

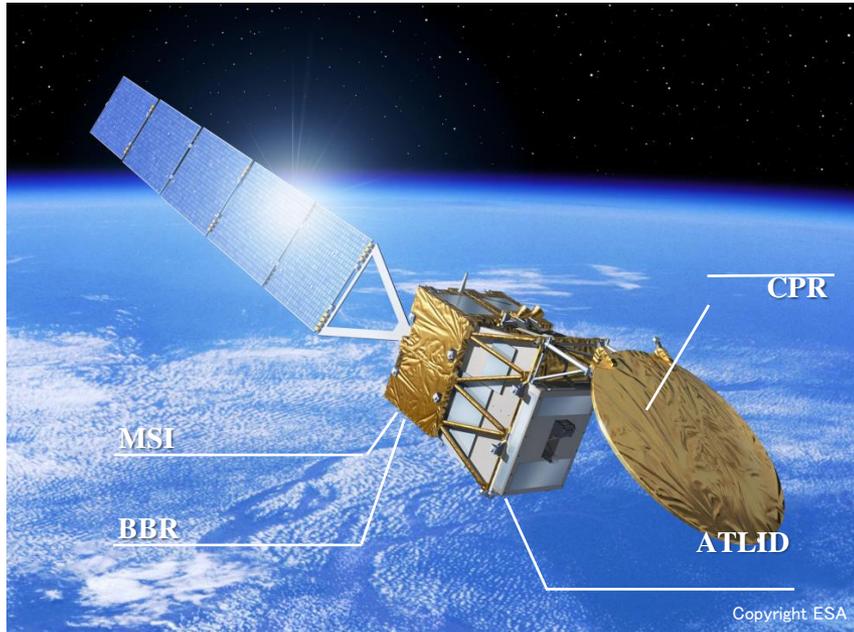
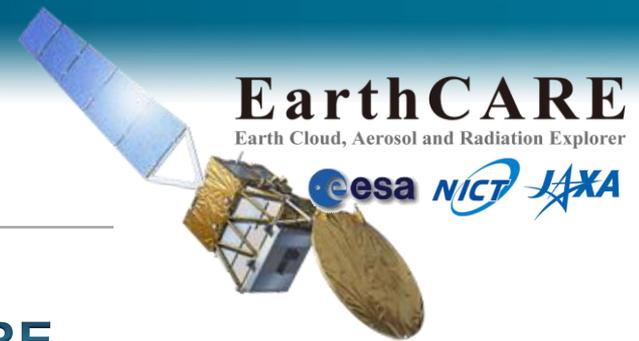
# EarthCARE Overview

Takuji Kubota

Earth Observation Research Center (EORC), JAXA

June 2021

# EarthCARE Satellite



Institutions	European Space Agency (ESA) / National Institute of Information and Communications Technology (NICT) / Japan Aerospace Exploration Agency (JAXA)
Launch	JFY2022 ( = Apr. 2022–Mar. 2023)
Mission Duration	3–years
Mass	Approx. 2200kg
Orbit	Sun-synchronous sub-recurrent orbit Altitude: approx. 400km Mean Local Solar Time (Descending): 14:00
Repeat Cycle	25 days
Orbit Period	5552.7 seconds
Semi Major Axis	6771.28 km
Eccentricity	0.001283
Inclination	97.050°

## EarthCARE

Earth Clouds, Aerosol and Radiation Explorer

EarthCARE is a joint Japanese-European mission to observe clouds, aerosols and radiation.

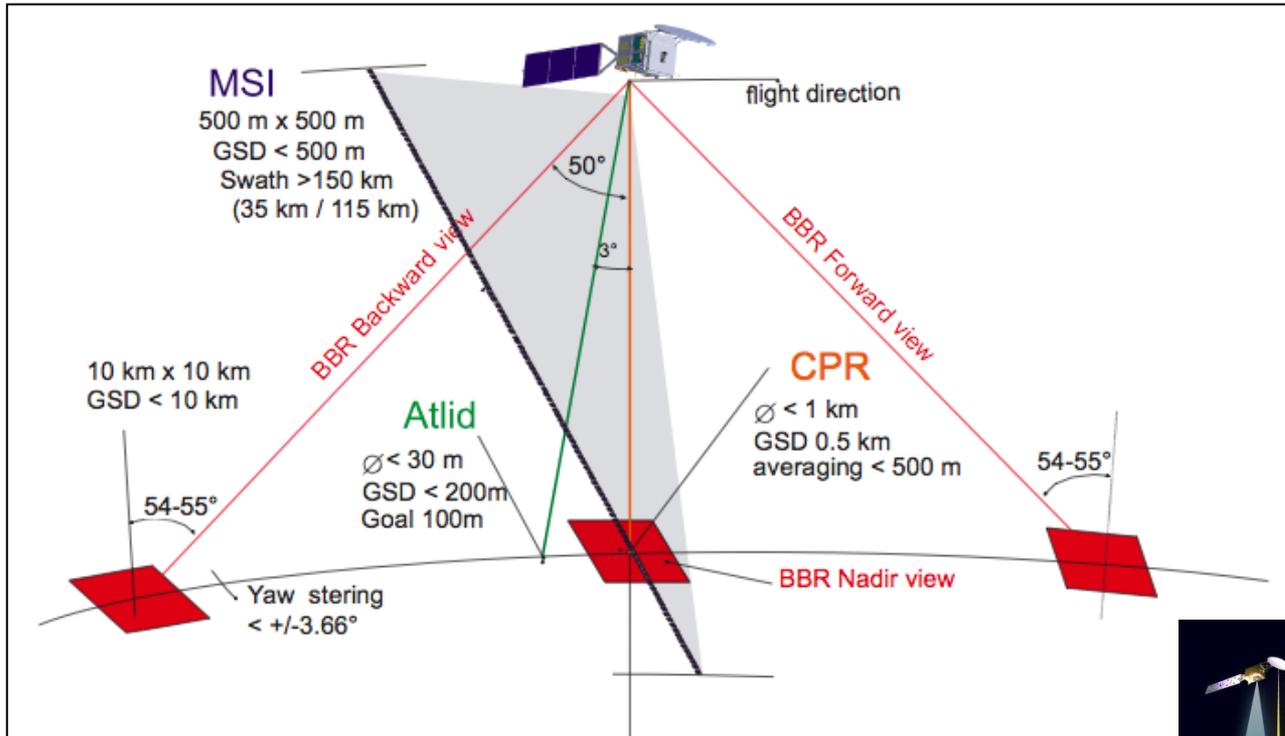
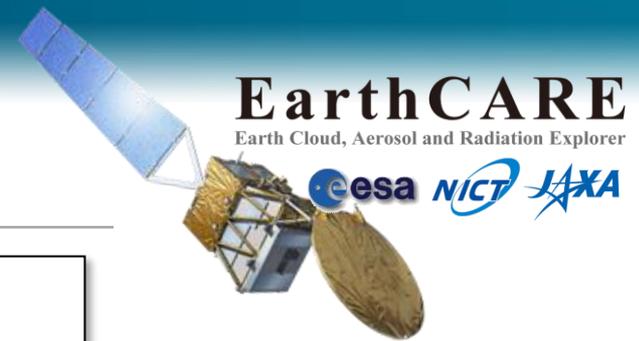
### Observation Instruments on EarthCARE

- CPR** Cloud Profiling Radar
- ATLID** Atmospheric Lidar
- MSI** Multi-Spectral Imager
- BBR** Broadband Radiometer



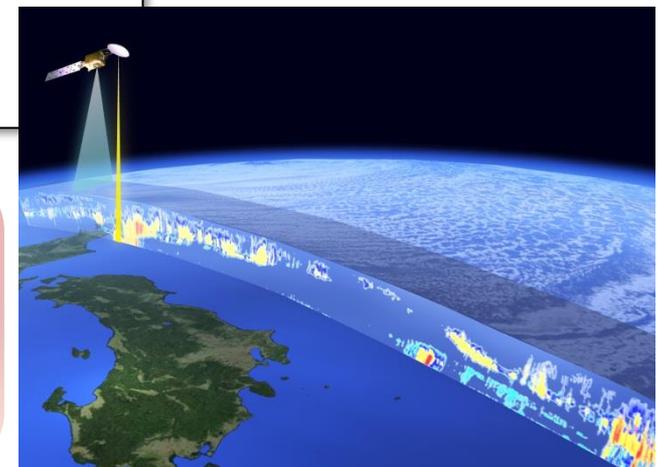
**Synergetic Observation by 4 sensors**

# Strategy



Observation of 4 sensors  
(movie)

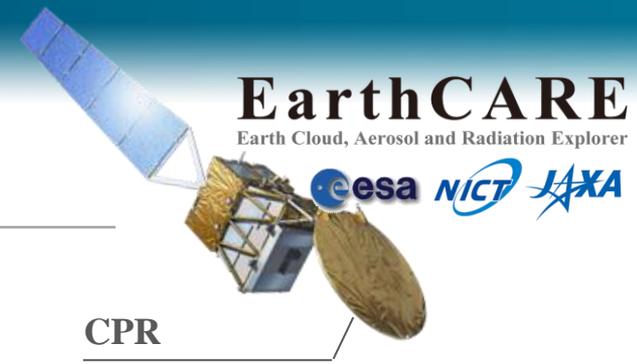
[https://www.eorc.jaxa.jp/EARTH CARE/museum/movie\\_gallery.html](https://www.eorc.jaxa.jp/EARTH CARE/museum/movie_gallery.html)



## Synergetic Observation by 4 Sensors on Global Scale

- 3-dimensional structure of aerosol and cloud including vertical motion
- Radiation flux at top of atmosphere
- Aerosol – cloud – radiation interactions

# Sensors



## CPR

### Cloud Profiling Radar

Instrument	94 GHz (W-band) Doppler Radar
Center Frequency	94.05 GHz
Sampling	Horizontal : 500 m Vertical : 500m (Oversampling 100m)
Footprint	Approx. 800m (Horizontal)
Pulse Repetition Frequency	6100 ~ 7500 Hz (Variable PRF)
Observation Height Range	Surface to 20km (low latitude), 18km, 16km, (high latitude)

### The World's First Satellite-borne Doppler Cloud Radar

CPR is a **94 GHz (W-band) Doppler Radar** jointly developed by Japan Aerospace Exploration Agency (JAXA) and National Institute of Information and Communications Technology (NICT).

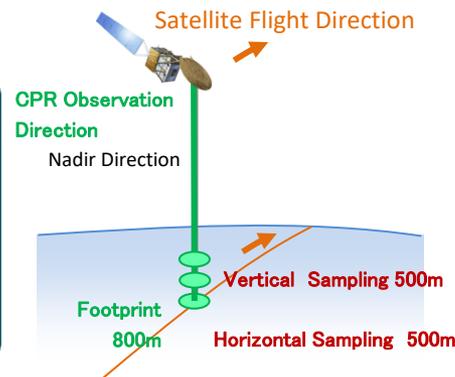
From its millimeter radar signal, it has the capability to observe **vertical distribution** and **physical characteristics** of **cloud** and **drizzle**.

In addition, information on the **in-cloud vertical motion** by **Doppler measurement function** has the potential to contribute to the understanding of cloud and precipitation process.

EarthCARE CPR has approximately **10 times higher sensitivity** compared to CloudSat CPR onboard in the A-Train Constellation.

### Observable Parameters

- |                        |                         |
|------------------------|-------------------------|
| Radar Reflectivity     | Liquid Water Content    |
| Doppler Velocity       | Ice Water Content       |
| Gas Attenuation Factor | Liquid Effective Radius |
| Cloud Mask             | Ice Effective Radius    |
| Cloud Particle Type    | Optical Thickness       |



# Photo of the EarthCARE/CPR

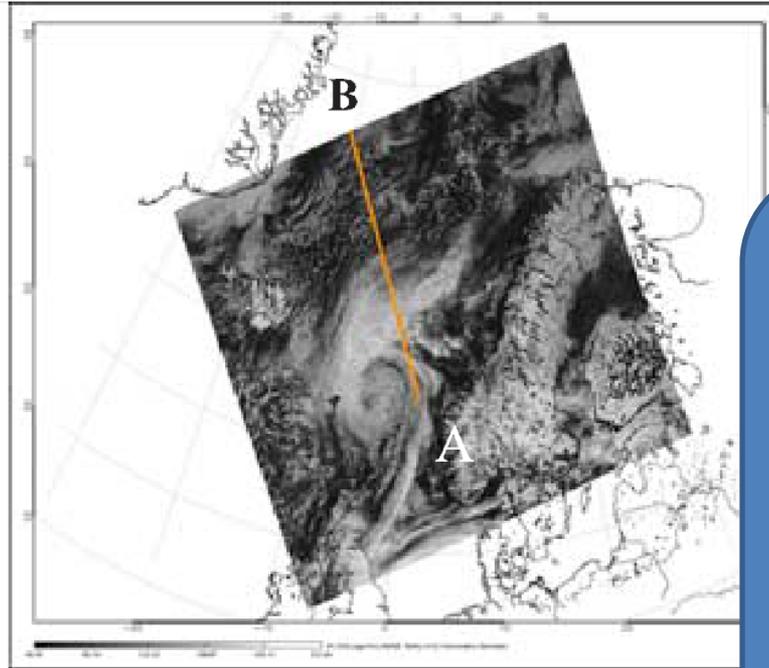


# CPR Observation (by NASA CloudSat)



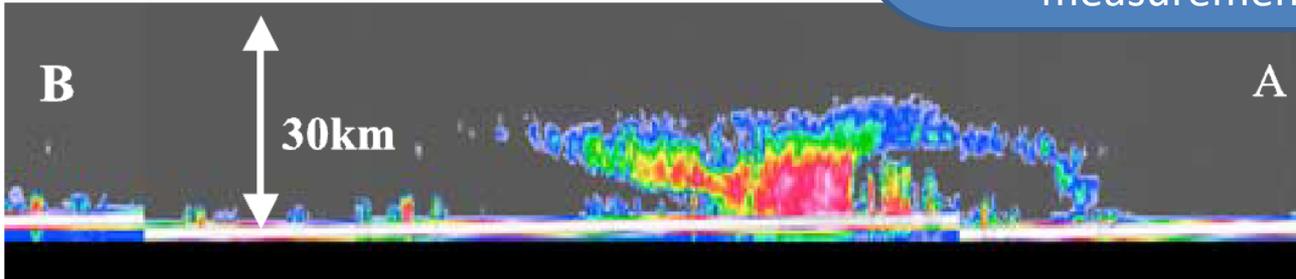
A orbit on 20 May 2006  
(Stephans et al. 2008)

A MODIS image of a  
warm frontal system

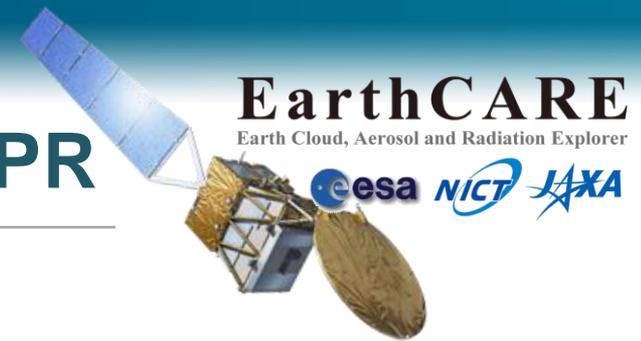


- Features of EarthCARE/CPR :
- More sensitivity than CloudSat/CPR by larger antenna size (2.5 m diameter) that is, -29dBZ → -35dBZ.
  - Capability of the doppler velocity measurement

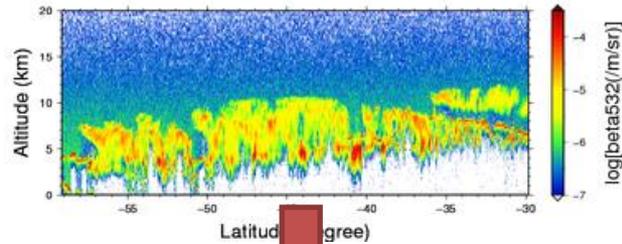
Cloud profiling radar  
(CPR) reflectivity by  
CloudSat satellite



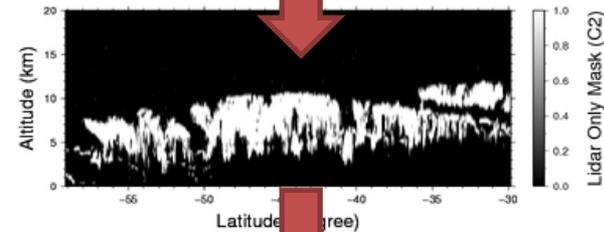
# Cloud Product by EarthCARE/CPR



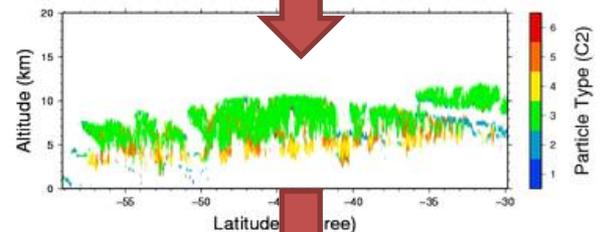
Observed data



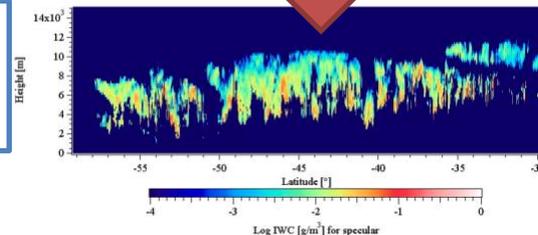
Cloud mask



Cloud Particle Type



Cloud Microphysics  
(LWC, reff, etc)

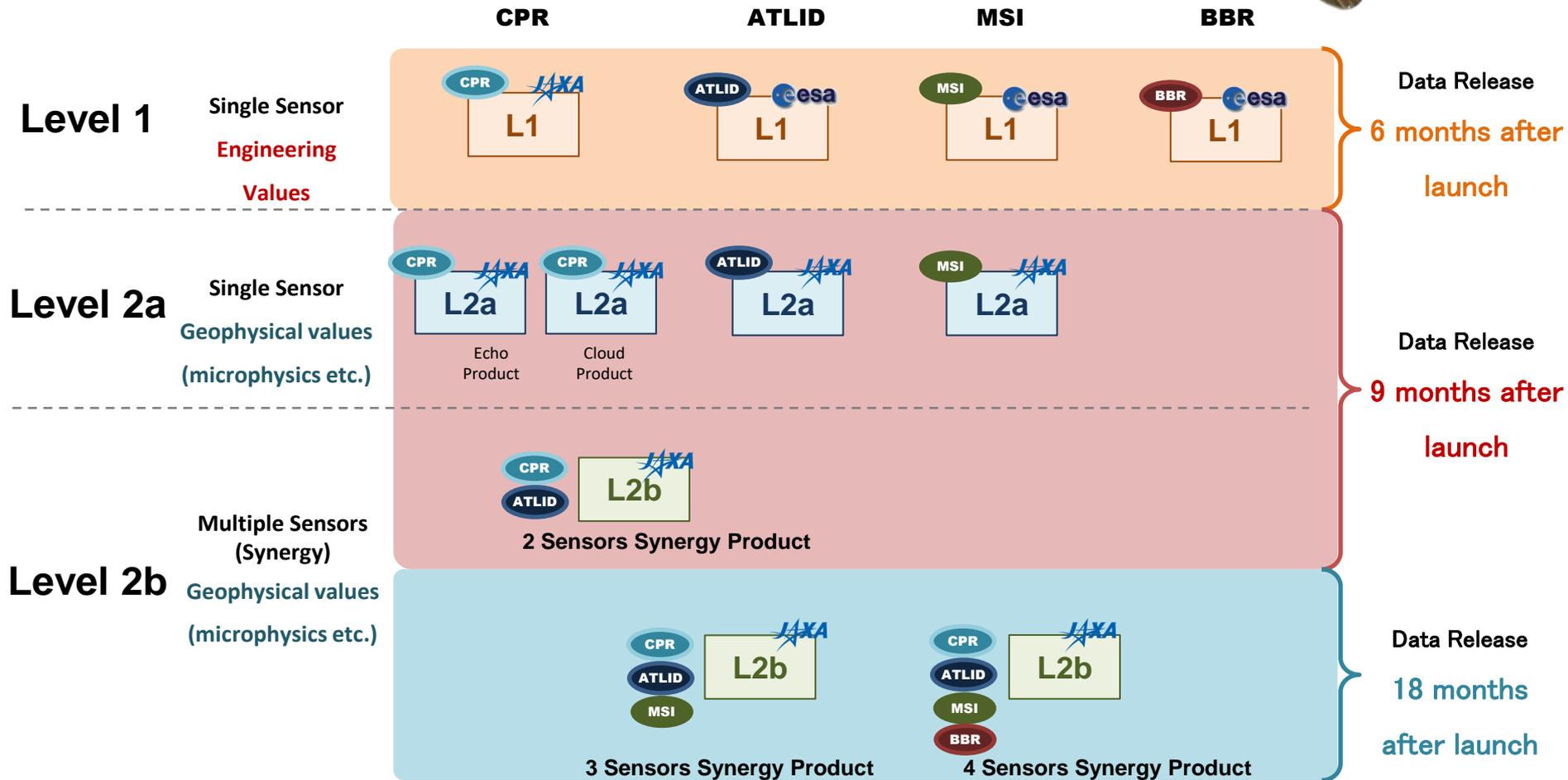
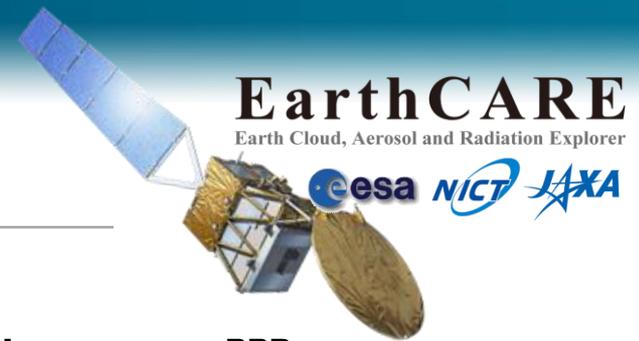


## EarthCARE JAXA Product List

Sensor(s)	Processing Level	Primary Parameters
CPR	L2a	Cloud Mask
		Cloud Particle Type
		Radar Reflective Factor with Attenuation Correction
		Liquid Water Content
		Ice Water Content
		Effective Radius of Liquid
		Effective Radius of Ice
Optical Thickness		

By Prof. H. Okamoto (Kyusyu Univ.)'s group

# JAXA & ESA Level 1 Product & JAXA Standard Level 2 Product



# EarthCARE JAXA Product



- Level 1 product will be developed by sensor provider agencies.
  - ✓ i.e. JAXA will provide CPR Level 1 product
- JAXA and ESA develop Level 2 geophysical products individually, under the framework of the Joint Mission Advisory Group (JMAG).
- **JAXA and ESA products will be distributed by both agencies.**
- For JAXA Level 2 Products, it is consisted by two categories;
  - **Standard Products**
    - strongly promoted to be developed and released
    - processed and released from **JAXA G-Portal**
    - all data will be able to be sent to ESA when produced
  - **Research Products**
    - promoted to be developed
    - released from **JAXA Earth Observation Research Center(EORC)**
    - some are planned to be upgraded to standard products

# EarthCARE Products

## JAXA & ESA Product (L1b/c:Stand-alone)



Sensor(s)	Processing Level	Product Name (Product ID for ESA)	Primary Parameter	Grid Spacing		File Unit File Format	Data Volume per day*
				Horizontal	Vertical		
CPR	L1b	CPR One-Sensor Received Power and Doppler Product	Received Echo Power / Radar Reflectivity Factor / Doppler Velocity / Pulse Pair Covariance / Spectrum Width	0.5 km	0.1 km	1/8 orbit HDF	51.3GB
			Surface Radar Cross Section	0.5 km	-		
ATLID	L1b	A-NOM	Rayleigh and Mie Backscattering coefficient * Mie component has horizontal and vertical depolarization component	0.285 km	0.103 km	1/8 orbit netCDF	91.6GB
MSI	L1b	M-NOM	Radiation Intensity * Visible(0.67 $\mu$ m), Near IR(0.865 $\mu$ m), SW IR(1.65 $\mu$ m, 2.21 $\mu$ m), LW IR(8.80 $\mu$ m, 10.80 $\mu$ m, 12.00 $\mu$ m)	0.5 km	-	1/8 orbit netCDF	83.9GB
BBR	L1b	B-NOM	SW and LW Radiation (Forward, Nadir, Backward)	10 km	-	1/8 orbit netCDF	2.3GB

Sensor(s)	Processing Level	Product Name (Product ID for ESA)	Primary Parameter	Grid Spacing		File Unit File Format	Data Volume per day*
				Horizontal	Vertical		
MSI	L1c	M-NOM	L1b Radiation Intensity (interpolated to the location of a reference band)	0.5 km	-	1/8 orbit netCDF	18.3GB

\* 125 files per day is assumed without compression. ATLID, MSI, BBR is ESA product.

# JAXA Standard Products (L2a:Stand-alone)



Sensor(s)	Processing Level	Product Name	Primary Parameter (Red: Spatial-integrated values will be also generated)	Grid Spacing		File Unit File Format	Data Volume per day*
				Horizontal	Vertical		
CPR	L2a	CPR One-sensor Echo Products	Integrated Radar Reflectivity Factor Integrated Doppler Velocity Gas Correction Factor	1 km	0.1 km	1/8 orbit HDF	116.0GB
CPR	L2a	CPR One-sensor Cloud Products	Cloud Mask / Cloud Particle Type / Liquid Water Content / Ice Water Content / Effective Radius of Liquid Water Cloud / Effective Radius of Ice Water Cloud	1 km	0.1 km	1/8 orbit HDF	131.8GB
			Optical Thickness	1 km	-		
ATLID	L2a	ATLID One-sensor Cloud and Aerosol Products	Feature Mask	0.2 km	0.1 km	1/8 orbit HDF	70.8GB
			Target Mask	1 km	0.1 km		
			Aerosol Extinction Coeff. / Aerosol Backscat. Coeff. / Aerosol Lidar Ratio / Aerosol Depolarization Ratio	10km	0.1 km		
			Cloud Extinction Coeff. / Cloud Backscat. Coeff. / Cloud Backscat. Coeff. / Cloud Depolarization Ratio	1 km	0.1 km		
			Cloud Depolarization Ratio	1 km	0.1 km		
MSI	L2a	MSI One-sensor Cloud Products	Cloud Flag including Cloud Phase / Optical Thickness of Liquid Water Cloud / Effective Radius of Liquid (1.6 $\mu$ m) / Effective Radius of Liquid (2.2 $\mu$ m) / Cloud Top Temperature / Cloud Top Pressure / Cloud Top Height	0.5 km	-	1/8 orbit HDF	163.6GB

\* 125 files per day is assumed without compression.

# JAXA Standard Products (L2b:Synergy)



Sensor(s)	Processing Level	Product Name	Primary Parameter (Red: Spatial-integrated values will be also generated)	Grid Spacing		File Unit File Format	Data Volume per day*
				Horizontal	Vertical		
CPR + ATLID	L2b	CPR-ATLID Synergy Cloud Products	Cloud Mask / Cloud Particle Type / Radar Reflective Factor with Attenuation / Liquid Water Content / Ice Water Content / Effective Radius of Liquid Water Cloud / Effective Radius of Ice Water Cloud	1 km	0.1 km	1/8 orbit HDF	136.7GB
			Optical Thickness	1 km	-		
CPR + ATLID + MSI	L2b	CPR-ATLID-MSI Synergy Cloud Products	Cloud Mask / Cloud Particle Type / Radar Reflective Factor with Attenuation / Liquid Water Content / Ice Water Content / Effective Radius of Liquid Water Cloud / Effective Radius of Ice Water Cloud	1 km	0.1 km	1/8 orbit HDF	136.7GB
			Optical Thickness / Liquid Water Path / Ice Water Path	1 km	-		
4 sensors	L2b	Four Sensors Synergy Radiation Budget Products	SW Radiative Flux / LW Radiative Flux	10 km	-	1/8 orbit HDF	7.3GB
			SW Radiative Heating Rate / LW Radiative Heating Rate	10 km	0.5 km		

\* 125 files per day is assumed without compression.

# JAXA Research Products (L2a:Stand-alone)



Sensor(s)	Processing Level	Status	Product Name	Primary Parameter (Red: Spatial-integrated values will be also generated)	Grid Spacing		File Unit File Format
					Horizontal	Vertical	
CPR	L2a	Red R	CPR One-sensor Doppler Products	Doppler velocity correction value (considering inhomogeneity) / Doppler velocity unfolding Value / Radar Reflective Factor with Attenuation	1 km	0.1 km	1/8 orbit HDF
		ER	CPR One-sensor Rain and Snow Products	Rain Water Content / Snow Water Content / Rain Rate / Snow Rate	1 km	0.1 km	1/8 orbit HDF
		ER	CPR One-sensor Vertical Velocity Products	Vertical Air Motion / Sedimentation Velocity	1 km	0.1 km	1/8 orbit HDF
ATLID	L2a	ER	ATLID One-sensor Aerosol Extinction Products	Aerosol Extinction Coefficient (Water Soluble) / Aerosol Extinction Coefficient (Dust) / Aerosol Extinction Coefficient (Sea Salt) / Aerosol Extinction Coefficient (Black Carbon)	1 km	0.1 km	1/8 orbit HDF
MSI	L2a	ER	MSI One-sensor Ice Cloud Products	Optical Thickness of Ice Cloud with Reflection method / Effective Radius of Ice Cloud (1.6 $\mu$ m) / Effective Radius of Ice Cloud (2.2 $\mu$ m) / Ice Cloud Top Temperature / Ice Cloud Top Pressure / Ice Cloud Top Height	0.5 km	-	1/8 orbit HDF
		ER	MSI One-sensor Aerosol Products	Aerosol Optical Thickness (Ocean) / Aerosol Optical Thickness(Land) / Angstrom Exponent (Ocean)	0.5 km	-	1/8 orbit HDF

# JAXA Research Products (L2b:Synergy)



Sensor(s)	Processing Level	Status	Product Name	Primary Parameter (Red: Spatial-integrated values will be also generated)	Grid Spacing		File Unit File Format
					Horizontal	Vertical	
CPR + ATLID	L2a	Red R	CPR-ATLID Synergy Particle Mass Ratio Products	Mass Ratio (2D_Ice/IWC)	1 km	-	1/8 orbit HDF
		ER	CPR-ATLID Synergy Rain & Snow Products	Rain Water Content / Snow Water Content / Rain Rate / Snow Rate	1 km	0.1 km	1/8 orbit HDF
		ER	CPR-ATLID Synergy Vertical Velocity Products	Vertical Air Motion / Sedimentation Velocity	1 km	0.1 km	1/8 orbit HDF
ATLID + MSI	L2a	ER	ATLID-MSI synergy Aerosol Components Products	Aerosol Extinction Coefficient (Water Soluble) / Aerosol Extinction Coefficient (Dust) / Aerosol Extinction Coefficient (Sea Salt) / Aerosol Extinction Coefficient (Black Carbon) / Mode Radius	10 km	0.1 km	1/8 orbit HDF
CPR + ATLID + MSI	L2a	LR	CPR-ATLID-MSI Synergy Cloud Doppler Products	Cloud Mask / Cloud Particle Type / Liquid Water Content / Ice Water Content / Effective Radius of Liquid Water Cloud / Effective Radius of Ice Water Cloud (with Doppler)	1 km	0.1 km	1/8 orbit HDF
				Optical Thickness / Liquid Water Path / Ice Water Path (with Doppler)	1 km	-	1/8 orbit HDF
		LR	CPR-ATLID-MSI Synergy Rain and Snow Products	Rain Water Content / Snow Water Content / Rain Rate / Snow Rate	1 km	0.1 km	1/8 orbit HDF
		LR	CPR-ATLID-MSI Synergy Vertical Velocity Products	Vertical Air Motion / Sedimentation Velocity	1 km	0.1 km	1/8 orbit HDF
		LR	CPR-ATLID-MSI Synergy Emission Method Products	Effective Radius of Ice Cloud derived from Emission Method / Optical Thickness of Ice Cloud derived from Emission	0.5 km	-	1/8 orbit HDF

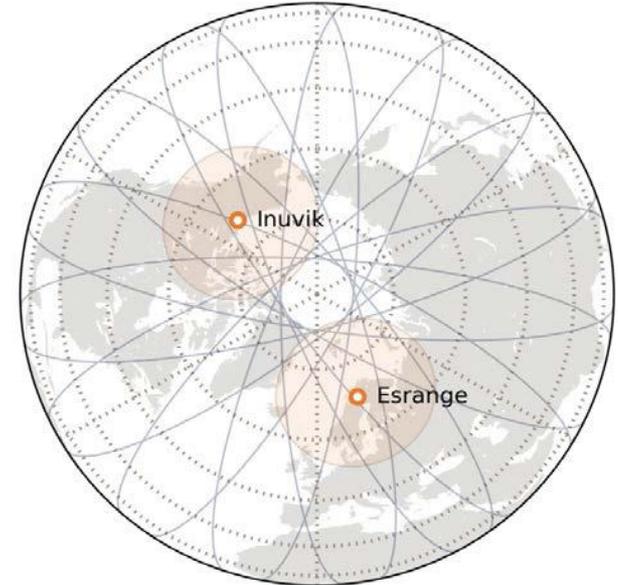
“Red R” = Research product, would be processed in JAXA EORC Research and Application System, and to be upgraded to standard after one year or later when the release accuracy is approved.  
 “ER” = Research product, would be processed in JAXA EORC Research and Application System. “LR” = Research product, would be processed in Japanese Laboratories

# Stations & Data latency



## ■ Stations:

- **Esrangle/Kiruna & Inuvik (SSC)**
- **Two 13-m antenna at each GS location**
- **10 combined passes per day baseline**
- **Kiruna: 10p/d, 5.6/7.9 mean/max minutes per pass**
- **Inuvik: 10p/d, 5.8/7.9 mean/max minutes per pass**

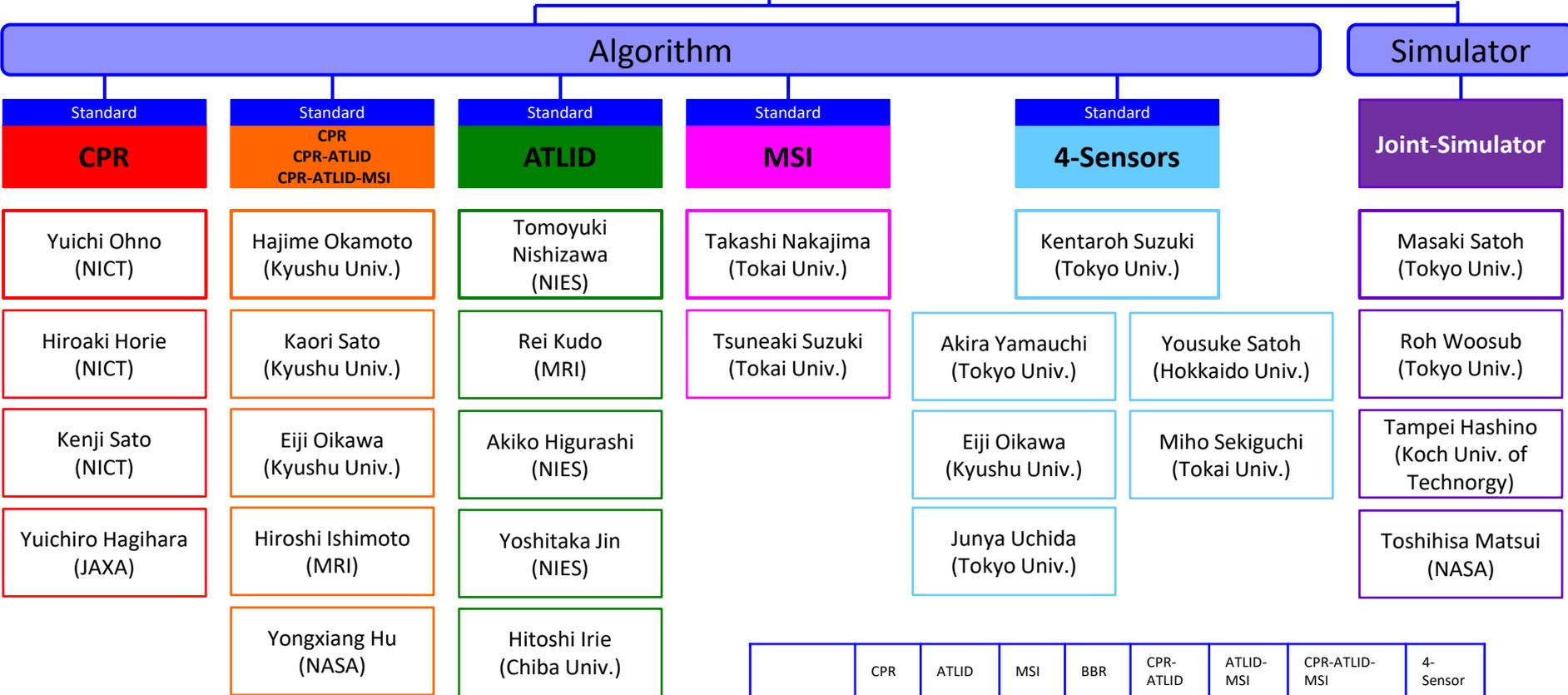
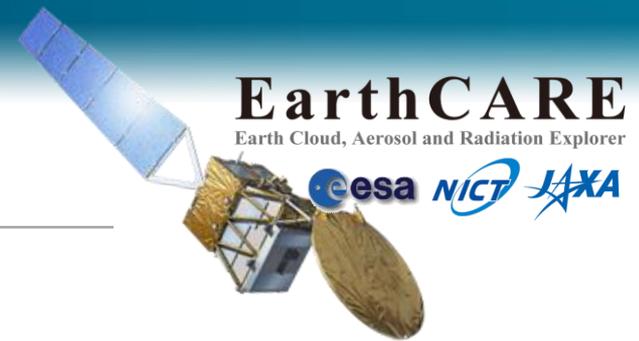


## ■ Data latency

- **a. Nominal (60% of data) : max. 93 minutes**
- **b. Worst case (blind orbits): 203 minutes max**

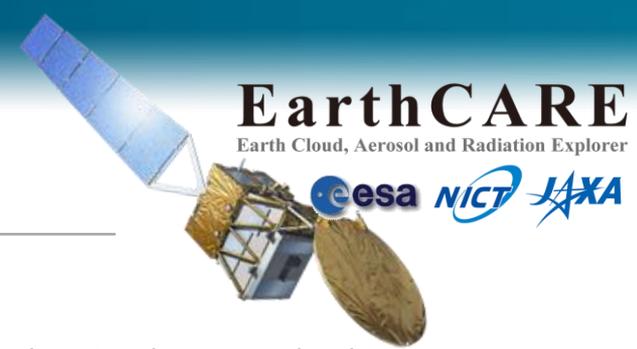
# EarthCARE JAXA Science Team

## Algorithm & Simulator (as of 2019)



	CPR	ATLID	MSI	BBR	CPR-ATLID	ATLID-MSI	CPR-ATLID-MSI	4-Sensor
Standard	■ ■	■	■	■	■	■	■ ■ ■	■
Research	■ ■	■	■ ■ ■	■	■	■	16 ■ ■ ■	■

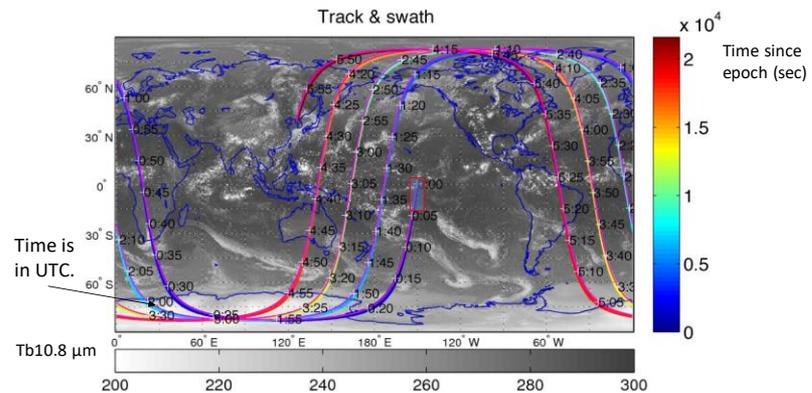
# JAXA Algorithm development with the Joint-Simulator L1 synthetic data



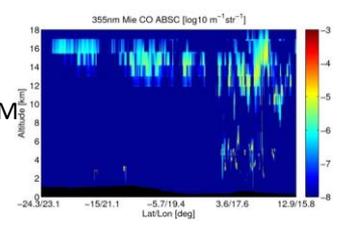
- Level 2 algorithm development ongoing
  - Now All JAXA EarthCARE L2 algorithms can input synthetic data with the JAXA/ESA L1 formats from the Joint-Simulator and output physical variables in the JAXA L2 format.
- JAXA L2 ATBD is provided in the JAXA/EORC Website: <http://www.eorc.jaxa.jp/EARTHCARE/index.html>

## EarthCARE L1 Simulation by the Joint-Simulator using NICAM-SPRINTARS data

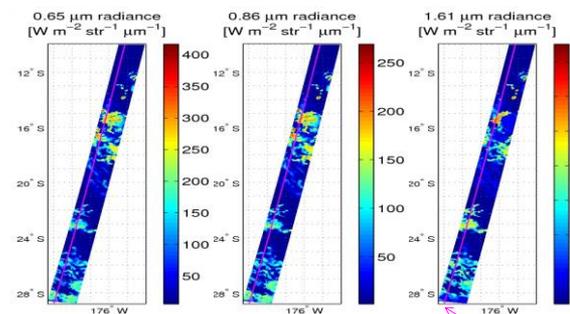
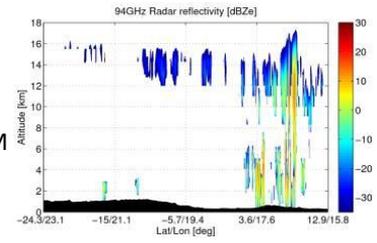
EarthCARE L1 data construction in Japan  
 Algorithms have been developed using the synthetic data by the Joint-Simulator in the JAXA EarthCARE Science team.



Lidar Simulation from NICAM (Last version: only cloud signals simulated)



CPR Radar reflectivity Simulation from NICAM



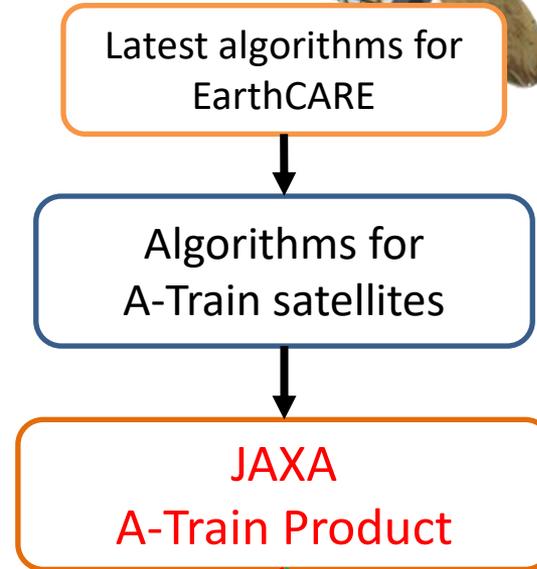
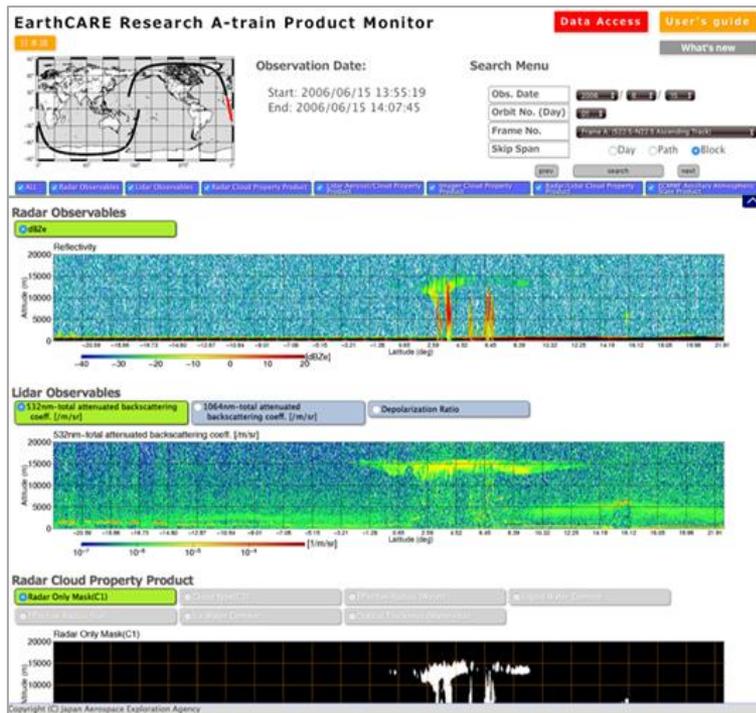
MSI simulation

- NICAM 3.5 km simulation, 2008 June 19<sup>th</sup> 00Z
- The data was interpolated based on the sampling procedure of each sensor.
- The orbit was simulated such a way that EarthCARE passes equator at 14:00 local time in the descending node.

# JAXA A-Train Product for EarthCARE



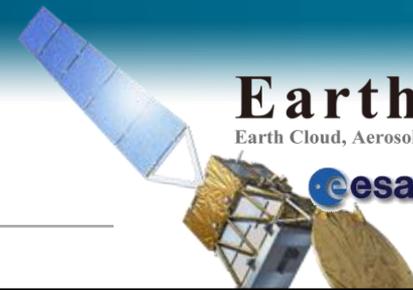
- JAXA has provided the "**EarthCARE Research A-Train Product**" since Oct. 2017.
  - [http://www.eorc.jaxa.jp/EARTHCARE/research\\_product/ecare\\_monitor\\_e.html](http://www.eorc.jaxa.jp/EARTHCARE/research_product/ecare_monitor_e.html)



Validation using heritages of the ground observations, "Japanese validation rehearsal"

Applications: Cloud/Aerosol/Radiation Process study, Model evaluations, ...etc.

Toward long-term dataset with the A-Train and the EarthCARE...



## Applications with weather/climate models

ECMWF & ESA joint works of the Data Assimilation are on-going.

Publications in the ECMWF:

<https://doi.org/10.1002/qj.3878>

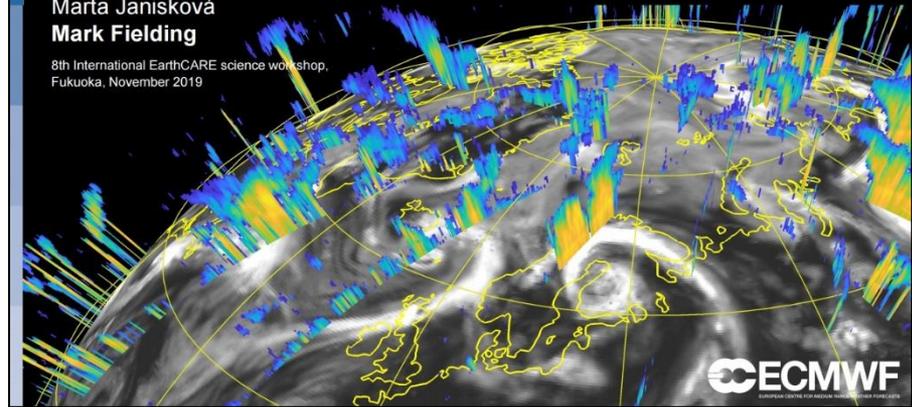
<https://doi.org/10.1002/qj.3879>

JAXA is now coordinating data assimilation studies with the JMA and evaluations of the Japanese climate models (JMA/MRI, MIROC, NICAM, ...).

### Potential of EarthCARE for improving weather forecasts via assimilation of radar reflectivity and lidar backscatter

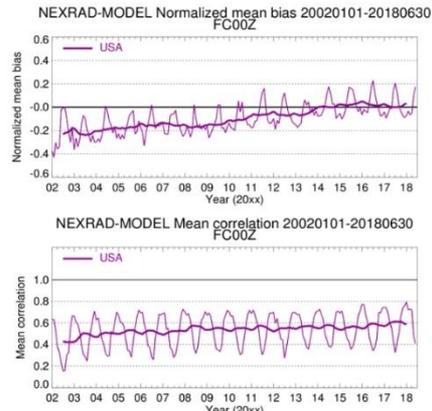
Marta Janisková  
Mark Fielding

8th International EarthCARE science workshop,  
Fukuoka, November 2019



#### Why assimilate EarthCARE?

- Weather forecast skill in global models continues to advance via improved model realism and improved initial conditions.
- Observations sensitive to water vapour and clouds have dominated recent observation capability. However, they do not constrain the full structure of clouds.
- EarthCARE radar and lidar observations could help fill the gap in information content and improve the usage of passive sensors by providing the correct vertical context of clouds.

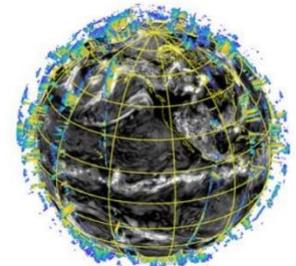


Short-term forecasts of precipitation over the US continue to improve

Thanks: Philippe Lopez

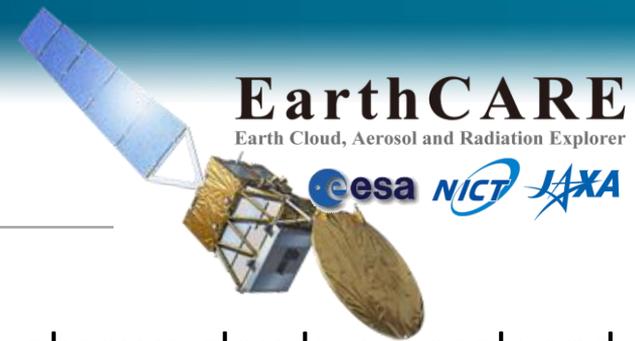
#### Progress towards assimilation of EarthCARE cloud radar and lidar observations

- The recent ESA project (finished Autumn 2018) developed technical capability to assimilate cloud radar and lidar observations at ECMWF, facilitating the:
  1. Monitoring of data quality in near real-time against the operational model.
  2. Model-to-observation evaluation of cloud and precipitation and subsequent model development.
  3. Potential for improving the model analysis leading to direct improvements of forecast skill.



Expected data coverage for 12 hours

# Summary



- EarthCARE Overview

- EarthCARE is a joint Japanese-European mission to observe clouds, aerosols and radiation (Overview paper: Illingworth et al. 2015, BAMS, <https://doi.org/10.1175/BAMS-D-12-00227.1> )
- will be launched in JFY2022 ( = Apr. 2022-Mar. 2023)
- Features of the EarthCARE/CPR developed by Japan
  - ✓ More sensitivity than CloudSat/CPR by larger antenna size (2.5 m diameter) that is, 29dBZ → -35dBZ.
  - ✓ Capability of the doppler velocity measurement

- Algorithm status

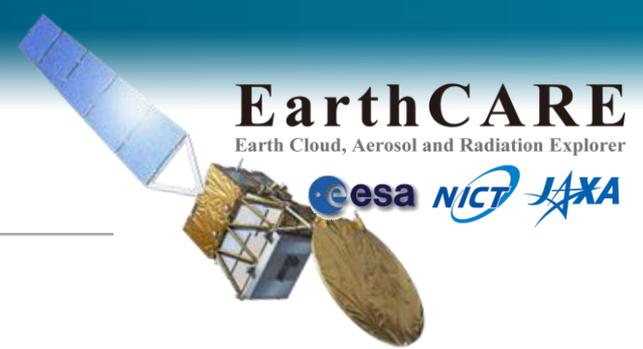
- Developments by 6 Algorithm PIs are ongoing.
- JAXA L2 ATBD is provided in the JAXA/EORC Website: <http://www.eorc.jaxa.jp/EARTHCARE/index.html>

- JAXA A-Train Product for EarthCARE

- [http://www.eorc.jaxa.jp/EARTHCARE/research\\_product/ecare\\_monitor\\_e.html](http://www.eorc.jaxa.jp/EARTHCARE/research_product/ecare_monitor_e.html)

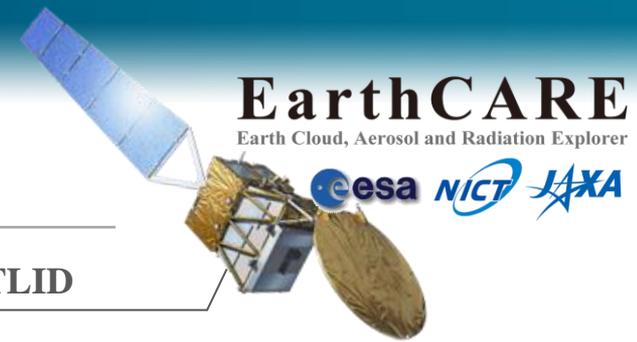
- Applications with weather/climate models

- Data assimilation, evaluations of climate models, ...



## Appendix

# Sensors



**EarthCARE**  
Earth Cloud, Aerosol and Radiation Explorer

ESA NICT JAXA

ATLID

## ATLID Atmospheric Lidar

Instrument	355nm High Spectral Resolution Lidar (HSRL)
Channel	- Rayleigh Channel - Mie Channel (Horizontal Polarization) - Mie Channel (Vertical Polarization)
Sampling	Horizontal : 285m / Vertical : 100m
Polarization	3 polarization angles
Observation Direction	2 – 3° Off Nadir (TBD)

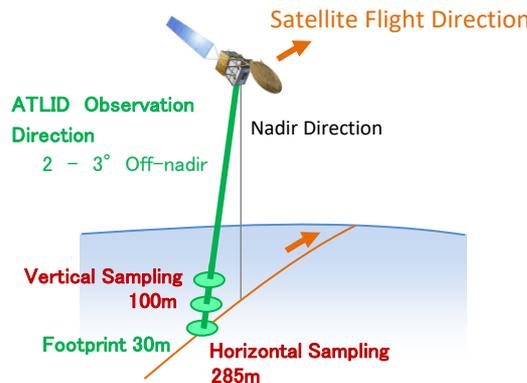
## Global Observation of Cloud and Aerosol Vertical Profile and Optical Properties

ATLID is a High Spectral Resolution Lidar (HSRL) developed by European Space Agency.

Different from the traditional Mie lidar, it has the capability to separate Rayleigh scattering signal (originate from atmospheric molecules) and Mie scattering signal (originate from aerosol and cloud) by high spectral resolution filter. Thus, it has the potential to independently retrieve **backscattering coefficient** and **extinction coefficient** of atmospheric particles.

### Observable Parameters

- Backscattering Coefficient
- Target Mask
- Feature Mask
- Extinction Coefficient
- Depolarization Ratio
- Lidar Ratio



## Observation of Fine Particles within the Atmosphere

By 355nm (UV) wavelength, ATLID has the capability to **detect fine particles, such as thin cloud and aerosol, that were difficult to be observed by radars**. In addition, it also has the capability to achieve information of **particle shapes** by polarization observation.

# Sensors

## MSI

### Multi-Spectral Imager

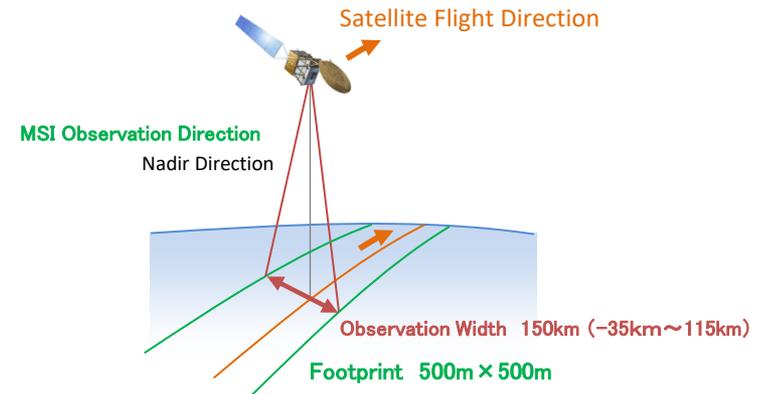
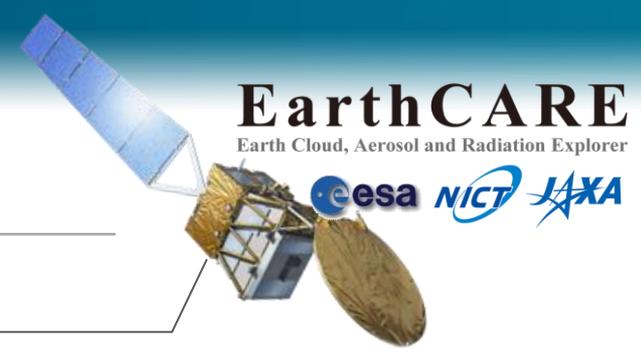
Instrument	Pushbloom Imager
Wavelength Band (Visible / Near-Infrared / Shortwave Infrared)	0.670 mm, 0.865 mm, 1.65 mm, and 2.21 mm
Wavelength Band (Thermal Infrared)	8.80 mm, 10.80 mm, and 12.00 mm
Observation Width	150 km (-35 km to +115 km)*
Footprint	500 m x 500 m

\*This asymmetry is intended to reduce the influence of sunglint

## Measurement of Cloud by Multiband

MSI is an optical sensors with 7 channels from visible to thermal infrared, which measures the **cloud distribution** and cloud physical properties including **cloud effective radius** and **optical thickness**.

MSI



## Observable Parameters

- Cloud Flag / Cloud Phase
- Liquid Optical Thickness
- Liquid Effective Radius (1.6 $\mu$ m)
- Liquid Effective Radius (2.2 $\mu$ m)
- Cloud Top Height
- Cloud Top Pressure
- Cloud Top Temperature

# Sensors

## BBR

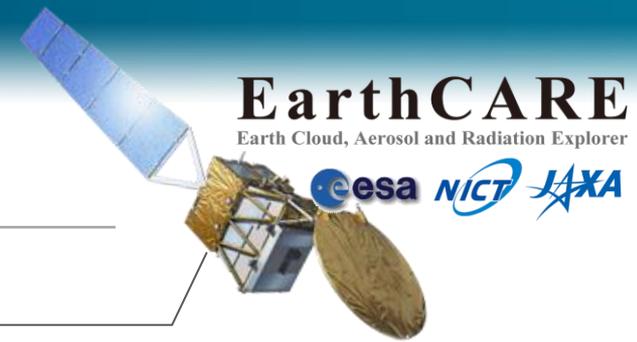
### Broadband Radiometer

Wavelength Range	- Short wave : 0.2 – 4.0 $\mu\text{m}$ - Long wave : 4.0 – 50 $\mu\text{m}^*$
Dynamic Range	- Short wave: 0 – 450 $\text{W}/\text{m}^2/\text{str}$ - Long wave: 0 – 130 $\text{W}/\text{m}^2/\text{str}$
Observation Direction	nadir, forward (55 deg), backward (-55 deg)
Footprint	10 km x 10 km

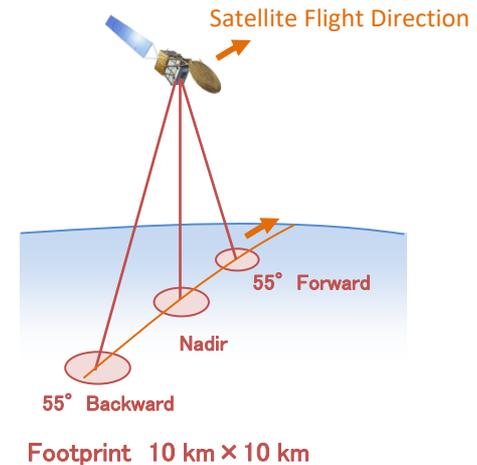
\*The spectral radiance in Long-wave channel is calculated from Short-wave and Total-wave (0.2- 50  $\mu\text{m}$ ) observations. (based on MRD)

## Measurement of Radiation Flux at Top of Atmosphere

BBR has the sensitivity to longwave and shortwave band, and has the potential for **longwave and shortwave radiation flux** at the top of atmosphere to be retrieved.



BBR



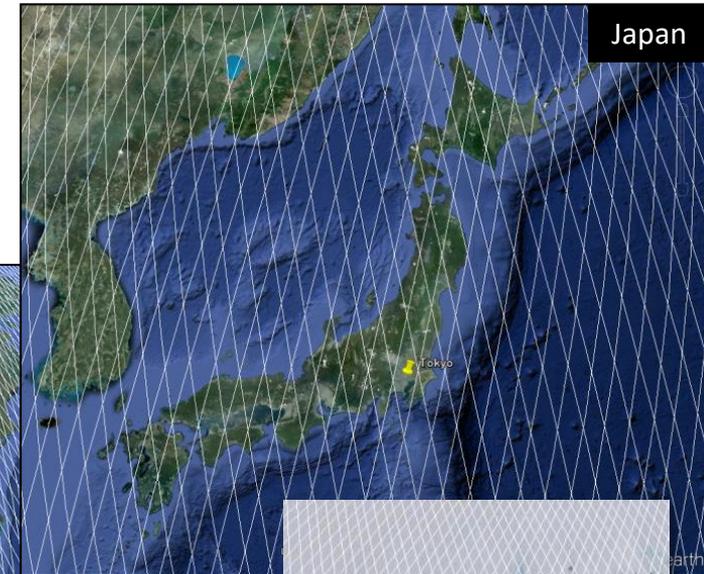
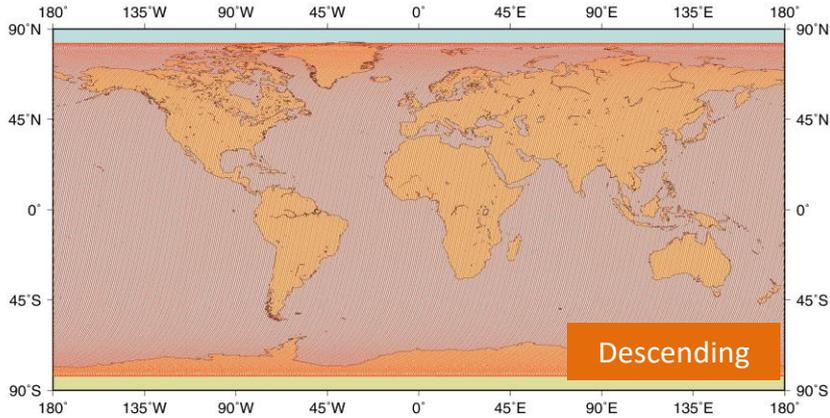
## Observable Parameters

Radiation (Longwave / Shortwave)  
Radiation Flux(Longwave / Shortwave)

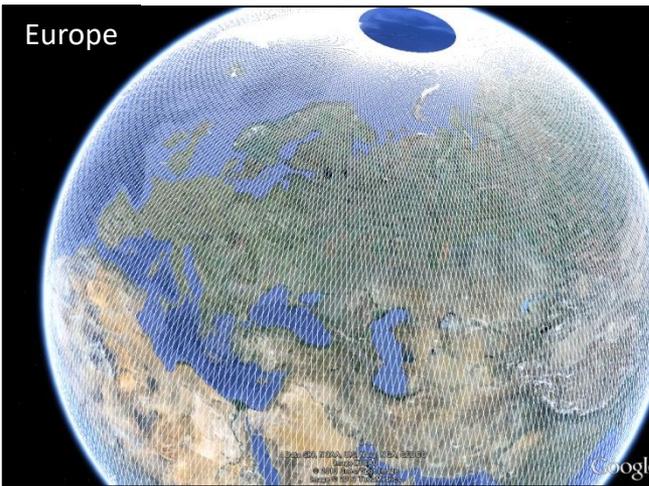
# EarthCARE Orbit



Mean Local Time : Approx. 14:00 (Descending)  
2:00 (Ascending)



Japan



Europe



USA



Showa Station

\* Longitude of Ascending Node is TBD.