Cloud thermodynamic phase retrieval from SWIR and lidar measurements with implication for vertical cloud heterogeneity

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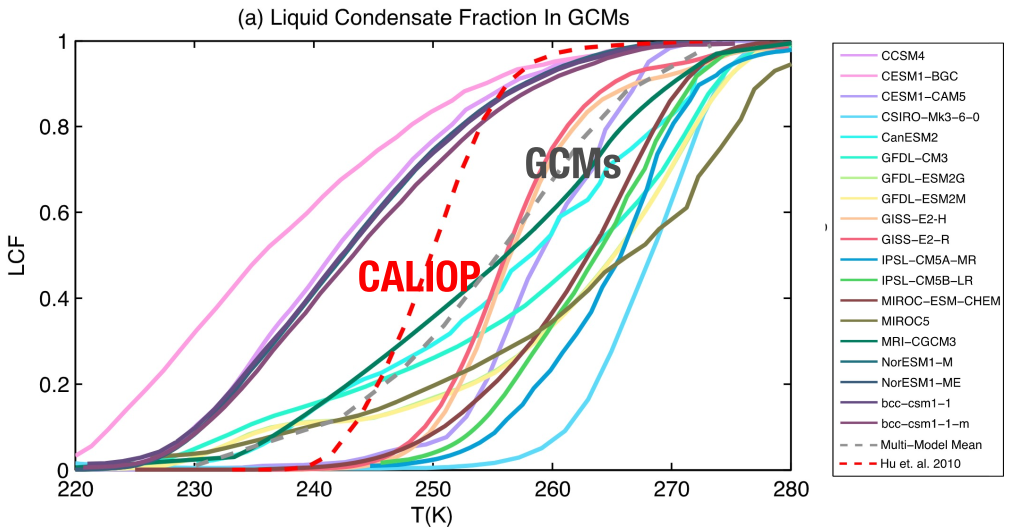
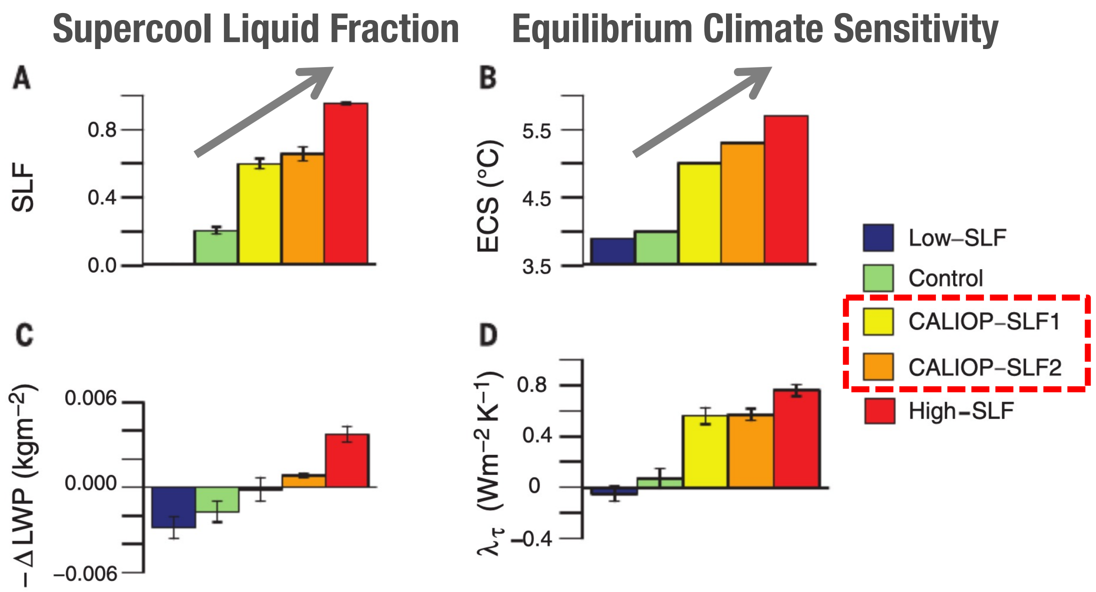
GCOM-C Poster Session (Poster ID: C010)

Importance of cloud thermodynamic phase description in climate models and its evaluation using CALIPSO lidar (CALIOP)

✓ Uncertainty in the representation of mixed-phase clouds in climate modelss
(McCoy et al., 2015)



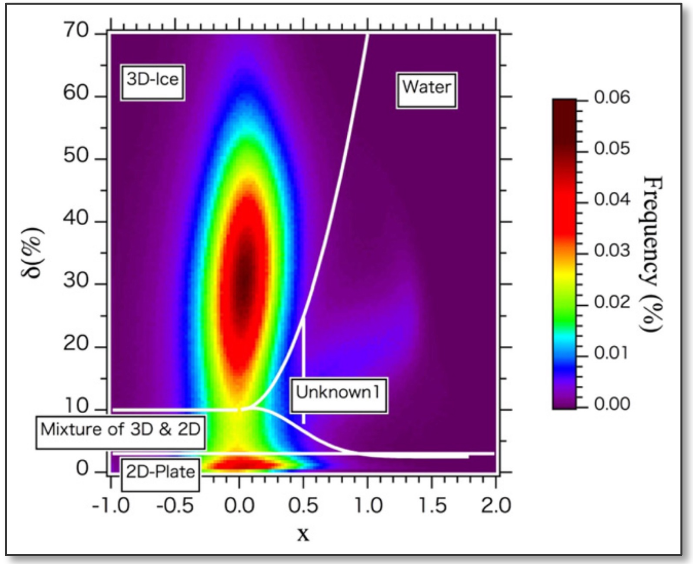
✓ Observational constraints on mixed-phase clouds imply higher climate sensitivity
(Tan et al., 2016)



➔ Cloud phase data from CALIOP are usually used to evaluate the representation of mixed-phase clouds in climate models. However, the lidar signal penetrates only to a relatively shallow layers (typically, optical depth < 5) and may therefore miss information on cloud phase in deeper layers.

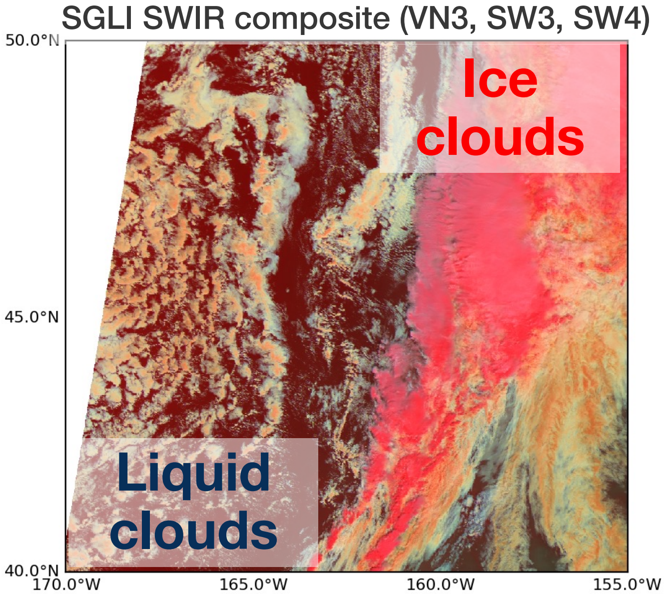
Satellite-based temperature-independent cloud phase determinations and their different characteristics

Polarization lidar
(CALIOP, ATLID)

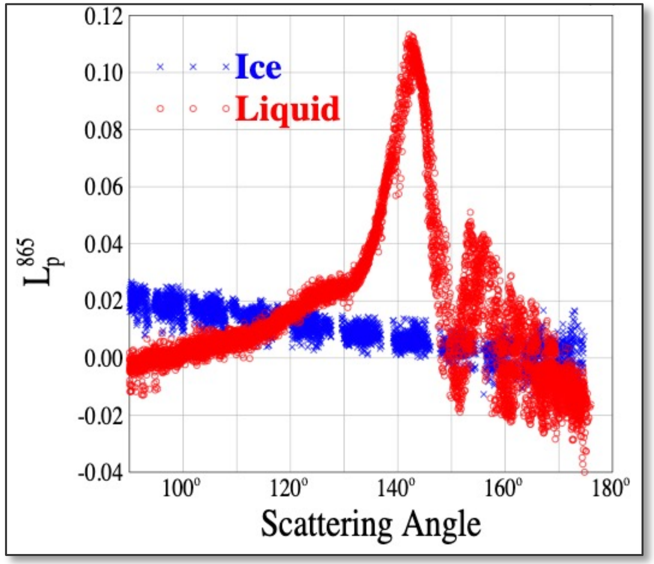


Hirakata *et al.*, 2014

Passive SWIR channels
(MODIS, SGLI, MSI)



Passive polarization
(POLDER, SGLI)



Riedi *et al.*, 2010

➔ Since SWIR channels are can sense cloud phase in optically deeper layers than lidar (and passive polarization), combining the two cloud phases derived from SWIR and lidar (or passive pol.) is expected to characterize the vertical inhomogeneity of cloud phase.

This study

1. Combines the two cloud phase products from the CALIPSO/CALIOP and Aqua/MODIS SWIRs to characterize vertical heterogeneity of cloud phase
   (An algorithm for cloud phase retrieval from SWIR measurements was developed (Nagao & Suzuki, 2021))

2. Interprets the vertical heterogeneity of cloud phase identified by the combination of CALIOP and MODIS SWIRs in terms of cloud vertical structure and droplet size vertical profiles by using MODIS TIRs and CloudSat/CPR

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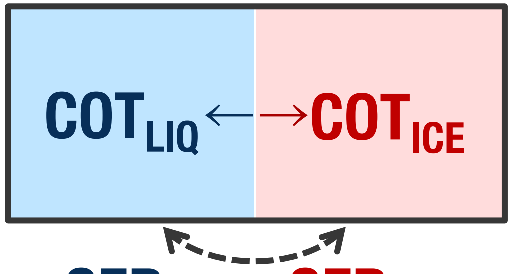
Implications for

✓ Using the SWIR-derived cloud phase in addition to the CALIOP-derived cloud phase to evaluate and constrain the representation of mixed-phase clouds in models

✓ Cloud phase retrieval from the combined use of SWIR & polarization channels of SGLI

Data 1: Cloud phase retrieval from SWIR channels

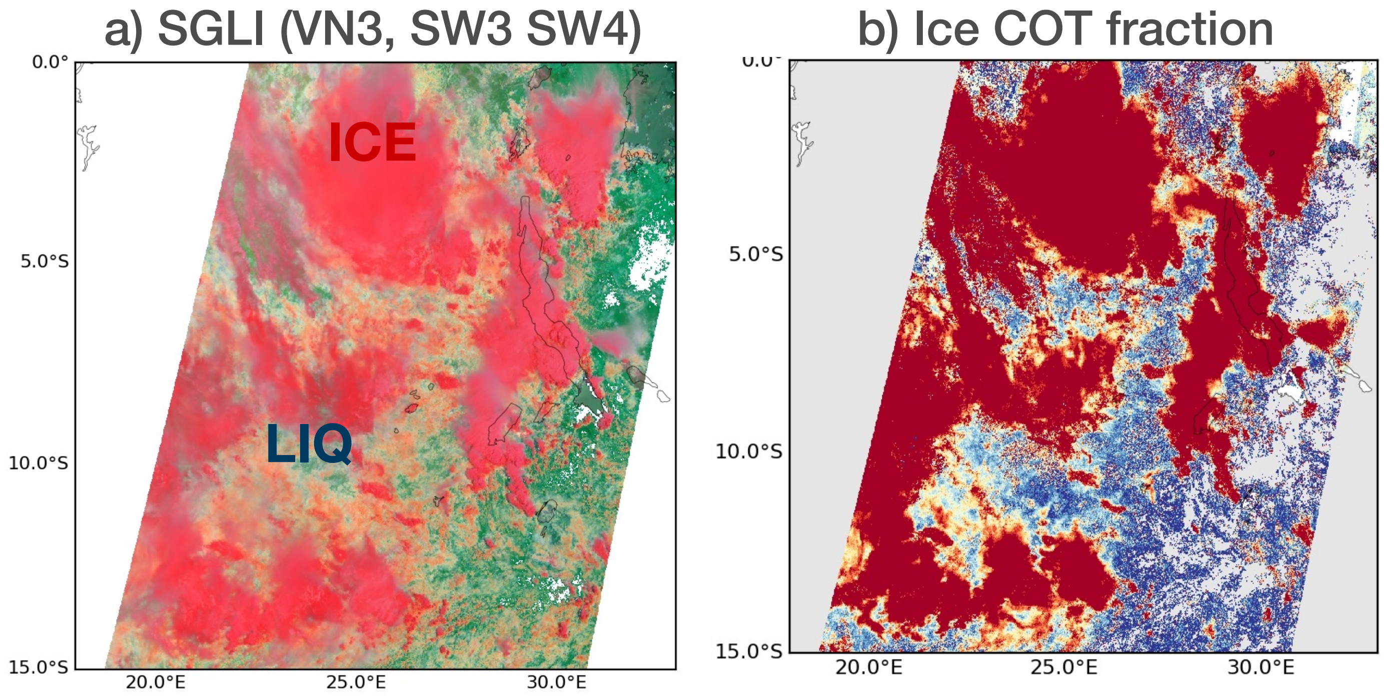
- **Approach** : Simultaneous retrieval of cloud properties and phase (Nagao & Suzuki, 2021)
- Models : A plane-parallel layer with LIQ & ICE cloud particles;
  Consider both COT_{LIQ} & COT_{ICE} as variable;
  Assume a CER common for both LIQ & ICE particles
- Inputs : 0.65, 0.86, 1.6, 2.1 μm bands of MODIS (add 1.05 μm band for SGLI)
- **Estimates** : Total COT, CER, Ice COT fraction



Assume $CER_{LIQ} = CER_{ICE}$

(Ice COT Fraction)

$$ICOTF = \frac{COT_{ICE}}{COT_{LIQ} + COT_{ICE}}$$



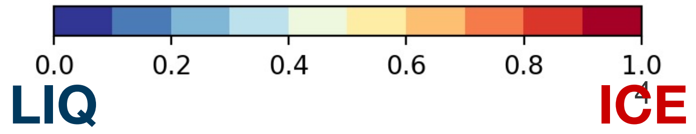
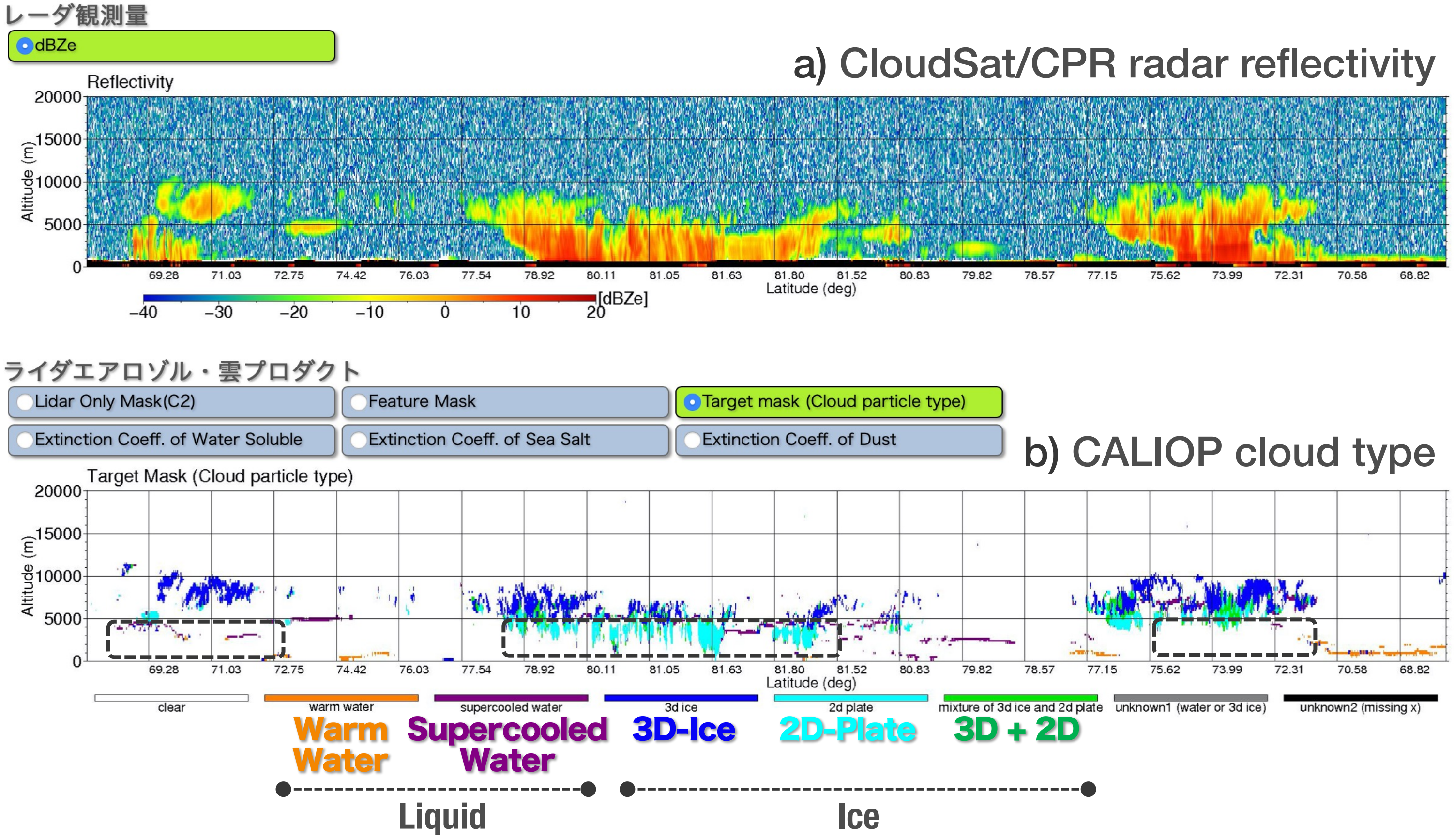


Fig.1 a) The RGB composite image using SWIR channels and **b)** ice COT fraction retrievals from SGLI

Nagao & Suzuki, 2021 ESS
https://doi.org/10.1029/2021EA001912

Data 2: Cloud phase product derived from CALIPSO lidar (CALIOP)

JAXA A-train Product



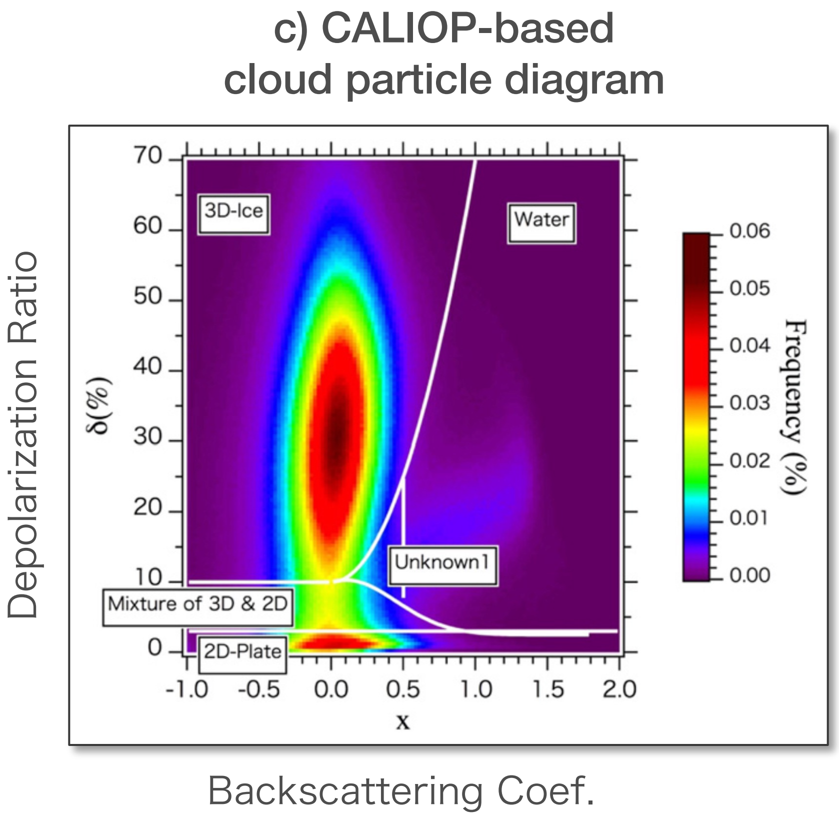
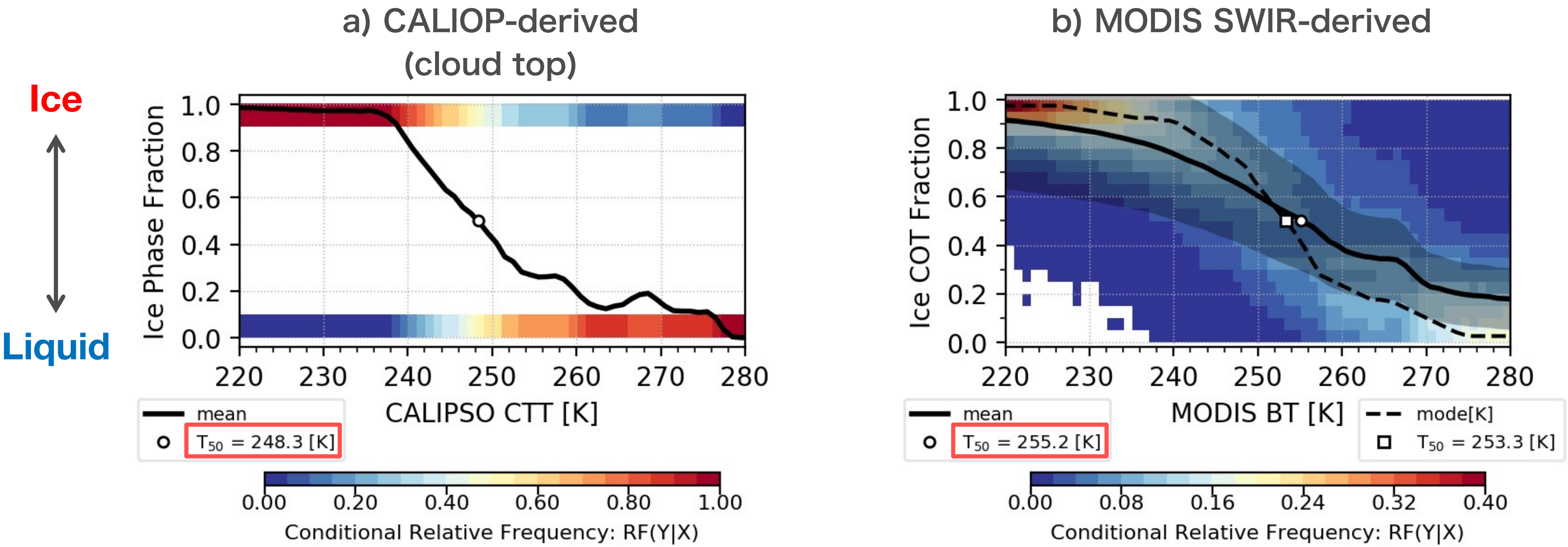


Fig. 2 a) CloudSat/CPR radar reflectivity (upper); **b)** CALIOP cloud type (lower) from JAXA A-Train product;
c) The cloud particle diagram used in CALIOP-based cloud type determination in Fig.2b

JAXA EarthCARE Research A-Train Product
https://www.eorc.jaxa.jp/EARTHCARE/research_product/ecare_monitor.html

Significant differences in ice-phase fractions derived from CALIPSO lidar (CALIOP) and MODIS SWIR observations



✓ The CALIPO-derived T50 (defined as the temperature at which the ice phase fraction reaches 50%) is about 7 K lower than SWIR-derived T50.

Fig. 3 a) The conditional relative frequency (color contour) and mean (solid) of CALIOP-derived ice phase fraction at cloud top, given CALIOP cloud top temperature (CTT). **b)** Similar to a) but the conditional relative frequencies, mean and mode (dashed) of MODIS SWIR-derived ice COT fraction (ICOTF), given brightness temperature (BT) at MODIS 11 μm band. The shading in b) represents the uncertainty in ICOTF retrieval.

Combined use of cloud phases from CALIOP and MODIS

The boundary between LIQ and ICE, determined using only the CALIOP cloud phase

Significant Discrepancies between CALIOP-derived and MODIS SWIR-derived cloud phases that may suggest vertical heterogeneity of cloud phase

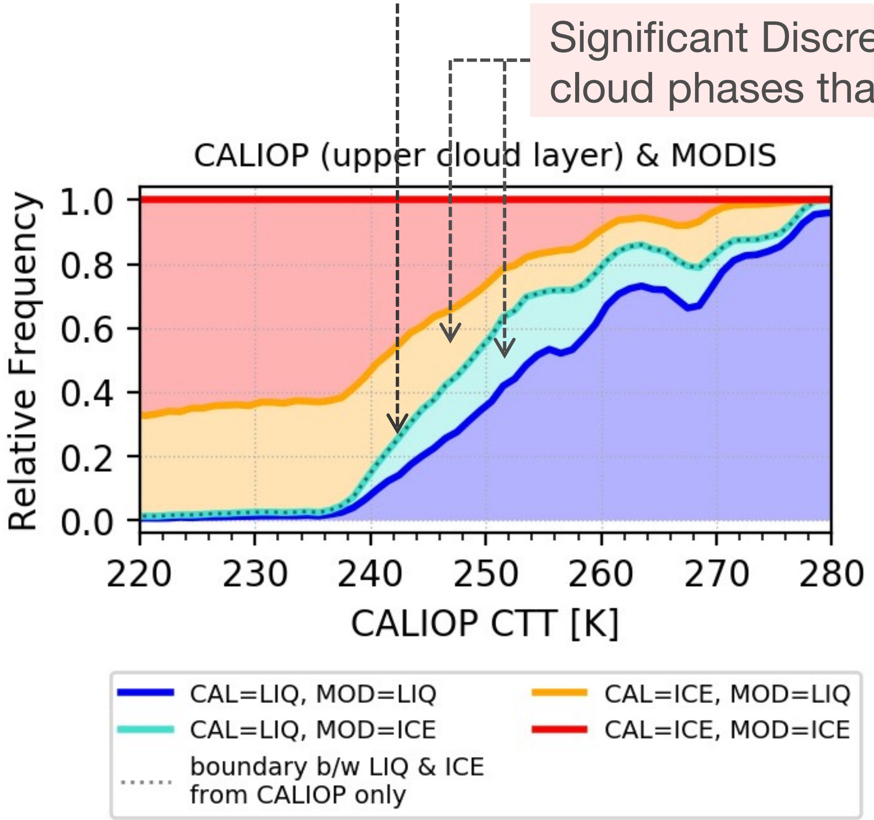
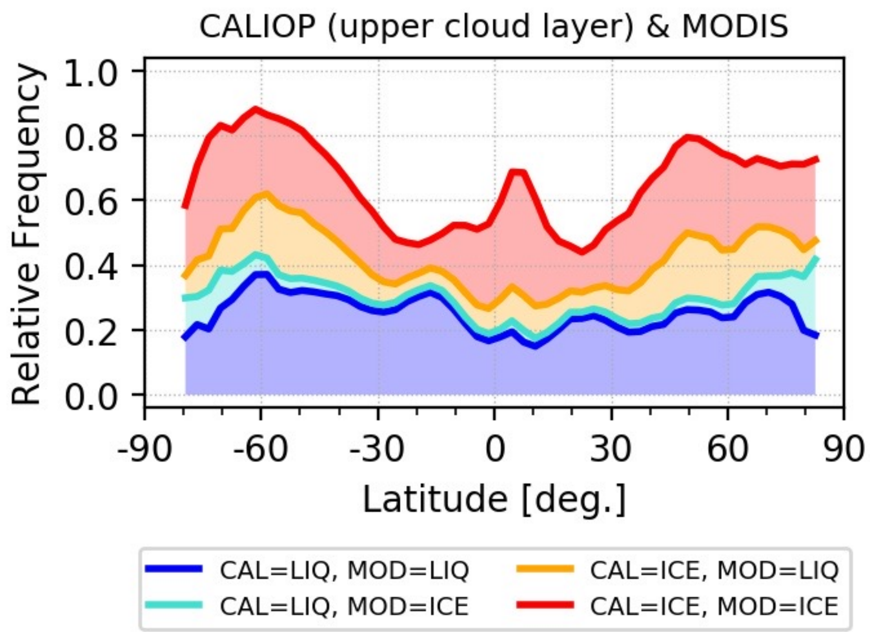


Fig. 4 a) The fractional occurrence of the combination of cloud phase classes from CALIOP and MODIS SWIR, given a CALIOP cloud top temperature (CTT).



- ✓ The **ICE/LIQ** is more common than **LIQ/ICE** everywhere except in the high latitudes (especially, 30° - 60°)
- ✓ **LIQ/ICE** increases relative to the high latitudes above 60°

Fig. 4 b) The zonal distributions of cloud phase fractional occurrence from the same data as in Fig. 3.

Interpretation in terms of vertical strieture using CALIOP CTT & MODIS BT

The small difference CALIPSO BT & MODIS BT suggests the presence of supercooled liquid near the top of ice clouds

The large difference b/w CALIPSO CTT & MODIS BT suggests a multi-layer cloud structure

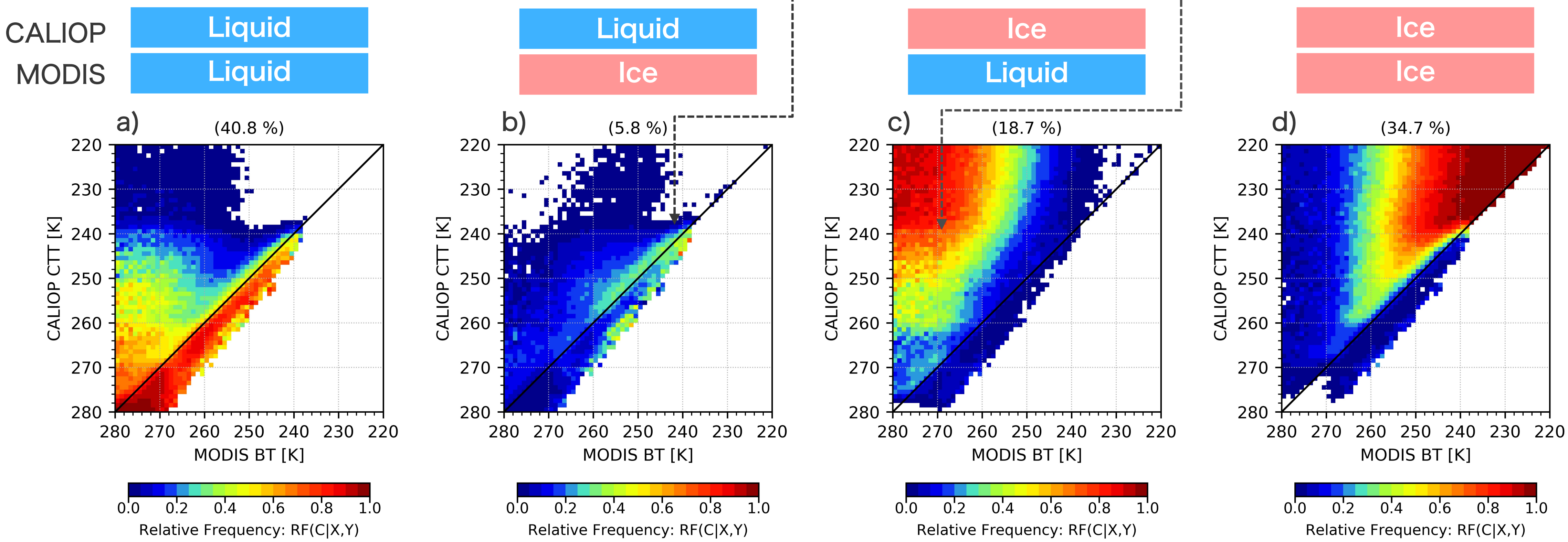
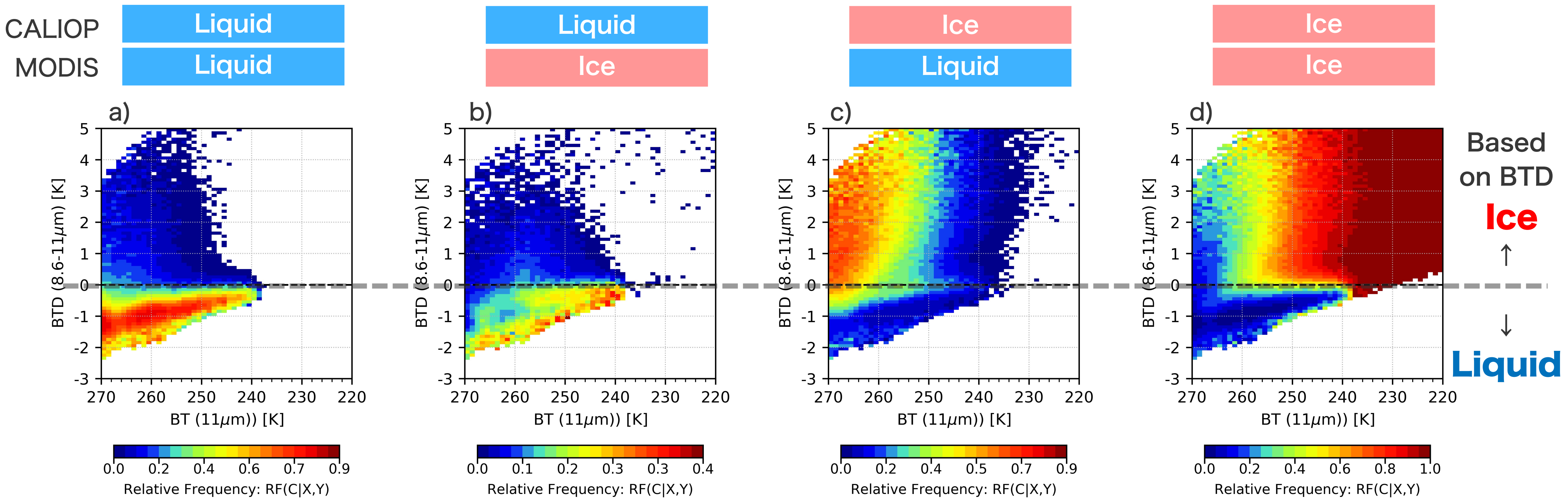


Fig. 5 The joint distributions of brightness temperature (BT) at MODIS 11 μm band and CALIOP cloud top temperature (CTT) for four classes, **(a)** LIQ/LIQ, **(b)** LIQ/ICE, **(c)** ICE/LIQ, and **(d)** ICE/ICE (denoted in CALIOP/MODIS). The numbers in brackets are the percentages of the number of data included in each. Note that the further away from the one-to-one line, the larger the difference between cloud top heights sensed by CALIPSO and MODIS TIR.

Consistency with cloud phase identified by MODIS BT difference

Fig. 6 The joint distributions of brightness temperature (BT) at MODIS 11 μm band and brightness temperature difference (BTD) between MODIS 8.6 μm and 11 μm bands.

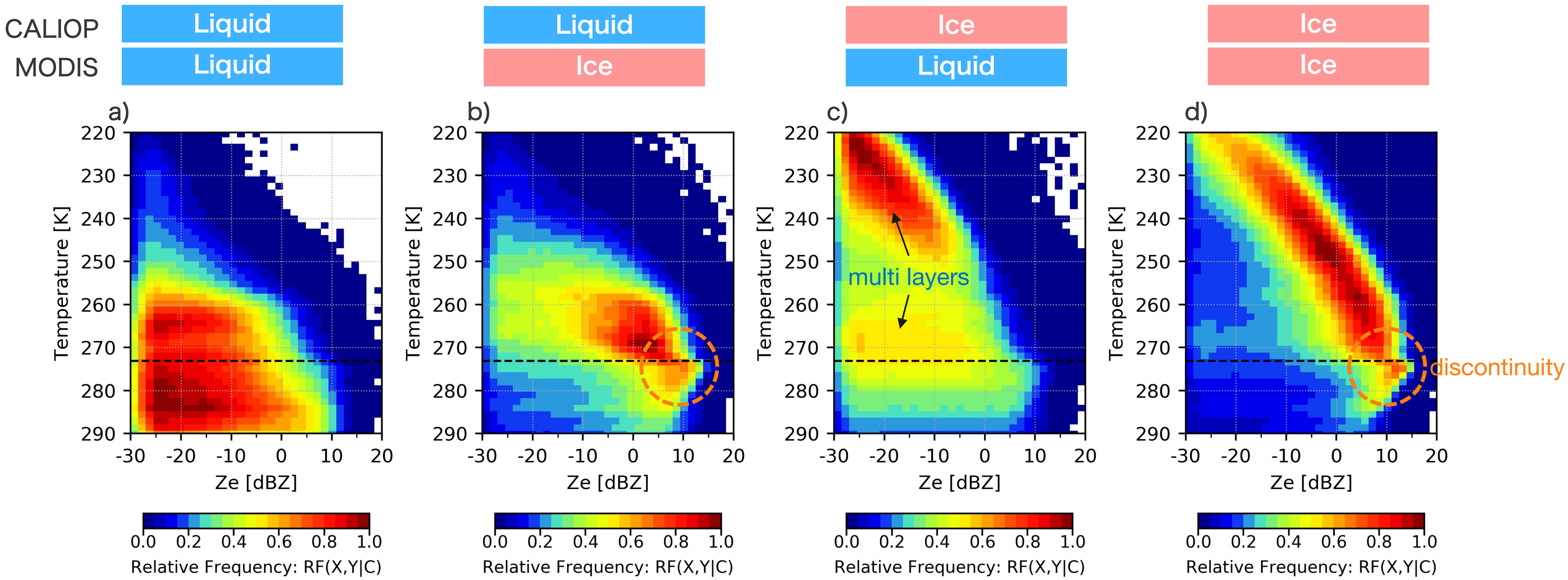


The negative BTD suggests liquid water clouds, consistent with the CALIPO-derived cloud phase.

The positive BTD suggests ice-phase clouds, consistent with the CALIPO-derived cloud phase.

Interpretation in terms of droplet vertical distribution using CloudSat/CPR

Fig. 7 The vertical distributions of radar reflectivity profiles observed from CloudSat/CPR with respect to temperature for four combinations of CALIOP and MODIS SWIR cloud phases.



Greater radar reflectivity compared to a) and c); its discontinuity around 273 K ➔ **Ice**

Smaller radar reflectivity compared to b) and d); Upper limit of CTT at around 255 K ➔ **Liquid**

Summary

Results

- Found a significant difference between the ice phase fractions derived from the CALIPSO lidar (CALIOP) and MODIS SWR observations (Figs. 3 & 4).
- Interpreted the discrepancy between the CALIOP-derived and MODIS SWIR-derived cloud phases (i.e., LIQ / ICE, ICE / LIQ cases) in terms of vertical inhomogeneity of cloud phase by using MODIS TIR and CloudSat/CPR observations (Figs. 5 - 7):

  CALIOPO / MODIS
  - LIQ / ICE: Ice clouds with supercooled water droplet (or layer) at the cloud tops
  - ICE / LIQ: Multi-layer cloud, where liquid water clouds covered by cirrus

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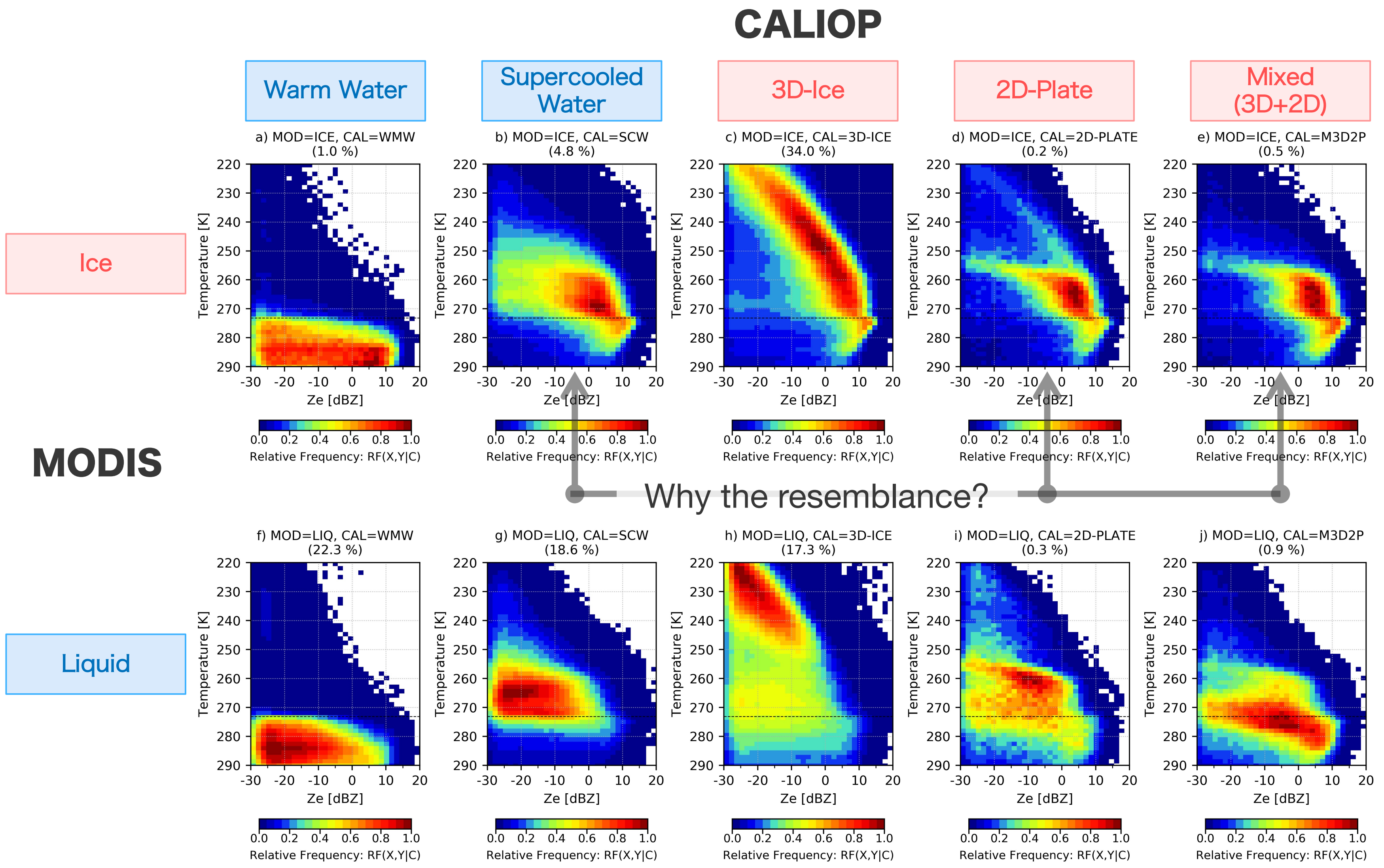
Implications

- The SWIR-derived ice-phase fraction (Fig. 3b), which sense cloud phase in deeper layers than CALIOP, can also be used to evaluate the cloud phase parameterization in models.
- The combined use of lidar and SWIR provides cloud phase statistics with implication for vertical inhomogeneity (Figs. 4), which may give stricter constrains on the representation of cloud phase in models.
- Combining the polarization and SWIR channels of GCOM-C/SGLI may also be able to characterize the vertical inhomogeneities of cloud phase, as in this this study.

Supplemental Slides

Implications for ice particle types in LIQ/ICE situations



- ✓ In the LIQ/ICE situation of the panel b), the ice particle type from CALIOP is usually not available due to the strong attenuation of the lidar signal by liquid water droplets at cloud tops.
- ✓ However, the similarity of b) with d and e expects that the LIQ/ICE case includes the 2D-plate or mixture (3D & 2D) types.

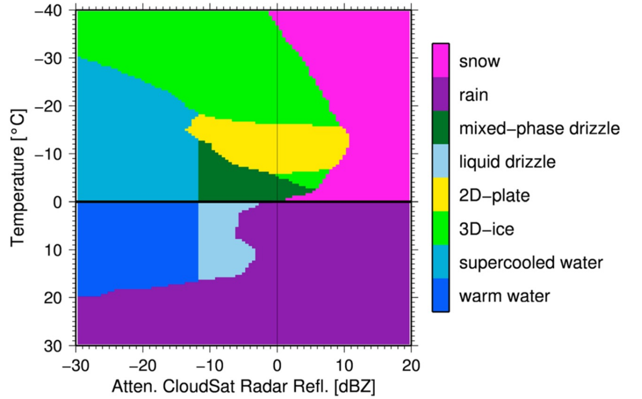
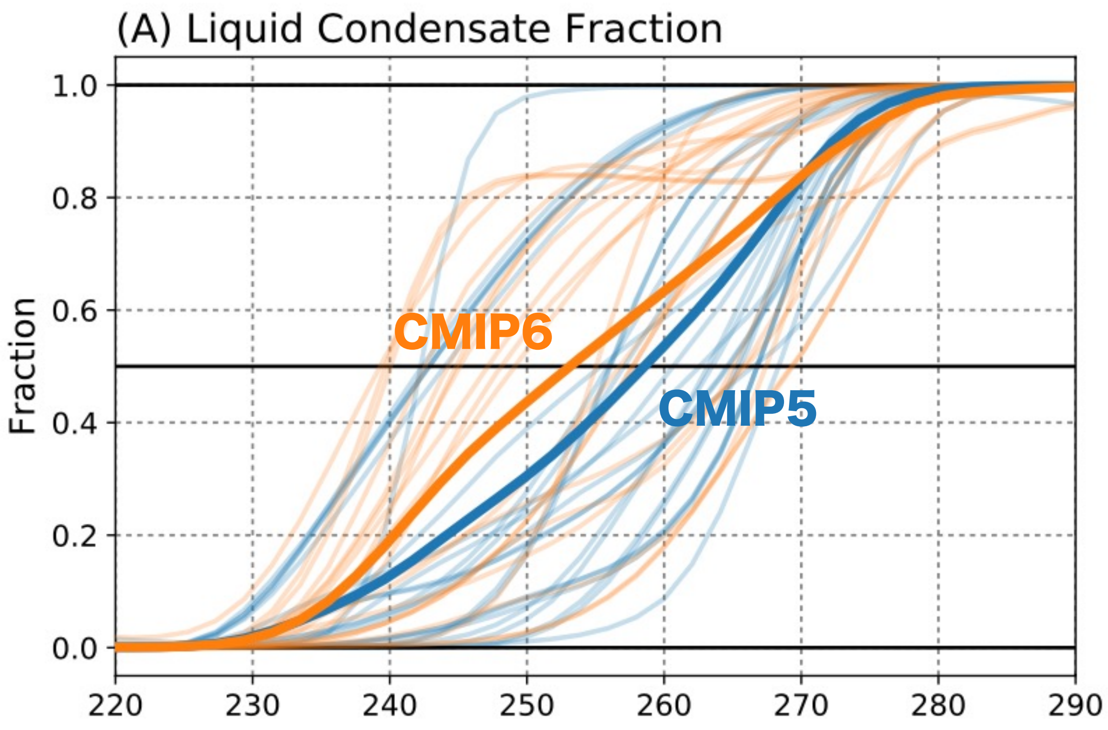


Figure 2. Radar reflectivity-temperature diagram for the initial hydrometeor type classification in the radar algorithm. In the precipitation correction, we modified the 0°C threshold for rain and snow separation to 2°C for convective clouds where the hydrometeor top temperature of the lowest hydrometeor was below 0°C.

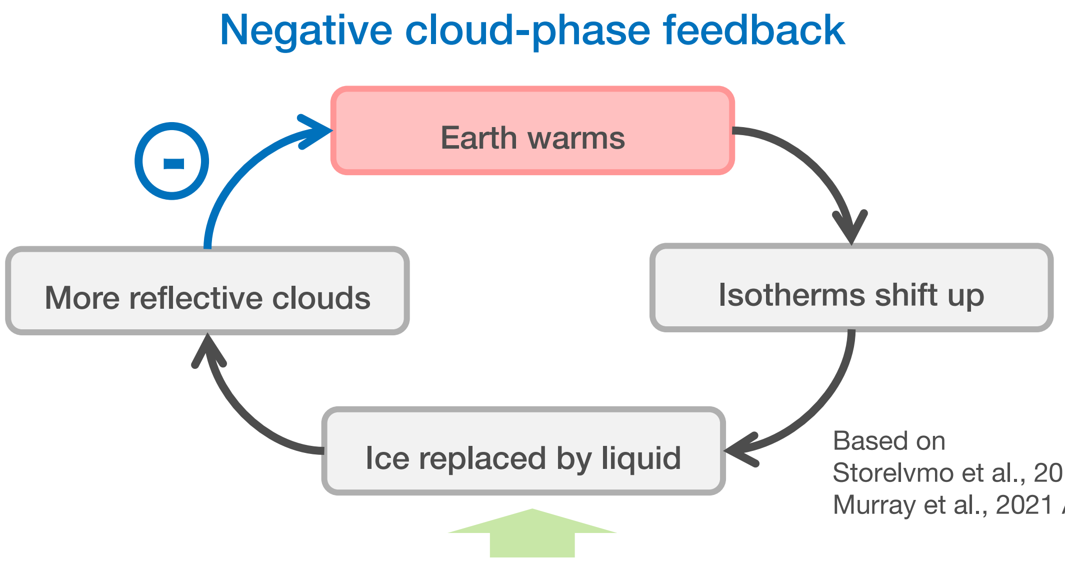
(Kikuchi et al., 2017 JGR)

Fig. 8 The vertical distributions of radar reflectivity profiles observed from CloudSat/CPR with respect to temperature for the ten classes from the combination of MODIS SWIR-derived cloud phase class and CALIOP-derived cloud particle type.

Implications for model evaluations



(Zelinka et al., 2020 JGR)



Based on
Storelvmo et al., 2015 CCCR
Murray et al., 2021 ACP

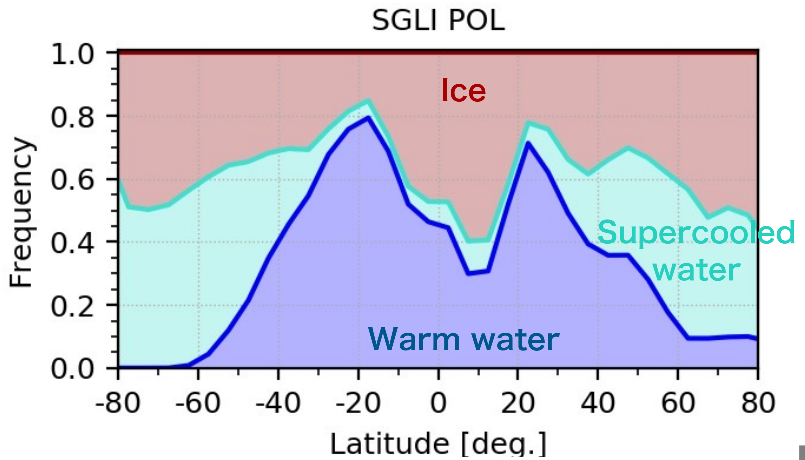
The strength of the cloud phase feedback depends on the amount of cloud ice in present day. (How much ice will be replaced by water due to global warming?)

- ✓ The improved cloud representation in the CMIP6 model increased SLF and weakened cloud phase feedback (Bjordal et al., 2020; Zelinka et al., 2020), reflects the knowledge of the ice phase fraction derived from CALIOP.
- ✓ The SWIR-derived cloud phase in addition to the CALIOP-derived cloud phase should provide more comprehensive constrains (i.e., about 7°C difference in T50 b/w CALIOP & MODS SWIR; vertical heterogeneity of cloud phase) on the representation of mixed-phase clouds in models.

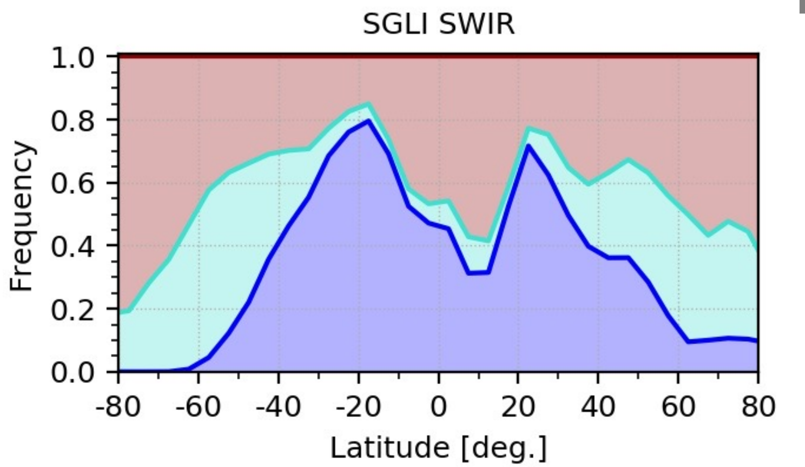
Implications for cloud phases from SGLI POL & SWIR

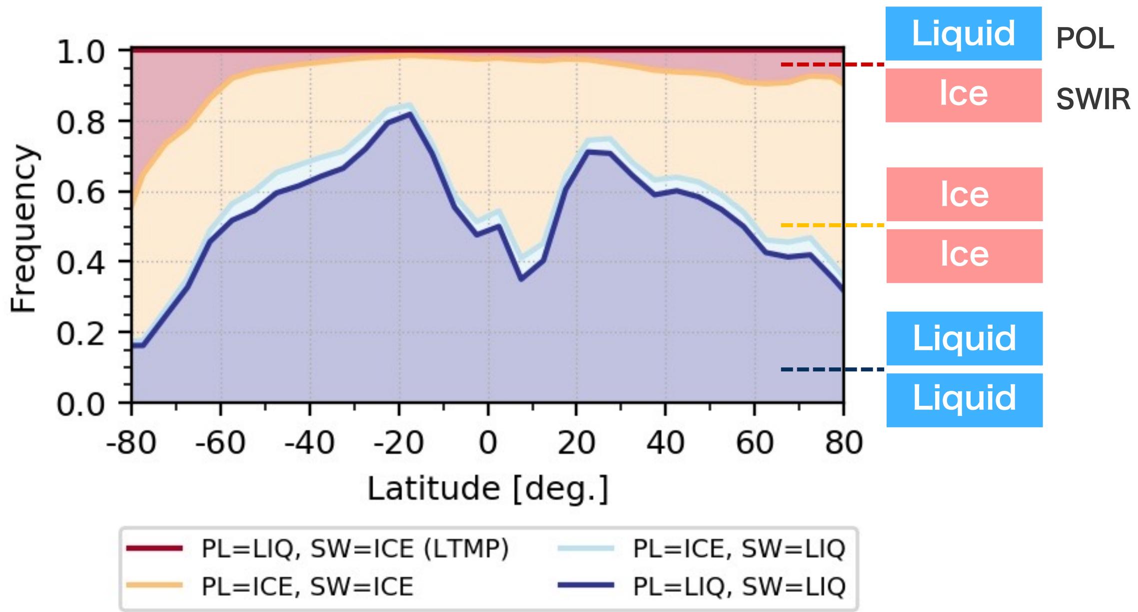
- Both the cloud phase determinations from POL & SWIR use ML-based algorithms with supervised data
- The relative increase in LIQ/ICE from SGLI POL/SWIR at higher latitudes is consistent with the result from CALIOP/MODIS-SWIR.

POL-derived



SWIR-derived





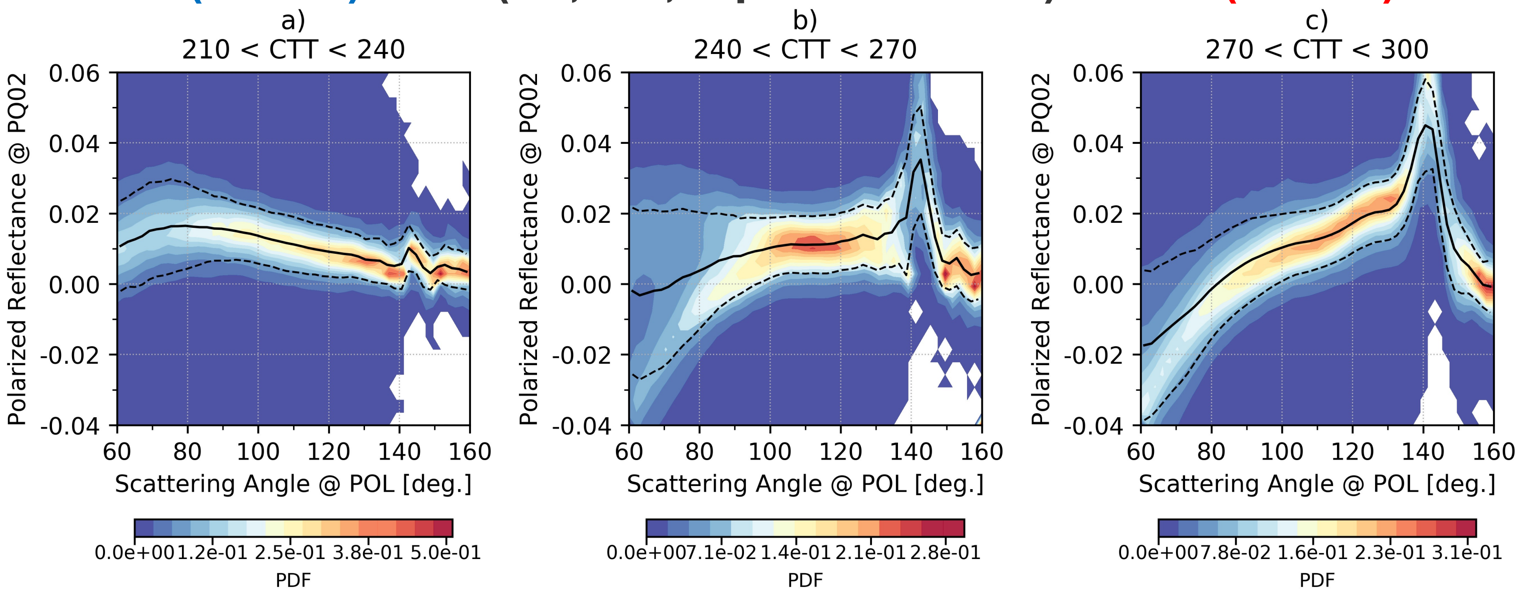
Principle of cloud phase discriminations using SGLI polarization channels

A) SGLI

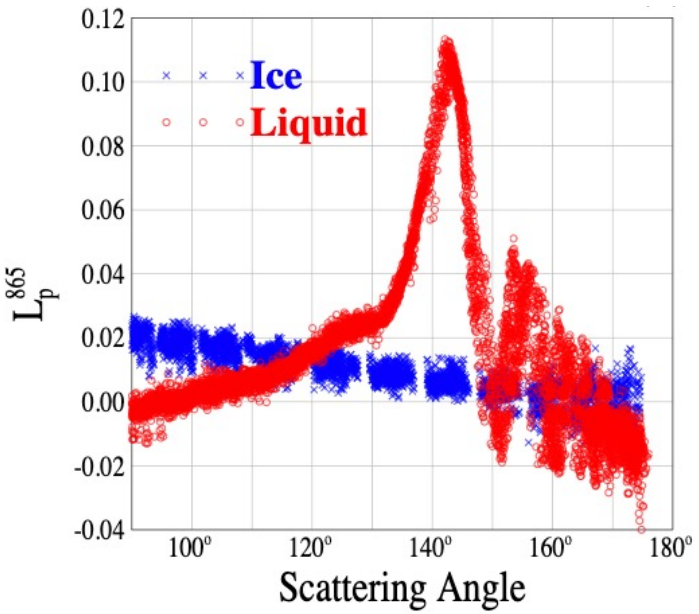
Confident ICE
(< 240 K)

Uncertain
(ICE, MIX, Supercooled water)

Confident LIQ
(> 270 K)



B) POLDER



[Riedi et al., 2010]