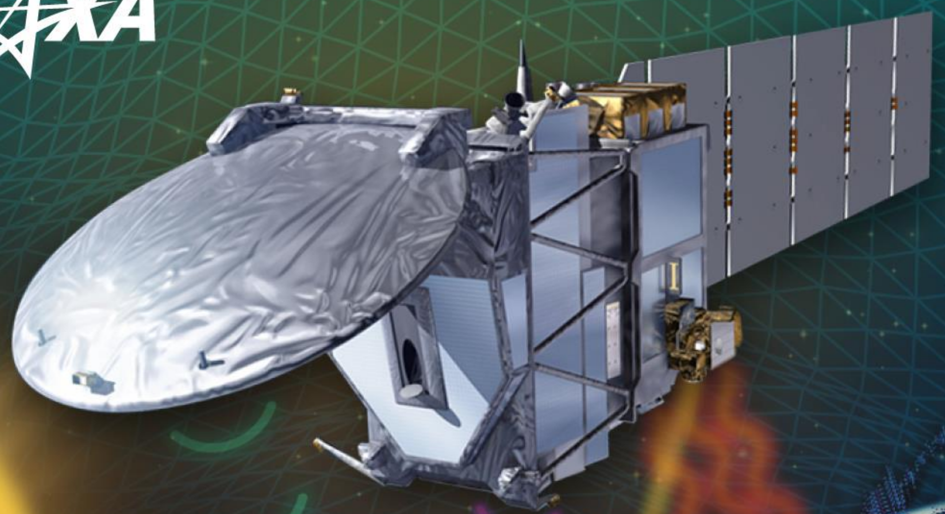
JAXA esa



ESA-JAXA Pre-Launch EarthCARE Science and Validation Workshop

13 – 17 November 2023 | ESA-ESRIN, Frascati (Rome), Italy

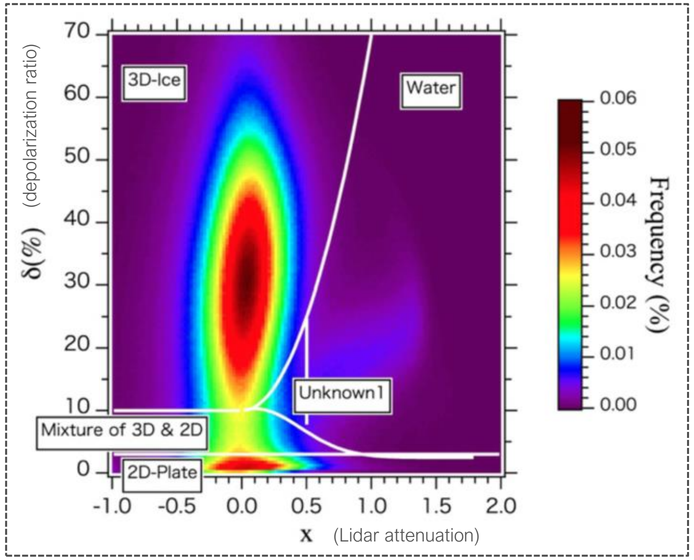
Combined use of passive and active remote sensing to characterize the vertical stratification of the cloud thermodynamic phase

Takashi M. Nagao[1] *and Kentaroh Suzuki*[1]

[1] *Atmosphere and Ocean Research Institute, The University of Tokyo, Japan*

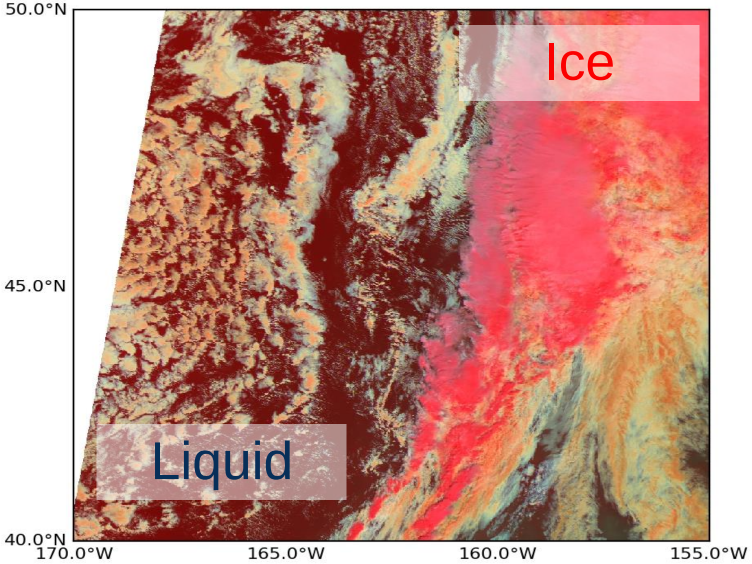
Three techniques for cloud phase determinations independent of the relationship between temperature and ice-phase fraction

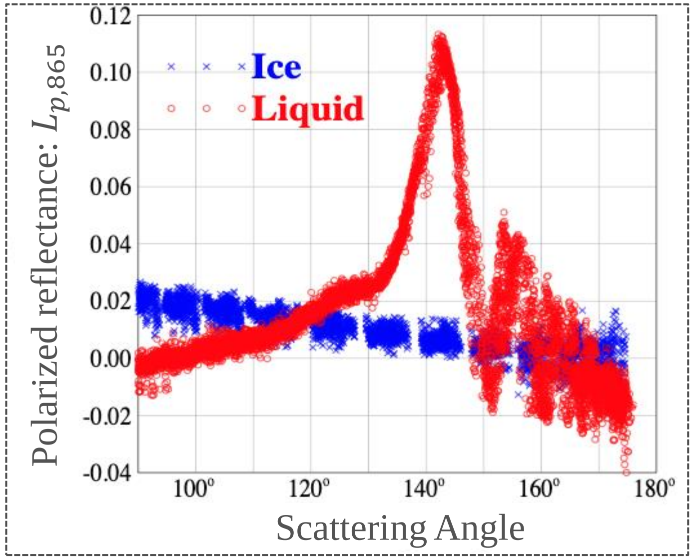
Active Lidar	Passive SWIR Meas.	Passive Polarimetry



(Hirakata et al., 2014)

(R,G,B) = (0.44, 1.6, 2.2 μm)





(Riedi et al., 2010)

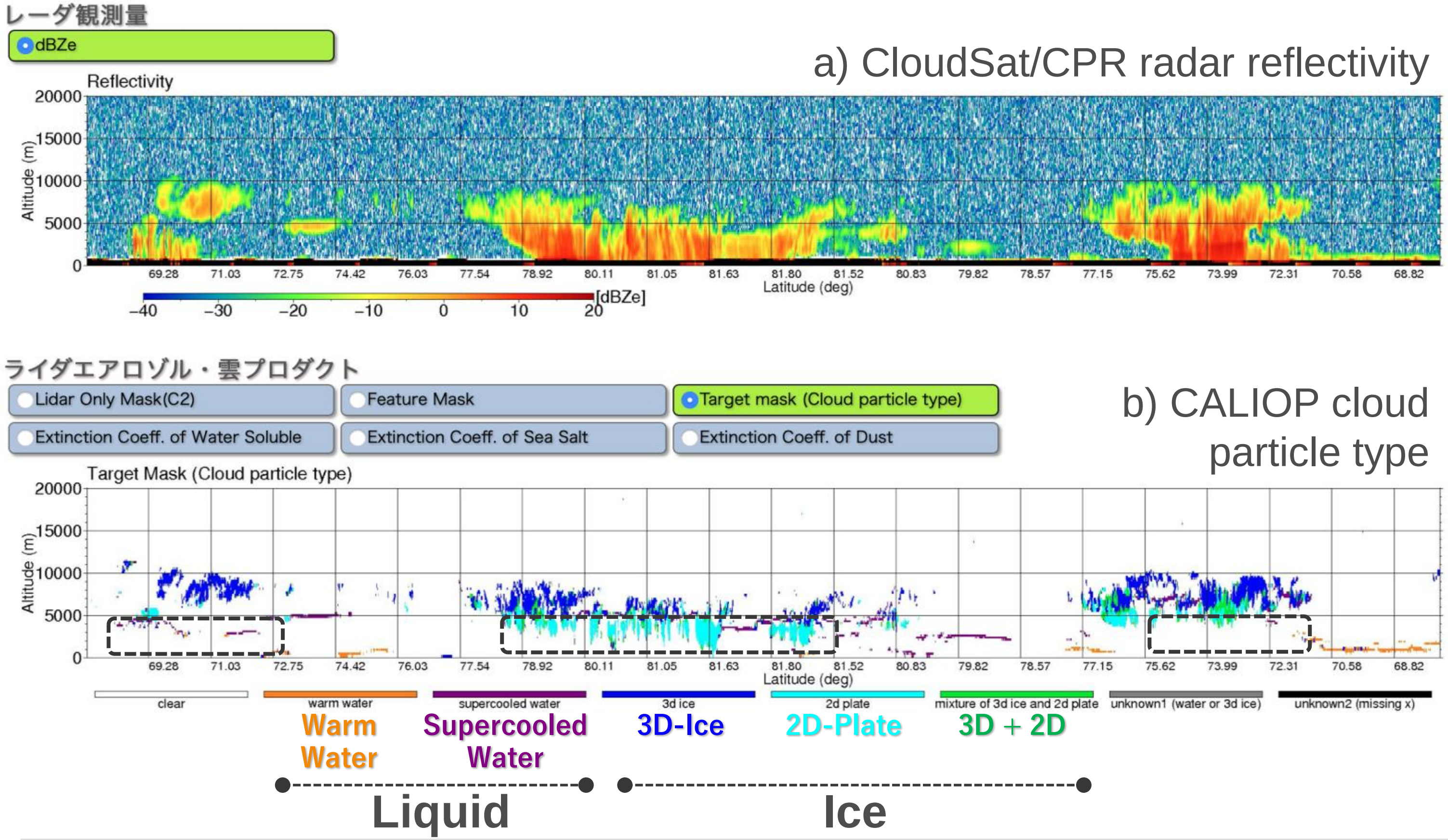
EarthCARE, A-Train

GCOM-C/SGLI

- These techniques have different penetration depths into clouds: Lidar & POL are limited to optically shallow layers, whereas SWIR can penetrate deeper into clouds (One sensor is not enough)
- We combine two cloud phase data from CALIPSO lidar & MODIS SWIRs to characterize the vertical stratification of the cloud phase; Mention the possible combination of SGLI SWIR & POL

Data 1: Cloud particle type derived from CALIPSO lidar (CALIOP)

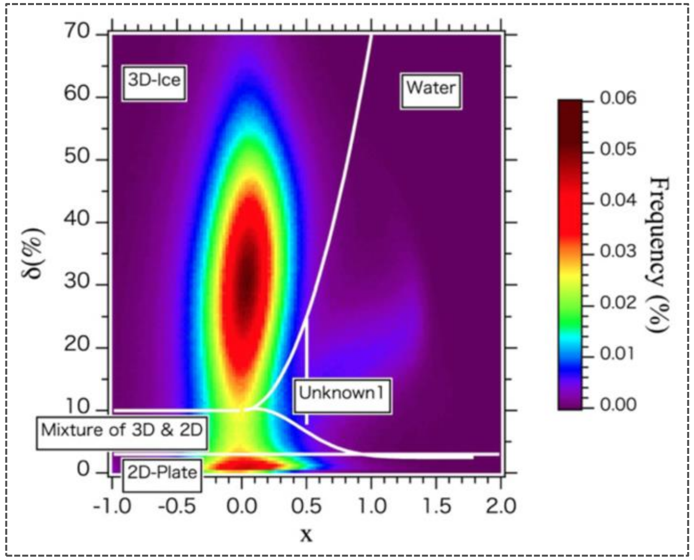
- Utilized the **CALIOP cloud particle type product** developed by Prof. Okamoto's group (Yoshida et al., 2010; Hirakata et al., 2014), available from the JAXA A-Train Product Monitor
- This product offers cloud particle types, but they were **binarized into liquid (0) or ice (1)** for our analysis, and the **ice phase fraction (0. – 1.)** was then calculated based on cloud bins detected



a) CloudSat/CPR radar reflectivity

b) CALIOP cloud particle type

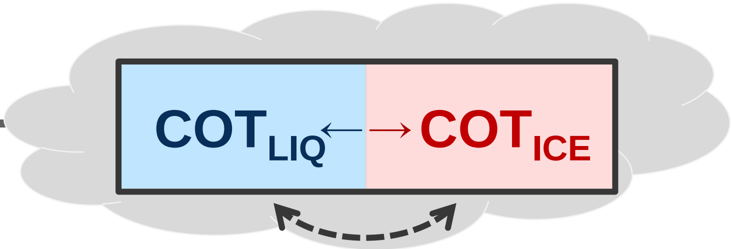
c) Principle of CALIOP-based cloud particle type determination



(Hirakata et al., 2014)

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

Data 2: Cloud phase retrieval from SWIR channels

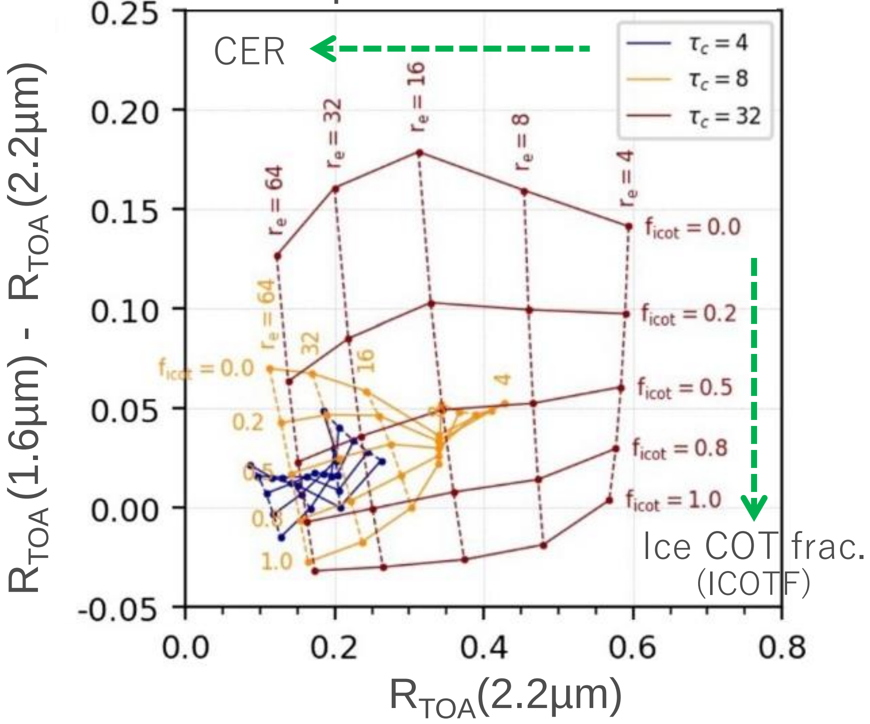


(Ice COT Fraction)

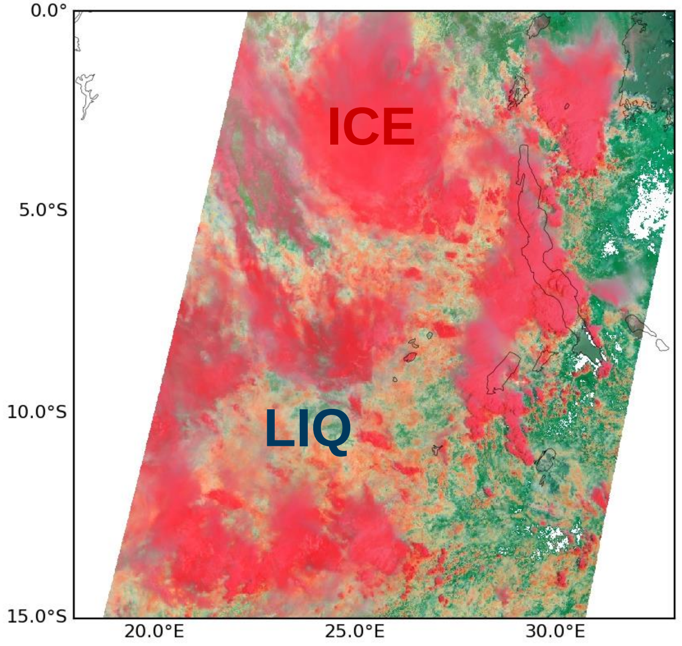
$$ICOTF = \frac{COT_{ICE}}{COT_{LIQ} + COT_{ICE}}$$

- **A SWIR-based cloud phase retrieval algorithm** utilizing the 1.6 & 2.1 μm channels was implemented for consistent application to MODIS & SGLI (Nagao & Suzuki, 2021).
- This algorithm retrieves total COT, CER, & **ice COT fraction** (ICOTF) to total COT, using two SWIRs & one VNIR

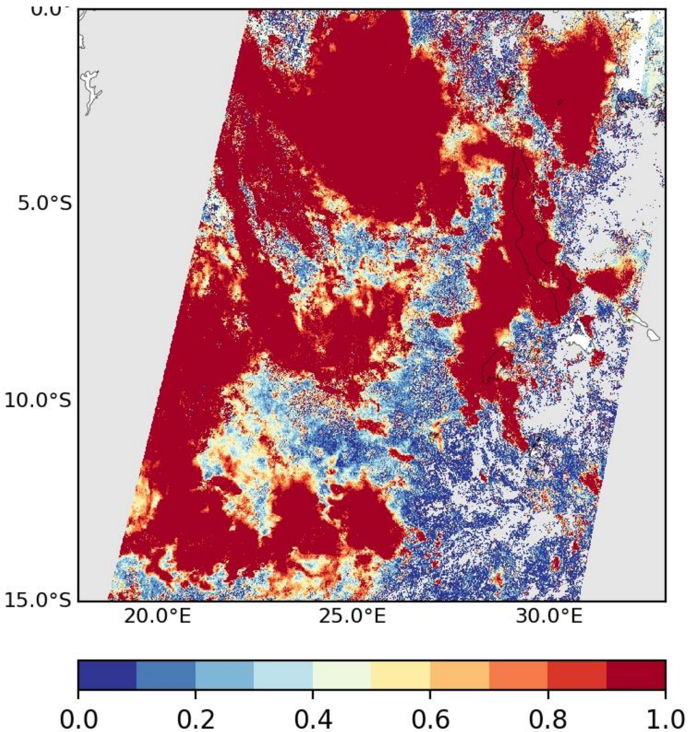
Principle of ICOTF retrieval



(RGB) = (0.44, 1.6, 2.2 μm)



Retrieved ice COT fraction

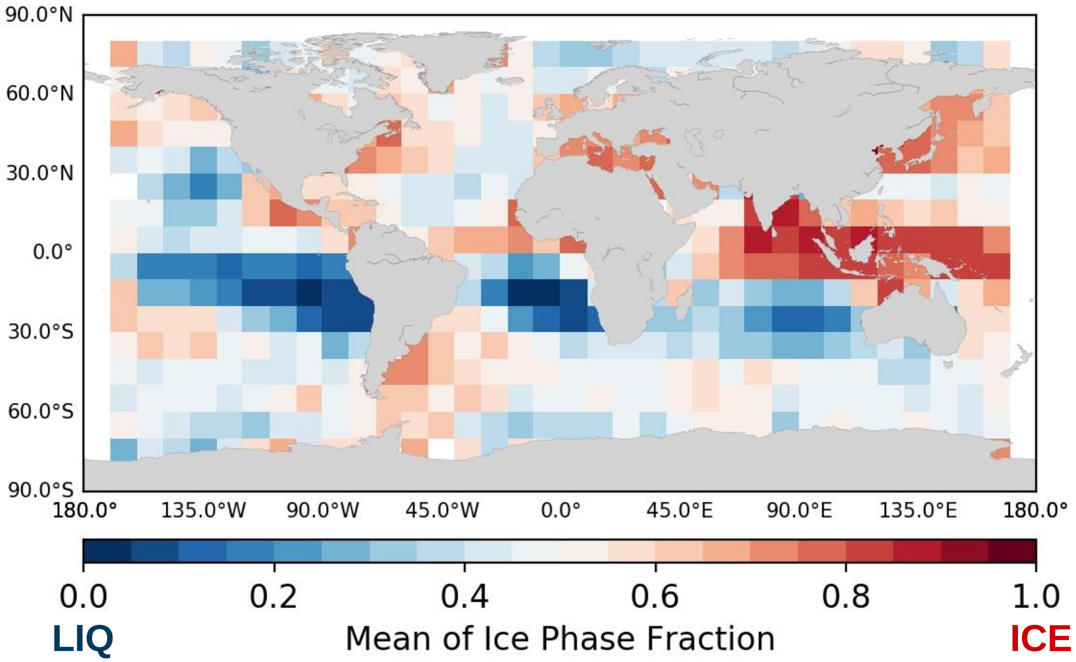


Nagao & Suzuki, 2021 ESS (https://doi.org/10.1029/2021EA001912)

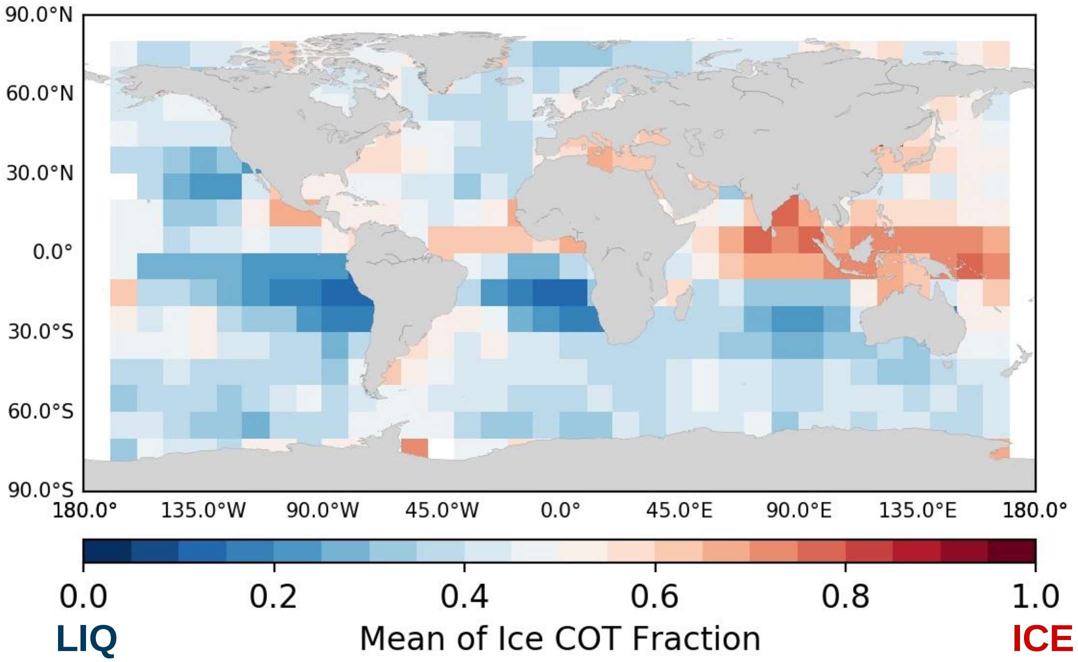
Comparing the global characteristics of the ice phase/COT fractions

- *Difference*: The CALIOP-derived ice phase fraction exhibits more values close to either 0 or 1 (dark blue & dark red)
- This study interpret this difference in context of the distinct penetration depths between lidar and SWIR, seeking insight into the vertical stratification of the cloud phase through their combined and complementary use

a) CALIOP-derived ice phase fraction*



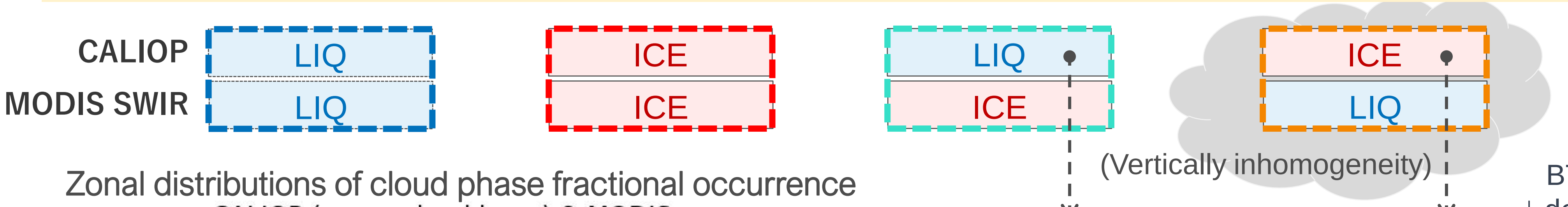
b) MODIS SWIR-derived ice COT frac.



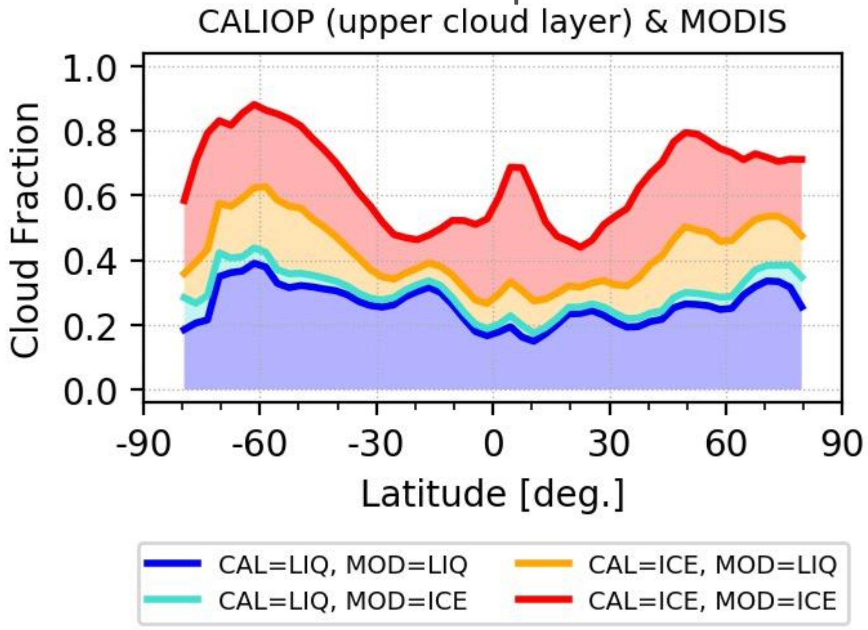
* The ice phase fraction was calculated based on all the cloud bins detected by CALIOP, regardless of whether they were single or multi-layer clouds

Combined use of the two cloud phases from CALIOP and MODIS SWIR

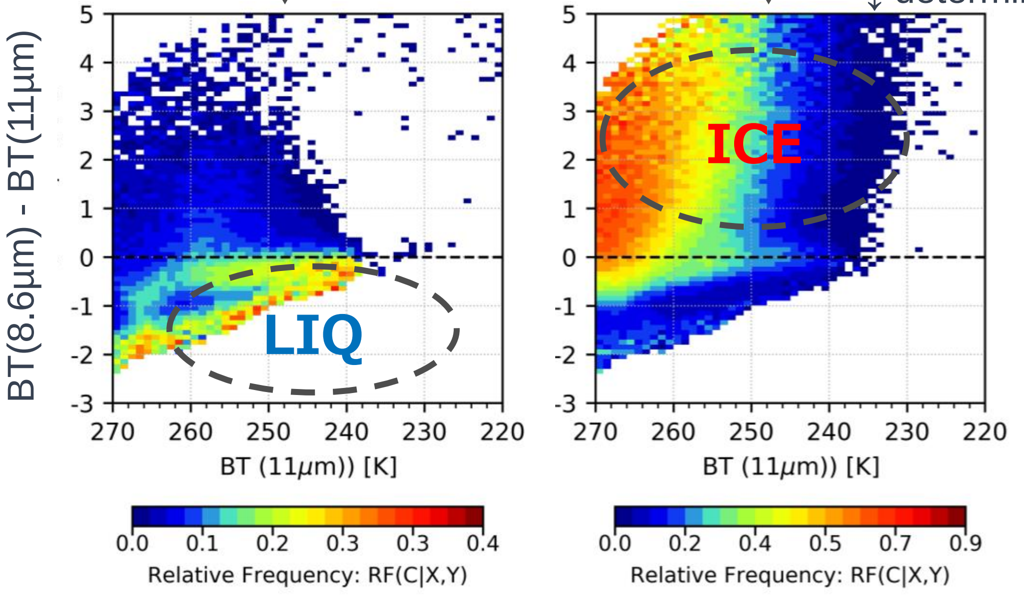
- First, the CALIOP-derived ice phase fraction and MODIS SWIR-derived ICOTF were binarized with a threshold value of 0.5 to obtain cloud phase classes for **'liquid (LIQ)'** and **'ice (ICE)'**. These cloud phase classes were then combined to define the four categories:



Zonal distributions of cloud phase fractional occurrence

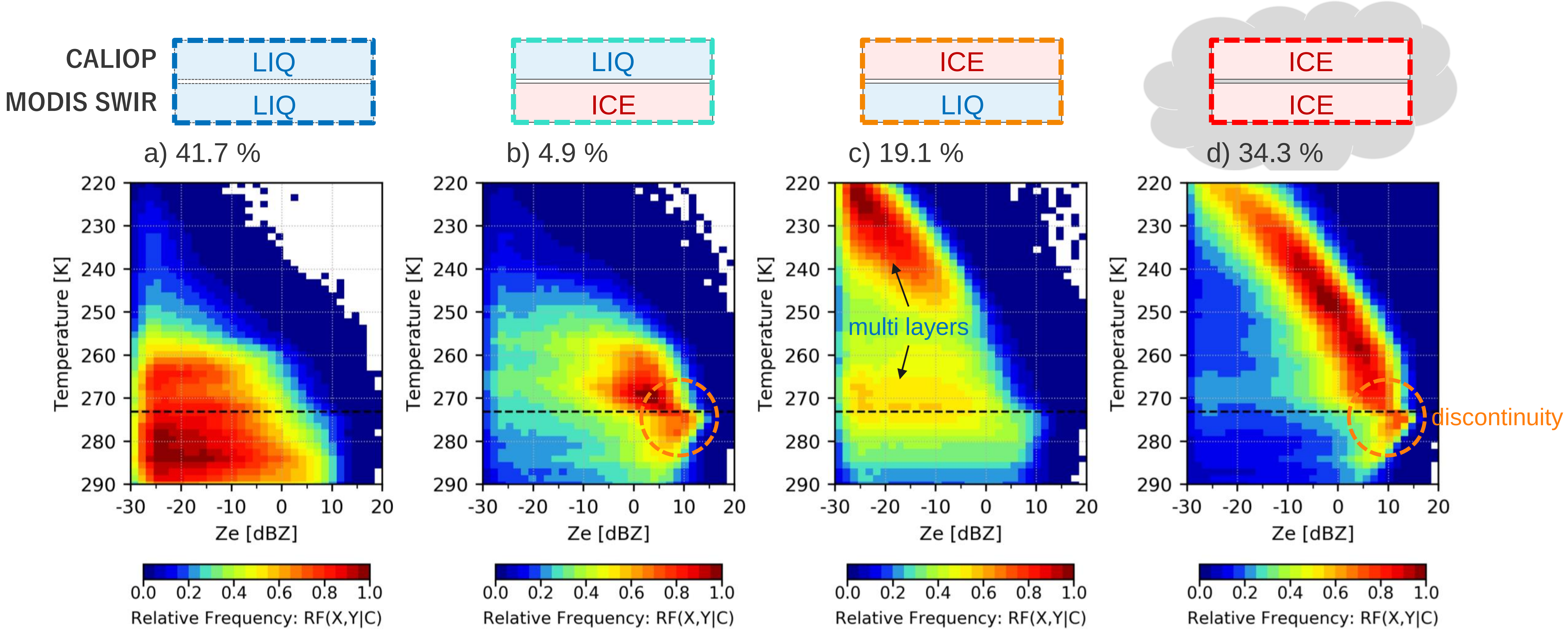


BTD-based cloud phase determination



- ✓ **LIQ/LIQ** and **ICE/ICE** can mainly increase vertically homogeneous **liquid** and **ice** clouds
- ✓ **LIQ/ICE** is thought to include **liquid-top mixed-phase clouds,** while **ICE/LIQ** would include **multi-layer clouds**, this conjecture is supported by BTD-based cloud phase identification

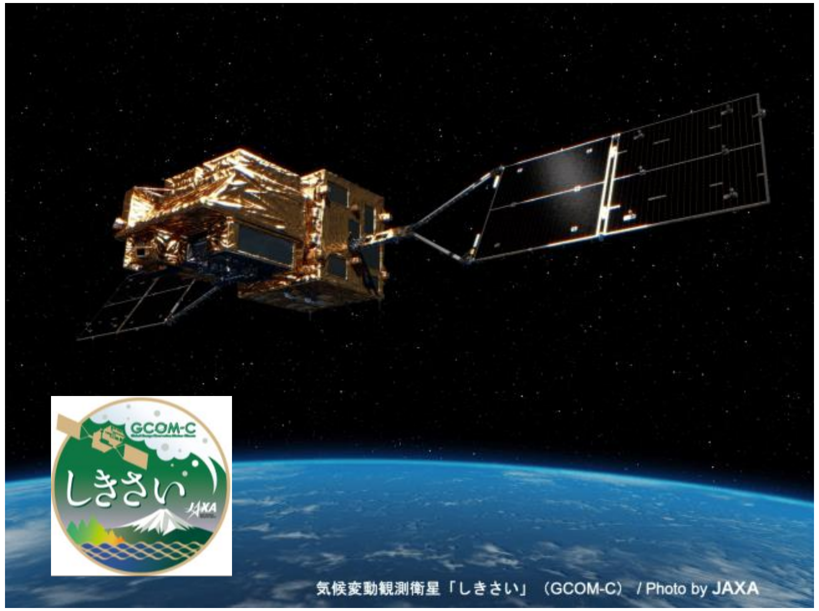
Interpretation in terms of droplet vertical distribution using CloudSat/CPR



- The four-categories of cloud phase were associated with the distinct droplet vertical profile
- When the SWIR-based cloud phase exhibits ICE (b, d), a similarity in Ze profiles are found
- This results suggest that the combined use of lidar & SWIR better characterizes vertical stratification of the cloud thermodynamic phase

GCOM-C / SGLI, the successor to ADEOS-II / GLI

GCOM-C



Launch Data	Dec. 24, 2017 (**in operation**)	
Orbit	Sun-synchronous (Descending local time: 10:30)	
Instrument	Second generation GLobal Imager (**SGLI**)	
	Wavelength	380 nm – 12 µm, 19 chs.
	Resolution	250 m - 1 km
	Swath	> 1000 km
	Obs. Freq.	2 - 3 day

SGLI channels

	CH	WL [nm]	IFOV [m]
VIS/NIR	VN1	380	250†
	VN2	412	
	VN3	443	
	VN4	490	
	VN5	530	
	VN6	565	
	VN7	673.5	
	VN8	673.5	
	VN9	763	
	VN10	868.5	
	VN11	868.5	
POL	P1	673.5	1000
	P2	868.5	

CH	WL [µm]	IFOV [m]	
SW1	1.05	1000	SWIR
SW2	1.38		
SW3	1.63	250†	
SW4	2.21	1000	
TI1	10.8	250†	TIR
TI2	12.0		

† 250 m resolution over land and coastal area, 1 km over offshore

SWIR & POL

→ two cloud phases

O_2 A-band & TIR

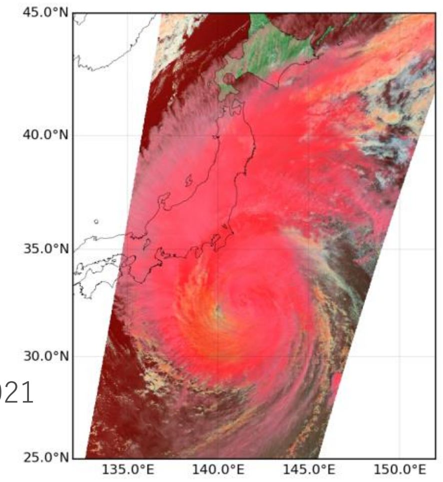
→ CGT (→ Nc w/ COT, CER)

→ CBH → downward LW Flux

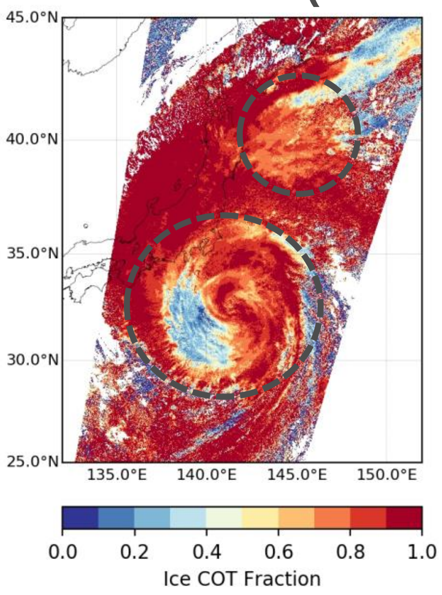
Comparing the SWIR- & POL-based cloud phases (preliminarily)

1st Oct. 2021
Japan

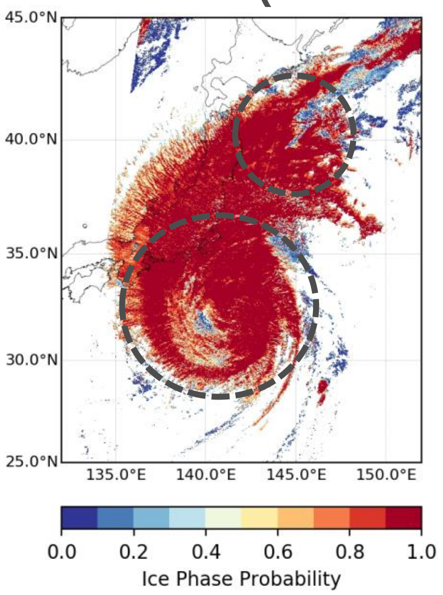
RGB (0.44, 1.6, 2.2 μm)



SWIR-based (ICOTF)

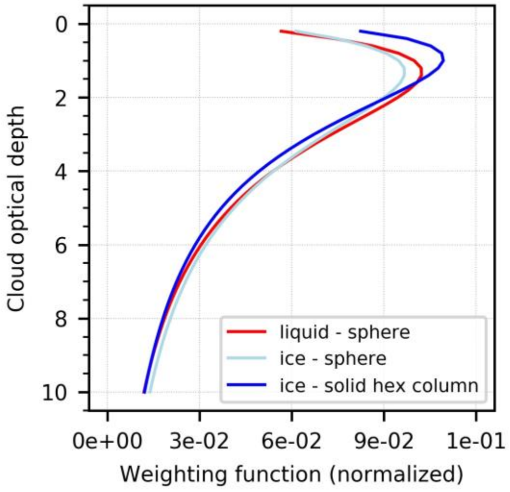


POL-based (Ice Prob.)

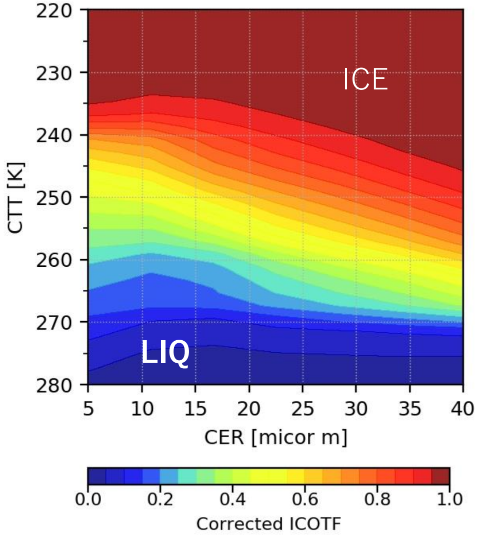


< weighting function >

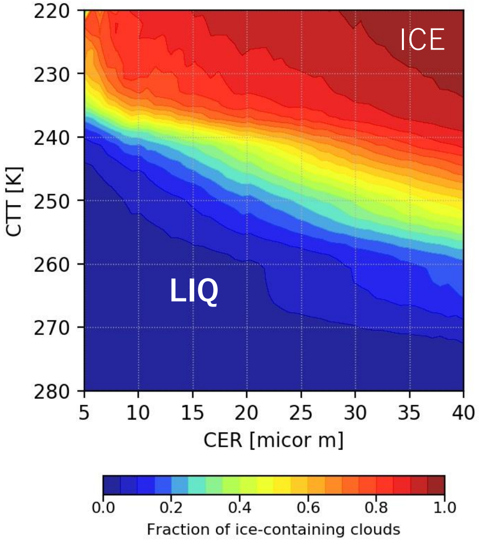
R_{TOA} @ SWIR



SWIR-based

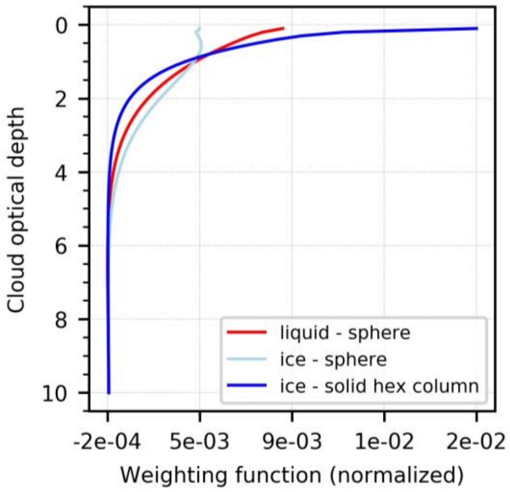


POL-based



Fractional occurrence of ice phase

$R_{p,\,TOA}$ @ PL

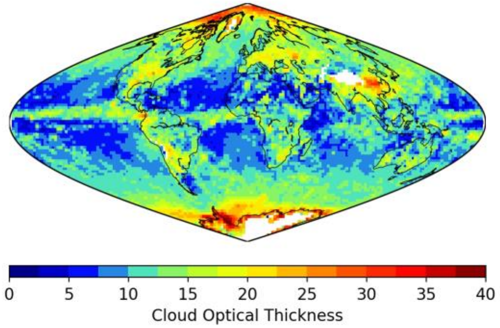


SGLI-based cloud and radiation product: global

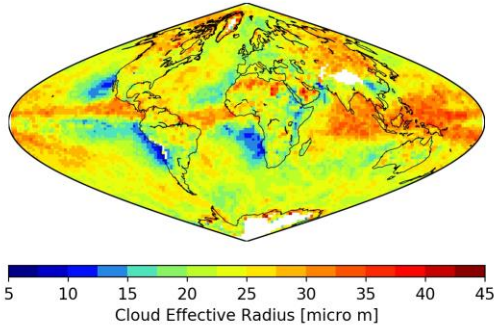
Cloud properties

(Jan. – Nov. 2021)

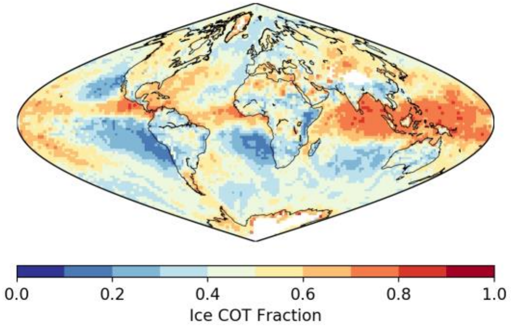
COT



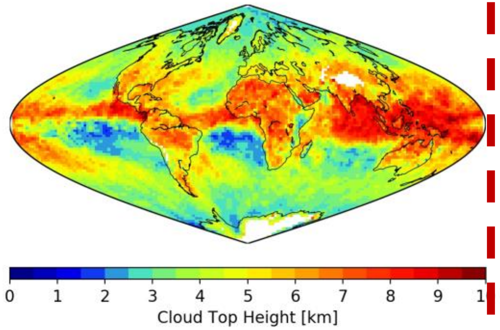
CER



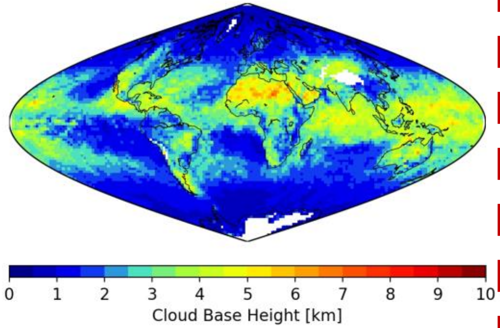
Cloud phase (ICOTF)



CTH

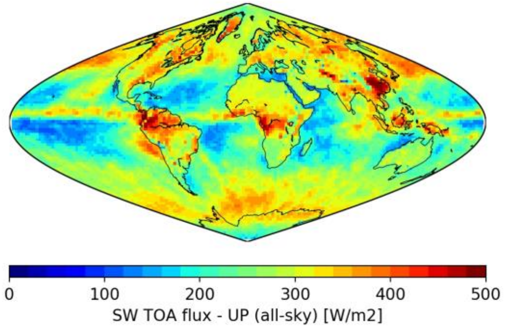


CBH

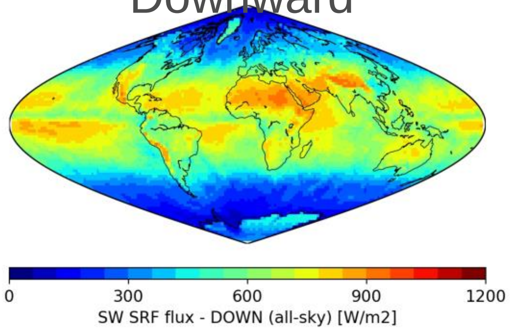


Radiative flux

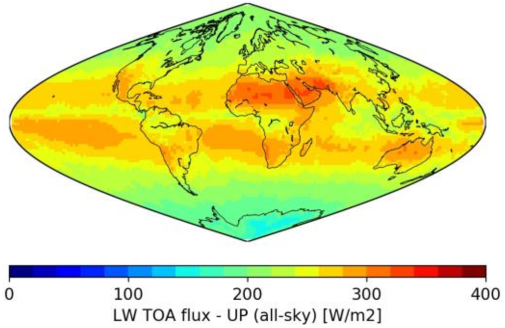
SW @ TOA - Upward



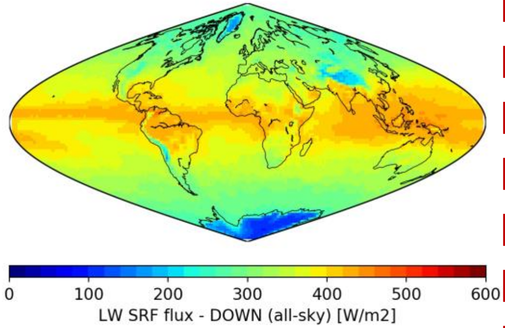
SW @ SFC - Downward



LW @ TOA - Upward

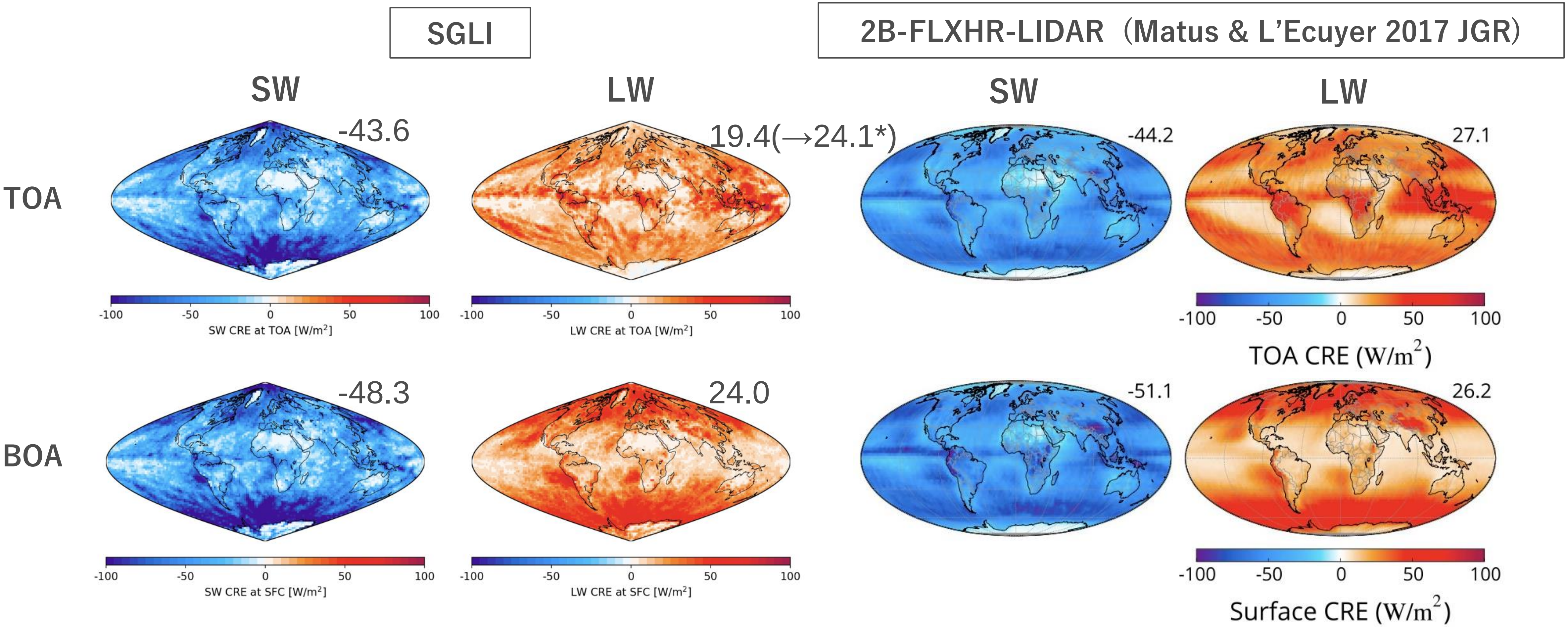


LW @ SFC - Downward



- Retrieved cloud property using the SGLI multi-channels with our implemented algorithm and then estimated the shortwave/longwave (SW/LW) radiative fluxes at TOA/SFC

SGLI-estimated of cloud radiative effect (preliminarily)



- The SGLI-based CRE estimates were consistent with the CRE based on the A-train multi-sensor observations. However, there remains some negative bias in the upward LW due to an underestimation of ~ 1 km in the TIR-based CTH retrieval for ice clouds.

* if the ~ 1 km CTH bias is corrected

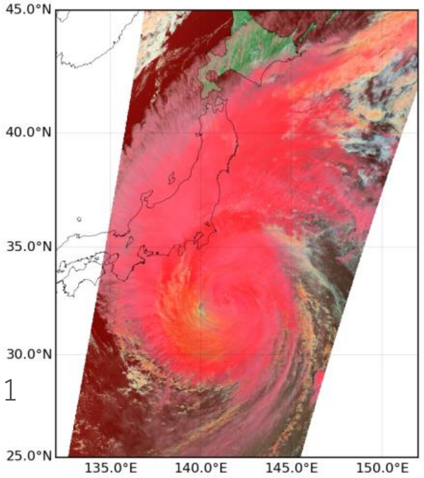
Summary

- The two pieces of cloud phase information obtained from active lidar and passive SWIR, each binarized into liquid or ice, were then combined to define the four categories of cloud phases
- Then investigated through comparisons with CloudSat/CPR radar profile statistics to illustrate how cloud vertical structures vary systematically with the four categories of cloud phase
- The results suggest that the combined use of complementary information from three sensors (lidar, SWIR, and radar) can better characterize the vertical structures of the cloud thermodynamic phase
- While combination between lidar and SWIR are limited along the spacecraft track, the combination of SGLI SWIR and POL is another possible candidate with an alternative to lidar that can provide wider horizontal coverage

- Also introduced the SGLI-derived cloud properties and radiation products that are worth comparing to EarthCARE observations to understand the vertical and horizontal structure of clouds. (we believe)

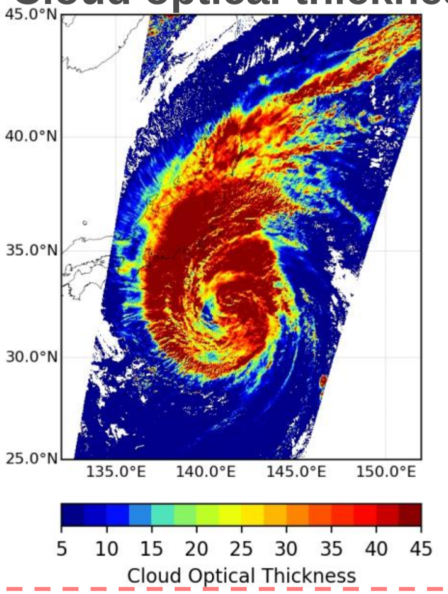
Example of SGLI-derived cloud property retrievals

RGB (0.44, 1.6, 2.2 μm)

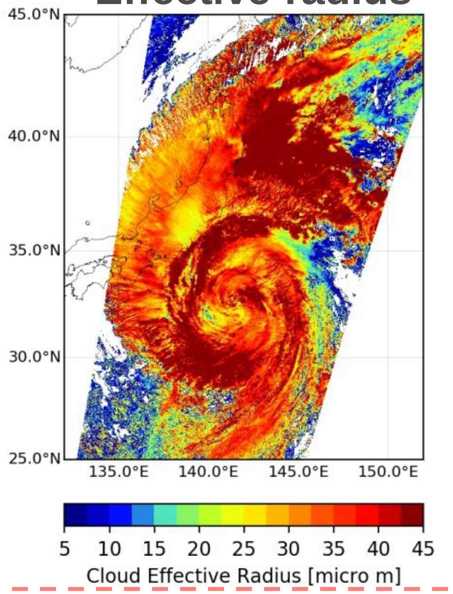


1st Oct. 2021
Japan

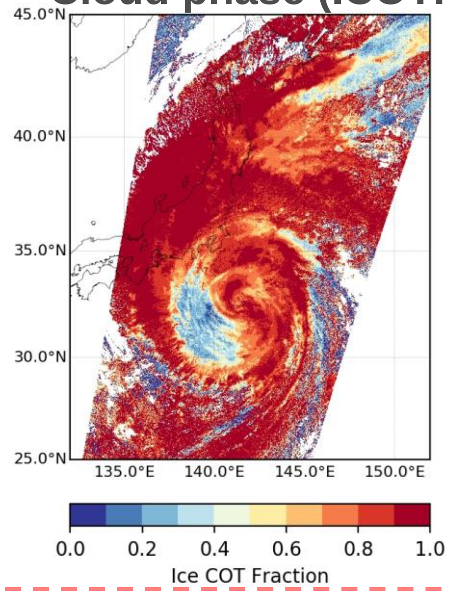
Cloud optical thickness



Effective radius



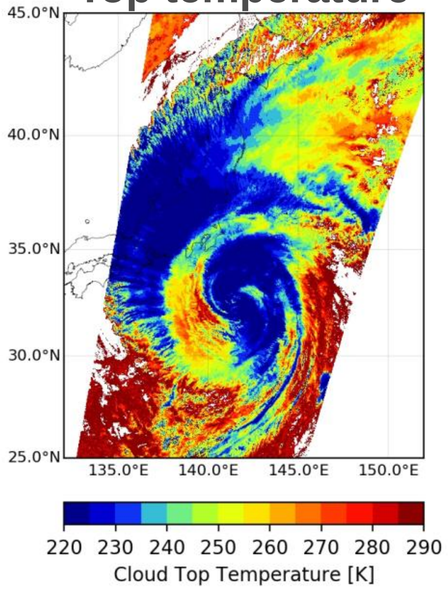
Cloud phase (ICOTF)



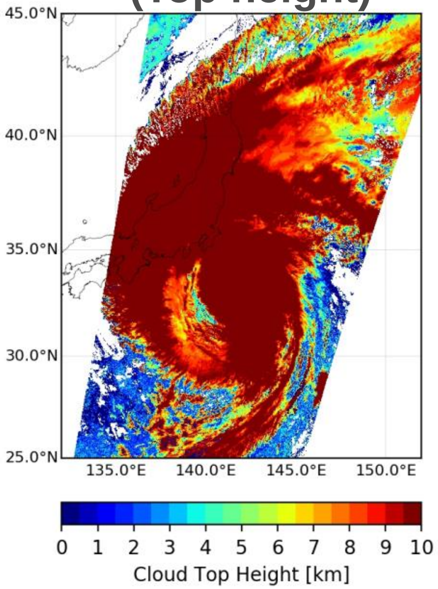
SWIRs
←

VIR & SWIR
O_2 A-band & TIR ↓

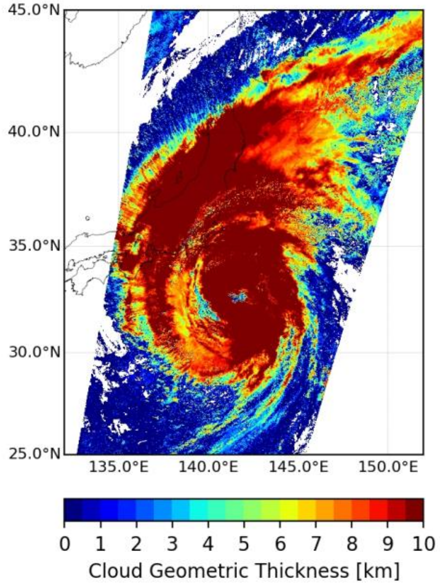
Top temperature



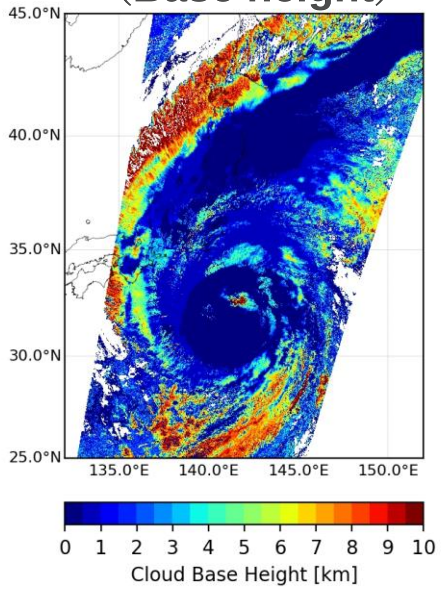
(Top height)



Geometric thickness



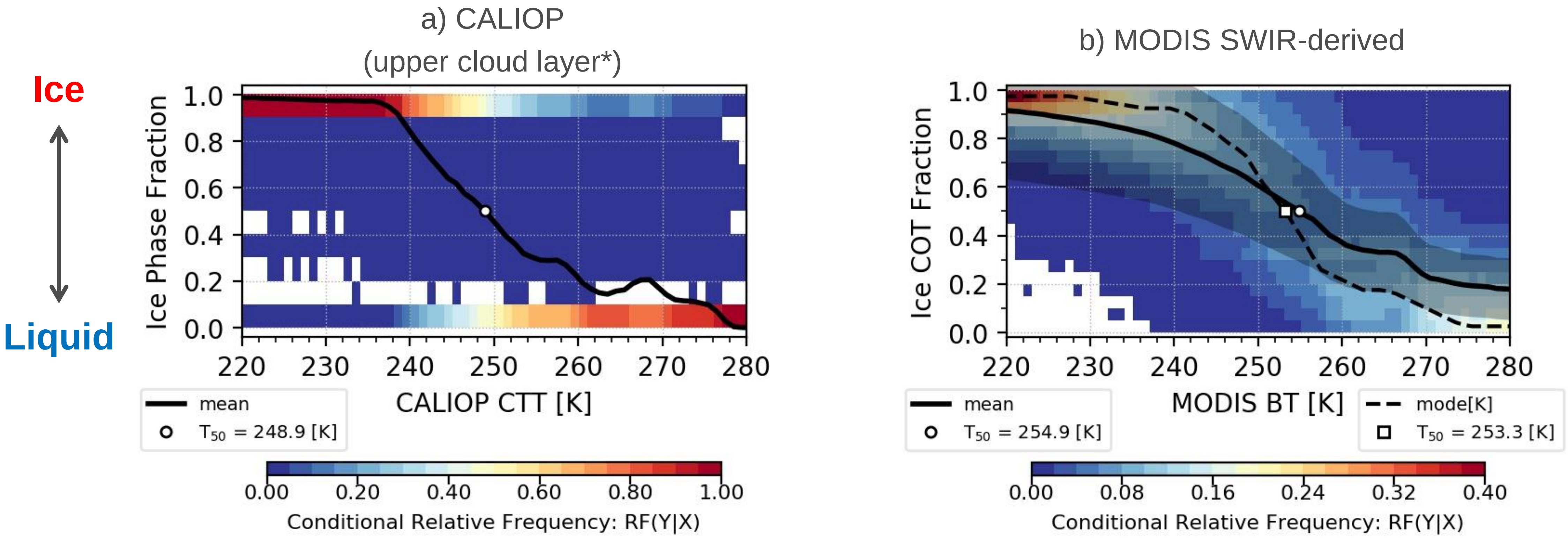
（Base height）



Comparing the temperature dependences of the ice-phase fractions

- *Difference*: The lidar-based ice-phase fraction was mostly either 0 or 1 (pure liquid or ice), whereas the SWIR-derived ICOTF continuously varied between 0 and 1 along with BT

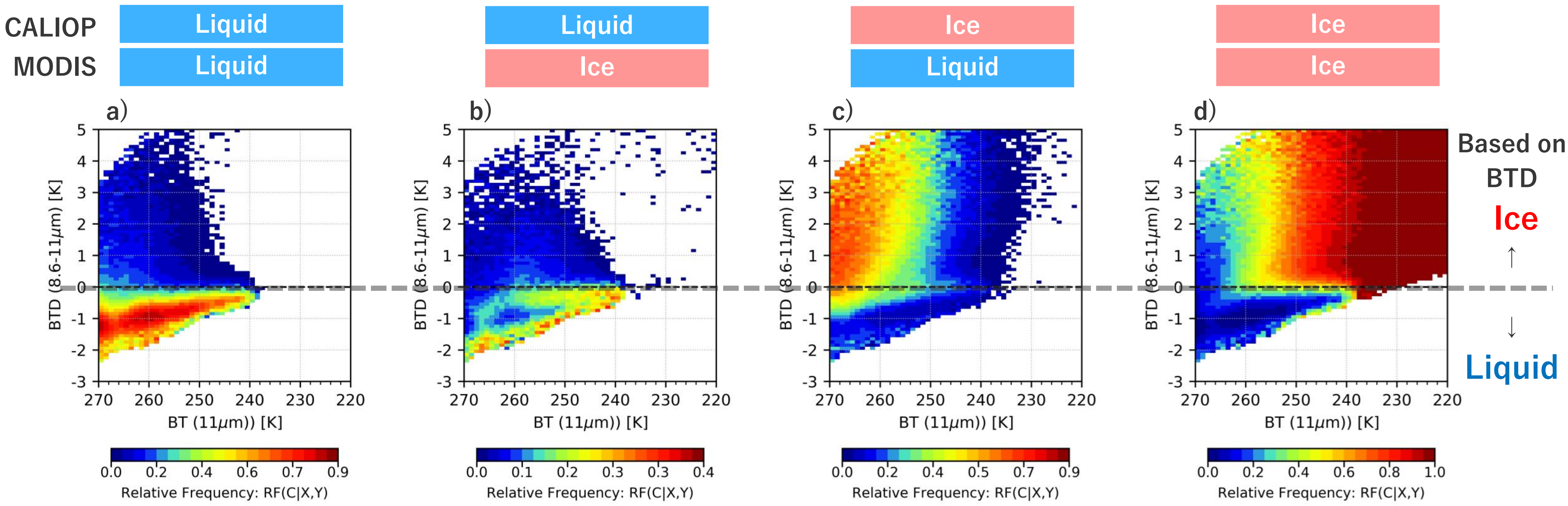
→ This study aims to interpret these differences in context of the distinct penetration depths between lidar and SWIR, seeking insight into the vertical stratification of the cloud phase through their combined and complementary use



* The ice phase fraction was calculated based on all CALIOP-detected cloud bins for single layer clouds, and only the first upper cloud for multi-layer clouds

Consistency with cloud phase identified by MODIS BT difference

Fig. 7 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.

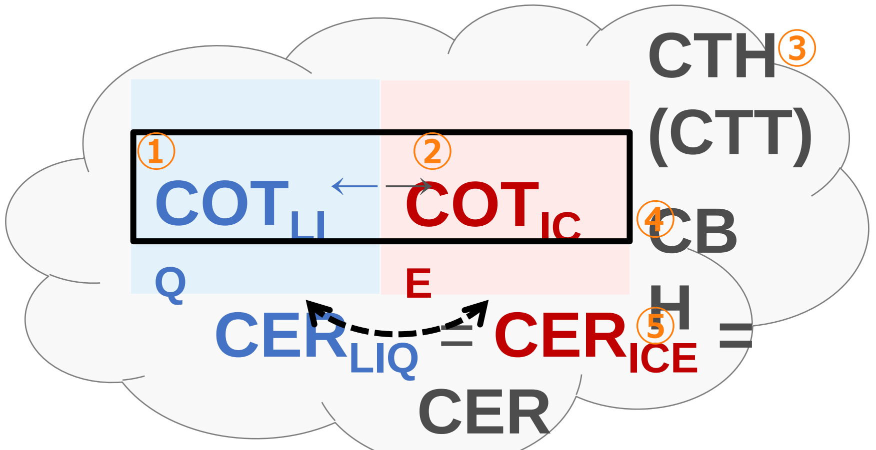


The negative BTD suggests liquid water clouds, consistent with the CALIPO-derived cloud phase.

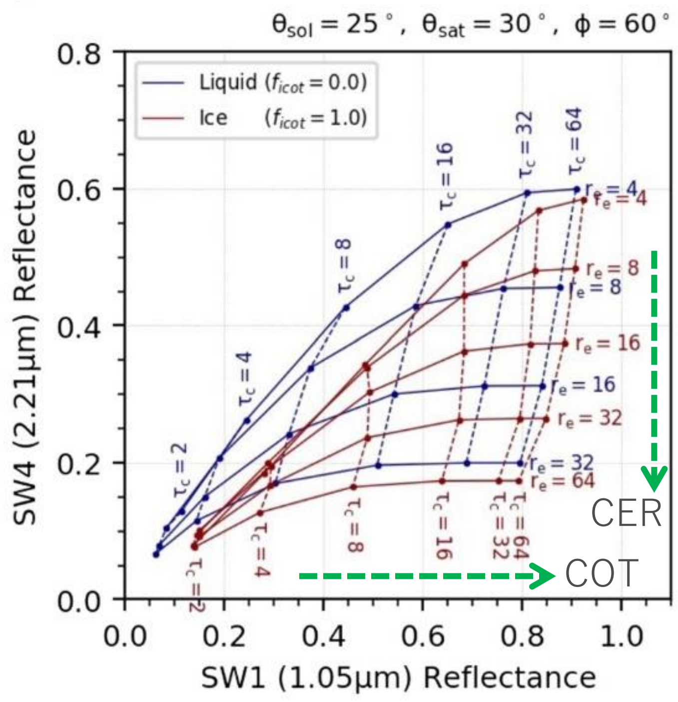
The positive BTD suggests ice-phase clouds, consistent with the CALIPO-derived cloud phase.

Principle of the retrieval algorithm

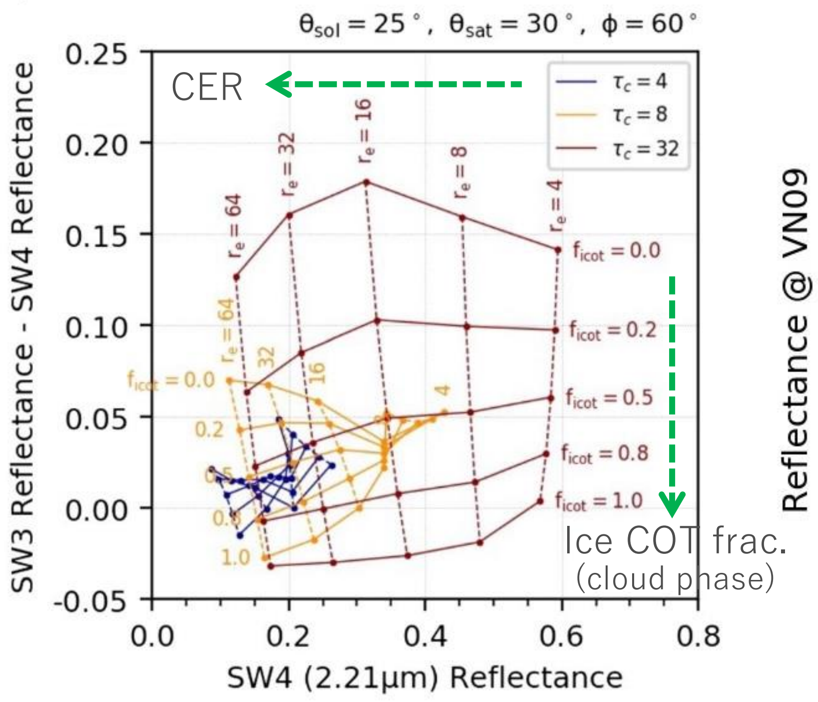
- Based on the combination three retrieval techniques:
  - (1) **COT & CER from VNR & SWIR**
  - (2) **CER & Cloud phase (Ice COT fraction) from SWIRs**
  - (3) **CTH & CGT from TIR & O_2 A-band**
- Assumes a plane-parallel layer with mixed LIQ & ICE
- Retrieves 5 variables with at least 5 channels of SGLI
- Searching a solution w/ LM iteration + OEM



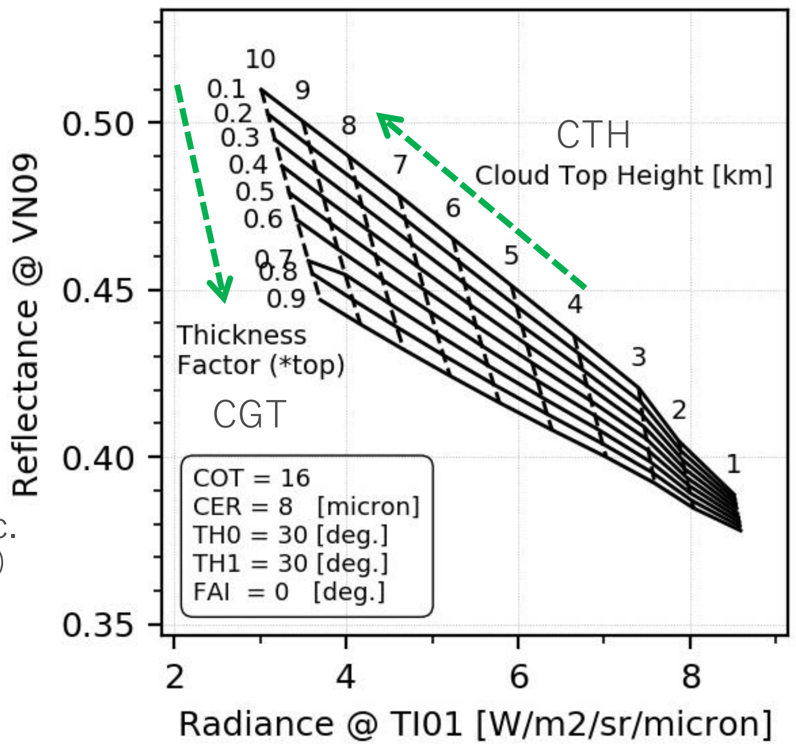
a) 1) COT & CER separation



b) 2) CER & cloud phase separation



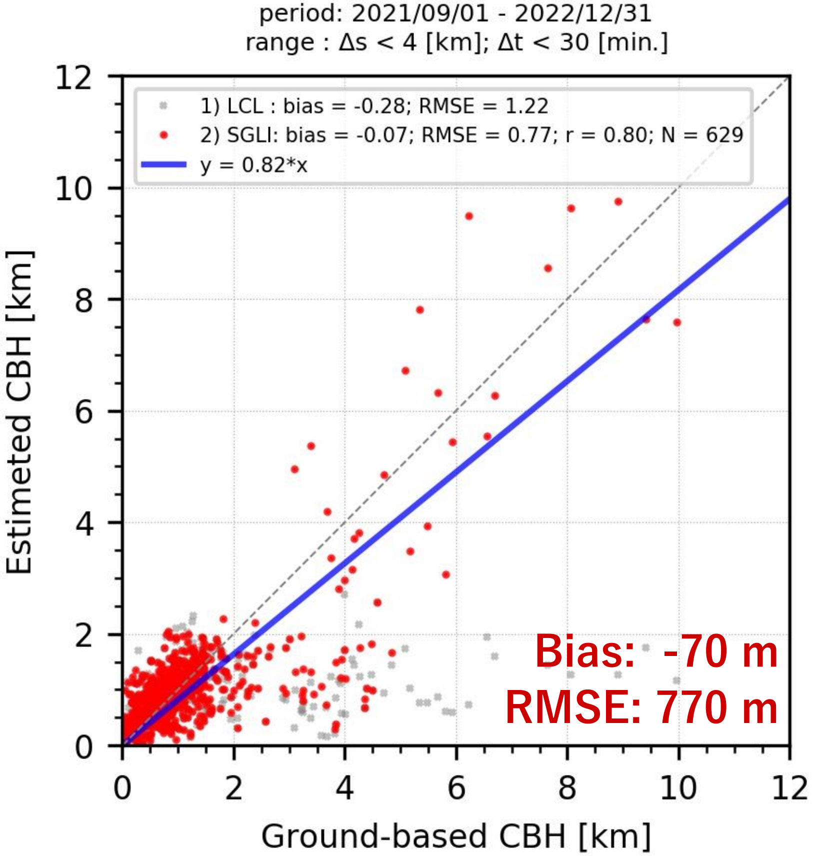
3) CTH & CGT separation



Validations with ground-based measurements

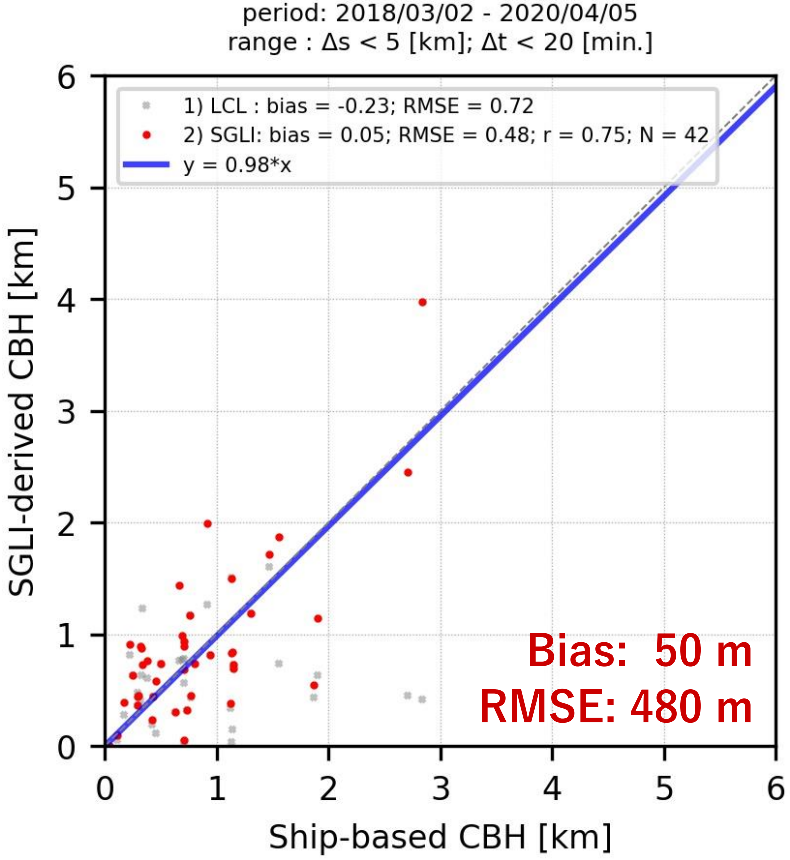
Cloud Base Height

vs. EUMETNET E-PROFILE (Ceilometer)



Cloud Base Height

vs. Ship-borne Ceilometer

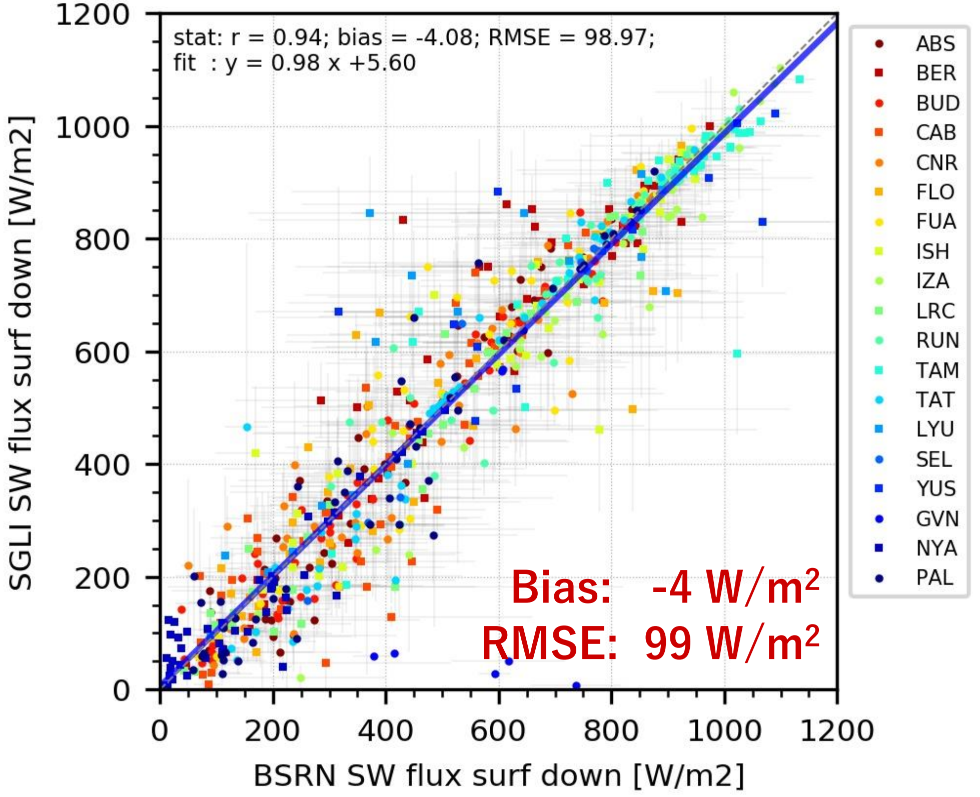


† Target accuracy
- CGT of water clouds ：300 m (Scene)
- CTH ：1 km (Scene)

Validation with ground-based measurements

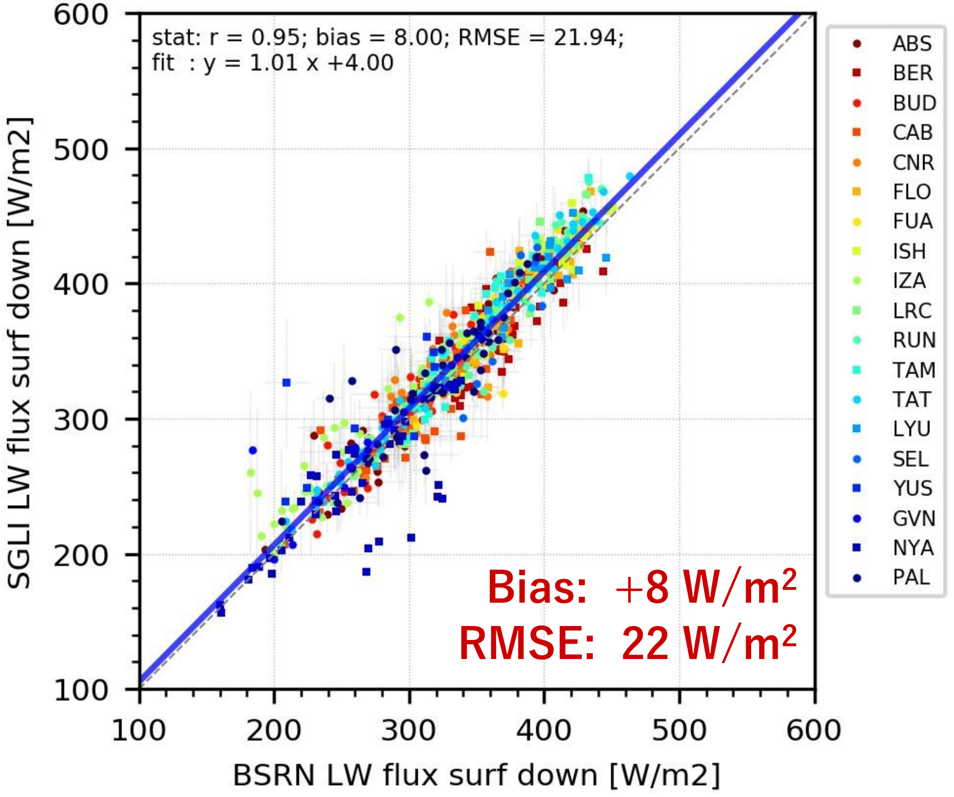
Downward SW flux (all-sky)

vs. BSRN



Downward LW flux (all-sky

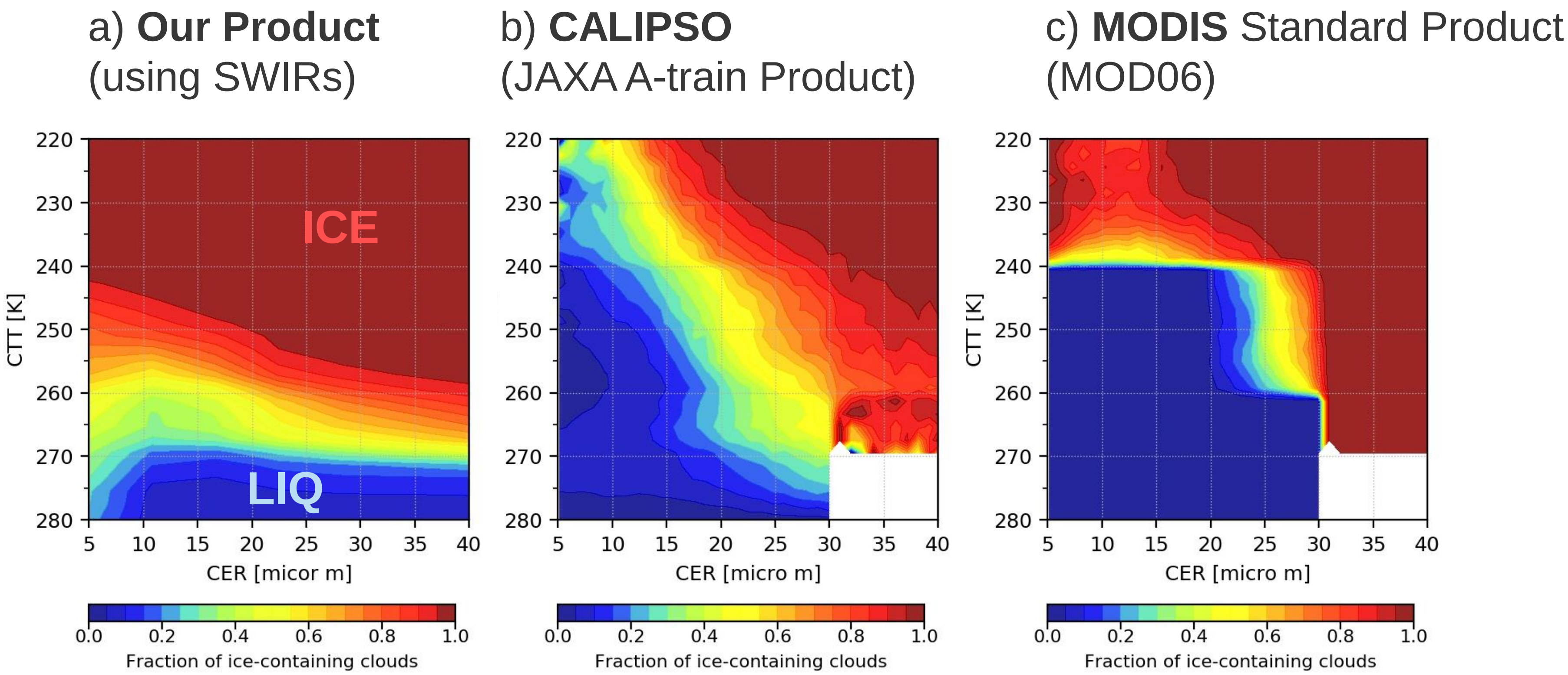
vs. BSRN



† Target accuracy
- Downward SFC LW： 10 W/m² (0.1 deg., monthly)
- Downward SRC SW：13 W/m² (0.1 deg., monthly)

Comparison of satellite-based cloud phase

< Fractions of Ice-Containing Clouds >



✓ Difference in ice cloud fraction change with respect to CTT

→ Need to investigate if the difference is due to algorithms or sensors

✓ MOD06 is likely to misidentify ice clouds as liquid water clouds.

- The CERs in b) c) and d) are obtained from MOD06. The absence of CER > 30 μm is probably is due to the maximum value of the liquid cloud CER of 30 μm in MOD06.

Title

タイトル