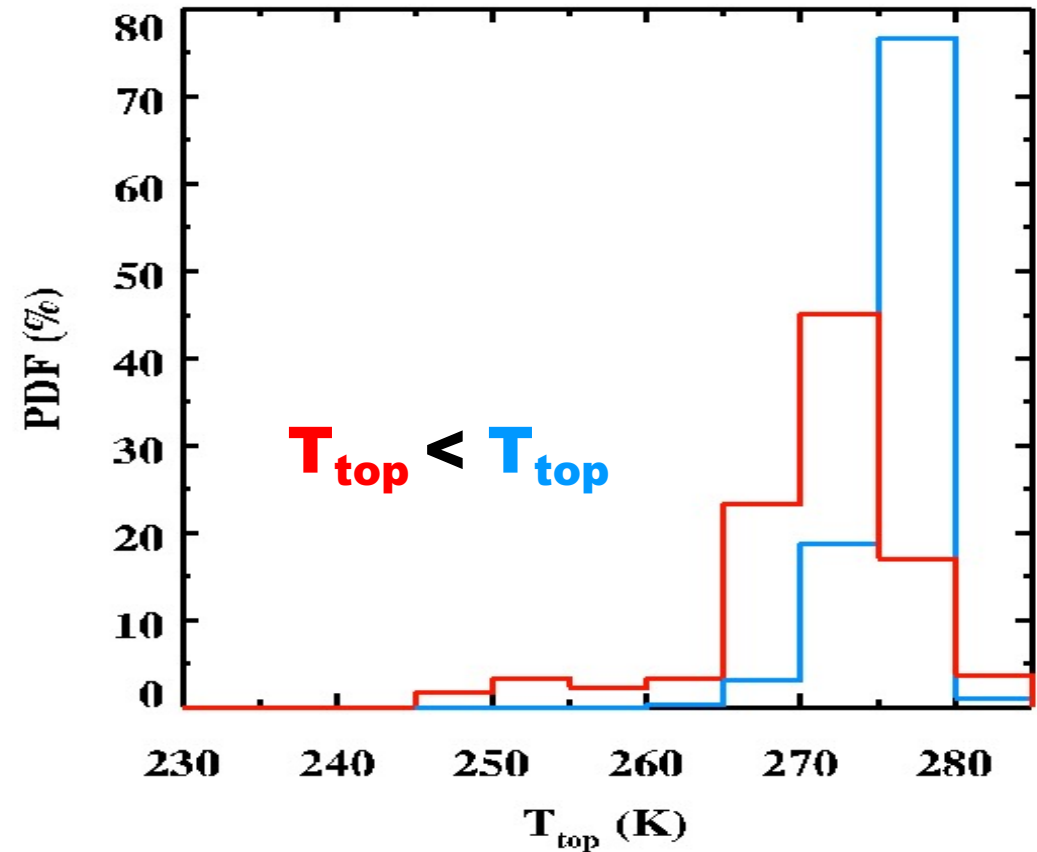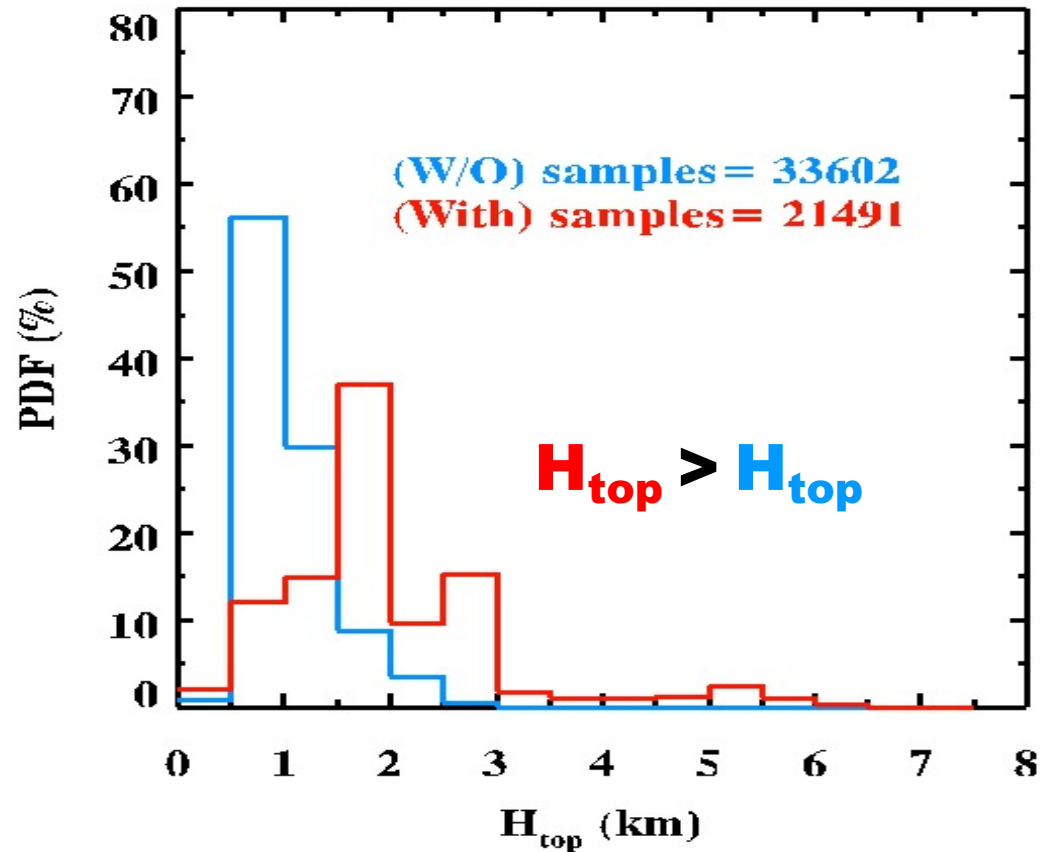
- When aircraft flew over ~ 50 °S, it observed the CN above MBL clouds.
- Using back trajectory, we can know if the air masses/CN come from Antarctic.
- If yes, then we define these cases as 'with' polar air mass influence; otherwise, 'w/o' polar air mass influence

Along the aircraft flight track at ~ 50 °S, we classify pixel-level cloud properties from H08 as a function of r_e with or without (W/O) polar air mass
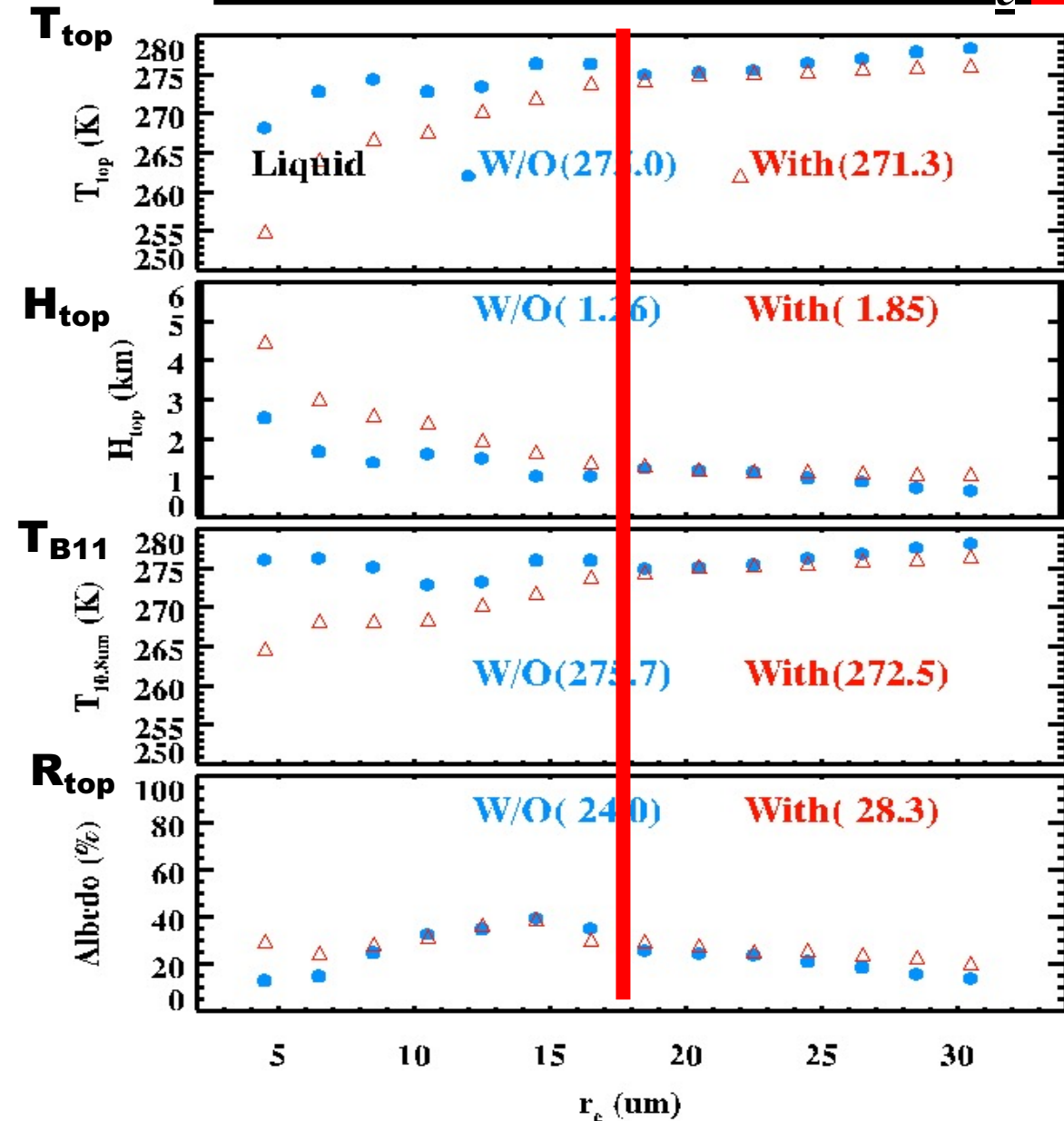
- ➤ **With polar air mass, T_{top} is 3.7K lower, H_{top} is 0.6 km higher, R_{toa} is 4.3% higher than those without.**
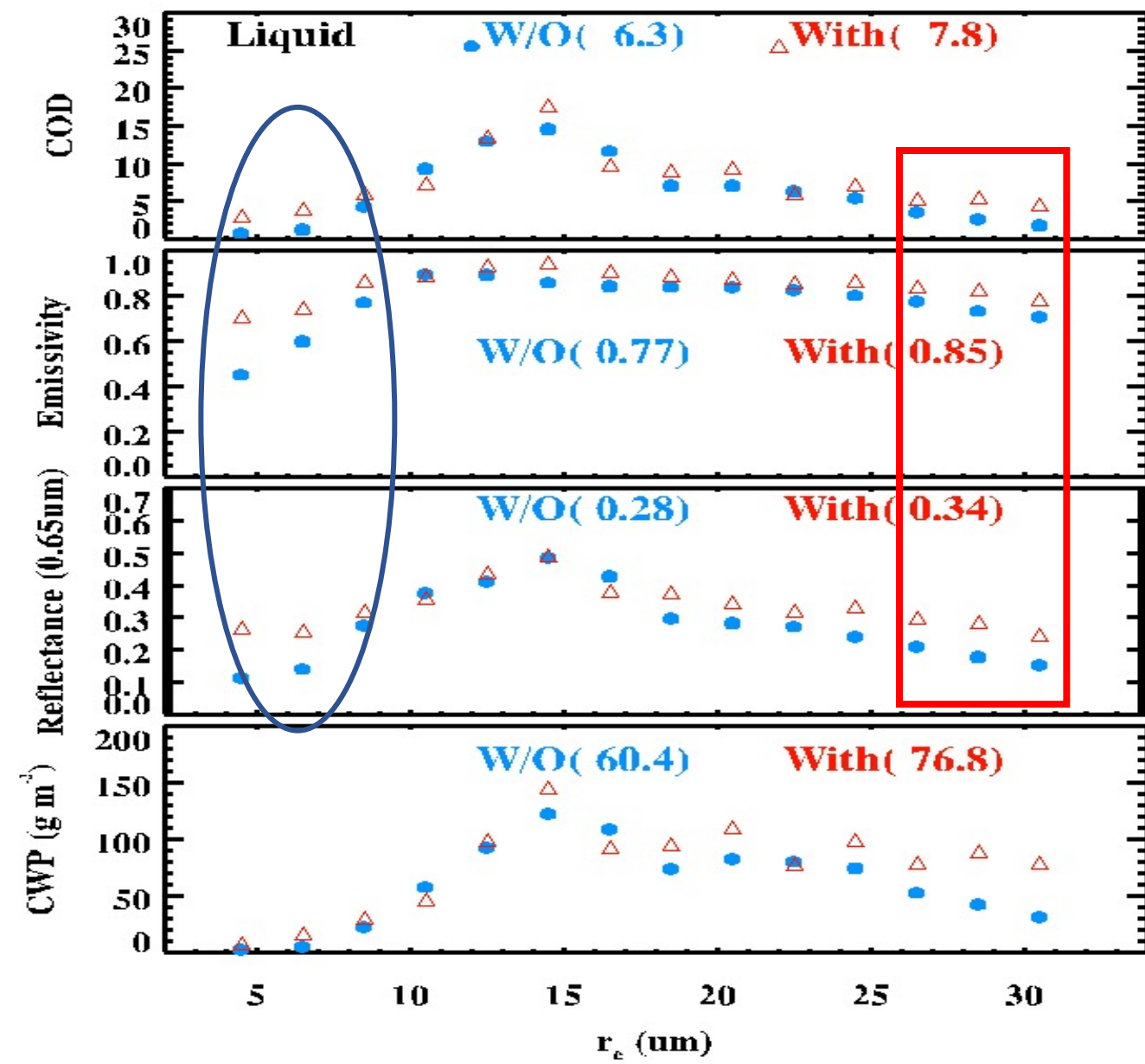
- ➤ T_{top} increase but H_{top} decrease with r_e.

- ➤ ΔT_{top} and ΔH_{top} between 'with' and 'w/o' decrease until $r_e \sim 18$ μm. After that, ΔT_{top} and $\Delta H_{top} \sim 0$.

- ➤ Small r_e: cloud edge/cloud top entrainment, more variations of cloud top height at this scenario.

- ➤ Large r_e: mature stage, less morphology, more process occurs at cloud base, not too much effect on the cloud top.

- **COD increase from 6.3 (W/O) to 7.8 (With), which results in ε increased from 0.77 to 0.85, R_{vis} from 0.28 to 0.34.**

- **Overestimated COD by 1.5, resulting in higher emissivity by 0.08→ underestimate 3.7 K T_{top} → overestimate H_{top} by 0.6 km. →lapse rate of 6.2 K/km.**

- **ΔCOD, Δε and ΔR_{vis} between 'with' and 'w/o' are larger for small r_e (<8 μm). After that, the differences become not significant.**

- **Similar results occur for large r_e (>26 μm).**

- **As more active drizzling occurs, the CWP decreases →COD decreases →Reflectance and emissivity decrease.**

Summary

1) From the latitudinal variations of CN, there is evidence of the Polar air mass overlaying the marine boundary layer;

2) Back trajectory analysis confirms that the elevated CN associated with the aloft polar air mass;

3) When the polar air mass over 50°S, we find the following results from pixel-level H08 cloud results:

- COD is increased by 1.5, resulting in higher emissivity by 0.08→ underestimate 3.7 K T_{top} → overestimate H_{top} by 0.6 km.
- R_{vis} also increases from 0.28 to 0.34