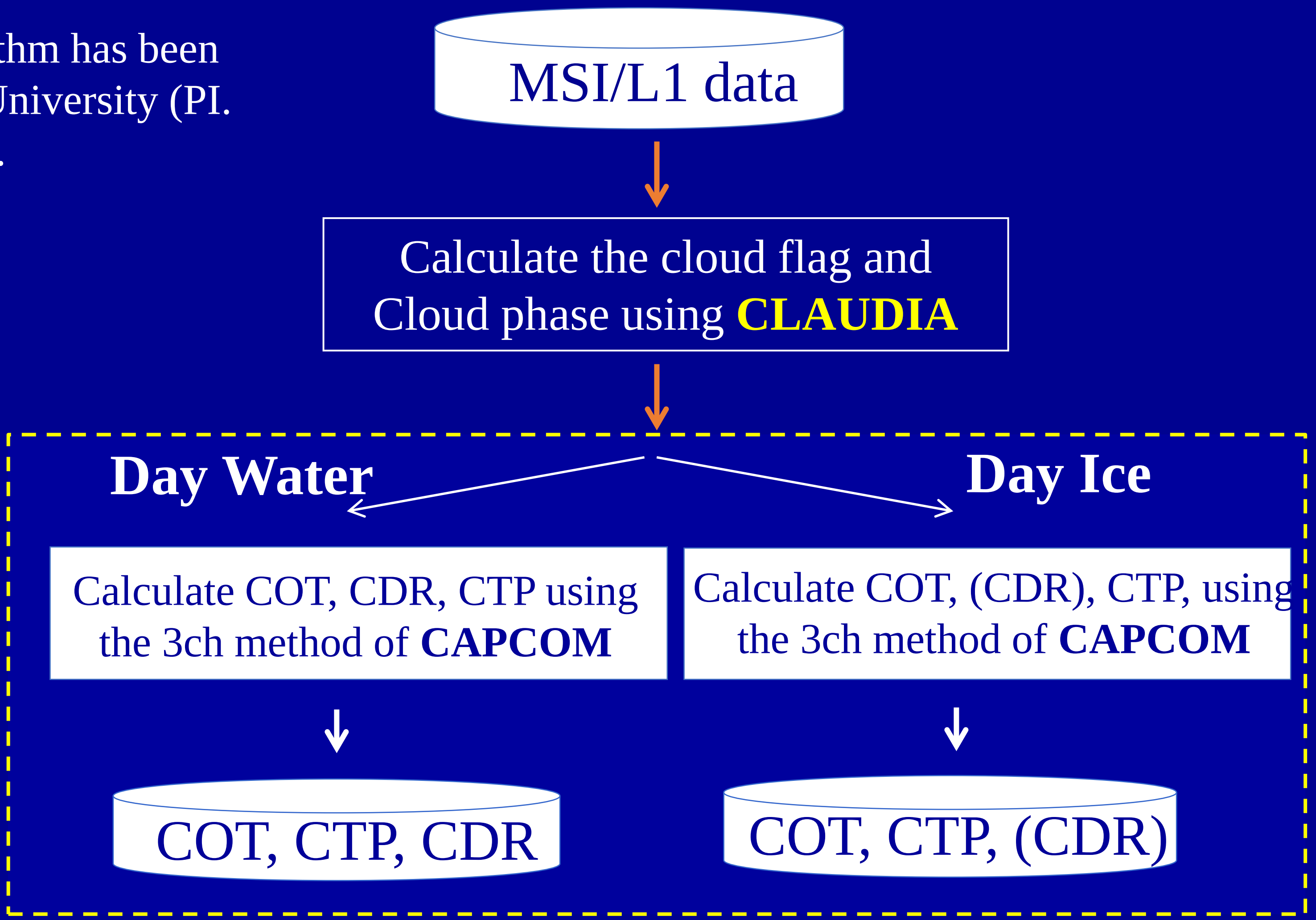
Development of the EarthCARE/MSI L2 Product Algorithm Using Nicam/joint-simulator Data

Minrui WANG, Takashi Y. NAKAJIMA
Tokai University Research & Information Center

ESA-JAXA Pre-Launch EarthCARE Science and Validation Workshop @ Frascati, Italy

EarthCARE/MSI cloud product process

JAXA MSI L2 algorithm has been developed by Tokai University (PI. Prof. T. Y. Nakajima).



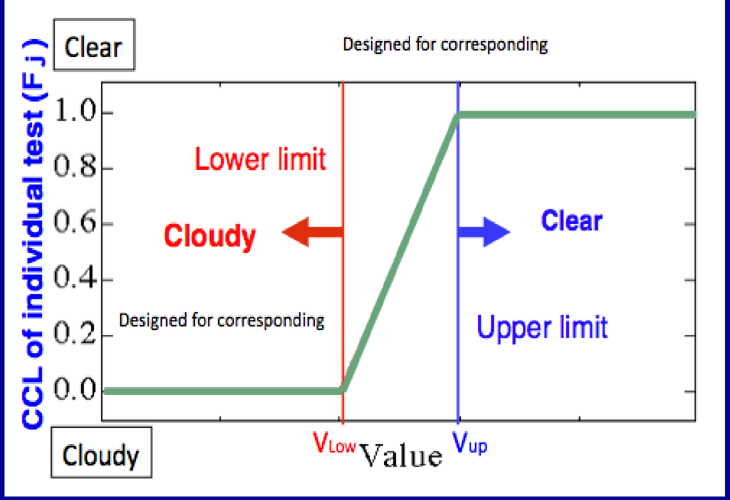
Cloud Optical Thickness (COT), Cloud Droplet effective Radius (CDR), Cloud Top Pressure (CTP)

Cloud detection algorithm (CLAUDIA):

Ishida and Nakajima (JGR 2010)

Concept of the Clear Confidence Level (CCL)

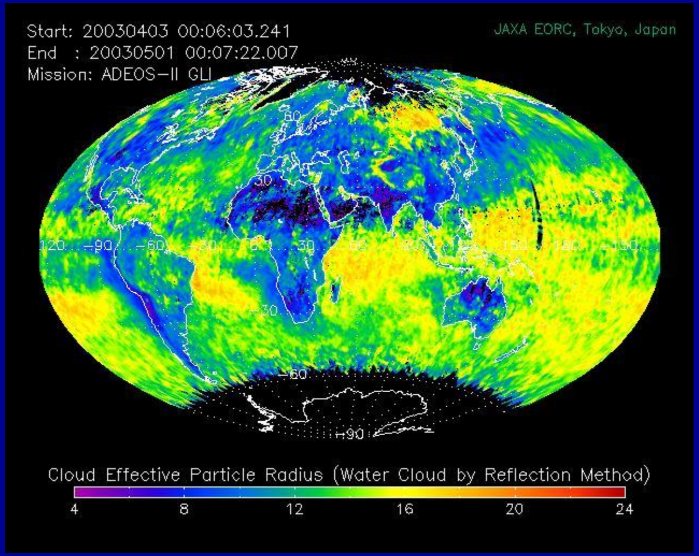
- **Quantitatively evaluate cloud existence by the CCL (value of 0 to 1)**
- **Two thresholds (Upper limit and Lower limit) for each individual test**



Retrieval algorithm for the cloud properties (CAPCOM):

Nakajima and Nakajima (JAS 1995)
Kawamoto et al. (2001) etc.

- The CAPCOM uses LUT (Look up Table)-Iteration Method to retrieve the cloud optical and microphysical properties from satellite-derived non-absorption and absorption band.

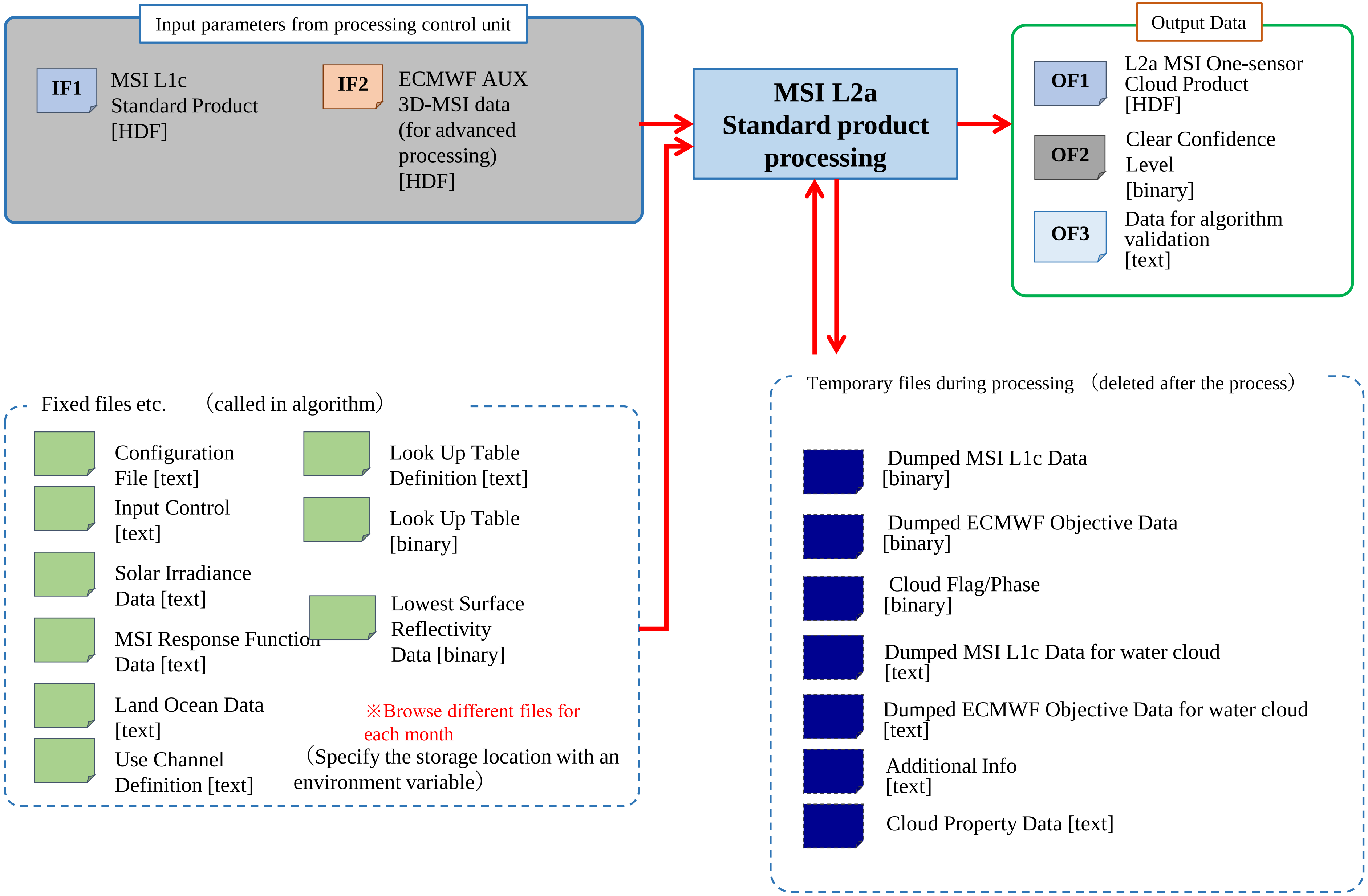


MSI L2a standard product processing (ver0.4)

Outline of processing
（Algorithm development in Tokai U.)

2023/7/31 released

I/O interface



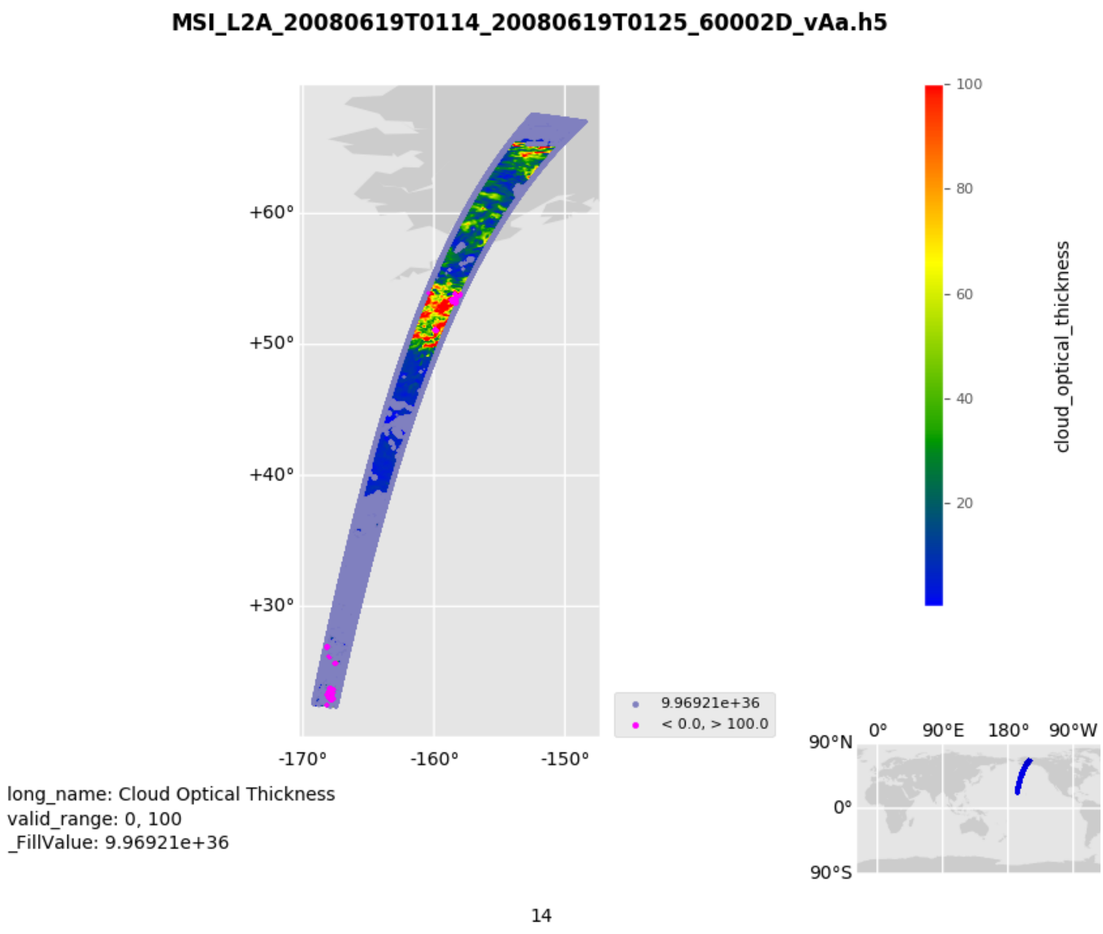
15 Scenes of JAXA L1C data generated by NICAM/Joint Simulator

Scene No.	Time (UTC)	Scene No.	Time (UTC)
Scene 1（60001F）	00:05~00:16	Scene 9（60002F）	01:38~01:49
Scene 2（60001G）	00:17~00:27	Scene 10（60002G）	01:50~02:00
Scene 3（60001H）	00:28~00:39	Scene 11（60002H）	02:01~02:11
Scene 4（60002A）	00:40~00:51	Scene 12（60003A）	02:12~02:23
Scene 5（60002B）	00:52~01:02	Scene 13（60003B）	02:24~02:35
Scene 6（60002C）	01:03~01:13	Scene 14（60003C）	02:36~02:46
Scene 7（60002D）	01:14~01:25	Scene 15（60003D）	02:47~02:58
Scene 8（60002E）	01:26~01:37		

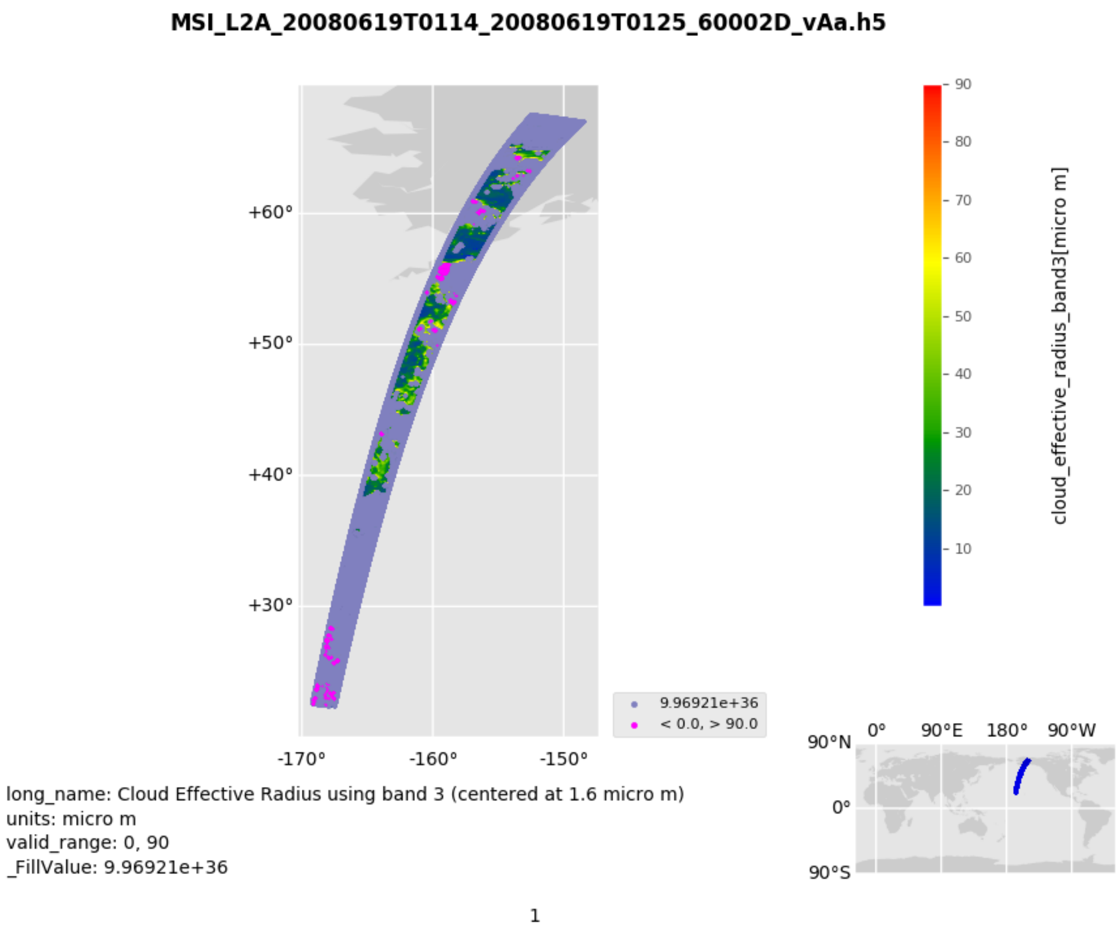
- Date: 2008/06/19
- Local daytime scene in red(end with C, D, E, F)
- Local nighttime scene in blue(end with G, H, A, B)

MSI L2A water cloud product

Cloud Optical Thickness

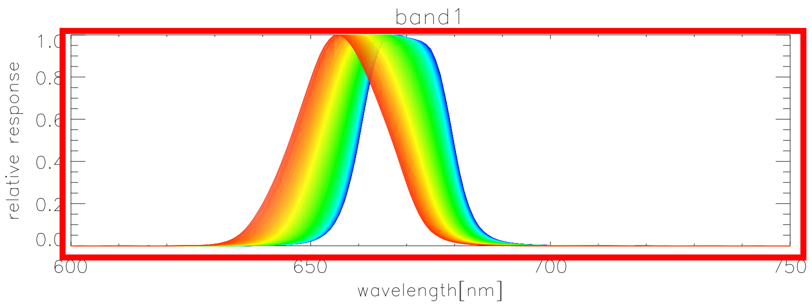


Cloud Effective Radius using band 3

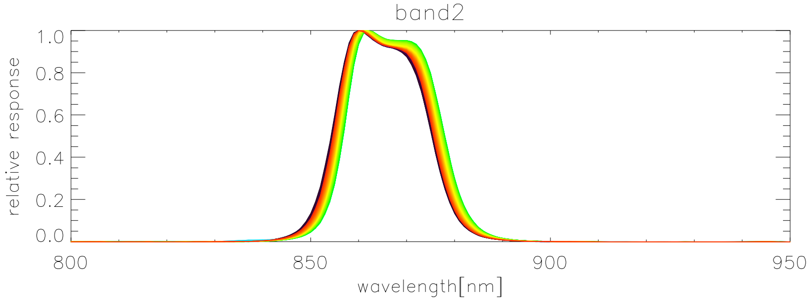


SMILE in EarthCARE/MSI Band 1 and Band 3

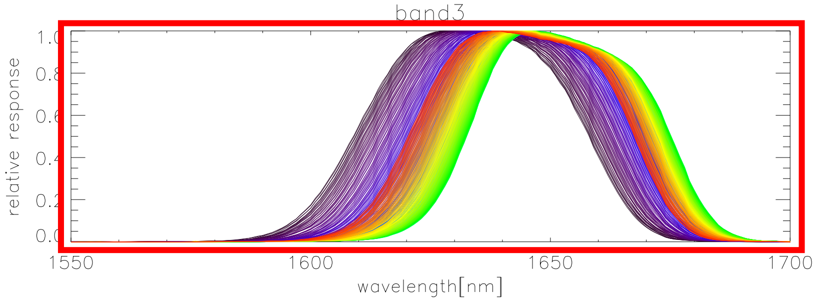
Band1



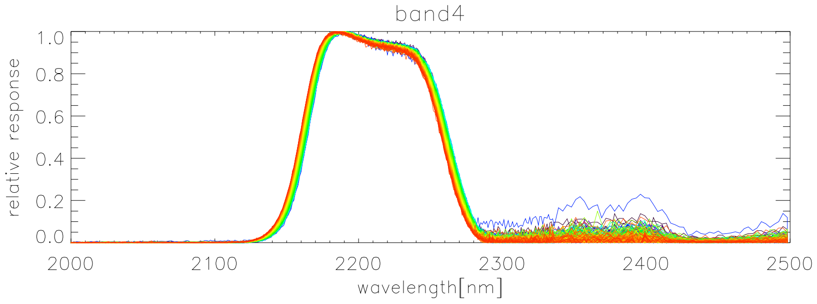
Band2



Band3



Band4

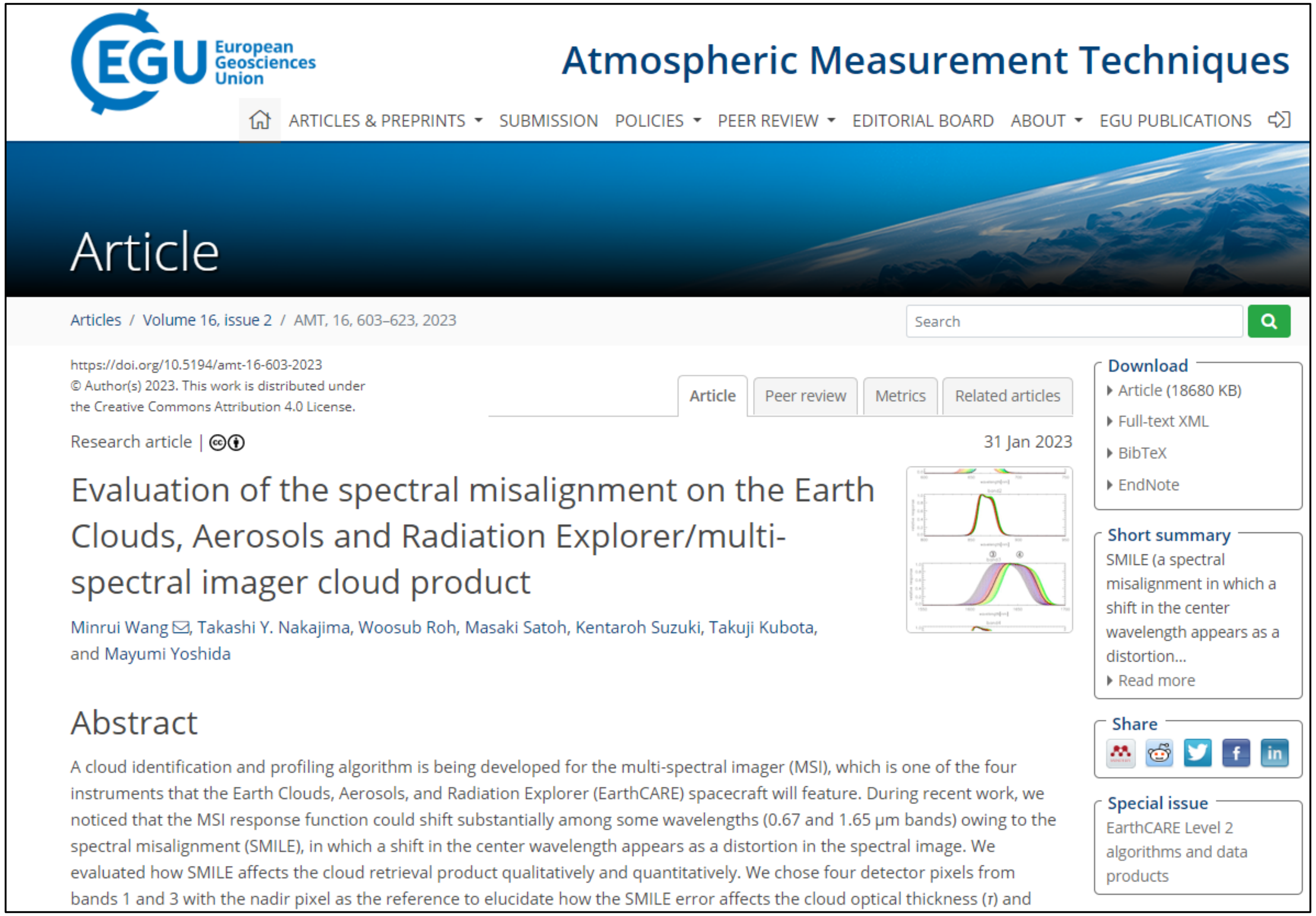


Band #	Wavelength (μm)	IFOV (km)
1	0.67	0.5
2	0.865	0.5
3	1.65	0.5
4	2.21	0.5
5	8.8	0.5
6	10.8	0.5
7	12.0	0.5

- The MSI has Spectral MIsaLignmEnt (SMILE), which is a center wavelength shift that appears as distortions of spectrum images due to misalignment.

Evaluating SMILE on EarthCARE/MSI cloud product

- A paper describing an evaluation of the Spectral MIsaLignmEnt (SMILE) on the MSI cloud product (Wang et al. 2023) was published in Jan. 2023.
  - Wang, M., Nakajima, T. Y., Roh, W., Satoh, M., Suzuki, K., Kubota, T., and Yoshida, M.: Evaluation of the spectral misalignment on the Earth Clouds, Aerosols and Radiation Explorer/multi-spectral imager cloud product, Atmos. Meas. Tech., 16, 603–623, https://doi.org/10.5194/amt-16-603-2023, 2023.
  - This paper used the Japanese synthetic MSI L1 data (Roh et al. 2023)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Research article | 31 Jan 2023

Evaluation of the spectral misalignment on the Earth Clouds, Aerosols and Radiation Explorer/multi-spectral imager cloud product

Minrui Wang, Takashi Y. Nakajima, Woosub Roh, Masaki Satoh, Kentaroh Suzuki, Takuji Kubota, and Mayumi Yoshida

Abstract

A cloud identification and profiling algorithm is being developed for the multi-spectral imager (MSI), which is one of the four instruments that the Earth Clouds, Aerosols, and Radiation Explorer (EarthCARE) spacecraft will feature. During recent work, we noticed that the MSI response function could shift substantially among some wavelengths (0.67 and 1.65 μm bands) owing to the spectral misalignment (SMILE), in which a shift in the center wavelength appears as a distortion in the spectral image. We evaluated how SMILE affects the cloud retrieval product qualitatively and quantitatively. We chose four detector pixels from bands 1 and 3 with the nadir pixel as the reference to elucidate how the SMILE error affects the cloud optical thickness (τ) and

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Short summary
SMILE (a spectral misalignment in which a shift in the center wavelength appears as a distortion...
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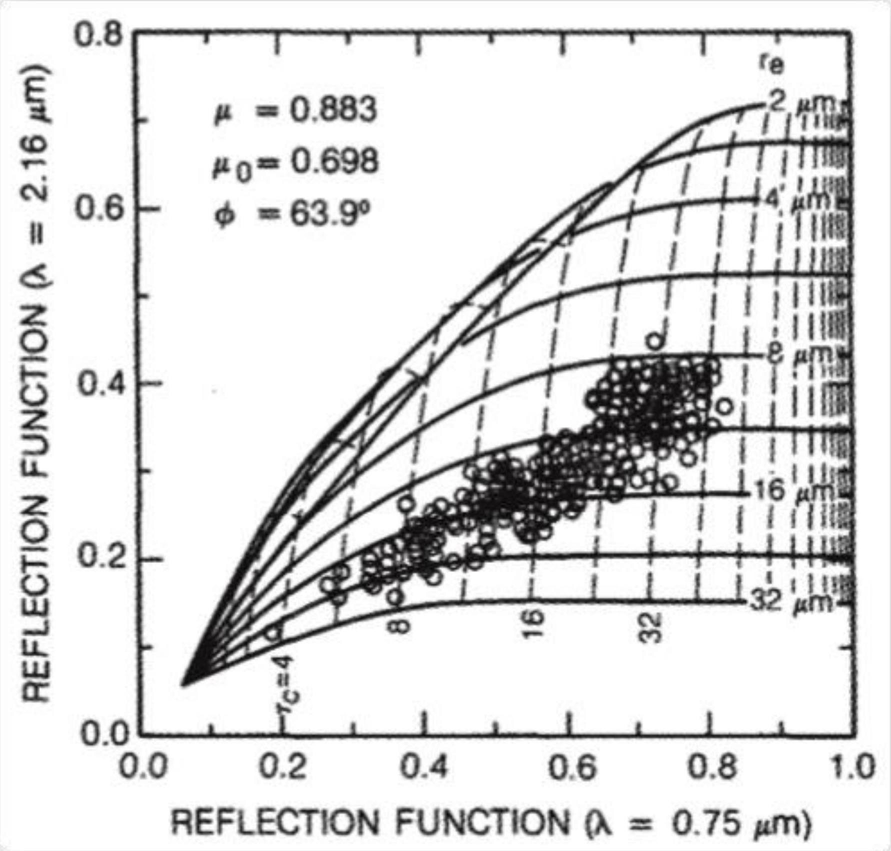
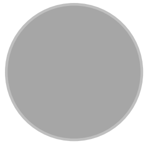
Nakajima-King Diagram

- To evaluate the error caused by the SMILE in the radiative transfer, we used Nakajima-King diagrams.
- Nakajima-King diagrams were developed for estimating COT and CDR using two wavelength observations in the visible light (e.g., band 1 of MSI) and near-infrared light (e.g., band 3 of MSI) regions (Nakajima and King, 1990; Nakajima et al., 1991).
- These diagrams are used as the basis of remote sensing of cloud characteristics from visible and near-infrared light observations.

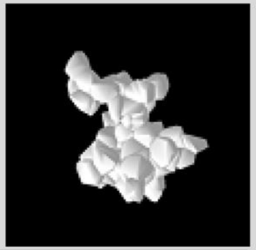


From Nakajima and King (1990)

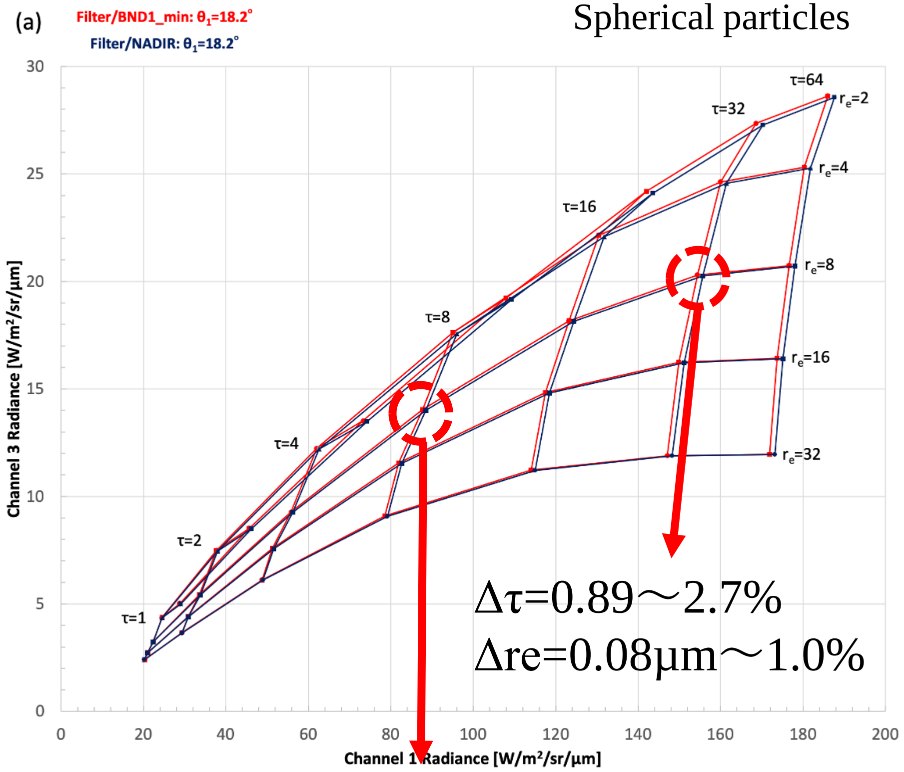
Nakajima-King Diagram: Case PixMS of Band1



Spherical particles

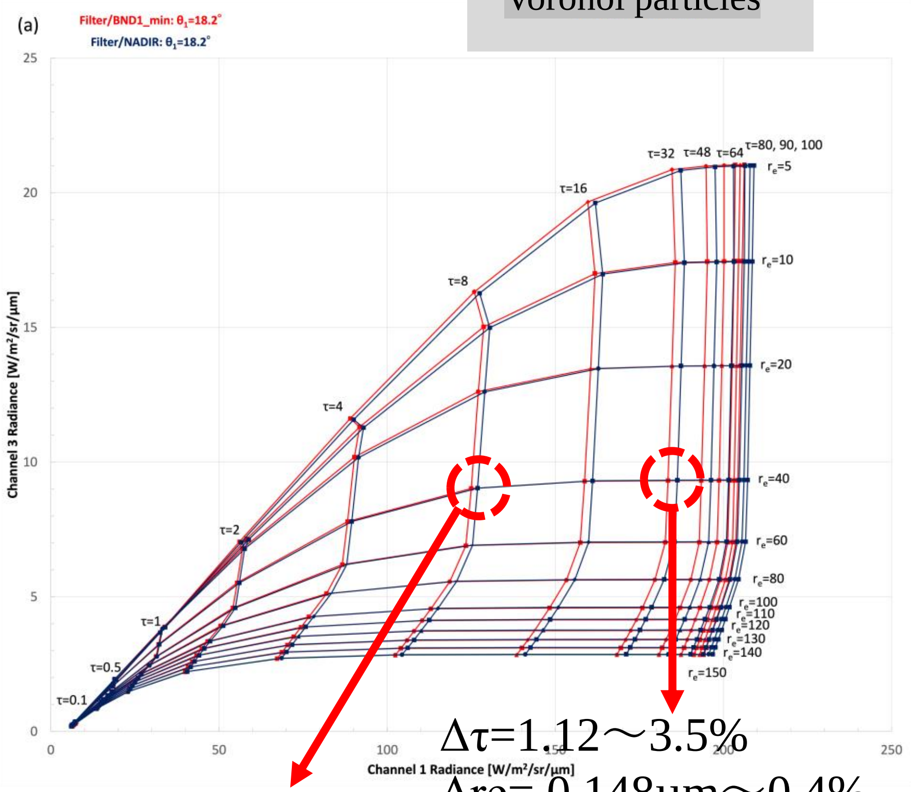


Voronoi particles



Δτ=0.89～2.7%
Δre=0.08μm～1.0%

Δτ=0.19～2.3%
Δre= 0.13μm～1.6%



Δτ=1.12～3.5%
Δre= 0.148μm～0.4%

Δτ=0.176～2.2%
Δre= 0.113μm～0.3%

Shallow water cloud

Deep convective cloud

Summary for the SMILE error (Shallow Water Cloud)

		$\tau = 8$, $r_e = 8\ \mu m$		$\tau = 32$, $r_e = 8\ \mu m$	
		$\Delta\tau$	$\Delta r_e(\mu m)$	$\Delta\tau$	$\Delta r_e(\mu m)$
θ_0=60° SWC	pix_BND1_min	0.19(2.3%)	0.13(1.6%)	0.89(2.7%)	0.08(1.0%)
	pix_BND1_max	0.02(0.2%)	0.23(2.8%)	0.11(0.3%)	0.14(1.7%)
	pix_BND3_min	0.03(0.3%)	0.38(4.8%)	0.13(0.4%)	0.21(2.6%)
	pix_BND3_max	0.05(0.6%)	0.50(6.2%)	0.24(0.7%)	0.38(4.7%)
θ_0=20° SWC	pix_BND1_min	0.08(1.0%)	0.11(1.4%)	0.16(0.5%)	0.07(0.9%)
	pix_BND1_max	0.008(0.1%)	0.23(2.9%)	0.05(0.2%)	0.14(1.8%)
	pix_BND3_min	0.02(0.2%)	0.46(5.7%)	0.05(0.2%)	0.25(3.1%)
	pix_BND3_max	0.03(0.3%)	0.51(6.3%)	0.11(0.3%)	0.37(4.6%)

※cth=cloud top height

※ θ_0=solar zenith angle, τ =optical thickness, r_e=effective radius of cloud droplet

Summary for the SMILE error (Deep Convective Cloud)

		$\tau = 8$, $r_e = 40\mu m$		$\tau = 32$, $r_e = 40\mu m$	
		$\Delta\tau$	$\Delta r_e(\mu m)$	$\Delta\tau$	$\Delta r_e(\mu m)$
θ_0=60° DCC	pix_BND1_min	0.176(2.2%)	0.113(0.3%)	1.120(3.5%)	0.148(0.4%)
	pix_BND1_max	0.011(0.1%)	0.348(0.9%)	0.062(0.2%)	0.411(1.0%)
	pix_BND3_min	0.014(0.2%)	1.310(3.3%)	0.095(0.3%)	1.470(3.7%)
	pix_BND3_max	0.035(0.4%)	0.282(0.7%)	0.220(0.7%)	0.394(1.0%)
θ_0=20° DCC	pix_BND1_min	0.020(0.2%)	0.168(0.4%)	0.103(0.3%)	0.196(0.5%)
	pix_BND1_max	0.003(0.04%)	0.398(1.0%)	0.023(0.1%)	0.497(1.2%)
	pix_BND3_min	0.004(0.1%)	1.370(3.4%)	0.024(0.1%)	1.650(4.1%)
	pix_BND3_max	0.004(0.1%)	0.405(1.0%)	0.030(0.1%)	0.550(1.4%)

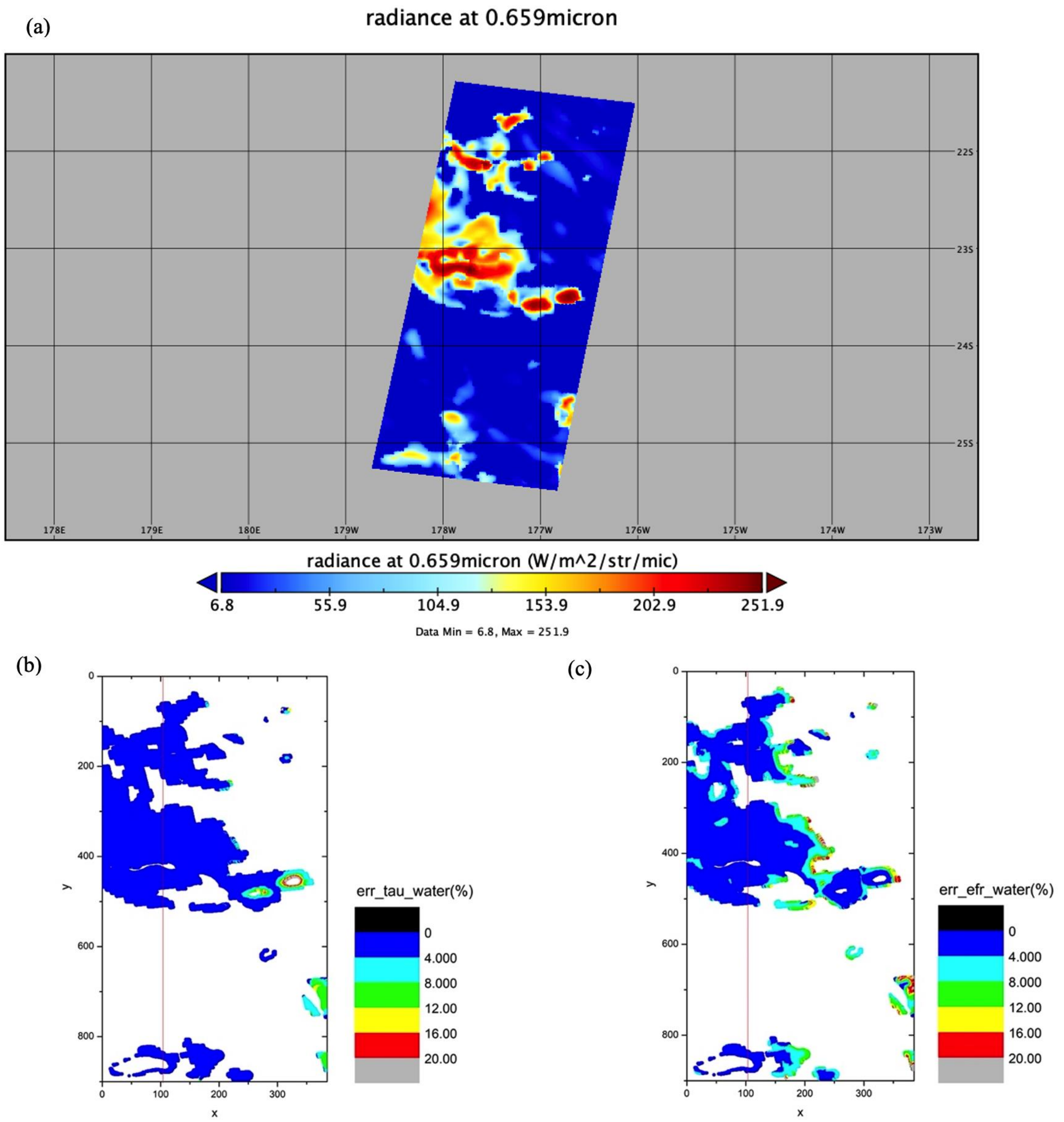
※cth=cloud top height

※ θ_0=solar zenith angle, τ =optical thickness, r_e=effective radius of cloud droplet

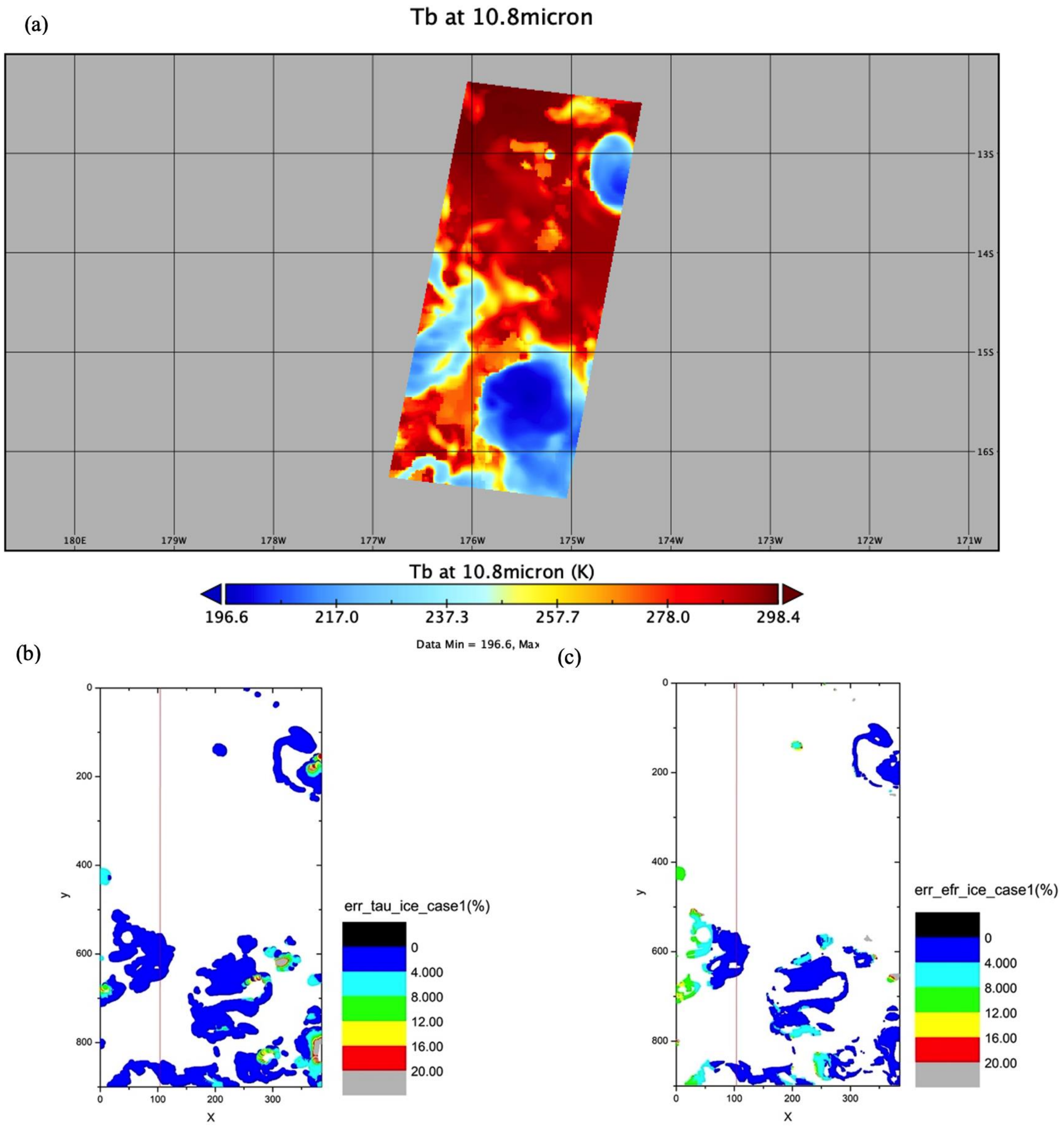
Spatial Error distribution evaluation using NICAM/Joint-Simulator data

- The synthetic MSI L1 data for MSI cloud product algorithm were created by the Joint-Simulator (Hashino et al., 2013; Satoh et al., 2016), and input 3.5-km-mesh global atmospheric simulation data.
- The data were calculated by a global storm-resolving atmospheric model, Nonhydrostatic Icosahedral Atmospheric Model (NICAM) (Tomita and Satoh, 2004; Satoh et al., 2008, 2014).
- The SMILE was considered using response functions depending on the pixel number from ESA.
- MSI data were generated using the fixed response function at the nadir location as the control data.
- By applying the MSI algorithm to the nadir and SMILE sets of simulated radiance data, we compared the two sets of cloud retrieval product and evaluated the error caused by SMILE.

- Panel (a) shows the radiance at 0.659 μm (band 1 of MSI) , which indicates the approximate location of target clouds by marking areas with relatively high radiance (red-orange zone).
- For shallow warm clouds, 71,870 of the 344,064 pixels were defined as water clouds by the MSI cloud profiling algorithm.
- The average error of COT was 0.89 %, whereas the average error of CDR was 3.13 %.



- Panel (a) shows brightness temperature at 10.8 μm (band 6 of MSI) , which indicates the approximate location of target clouds by marking areas with elatively low brightness temperature (blue zone).
- For deep convective clouds, 29,501 of the 344,064 pixels were defined as ice cloud by the MSI cloud profiling algorithm.
- The average error of COT was 1.38 %, whereas the average error of CDR was 3.60 %.



Summary

- We developed the EarthCARE/MSI L2 cloud product algorithm for shallow water cloud (normal product).
  - To support the further multi-sensors researches, implementation of deep convective cloud (ice cloud) product for researchers is on going, estimated to be finished by the end of 2023.

- Based on Nakajima-King diagram and CAPCOM, the influence of SMILE to the cloud retrieval is not so significant for oceanic cases.
  - Typical case of shallow water clouds τ=8, r_e=8μm, $\Delta\tau$=0.19～2.3%, Δr_e=0.50μm～6.2% when solar zenith angle is 60 degrees.
  - Typical case of deep convective clouds τ=8, r_e=40μm, $\Delta\tau$=0.18～2.2%, Δr_e=1.4μm～3.4% when solar zenith angle is 60 degrees.

Summary

- Our spatial error distribution results showed that $\Delta\tau$ and Δr_e were 0 at the 102nd pixel (nadir), and the error tended to increase gradually from the nadir toward both sides, which was especially significant for deep convective cloud.
- Be similar with the averaged error from CAPCOM radiative transfer simulation, Δr_e was larger than $\Delta\tau$ in the spatial distribution.
- In most oceanic cases, both $\Delta\tau$ and Δr_e were less than 10 %.
- Generally, the results of the NICAM/Joint-Simulator data matched those of the CAPCOM radiative transfer simulation well, suggesting that the error in COT and CDR caused by the SMILE was not significant, and could be regarded as negligible in most oceanic cases.

Summary

- However, our simulations are based on observations over oceanic areas, which is much less strongly influenced by surface albedo than land areas.
- The surface albedo values used in the NICAM/Joint-Simulator data were 0.04–0.05, which did not change substantially throughout the scene. But things could be much more complicated in observations over land areas.
- For the VIS channel (band 1 of MSI), which is close to the red edge of green vegetation, small shifts in the central wavelength can lead to uncertainties due to the rapid change in surface reflectance.
- Therefore, for the aerosol product algorithm development (by Dr. Mayumi Yoshida), adjustment is required to deal with the influence of SMILE.

CLAUDIA-2（Cloud and Aerosol Unbiased Decision Intellectual Algorithm-2

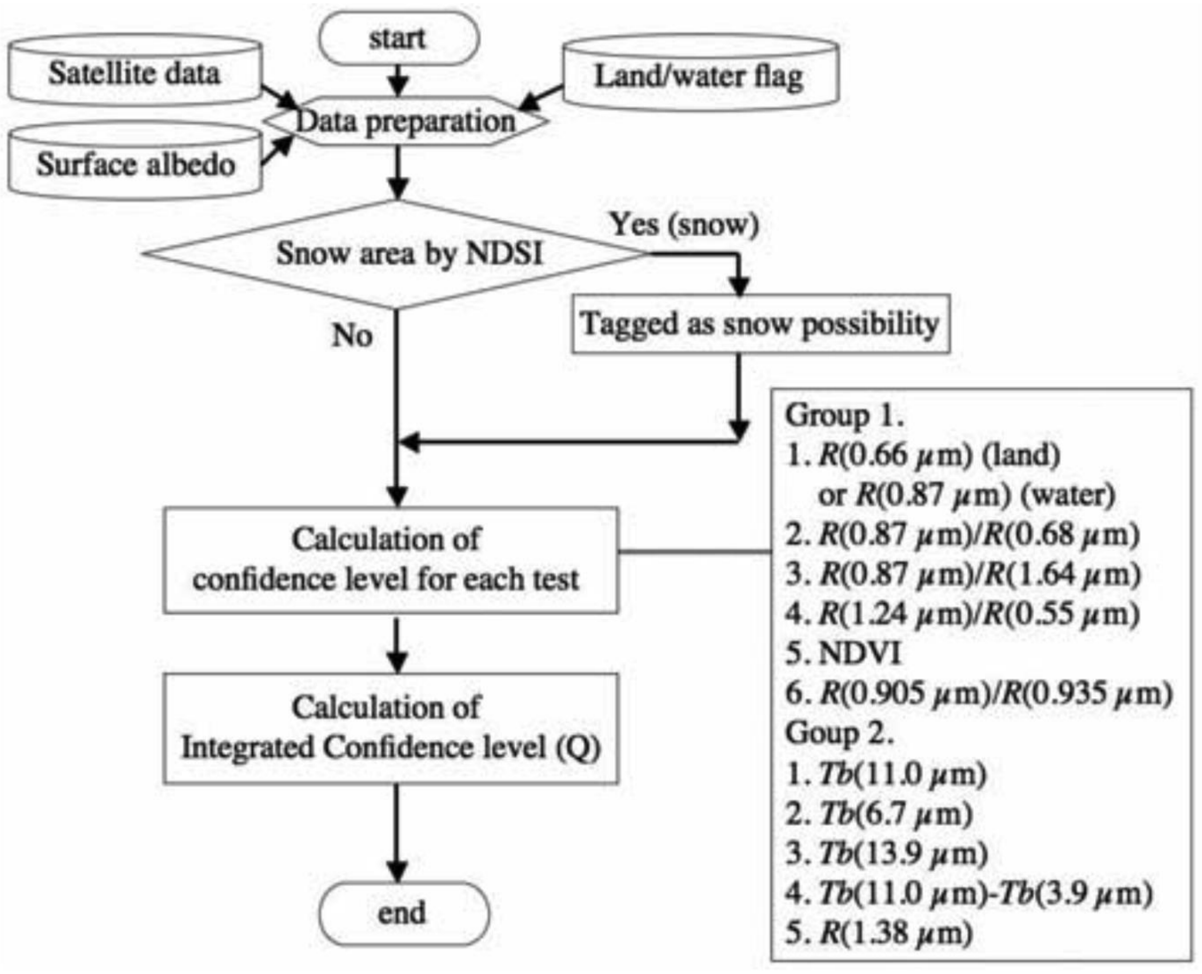


Figure 3. Flow of the cloud detection algorithm.

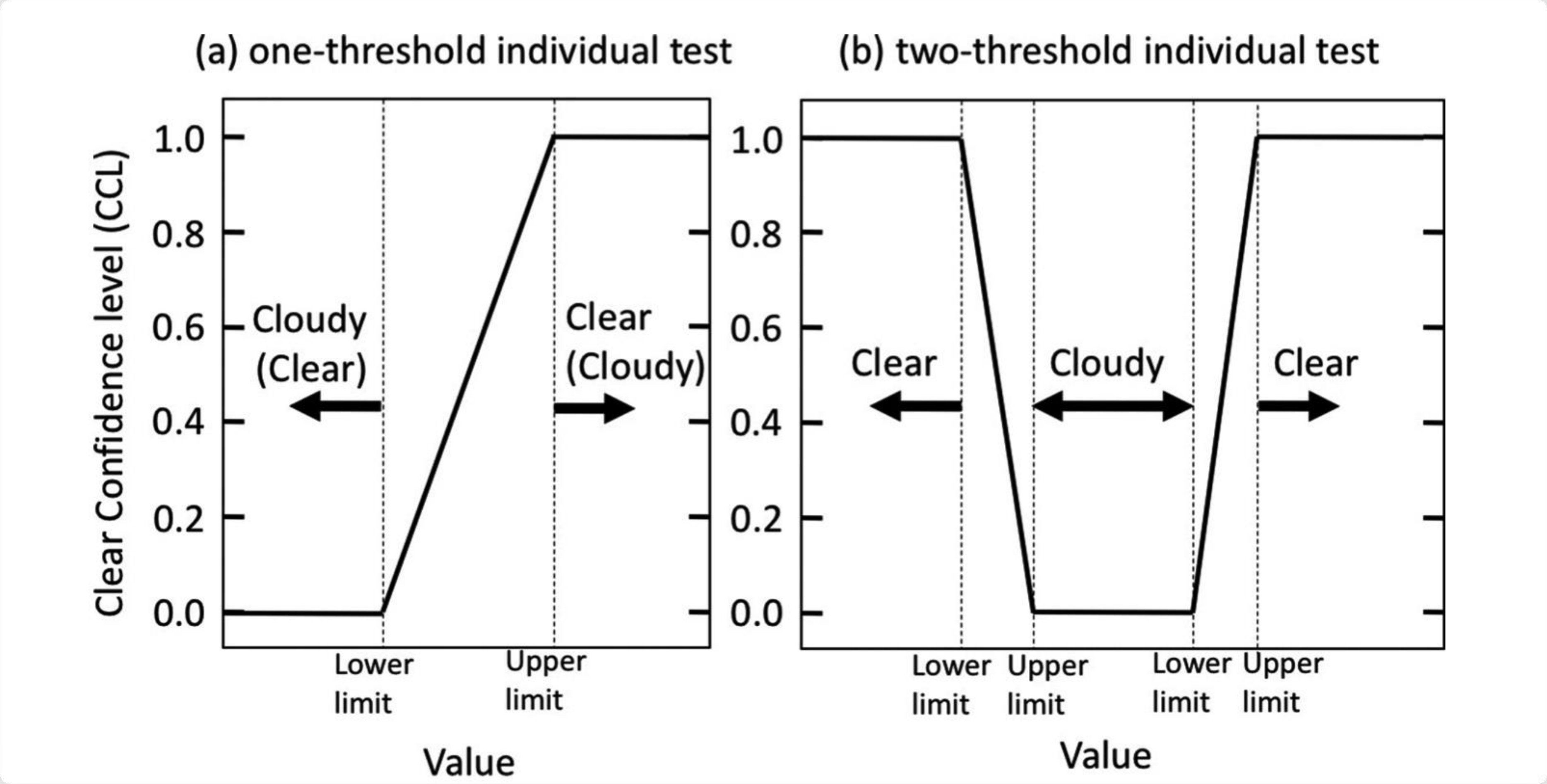
Table 2. Threshold Tests and the Targets

Group	Threshold Tests	Targets
1	$R(0.87\ \mu m)$	Optically thick clouds over ocean
	$R(0.64\ \mu m)$	Optically thick clouds over land
	$R(0.87\ \mu m)/R(0.64\ \mu m)$	Optically thick clouds
	NDVI	Clouds over deep forest
	$R(1.24\ \mu m)/R(0.55\ \mu m)$	Clouds over bare and half vegetation
	$R(0.87\ \mu m)/R(1.64\ \mu m)$	Clouds over bright desert
	$R(0.905\ \mu m)/R(0.935\ \mu m)$	Clouds over the Sun glint areas of ocean
2	$T_b(11.0\ \mu m)$	High (geometrically thick) clouds
	$T_b(6.7\ \mu m)$	High thin clouds (including cirrus)
	$T_b(13.9\ \mu m)$	High thin clouds (including cirrus)
	$T_b(11.0\ \mu m) - T_b(3.9\ \mu m)$	Optically thick clouds
	$R(1.38\ \mu m)$	Thin cirrus

- MSIではGroup1を4種類、Group2を1種類それぞれテストを行い、最終的に両者をマージしてCCLの実数値を求める。

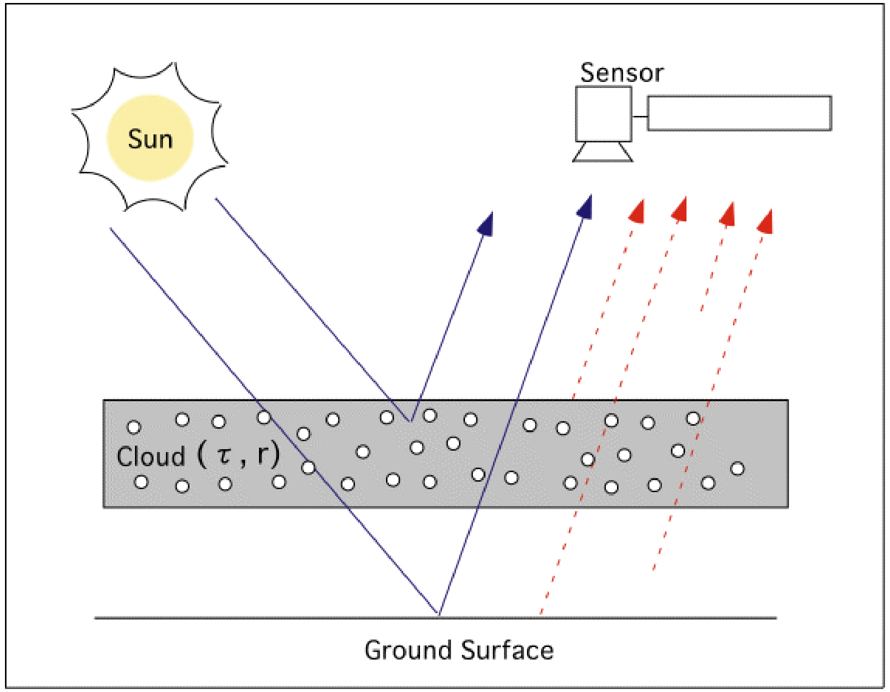
Ishida and Nakajima, 2009より

CLAUDIA-2（Cloud and Aerosol Unbiased Decision Intellectual Algorithm-2

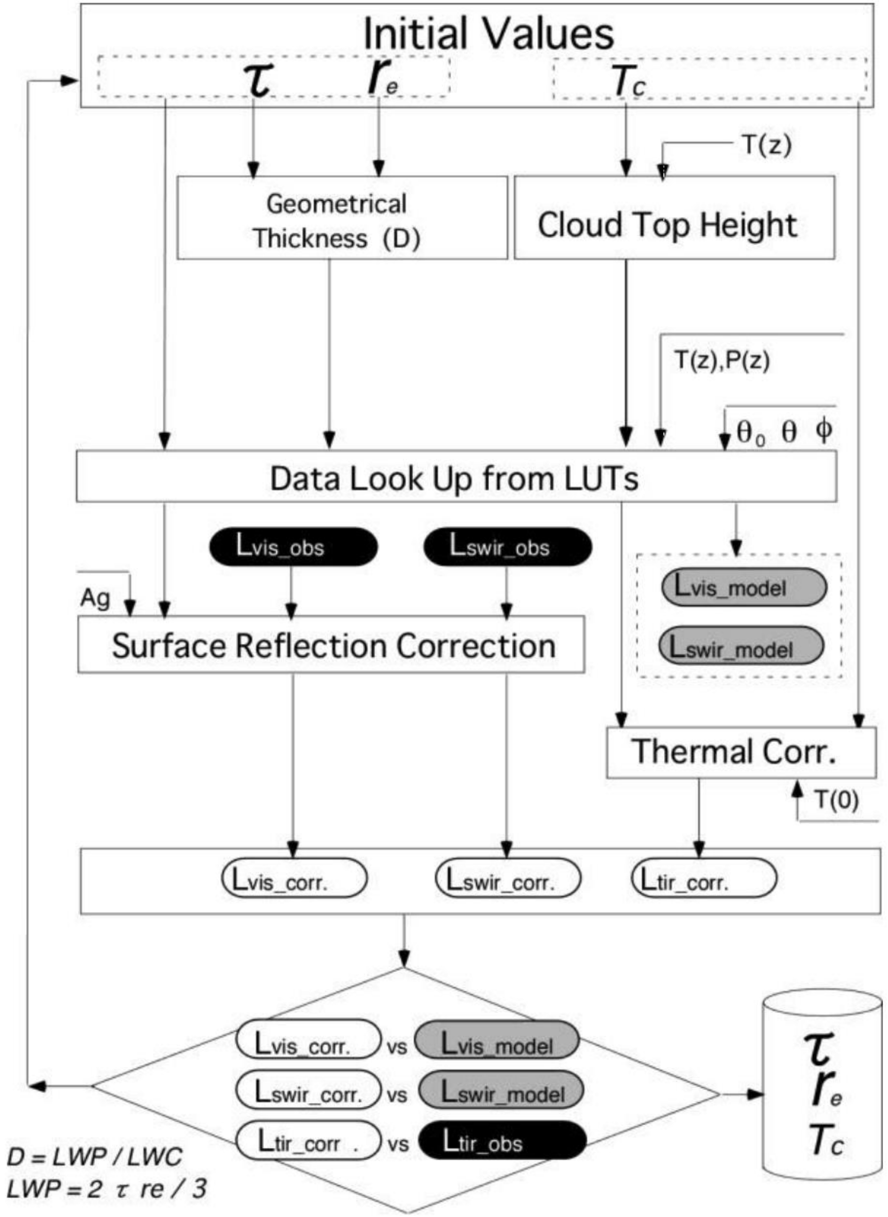


- 晴天信頼度（Clear Confidence Level, CCL）によって曇と晴、あるいはその間の状態を表現する（0.0が完全に曇、1.0は完全に晴）

CAPCOM

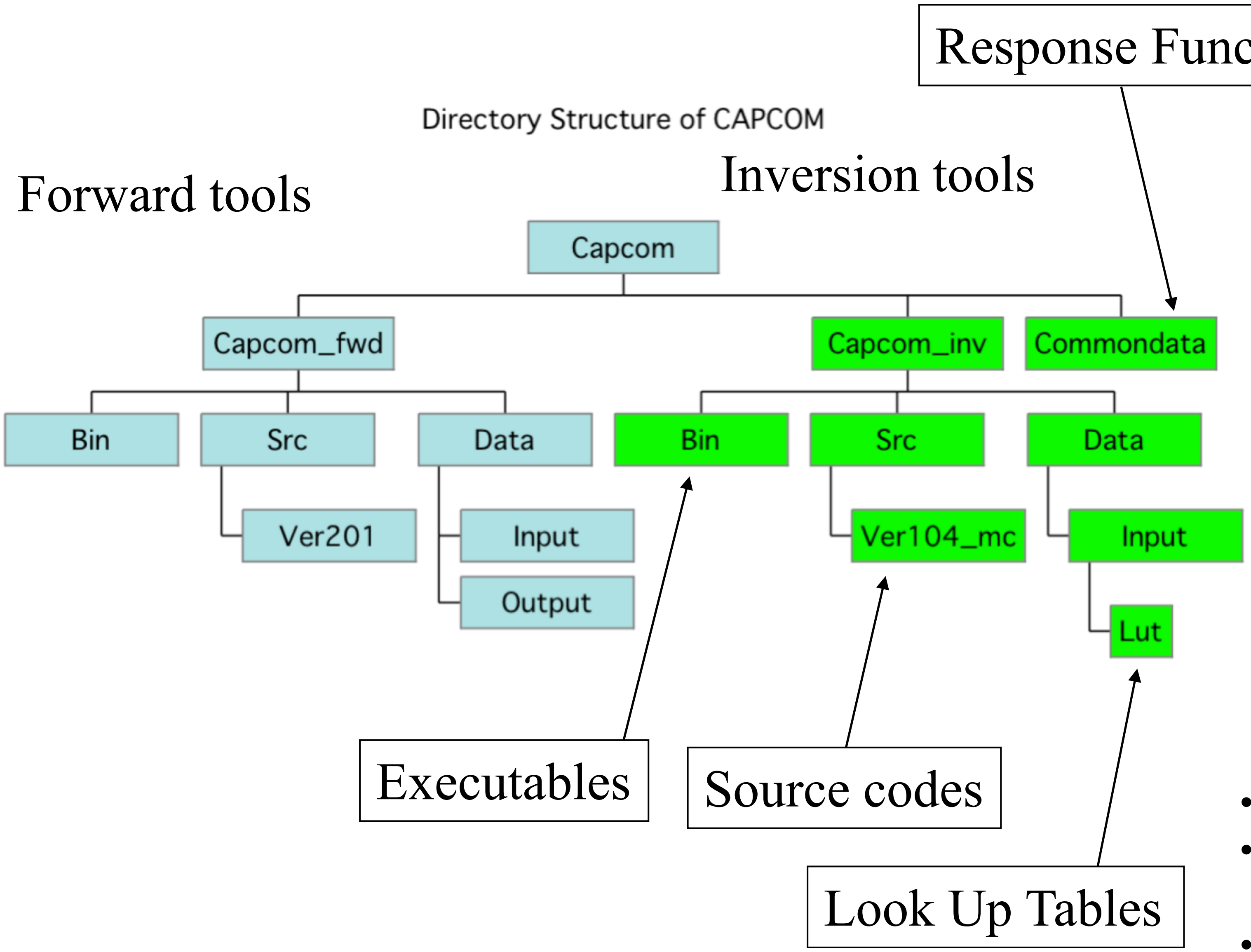


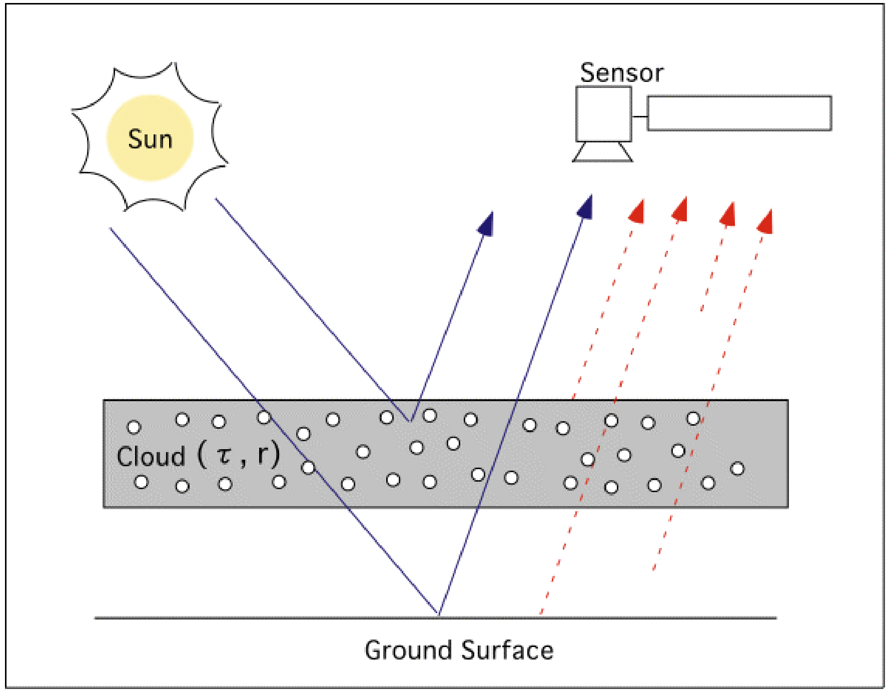
Three steps of cloud remote sensing



- Modeling of atmospheric scattering.
- Generating LUT by using an “forward program” such as radiative transfer.
- Retrieve target physical parameters by use of an “inversion program”.

Retrieval algorithm for the cloud properties (CAPCOM)





Three steps of cloud remote sensing

- Modeling of atmospheric scattering.
- Generating LUT by using an “forward program” such as radiative transfer.
- Retrieve target physical parameters by use of an “inversion program”.

Setup of CAPCOM Forward Simulation

- **For shallow water clouds：**
- COT(τ)：1, 2, 4, 8, 16, 32, 48, 64
- CDR (Re)（μm）：2, 4, 8, 16, 32

- **For deep convective clouds：**
- COT(τ)：0.1, 0.5, 1, 2, 4, 8, 16, 32, 48, 64, 80 ,90 ,100
- CDR (Re)（μm）：5, 10, 20, 40, 60, 80, 100, 110, 120, 130, 140, 150

- (Number in red: typical case of each type of cloud)

Quantitative evaluation of SMILE

- To evaluate the error of COT and CDR quantitatively, we obtained the first derivation of radiance, ΔL, with respect to COT or CDR from the Nakajima-King diagram, as

$$dL/d\tau,\ dL/dRe$$

and then we obtained the reciprocals as

$$d\tau/dL,\ dRe/dL$$

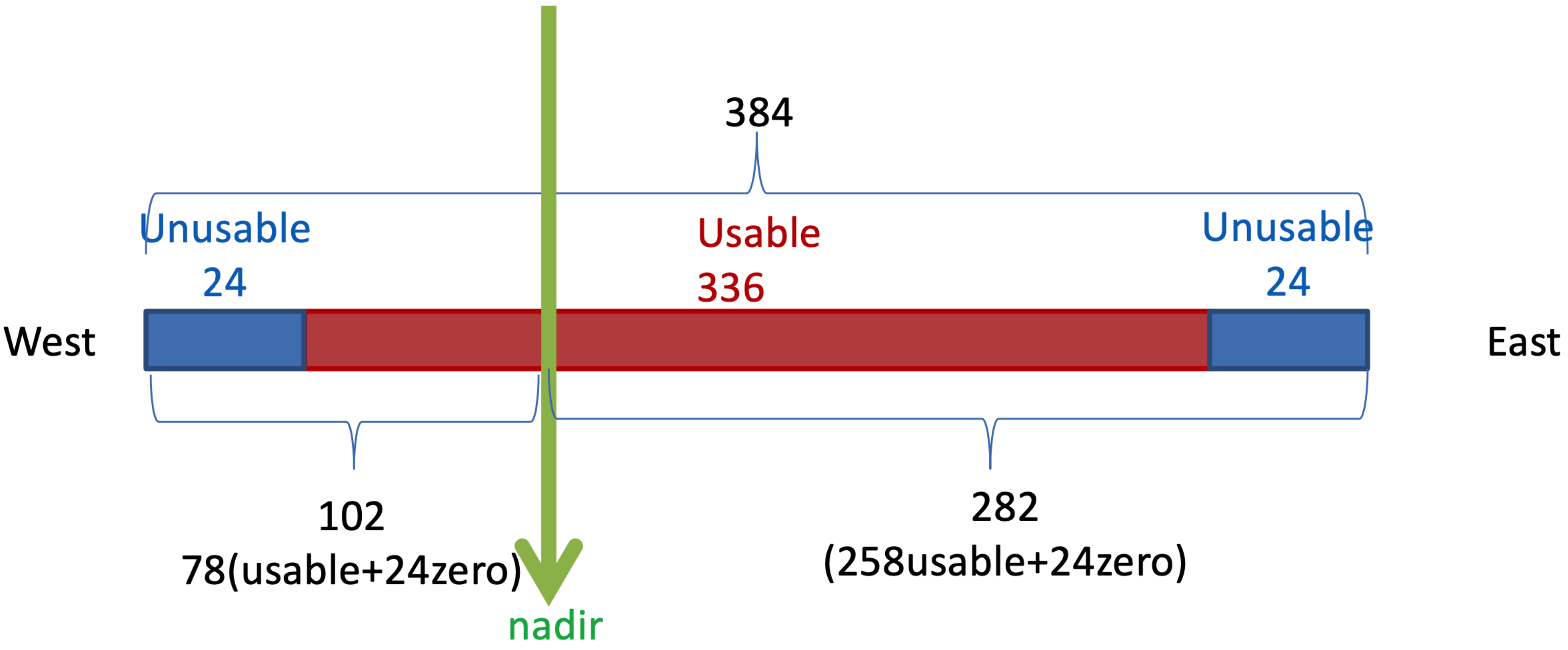
and multiplied them by the radiance deviation ΔL between the two response functions (at one of four selected pixels, and on the nadir location) to get the COT and CDR estimation errors, $\Delta\tau$ and Δr_e, respectively.

- As our evaluation criteria for the SMILE-based error, we performed the following analytical estimation of shortwave radiation (F_{sw}) due to CDR change under the assumed constant cloud water content, W.

$$F_{SW} = 343 \times 0.6 \times 0.81 \times 0.51 \times (1 - 0.51) \times \frac{\Delta r_e}{r_e} = 42 \times \frac{\Delta r_e}{r_e}$$

under the global mean distribution, if CDR decreased by 10 %, then F_{sw} would decrease by about 4.2 W/m^2. An error of this size or larger would be non-negligible in the cloud profiling algorithm of EarthCARE/MSI.

Descending node for daytime



- Start pixel is from west for descending on daytime