Clouds, their Properties, and their Climate Feedbacks: A symposium to celebrate William B. Rossow's science contributions and retirement, Davies Auditorium of the Shapiro Hall, Columbia University, New York,NY, June 6-8 2017

From CloudSat-CALIPSO to EarthCARE and new ground-based instruments

Hajime Okamoto, Kaori Sato and Shuichiro Katagiri
(RIAM, Kyushu University)

Profs. Rossow & Raschke in Tohoku University 2005

Prof. Rossow visited Tohoku University in Sendai, Japan, twice.
FOUR lectures for graduate students during his first visit on February 20 - 26, 2005.

Stimulating a student
in Sendai 2005.

During his second visit to Sendai, he gave two keynote lectures in International Symposium "Climate Change: Past and Future" in Tohoku University in 2006 (*21st Century Center of Excellences program) .

His suggestions to young scientists and students : (In the slide)

SKILLS NEEDED

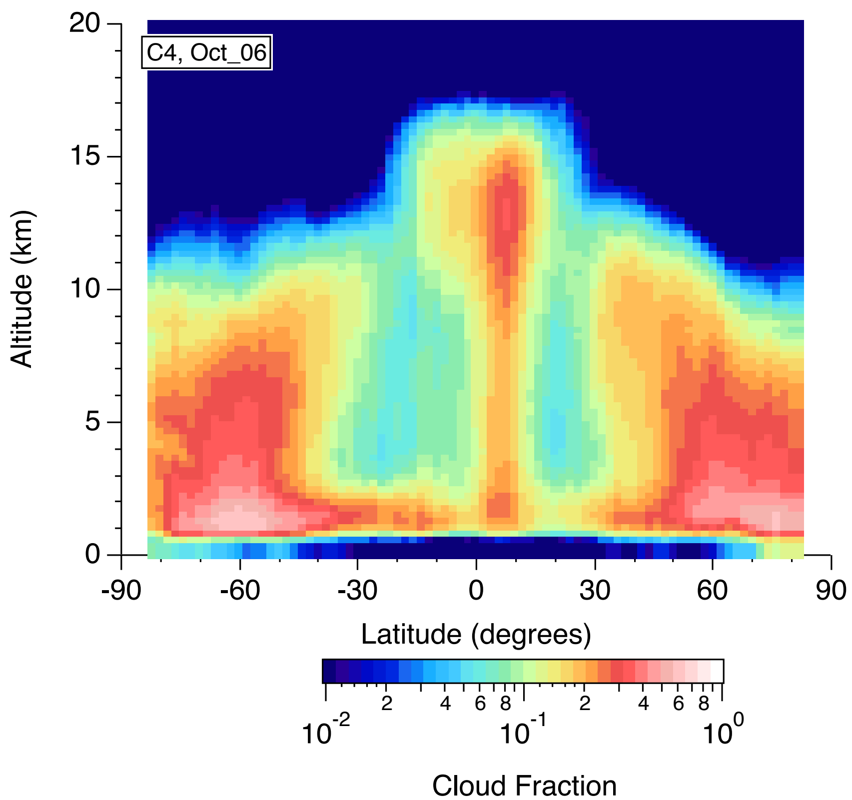
METHODS FOR CAREER ADVANCEMENT

Read (Everything) and Talk (to Everybody),

Get Out of the Office, Ask Questions, Make Choices

Keynote lecture at Sendai International Center February, 2006.

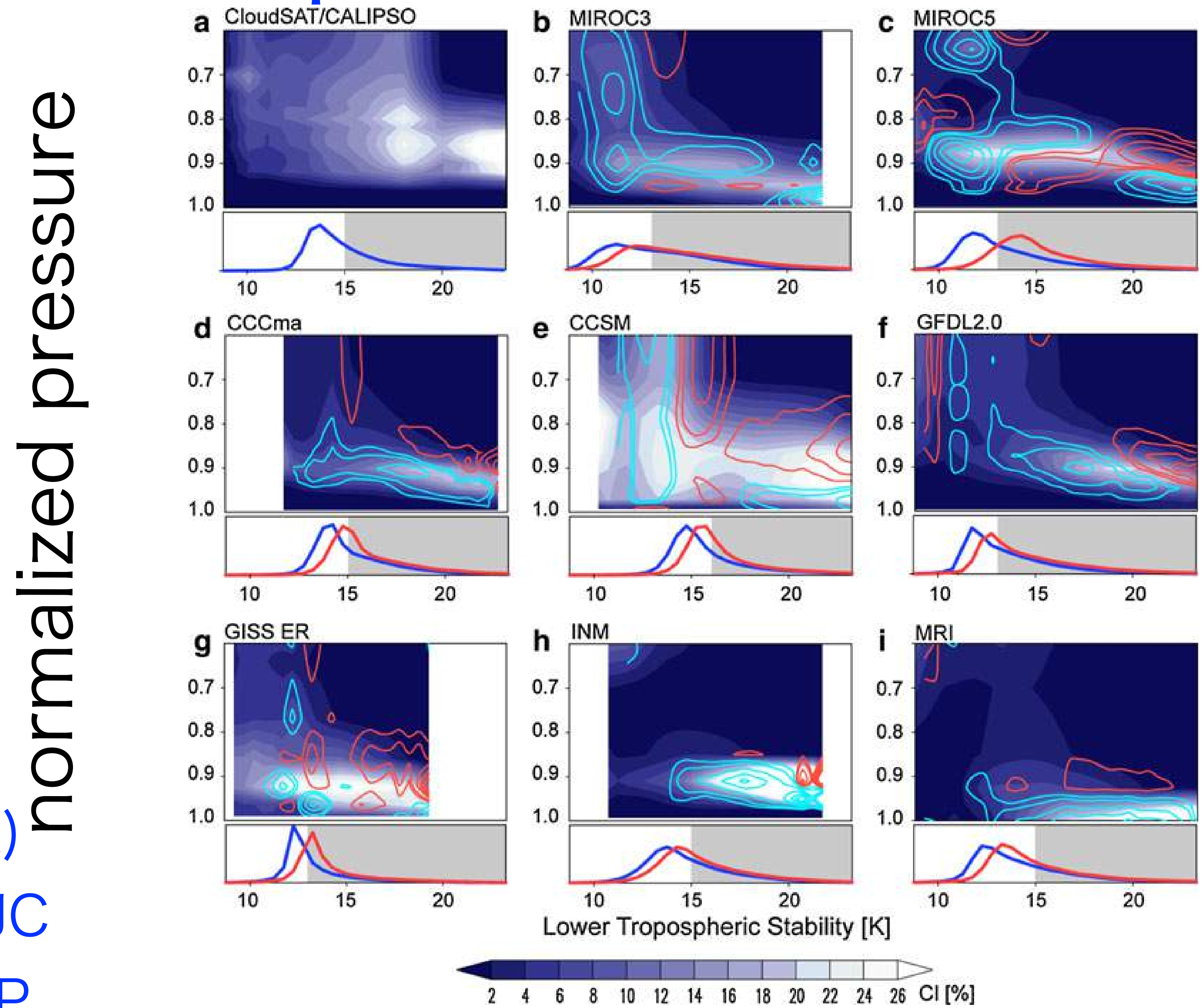
1.KU-mask: CF sorted by Lower Tropospheric Stability [K] in southern tropical ocean.



Cloud fraction from KU-mask (Hagihara et al., 2010JGR)

Rossow and Zhang 2010 JC for comparison with ISCCP.

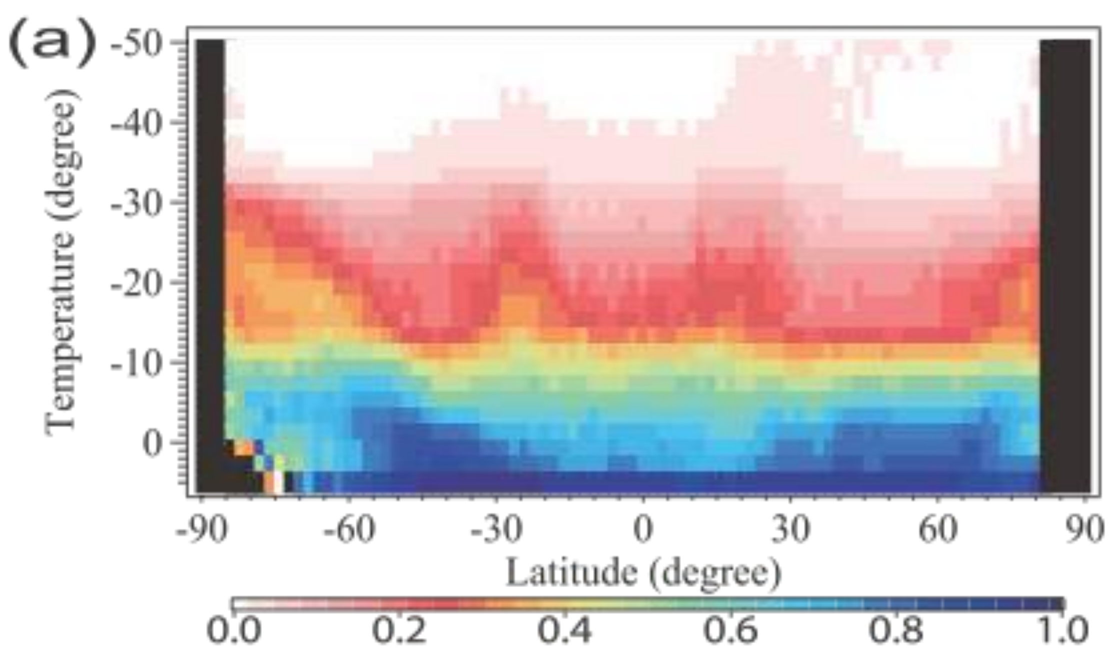
Vertical distribution of low cloud for LTS differs among GCMs and they failed to reproduce obs..

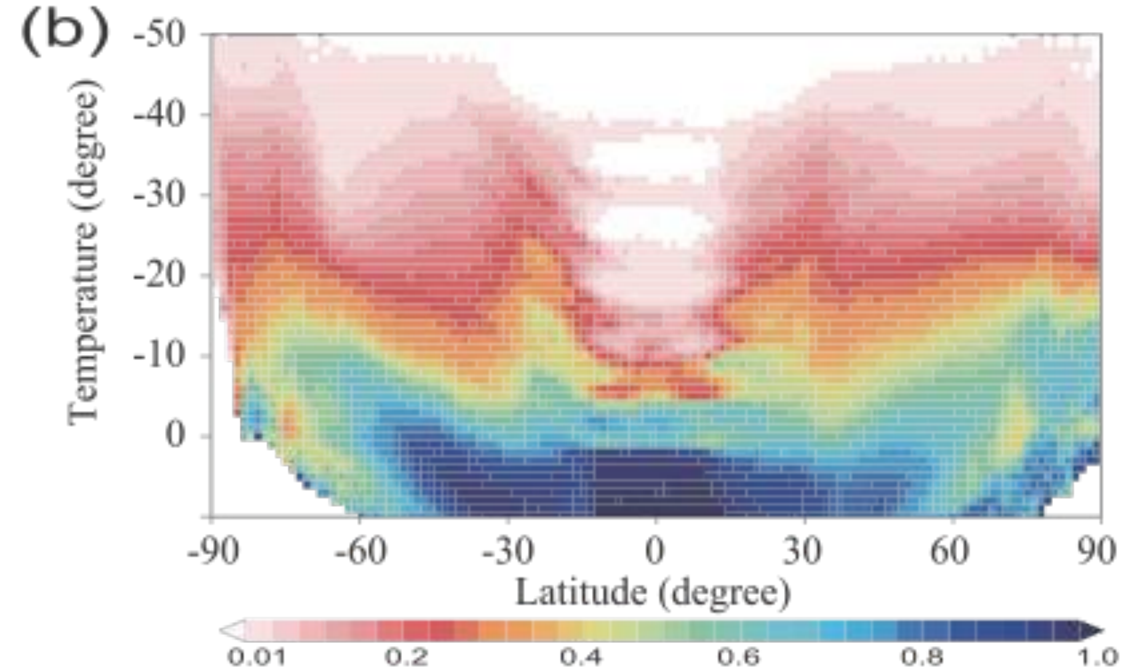


Lower Tropospheric stability [K] defined as difference in potential temperature between the 700 and 1000hPa levels.

(Watanabe et al., 2011Clim Dyn)

2. KU-type:
Zonal mean property of water-ice ratio on temperature agrees between KU-type for CALIPSO and GCM.

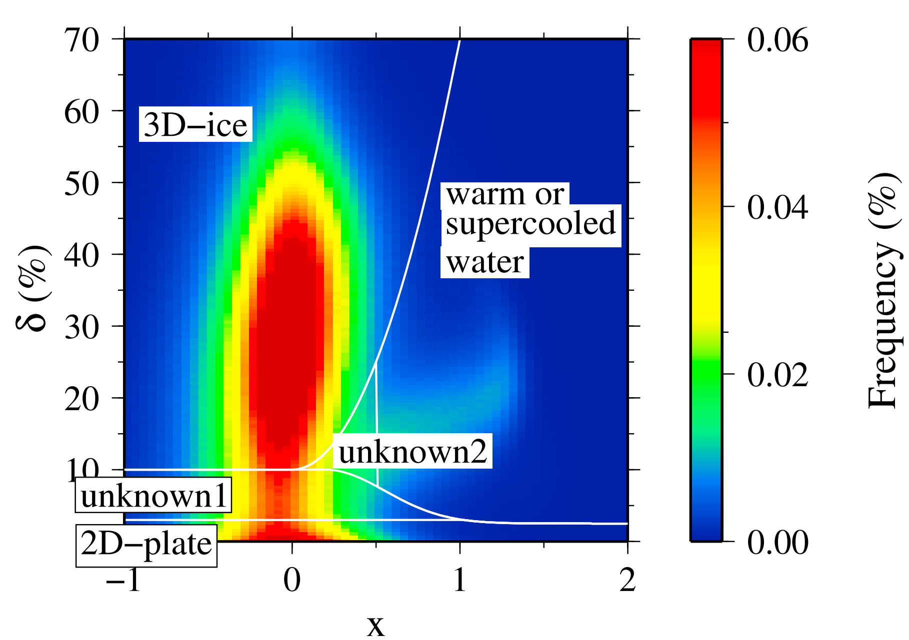




ice water ice water

KU-type products

MIROC 5 GCM



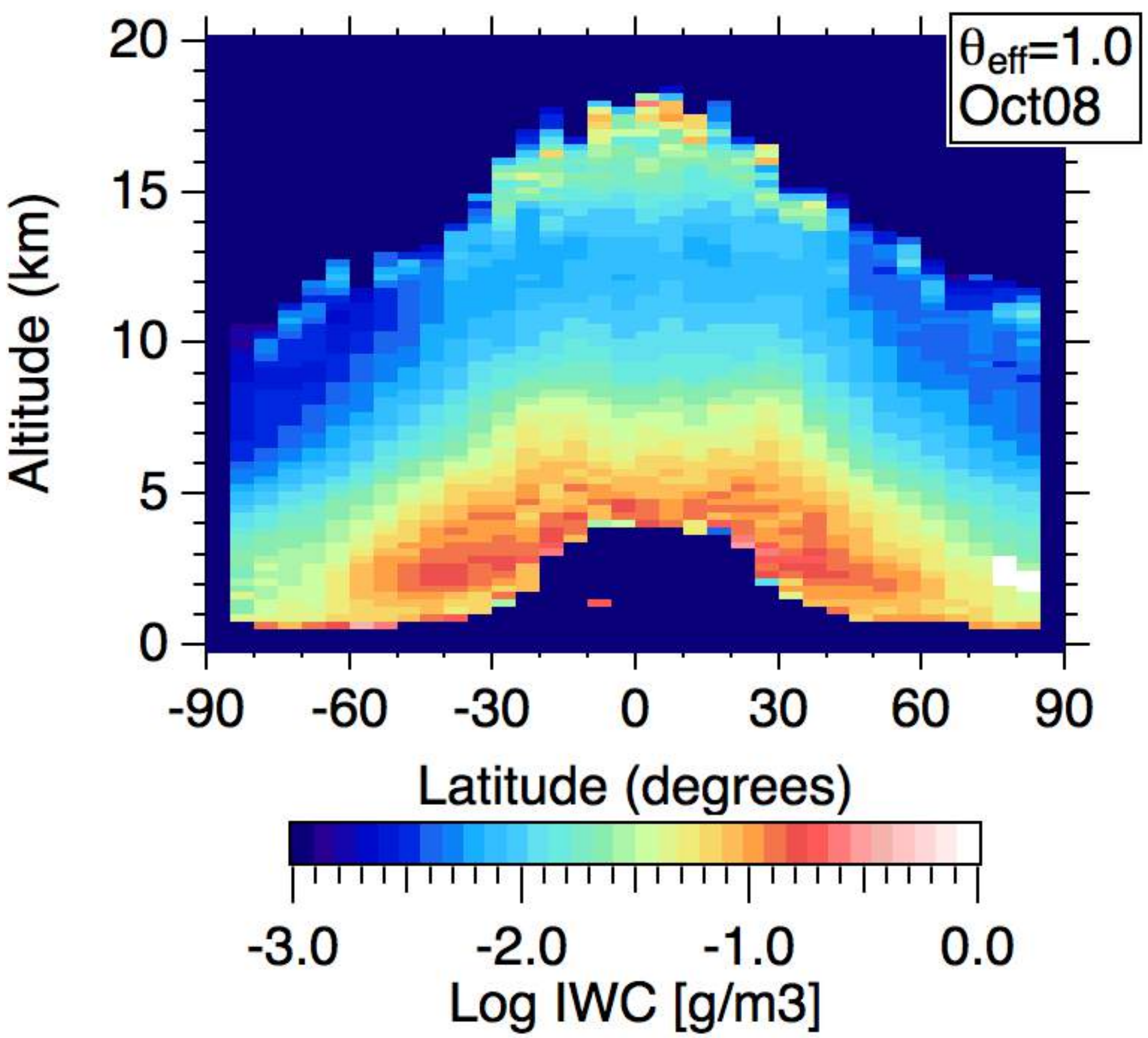
(Watanabe et al., 2010 J. Climate)

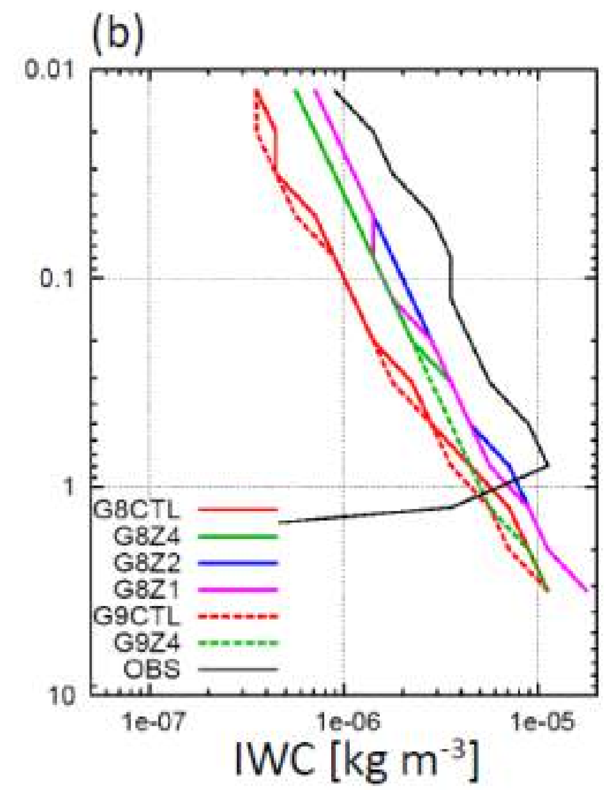
δ-X' diagram was used for ice/water partition.

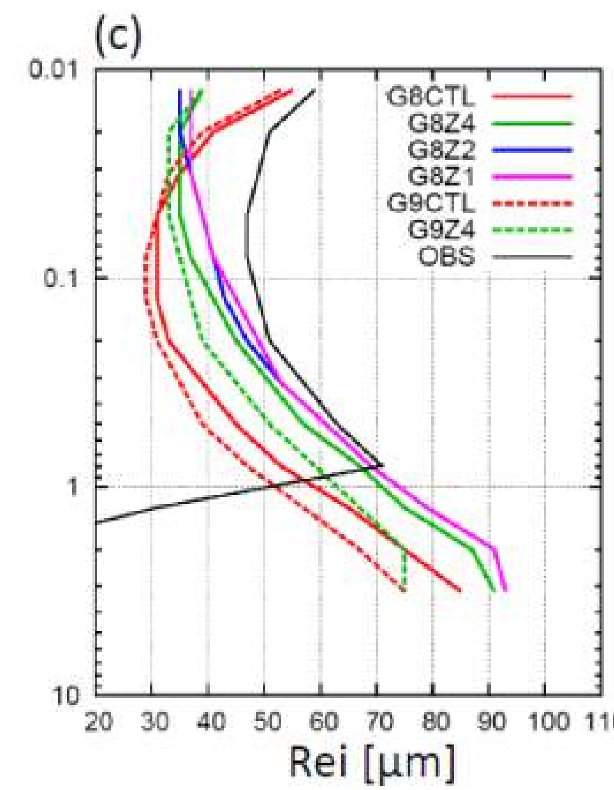
$X' = \log(\beta_i/\beta_{i+1})$

(Yoshida et al., 2010 JGR)

3. KU-micro: Global distribution of ice microphysics from CloudSat-CALIPSO and evaluation of NICAM.





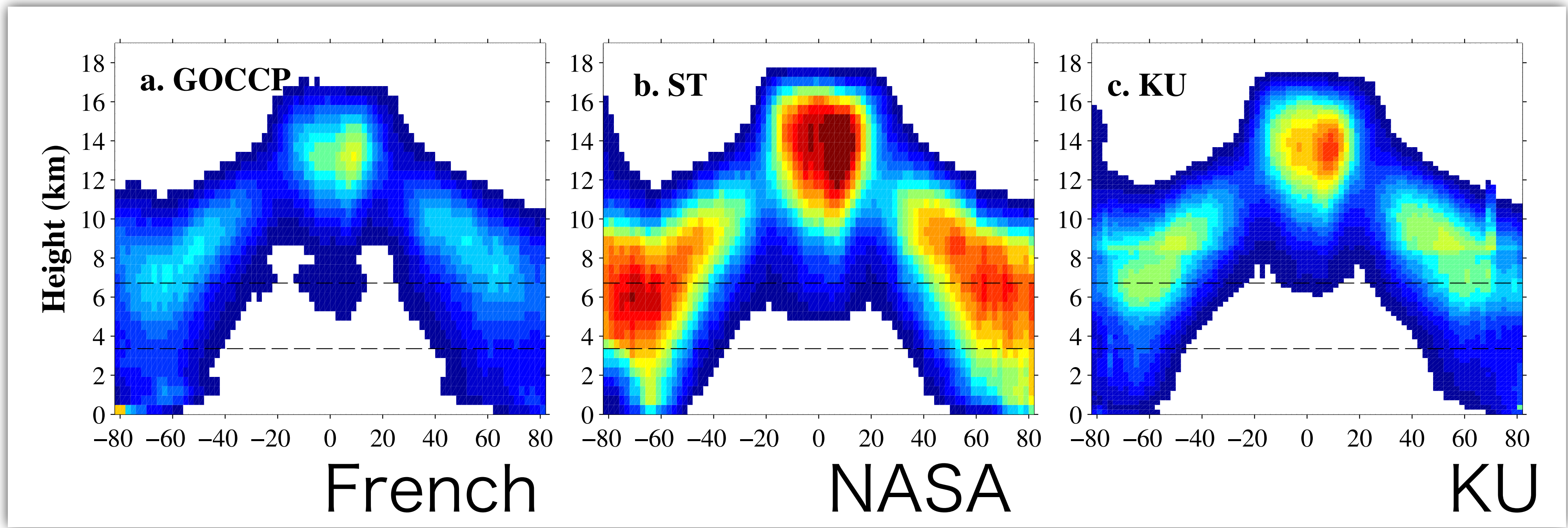


KU-micro
(Okamoto et al., 2010 JGR,
Sato and Okamoto 2011 JGR)

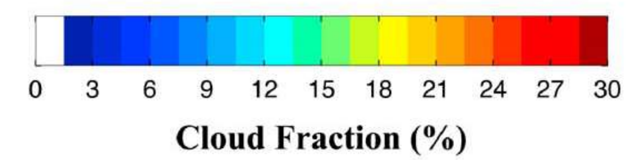
IWC in NICAM is underestimated in tropics. Vertical grid spacing <400m is necessary when NICAM with ΔH=14 and 28km in tropical cirrus.

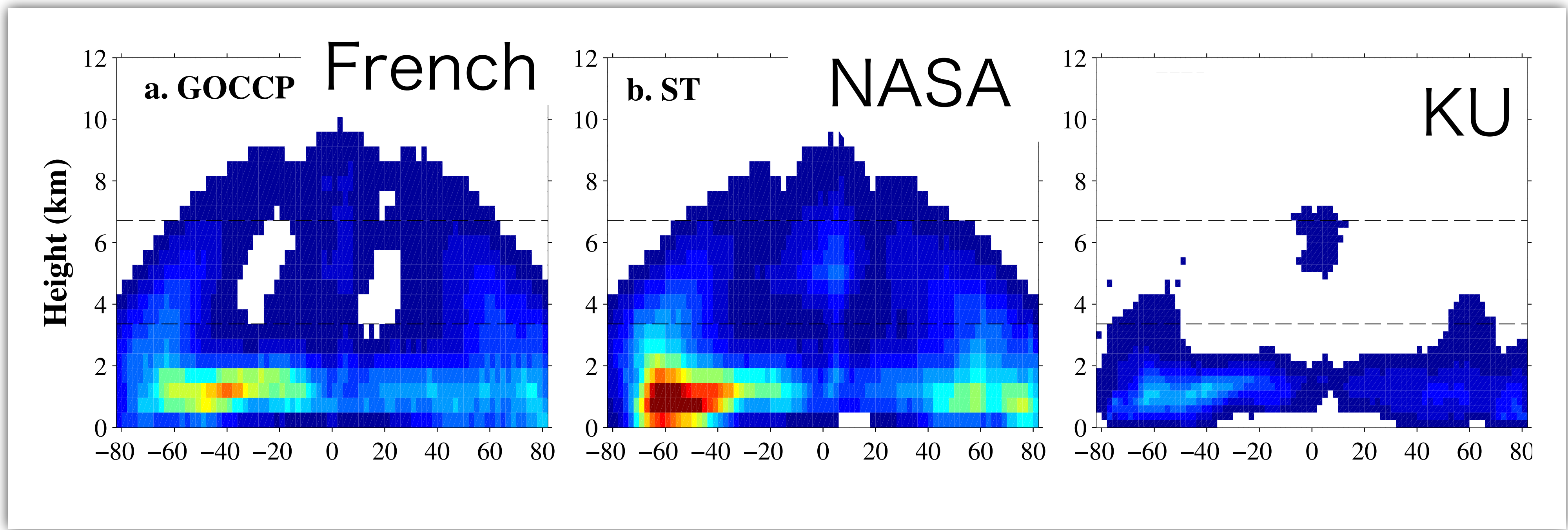
(Seiki et al., GRL 2015)

4. Differences in cloud fraction and water-ice partitions are large in three CALIPSO global products



ice cloud fraction





water cloud fraction

Cesana et al., 2016 JGR

due to different treatment of clouds/aerosol partitions, resolutions, fully attenuated pixels, multiple scattering

5. Development of Multi-Field of View Multiple Scattering Polarization Lidar (MFMSPL)

Simulation of space-borne lidar signals becomes possible.

8 telescopes are used and total FOV ~ 70mrad.

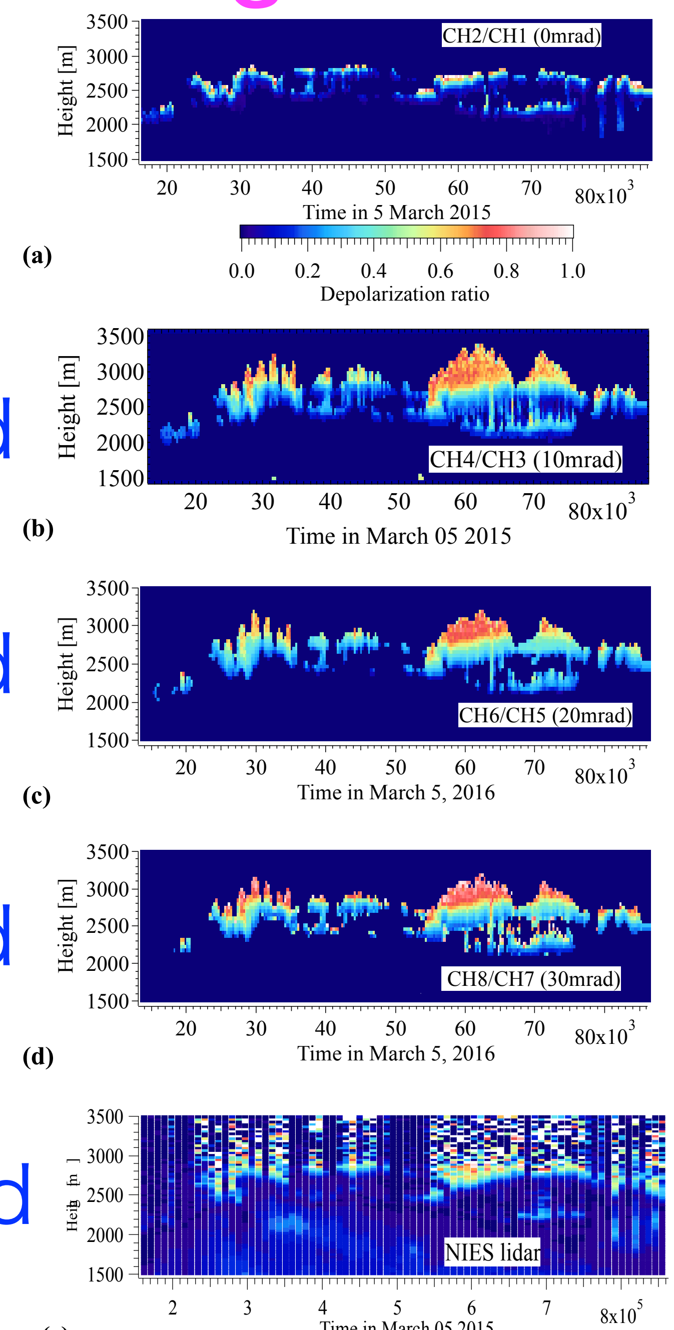
vertical

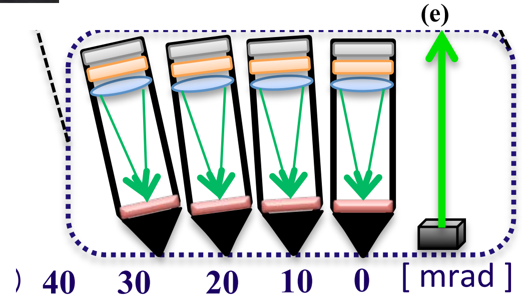
10mrad

20mrad

30mrad

40mrad



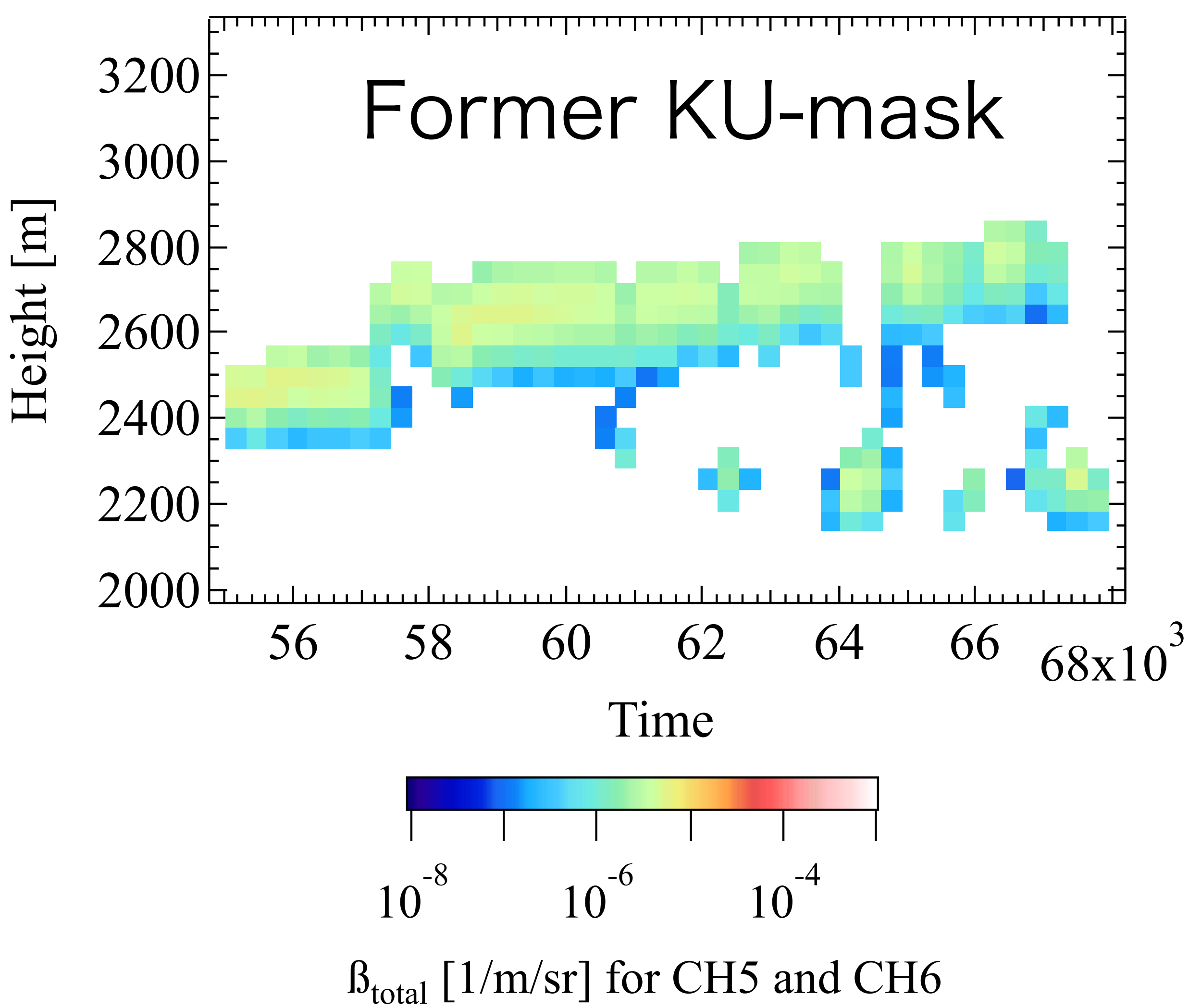


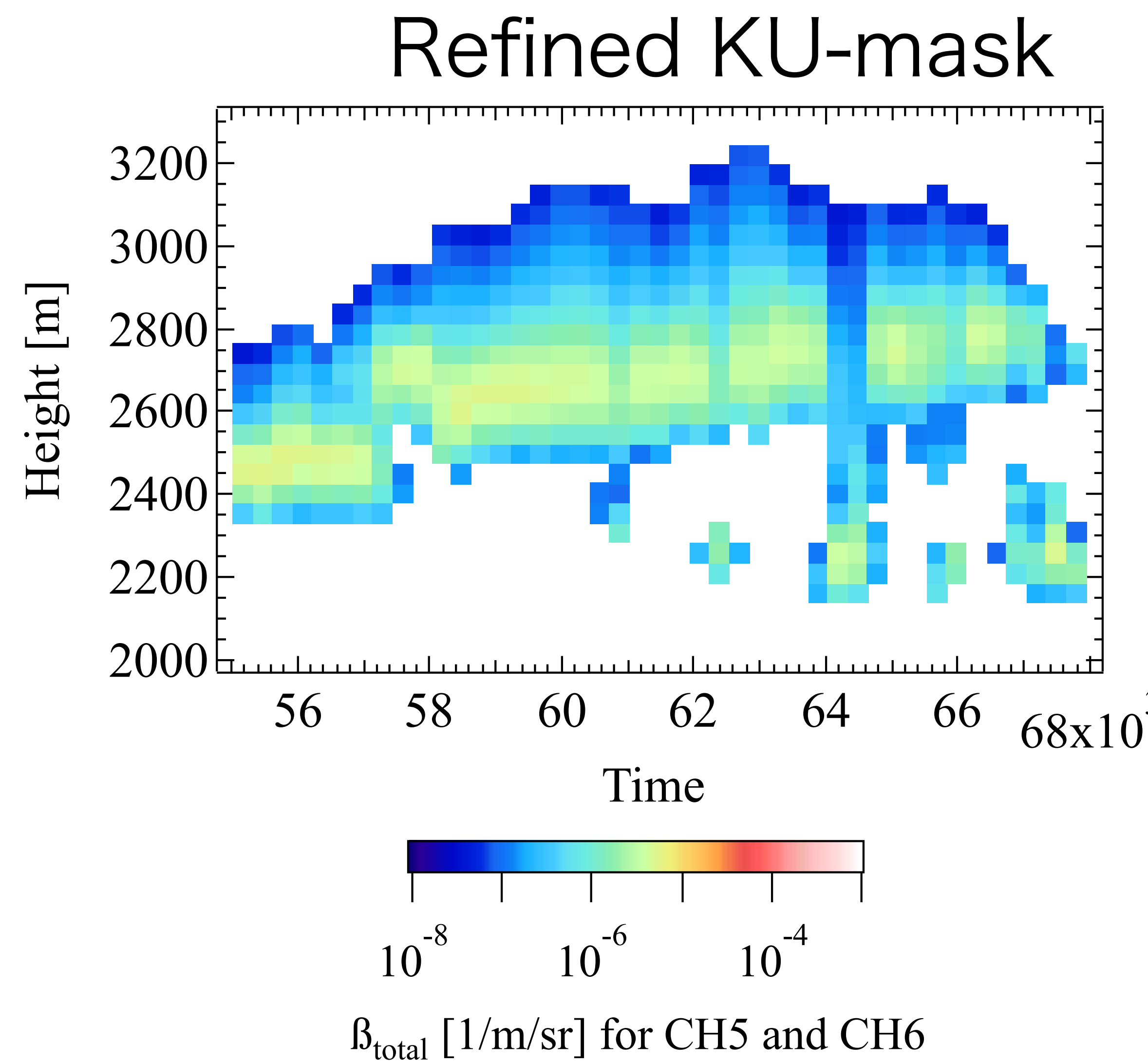
This is the first time that **depolarization** ratio for **optically thick clouds** was observed by ground-based lidar.

(Okamoto et al., 2016, Opt. Express.)

5-1. Refinement of cloud mask scheme
: using MFMSPL data in Tsukuba.

Current KU-mask underestimated cloud fraction in large τ.
Refined scheme overcomes the issue mainly by using different discrimination schemes at/below cloud top (above cloud bottom) for space-borne (ground-based) lidar.

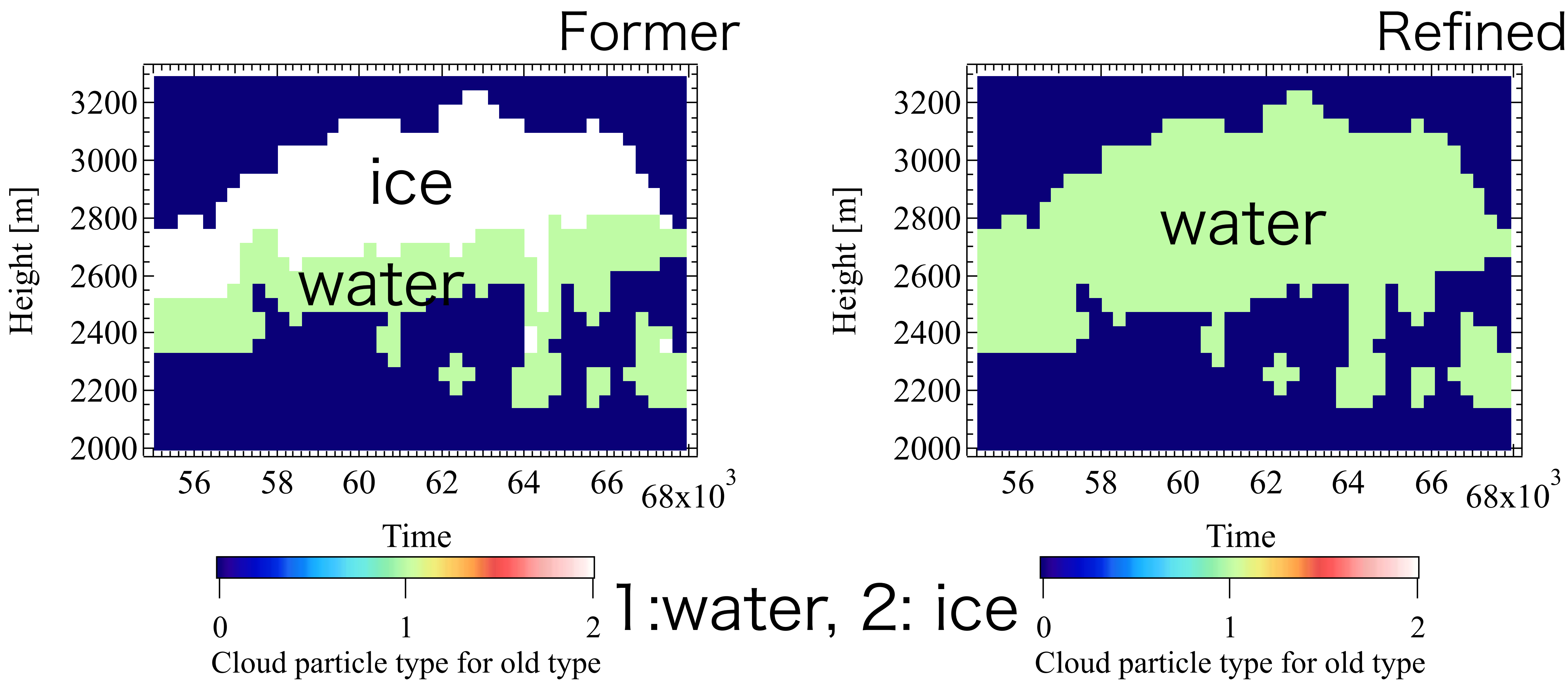




Okamoto et al., 2017 (in press)

5-2. Refinement of cloud particle phase algorithm by MFMSPL

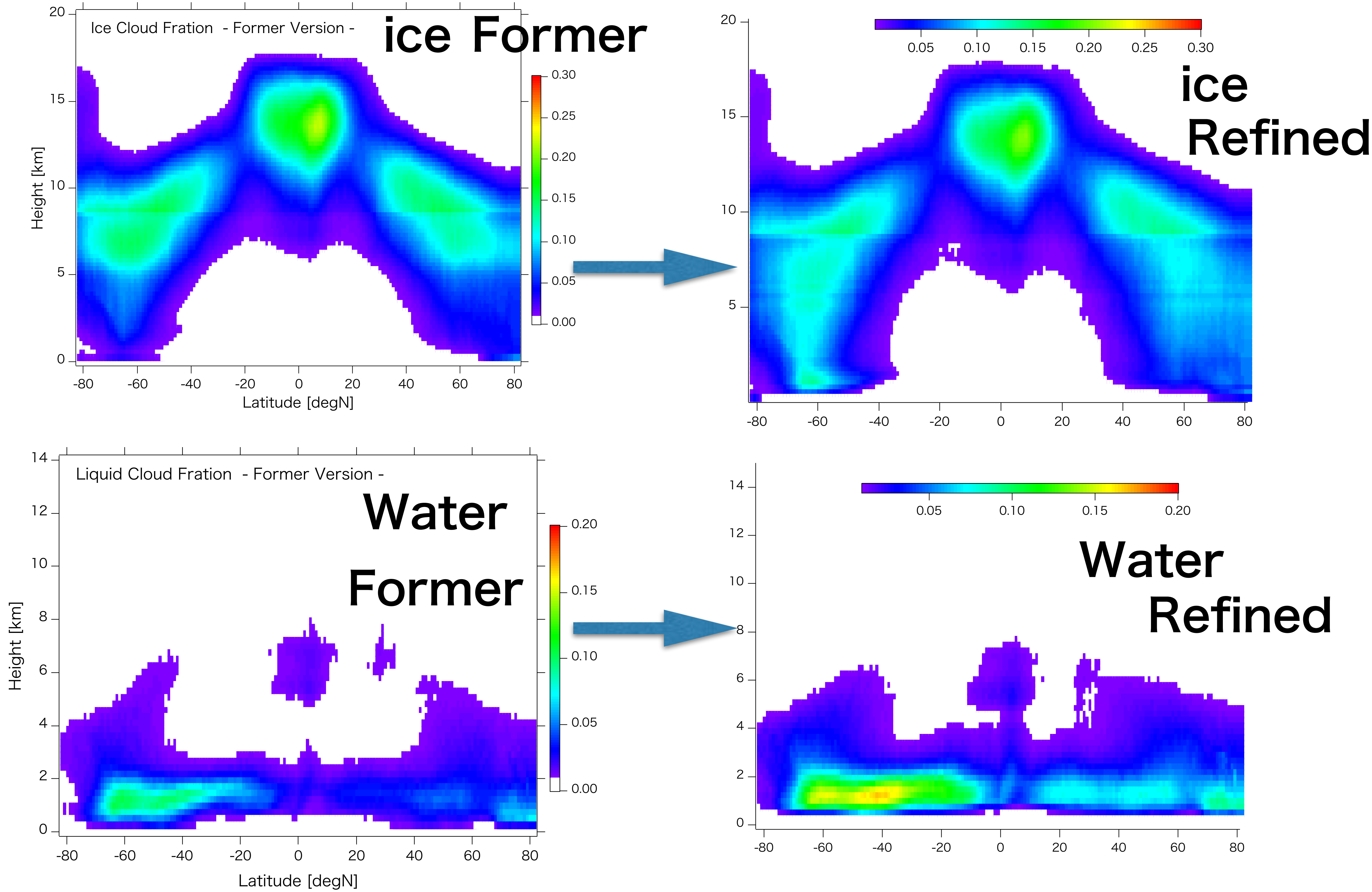
Former algorithm misclassified water as ice in regions where lidar signals are heavily attenuated. It leaded to underestimation of water cloud fraction. Refined algorithm overcomes the issue.



Okamoto et al., 2017 (in press)

5-3. Global analyses of ice and water cloud fraction: former versus refined schemes

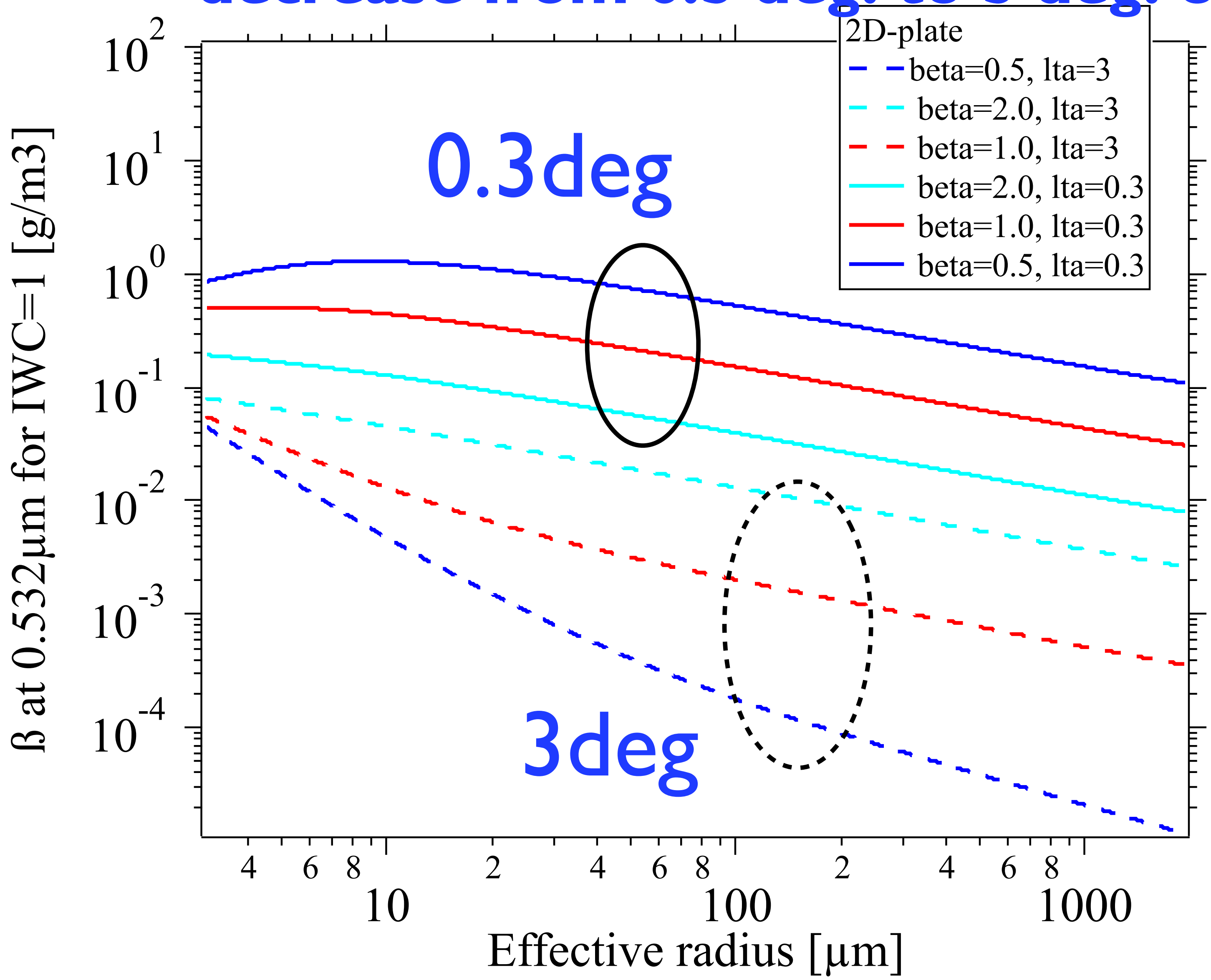
Low level water cloud fraction increases in refined scheme.

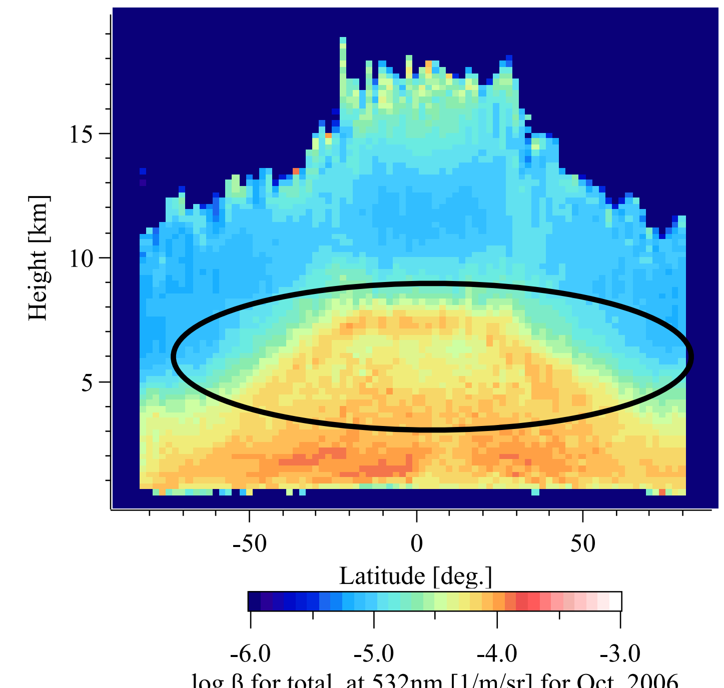


6. Revision of KU-micro for ice.

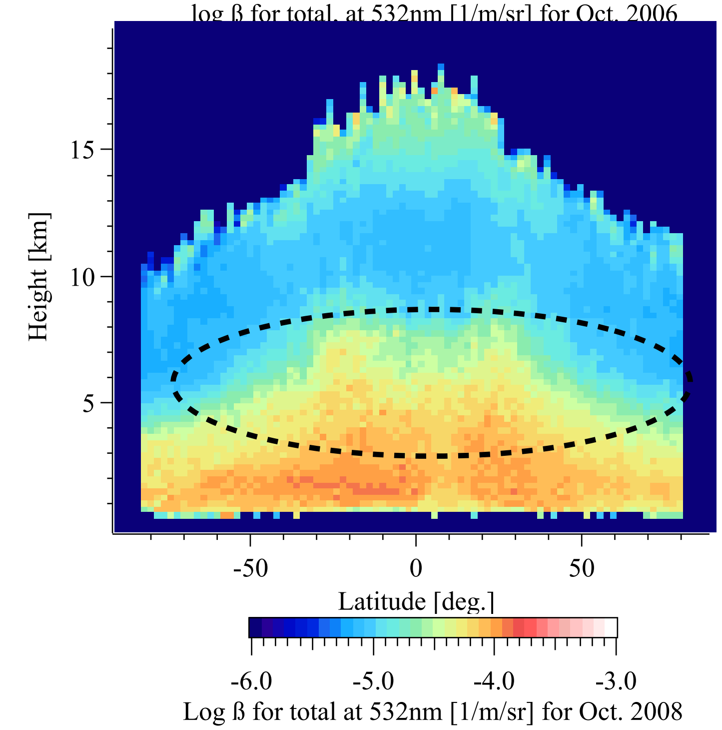
Refined look up tables for CALIPSO

Observed ß of radar-lidar overlapping ice clouds showed large decrease from 0.3 deg. to 3 deg. off nadir, i.e., after Nov.2007.





Oct.2006 CALIPSO nadir period (0.3deg.)

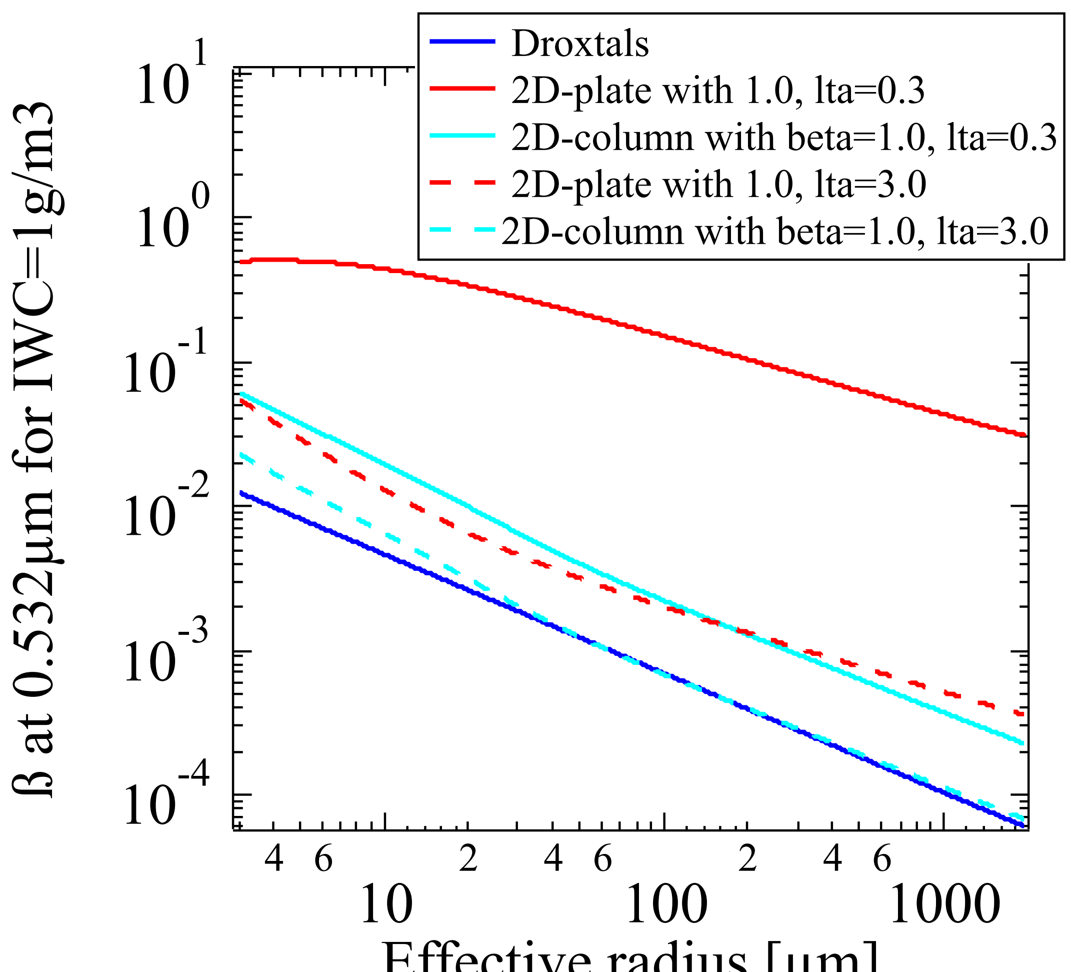


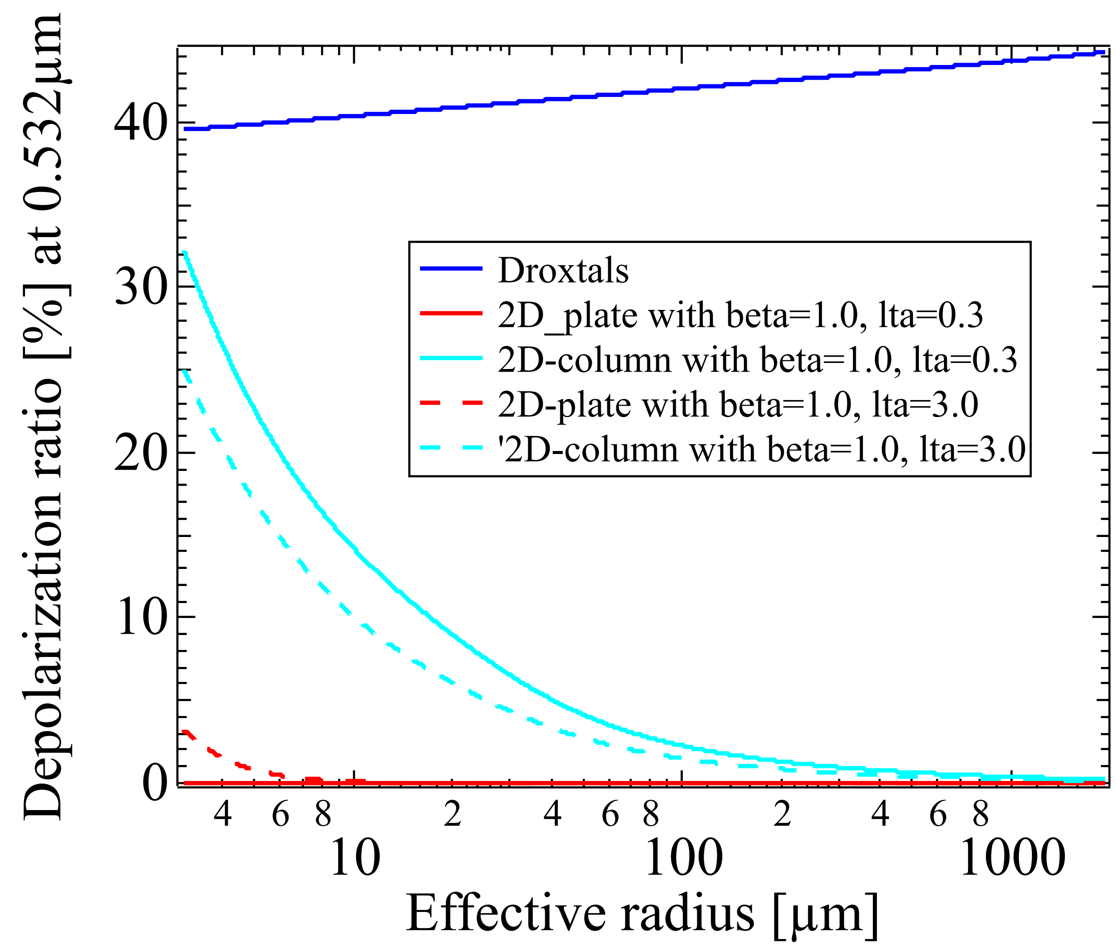
Oct.2008 off-nadir period (3deg.)

Backscattering coefficient of oriented ice plate depend on the detail of how they orient in horizontal plane.

6-2. Retrieval of ice microphysics from CloudSat-CALIPSO, Refined look up tables for CALIPSO analysis

to allow continuous retrievals of ice microphysics during whole CALIPSO and EarthCARE observation periods.





Physical optics was applied for ice particle models (Borovoi et al., 2012). Horizontally oriented ice plate model (2D-plates) could produce more than one order larger backscattering for nadir period (0.3 degrees-off nadir) than for off-nadir (3 degrees-off nadir) period, which is consistent with CALIPSO observations.

7. EarthCARE (Earth Clouds Aerosol Radiation Explorer)
JAXA-ESA joint mission

launch date : 2018
altitude : 393.14km

1. 94GHz Doppler cloud radar (CPR)

2. 355nm high spectral resolution lidar (ATLID)

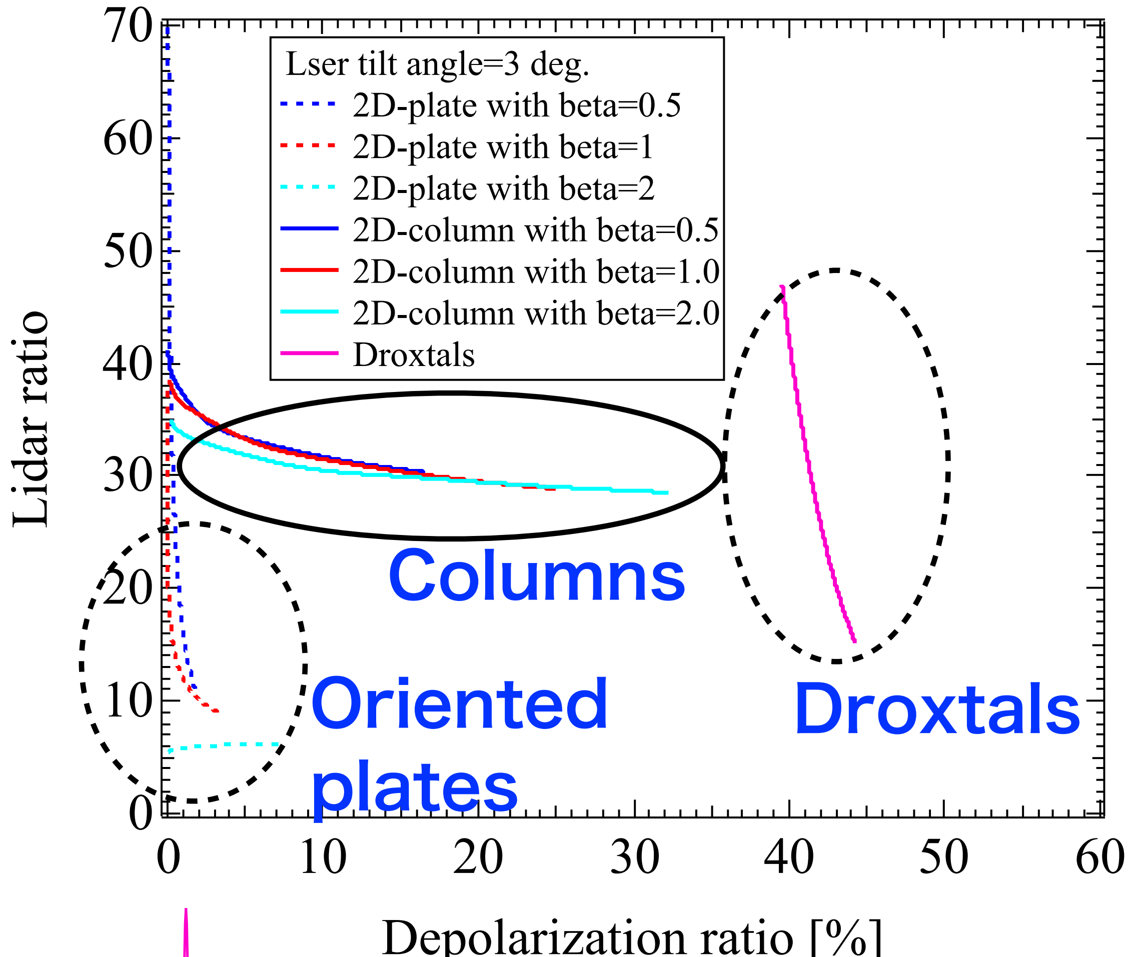
3. Multi-spectral imager (MSI) 7channels (0.69, 0.865, 1.65, 2.21,8.8, 10.8, 12.0μm)

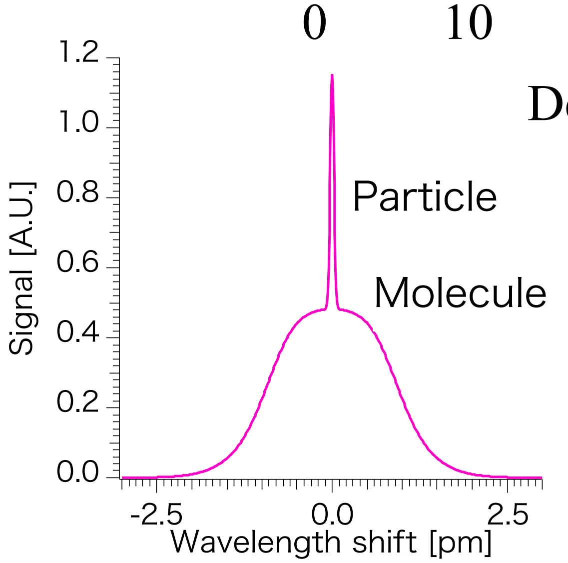
4. Broad band radiometer (BBR) 3 views

(Illingworth et al., 2015 BAMS)

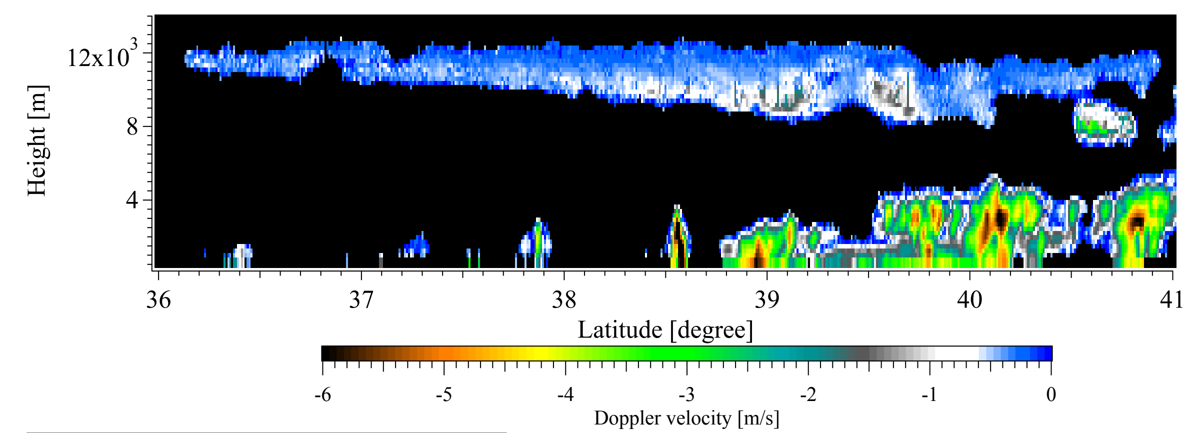
7. Expected products from EarthCARE with HSRL and Doppler capability

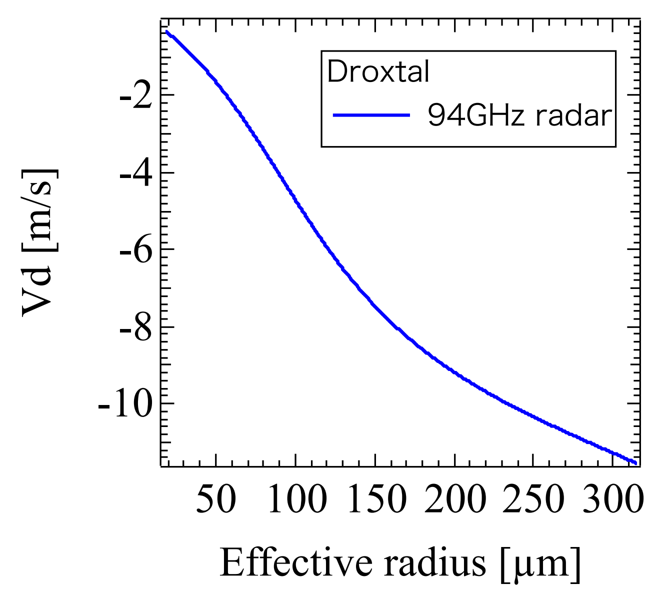
Ice particle type from HSRL function of ATLID

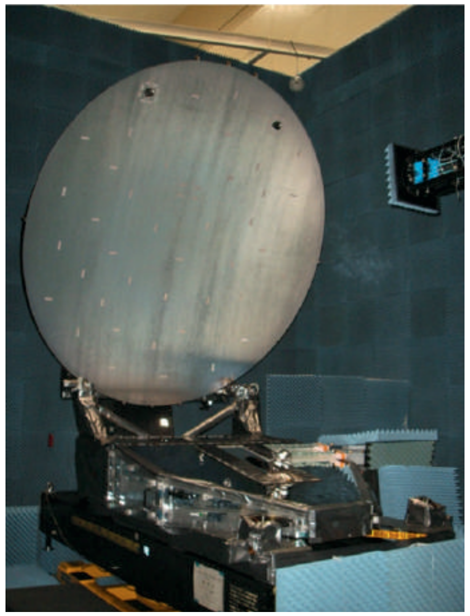




Simultaneous retrievals of vertical air motion, particle fall speed and particle mass flux from CPR-ATLID.







to evaluate cumulus convective parameterization and cloud parameterization

Summary

1. Refined KU-mask shows increase of low-level cloud fraction.
2. Refined KU-type shows increase of water cloud fraction.
3. LUTs for ice particles are updated in order to bridge the gap in retrieved microphysics among nadir- and off-nadir CALIPSO periods and also EarthCARE.
4. Fast semi-analytical approach for lidar multiple scattering is developed. Water microphysics is retrieved by CALIPSO(Sato's presentation).
5. Multiple scattering polarization lidar is developed and extension is planned to connect CALIPSO and ATLID on EarthCARE information.
6. EarthCARE is expected to provide vertical air motion, better particle typing, and cloud mass flux by Doppler function of CPR and high spectral resolution function of ATLID.

Thank you.

Get out of the office..

In Matsushima, 2005

In Sendai 2005

Doppler accuracy of EarthCARE CPR

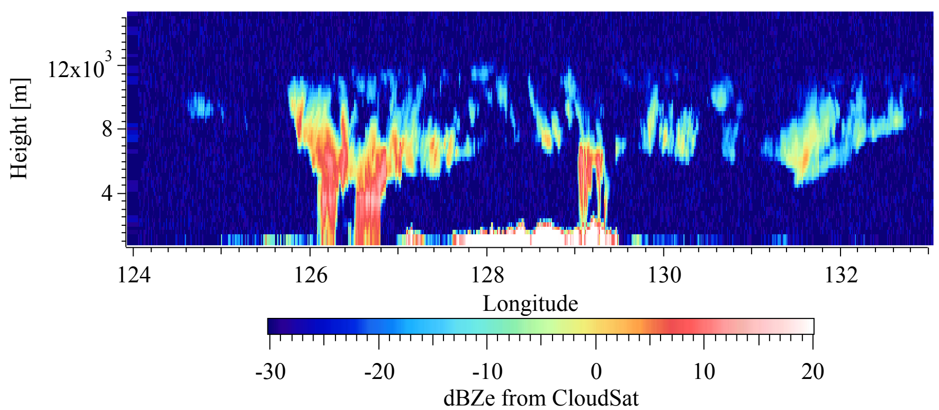
16km mode (PRF=7200Hz)a:

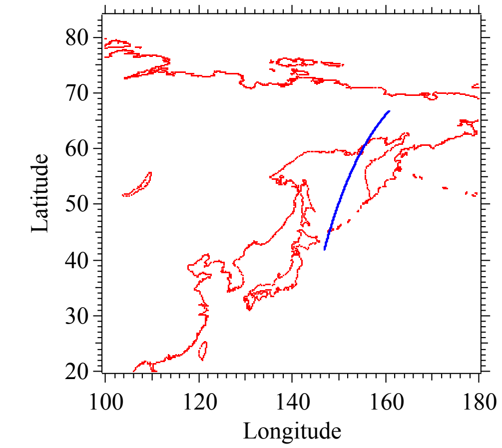
10km horizontal integration:
- 1.1m/s for -19dB (worst case).
- 0.6m/s for -19dB (best case).

1km horizontal integration:
- 1.3m/s for -14dBZ (worst case).
- 0.8m/s for -14dBZ (best case).
- Theoretical limit =0.2m/s

4-2. Refine of ice microphysics from CloudSat/CALIPSO

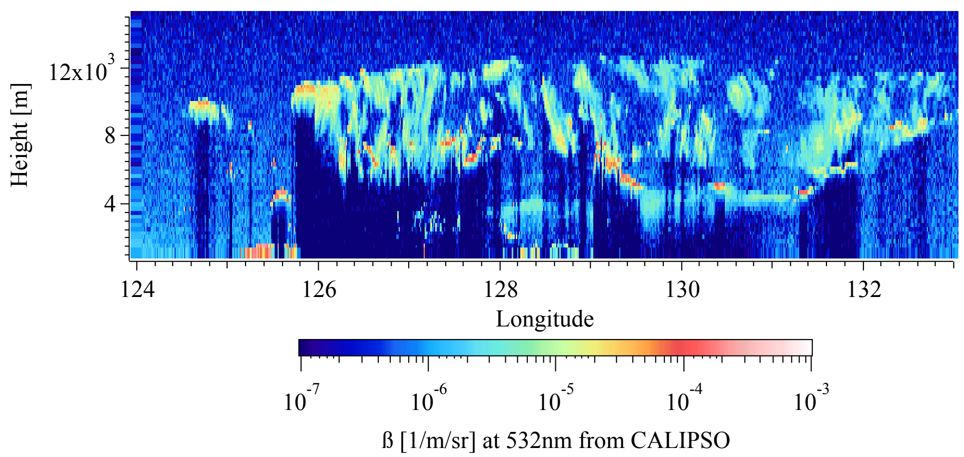
(a)





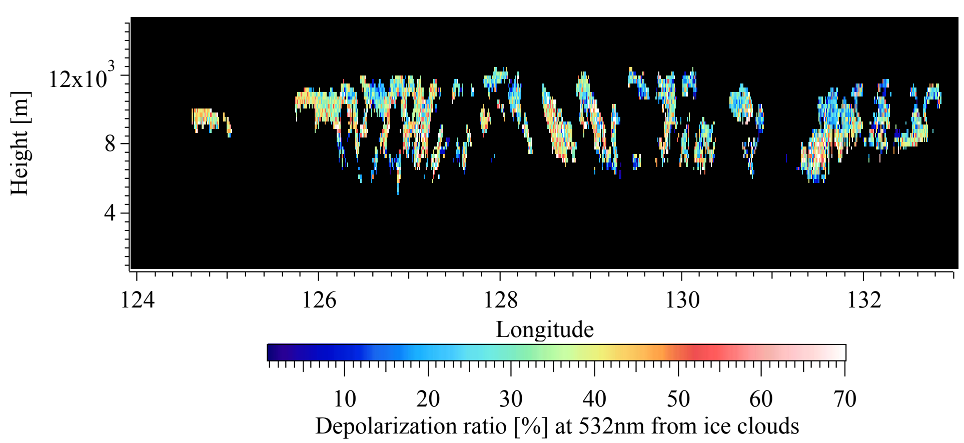
(b)

CloudSat

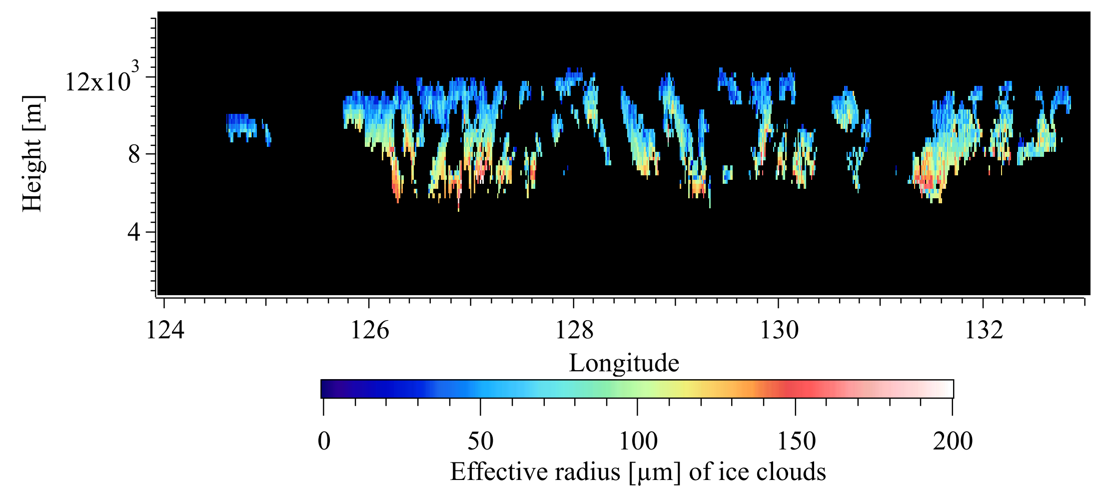


β (CALIPSO)

(c)

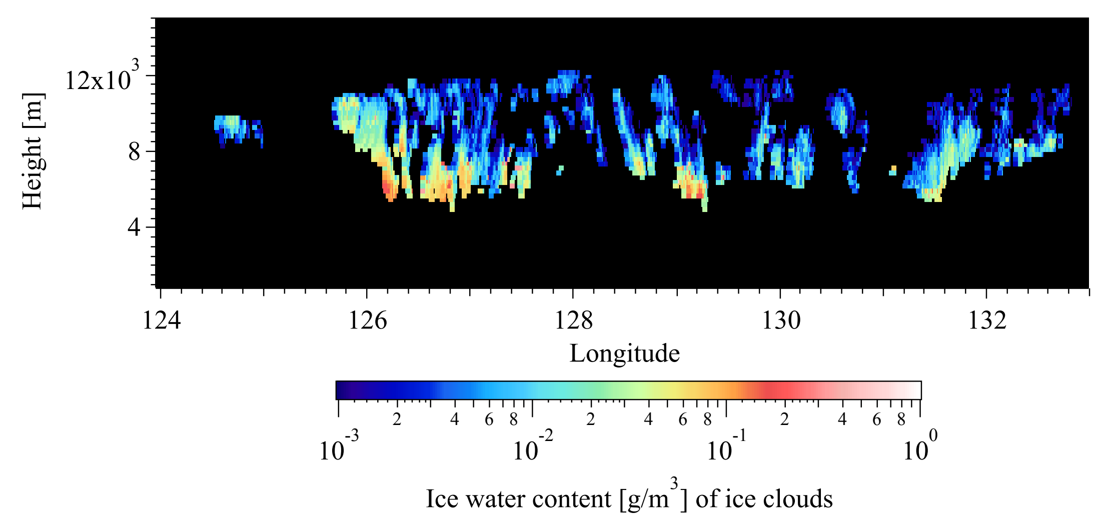


δ (CALIPSO)



(a)

Effective radius



IWC

(Okamoto 2016a)

Challenge and key questions;

1. Can we get sufficient information to test cumulus convective parameterization? Vertical velocity/terminal velocity in cloud only. Do we need clear airs motion?
2. Are accuracy of IWC/LWC and mass flux sufficient to quantify cloud life cycle?.
3. Do we need vertical profile of water vapor, clear sky velocity and aerosols in addition to cloud properties and in-cloud motion?
4. Can we correct non-uniform beam filling effect in Vd-> accuracy of velocity?.
5. Are LWP and IWP by EarthCARE better than those from single use of passive? : climate sensitivity depends on LWP?
6. Convert knowledge to GCMs, e.g., different resolutions.
7. Sufficient to discriminate ice, snow, graupel..?
8. What is the best way to avoid no observations after CloudSat/EarthCARE. note that only three years of EarthCARE. We need long records for climate change studies..

Features of EarthCARE compared with Cloudsat and Calipso

1. Doppler at 94GHz (~1m/s for 10km integration)
2. +8dB sensitivity (-36dBZ) -> better water cloud detection, better overlap between radar and lidar ->better accuracy for microphysical retrievals by radar-lidar.
3. Not suffer from contamination in CPR due to surface clutter in CloudSat ->better model for surface process and convection.
4. High Spectral Resolution Lidar at 355nm for ATLID->robust observations of extinction. Need to bridge the gap between CALIPSO at 532nm and ATLID at 355nm information, i.e., FOV of ATLID ~65μrad and satellite altitude ~400km, foot print size~30m. FOV of CALIPSO~130μrad and its altitude ~700km, foot print size~90m,

1. Overview of KU-algorithms and refinements

1. Cloud mask from CloudSat/CALIPSO (KU-mask)

Hagihara et al., 2010JGR, 2014JGR based on ship-borne lidar. Refined by using the ground-based multiple scattering polarization lidar (MFMSPL) (Okamoto et al. 2016 Opt. Express).

2. Cloud particle type from CloudSat/CALIPSO(KU-type)

CALIPSO-type: **Yoshida et al., 2010JGR** based on Monte Carlo simulations for single cloud layer by CALIPSO. **Refined by MFMSPL**.

CloudSat-type: Developed based on Yoshida et al., 2010 JGR (Kikuchi et al., submitted to JGR).

3. Ice and water cloud microphysics from CloudSat/CALIPSO (KU-micro)

Ice: **Okamoto et al., 2010 JGR, Sato and Okamoto 2011 JGR. Refined LUT.**

Water: Sato et al.,

There are large gaps between space borne lidar and ground based one.

・**CALIPSO lidar CALIOP** has FOV~130 μrad and satellite altitude of ~700km and resultant **foot print size ~90m** on ground.

・JAXA-ESA mission EarthCARE has high spectral resolute lidar **EarthCARE-ATLID** and its FOV~65 μrad and satellite altitude ~400km, foot print size~**30m**.

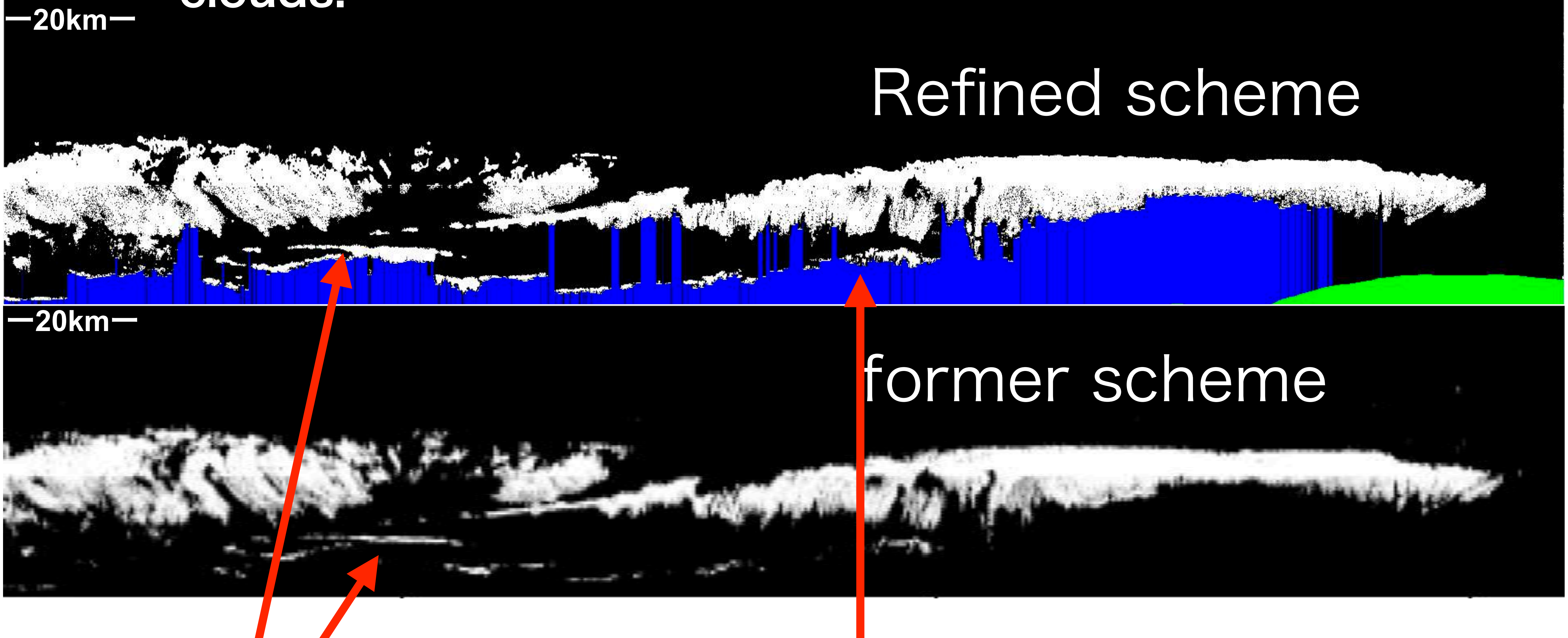
・Typical conventional lidar has FOV~1mrad and foot print size~**1m** at 1km. Maximum optical thickness~3.

Space-borne lidar is expected to provide better estimates of cloud physical properties (at least complementary with cloud radar. (remember CloudSat product relies on temperature to partition ice and water). We might fill the gaps to evaluate satellite algorithms and products.

New Ver.

1-3. Development of CALIPSO-cloud mask; example

Refined scheme shows improvements in detection of clouds.



Blue : fully attenuated pixel.

Low level cloud detections have been improved in largely attenuated regions by the refined scheme.

Katagiri et al., 2017 (in prep.)