JAXA's Passive Microwave Imagers (AMSR) and Cloud/Precipitation Radars (CPR/DPR)

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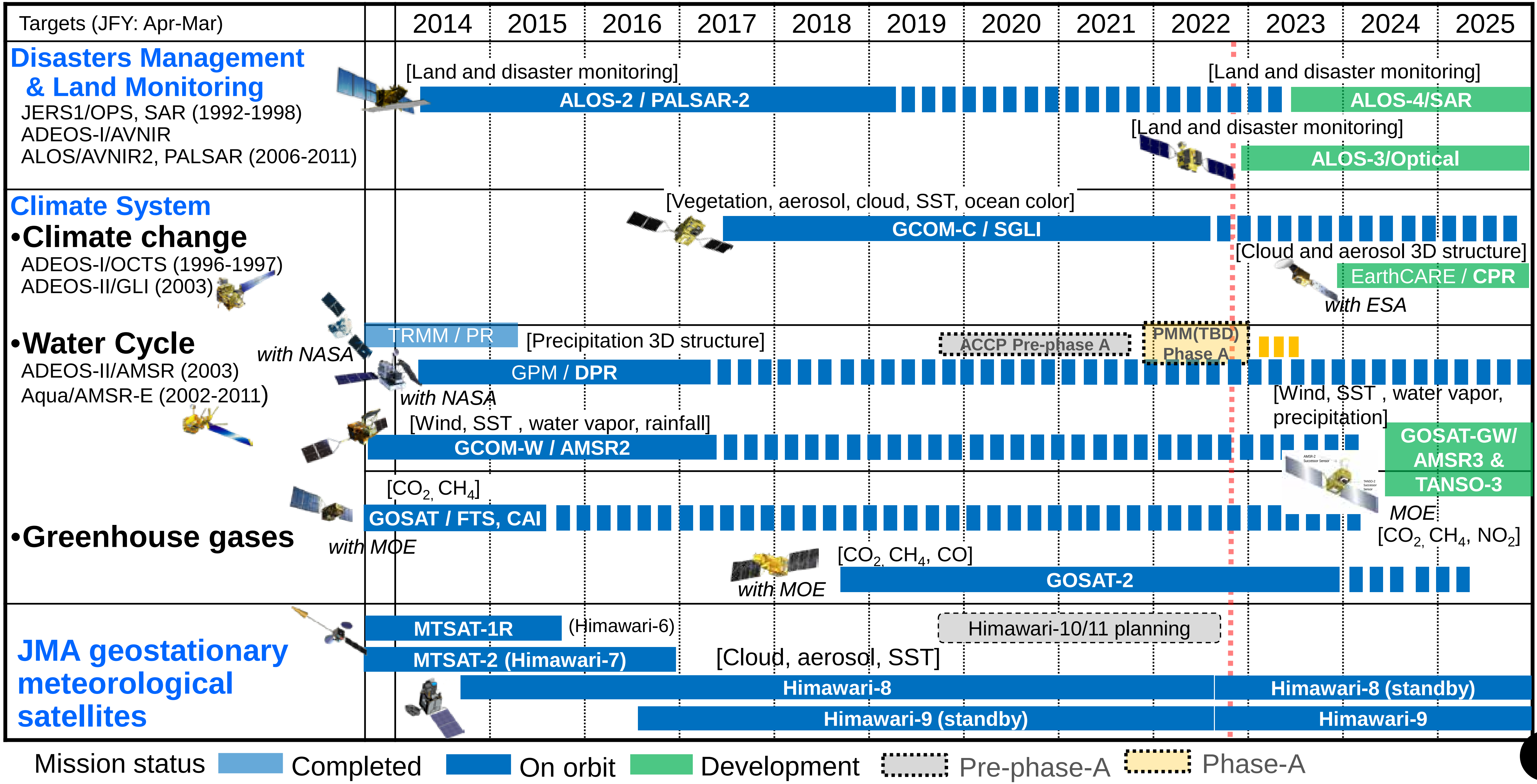
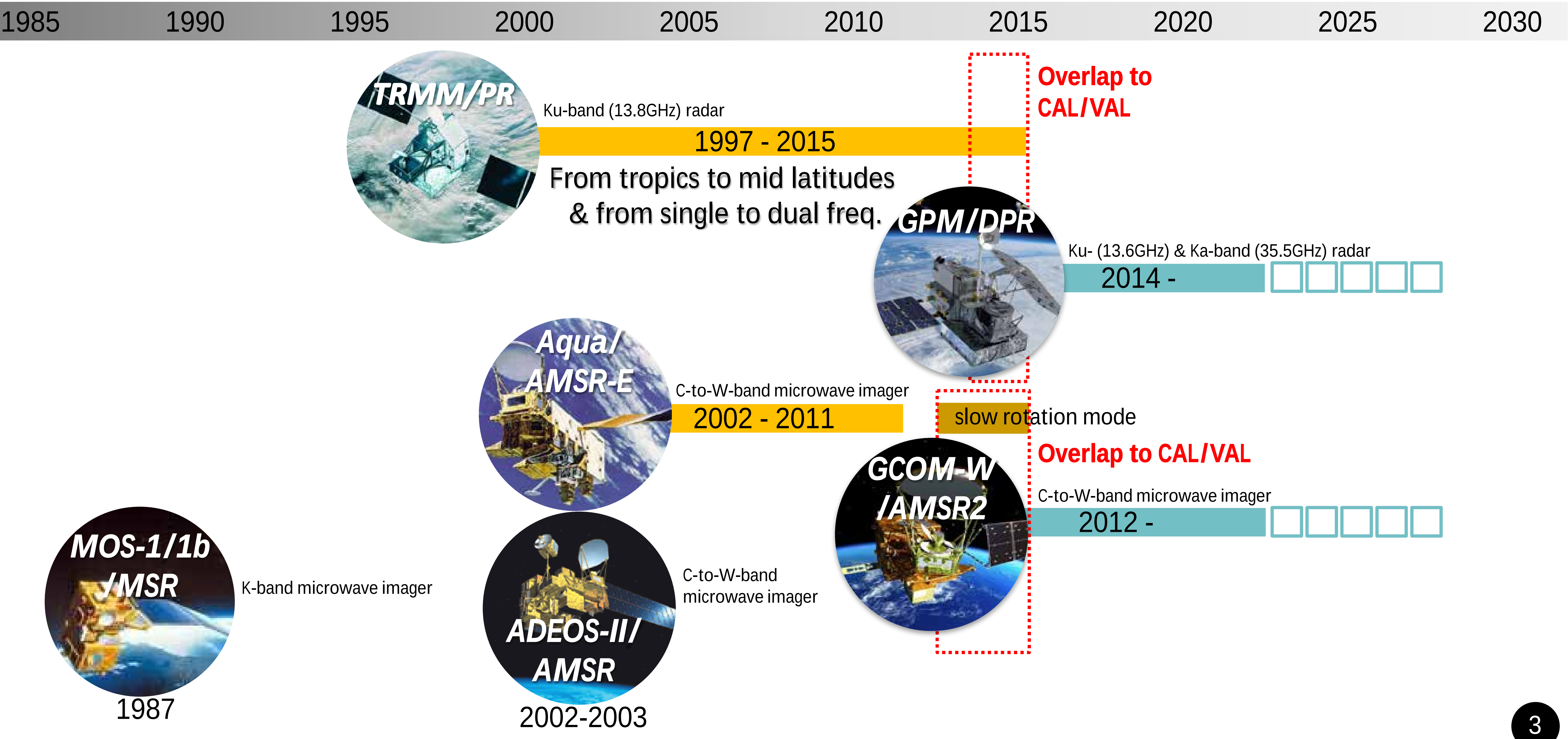
"Precipitation Estimation from LEO Satellites:

Japanese Earth Observation Satellites/Sensors



Precipitation-related Missions in Japan



History of Passive Microwave Observations

- With experience of development and operation of MSR, JAXA developed 1st generation of AMSR (AMSR and AMSR-E) with large antenna size and C-band channels. AMSR-E continuous its science observation about 9.5-year, and its high capabilities enable to expand utilizations in operational and research areas.
- 2nd generation of AMSR (AMSR2) was launched in 2012 and succeeds AMSR-E observations to establish its data utilization in various areas.
- 3rd generation of AMSR (AMSR3) is under development and to be launched in JFY2024.

1987

MSR

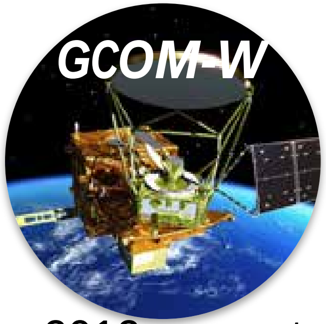
- 2-channel in 23GHz & 32GHz
- Antenna size: 0.5m
- Spatial resolution: 23-32km
- Swath width: 317km

2002-2011

AMSR

AMSR-E

- 6-frequency, 14-channel
- Antenna size: 1.6m
- Spatial resolution: 6-74km
- Swath width: 1450km



2012-present

Succeed AMSR-E observation

AMSR2

- Improved onboard calibration
- Additional 7GHz channels to mitigate impact of RFIs
- 2-m antenna

after 2024

Continue & improve AMSR-E/AMSR2 observation

AMSR3

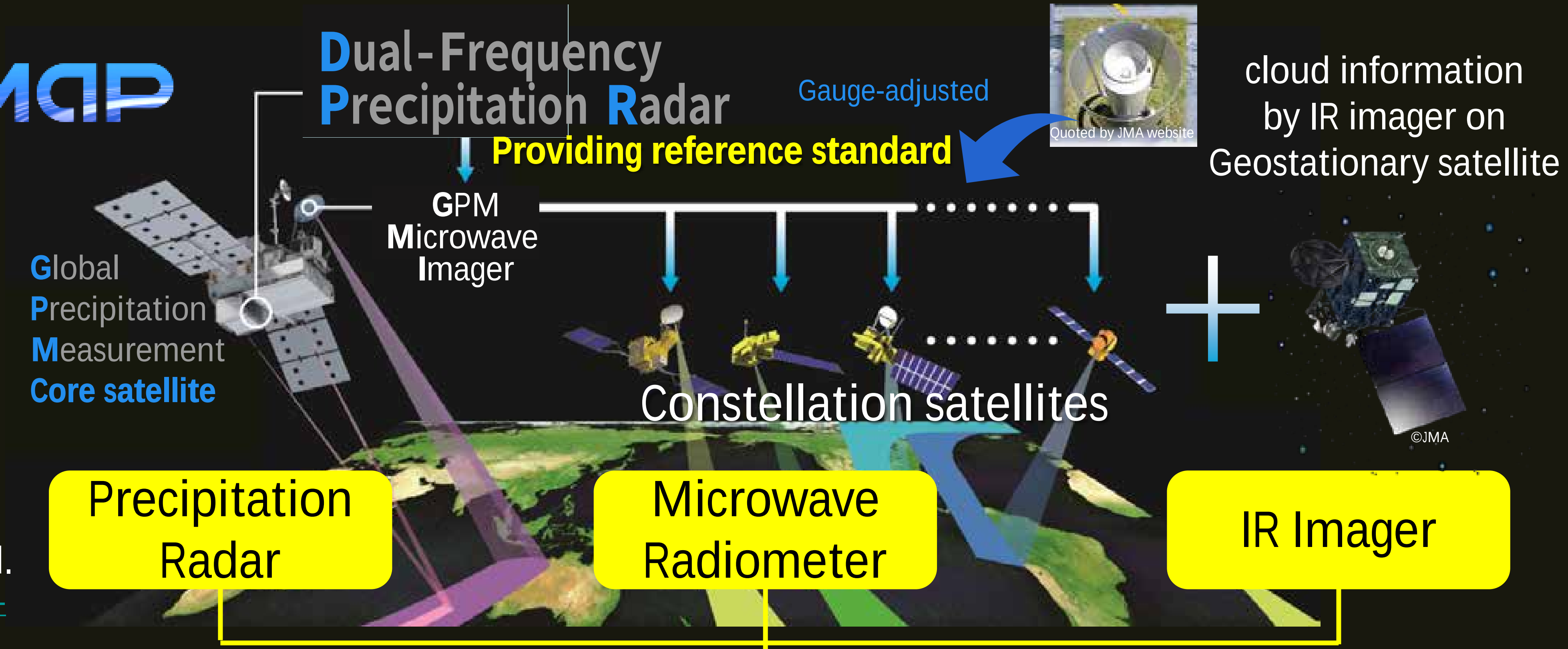
- New high-frequency channels for snowfall and NWP
- Additional 10GHz channels with better NEDT for robust SST

Japanese Multi-satellite Precipitation Product
Global Satellite Mapping of Precipitation (GSMaP)

GSMaP

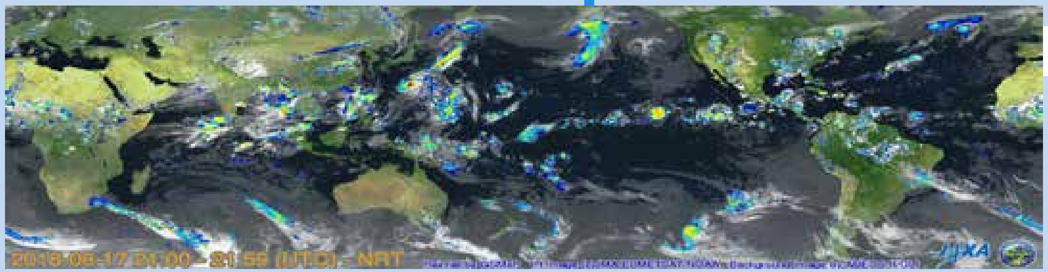
Registered users:
6061 users
131 countries
(May 2020)

Recently, a GSMaP's review paper, Kubota et al. (2020) was published.
https://doi.org/10.1007/978-3-030-24568-9_20



Multi-satellite Precipitation Product

- hourly global rainfall data
- 0.1x0.1deg. lat/lon
- Various version such as realtime for monitoring or long-term gauge-adjusted for climatological purposes

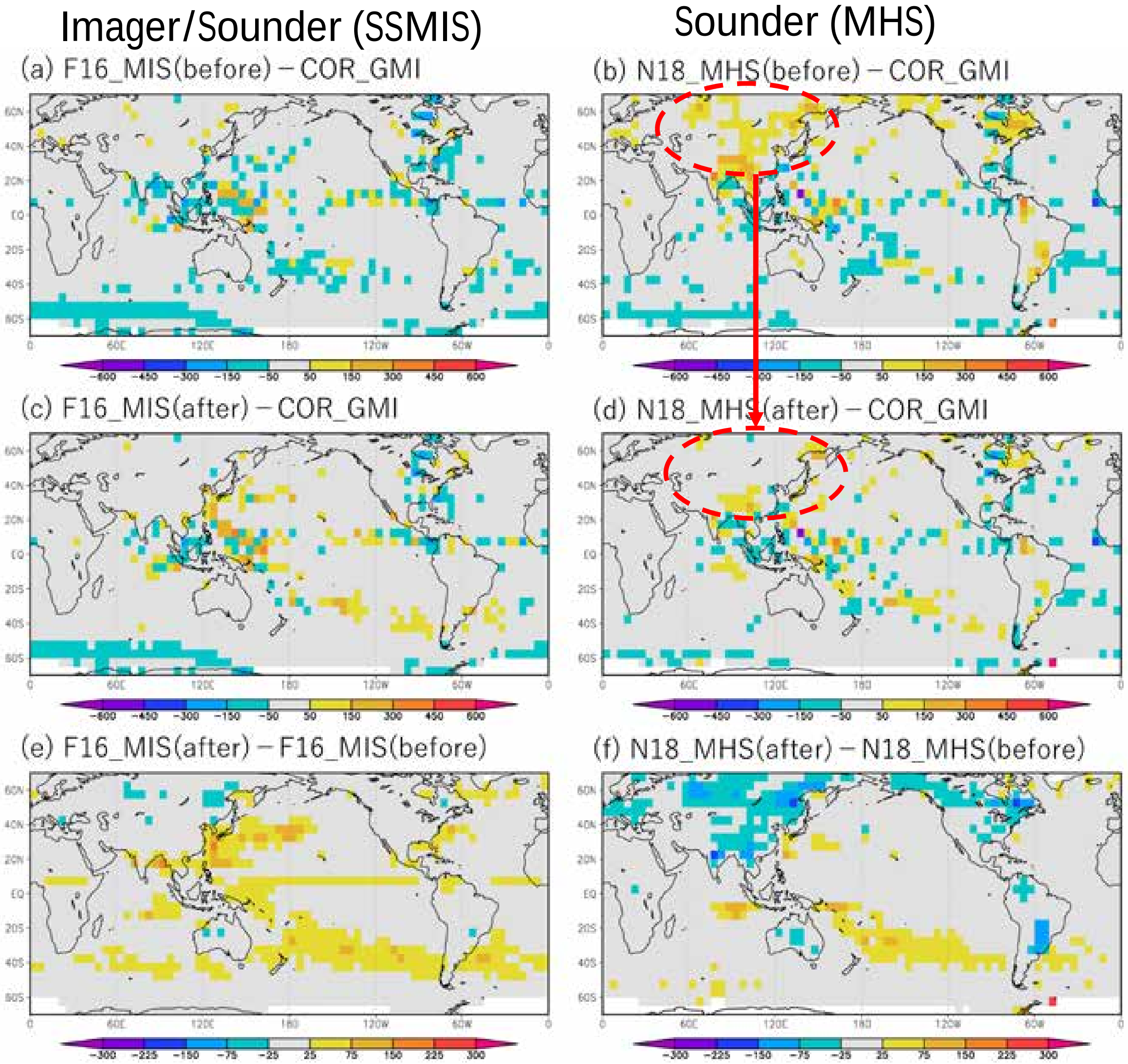


distribution

- website
- netCDF
- GeoTIFF
- CSV
- Binary
- png

Implementation of a Rainfall Normalization Module for GSMaP Microwave Imagers and Sounders

- GSMaP products have been calculated using various microwave imagers/sounders (PMW sensors) data.
- Difference of rainfall estimates exists among the PMW sensors due to specifications, algorithms, etc...
- Against the discrepancy among the PMW sensors, the GSMaP has developed the correction method as the "Method of Microwave Rainfall Normalization (MMN)" (Yamamoto and Kubota 2022).

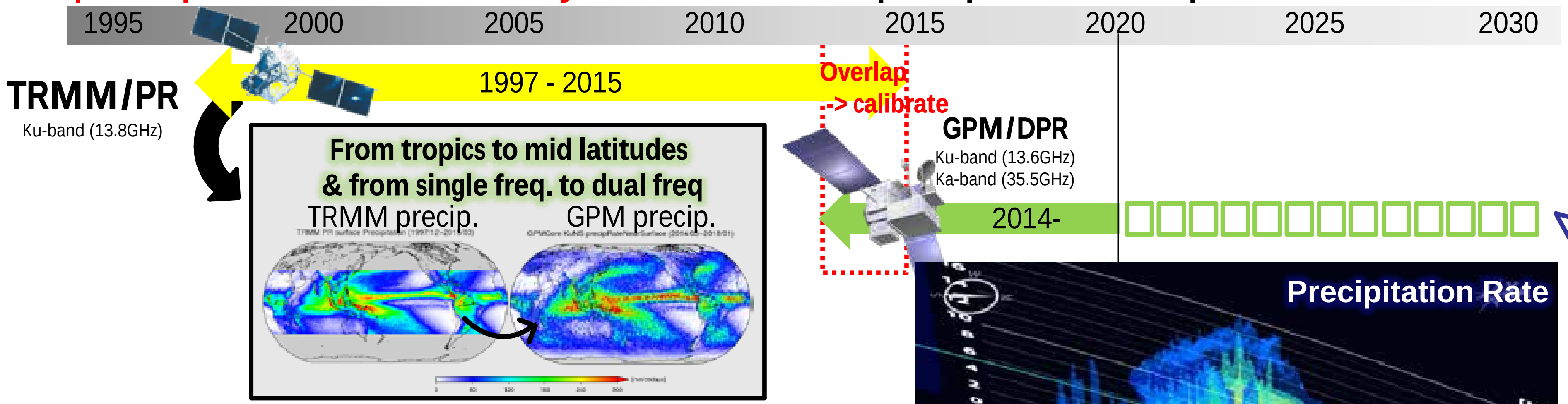


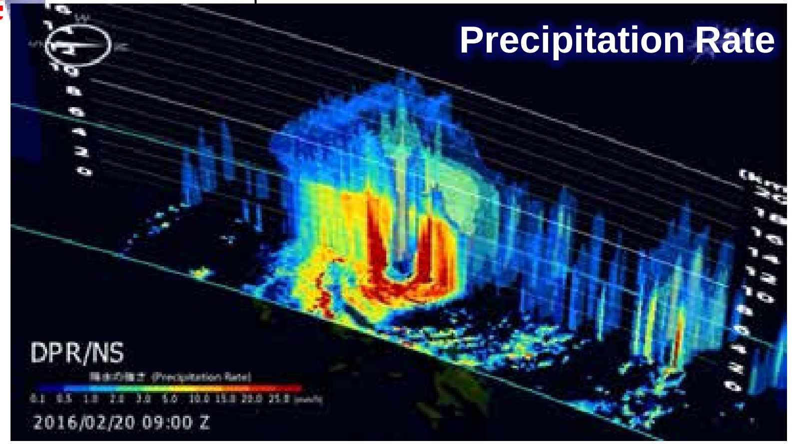
- The basic idea of the MMN module is to calibrate target PMW sensors with reference sensors using the cumulative distribution function (CDF) of the rain rate.
- The reference sensor:
  - 2014-Current: GPM/GMI
  - 1998-2014: TRMM/TMI
- Bias in the monthly mean rainfall between the target PMW sensors (F16_MIS and N18_MHS) before and after the MMN correction and COR_GMI)
- à A more distinct tendency can be seen for N18_MHS (Microwave sounder)

Yamamoto and Kubota, 2022, https://doi.org/10.3390/rs14184445

History of Active Microwave Observations

- JAXA has developed the spaceborne precipitation radars such as Precipitation Radar (PR) onboard Tropical Rainfall Measuring Mission (TRMM) launched in 1997 and Dual-frequency Precipitation Radar (DPR) aboard Global Precipitation Measurement (GPM) Mission Core Observatory launched in 2014.
- Both radars have been developed to observe three-dimensional structure of global precipitation accurately, under the equal partnership with NASA.





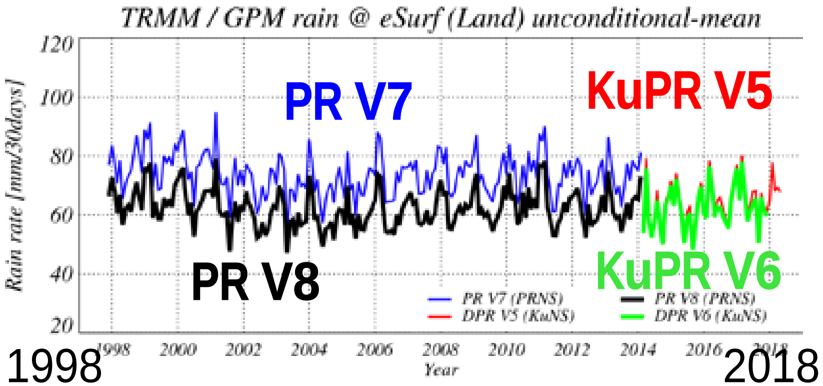
The data record of spaceborne precipitation radars is more than 20 years!

The product developed by considering the continuity between TRMM and GPM is available with common algorithm and data format.

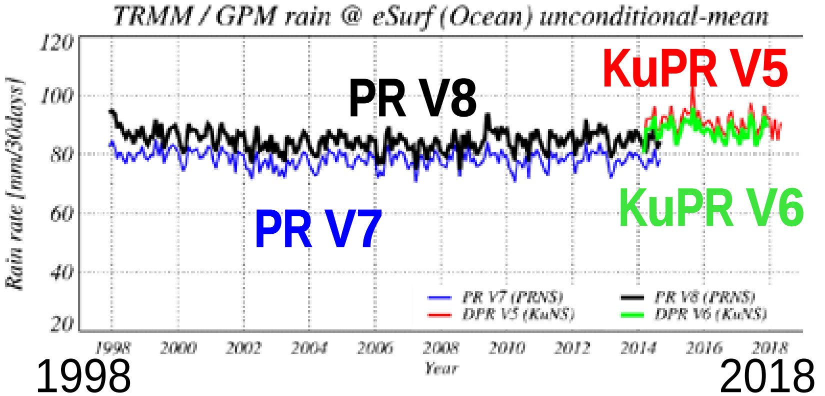
Monitoring of long-term precipitation radar datasets by TRMM/PR (1997-2015) and the GPM/DPR (2014-)

- GPM/DPR's calibration factors was changed in V05 released on May 2017, and TRMM/PR's calibration factors was also changed in TRMM/PR-L1 V8 (GPM TRMM V05) L1 released on Oct. 2017.
  - Calibration paper : Masaki et al. 2020, https://doi.org/10.1109/TGRS.2020.3039978
- Better continuity was realized in the TRMM/PR-L2 V8 (GPM TRMM V06) and GPM/DPR-L2 V06 released in Oct. 2018, by using common precipitation estimation algorithms between the TRMM/PR and the GPM/KuPR.
  - Precipitation algorithm paper: Seto et al. 2021, https://doi.org/10.2151/jmsj.2021-011

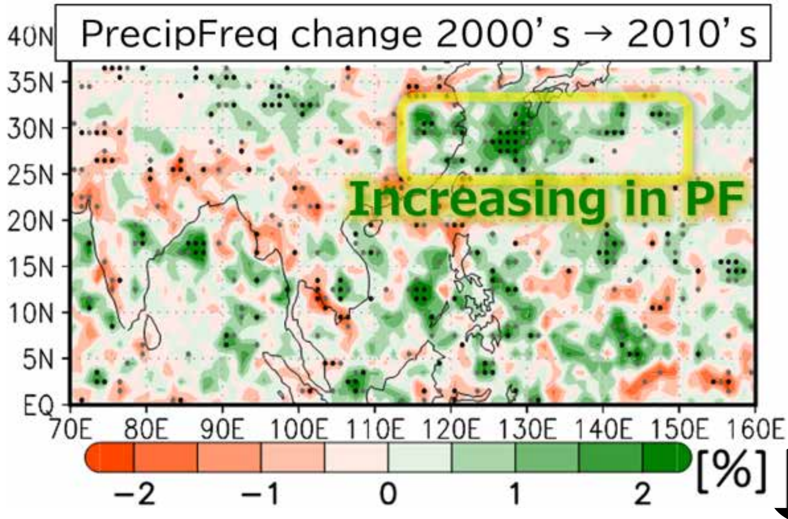
Over-land surface precipitation rates averaged in 35S-35N.



Over-ocean surface precipitation rates averaged in 35S-35N.



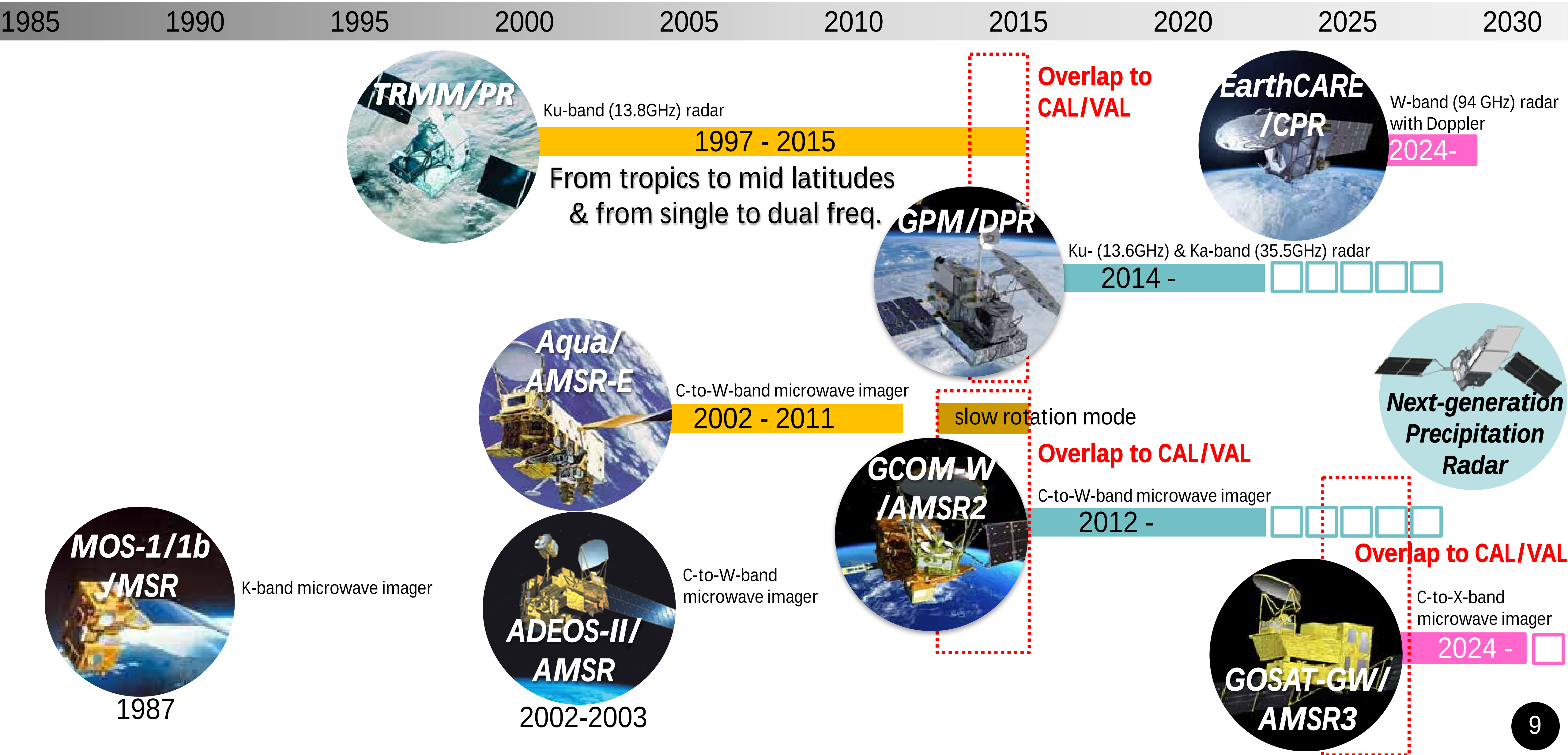
Takahashi and Fujinami (2021) showed **recent decadal enhancement of Meiyu-Baiu heavy rainfall** over the East Asia using the TRMM/PR & GPM/DPR dataset.



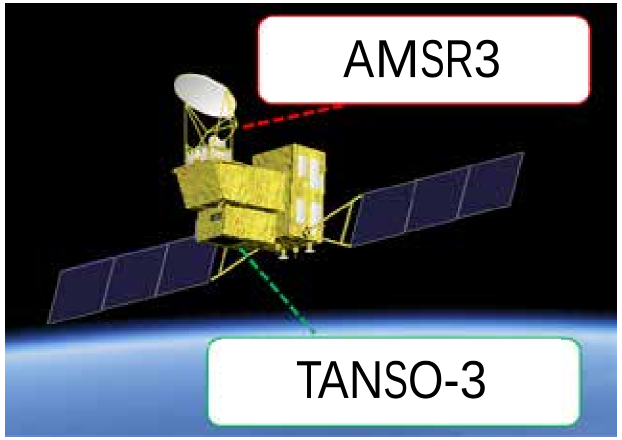
à These dataset was used long-term precipitation analyses.

Takahashi, H.G., Fujinami, H. Recent decadal enhancement of Meiyu–Baiu heavy rainfall over East Asia. *Sci. Rep.* 11, 13665 (2021).
https://doi.org/10.1038/s41598-021-93006-0
https://earth.jaxa.jp/en/earthview/2021/08/02/5584/index.html

Precipitation-related Missions in Japan



Future Missions: GOSAT-GW (Global Observation SATellite for Greenhouse gases and Water cycle)

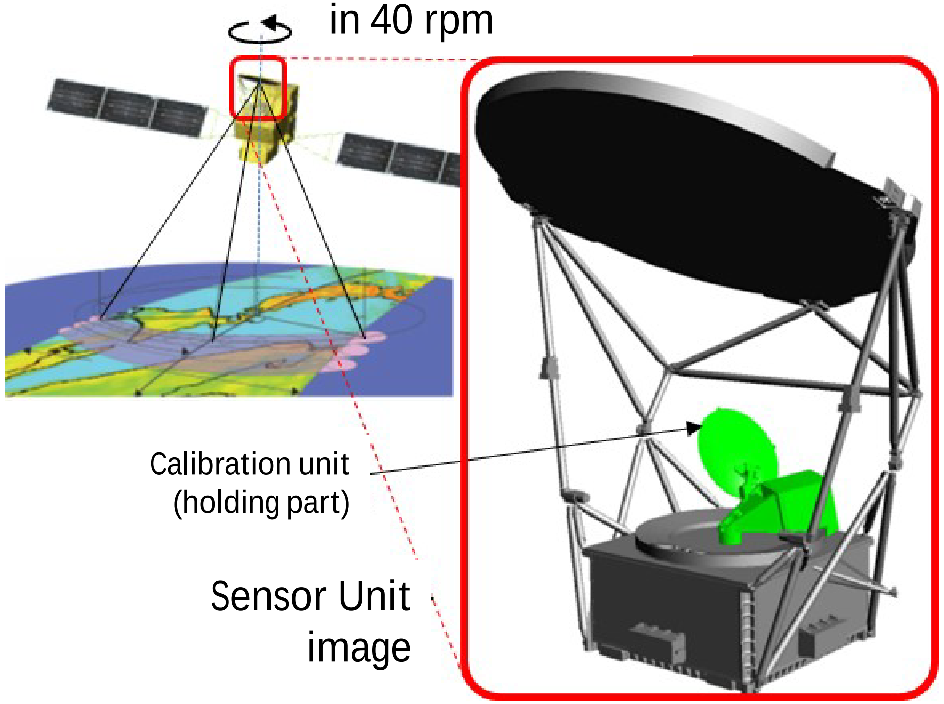


- GOSAT-GW will carry two instruments, AMSR3 & TANSO-3.
  - **AMSR3**, developed by JAXA, will succeed AMSR series observations adding new high-frequency channels for solid precipitation retrievals and water vapor analysis in NWP.
  - **TANSO-3**, developed by Japanese Ministry of the Environment (MOE), will improve observation capability of greenhouse gases from GOSAT-2/TANSO-2. (Choose grating spectrometer to enable spatially detailed observation)
  - Target launch is **JFY2024** (Apr. 2024 - Mar. 2025)
- Status of development
  - Jun. 2018： Mission Definition Review (MDR)
  - Jul. 2018: Project Preparation Review
  - Nov. 2019: Project Readiness Review
  - Dec. 2019： Established GOSAT-GW Project
  - Aug. 2020： Preliminary Design Review (PDR) of AMSR3 system
  - Dec. 2020： PDR of TANSO-3 system
  - Mar. 2021: PDR of GOSAT-GW satellite system
  - Oct. 2021: Critical Design Review (CDR) of AMSR3 system
    - Currently, AMSR3 flight components are manufacturing and testing
  - Spring 2023: CDR of GOSAT-GW satellite system

Satellite specification

Orbit	Type	Sun-synchronous, Sub-recurrent orbit
	Altitude	**666km, recurrent cycle 3days** (same as GOSAT)
	MLTAN	13:30±15min (same as GCOM-W)
Mass		2.6 ton (Including propellant)
Power		> 5.3 kW
Design life		**> 7 years**
Launch vehicle		H-IIA rocket
Mission data downlink rate		Direct transmission with X-band: 400 Mbps Direct transmission with S-band: 1 Mbps (Only for AMSR3)
Instrument		TANSO-3 (for GHG) AMSR3 (for Water Cycle)

Future Missions: AMSR3 Sensor Specification



Center frequency [GHz]	Polarization	Band width [MHz]	NEDT (1σ)	Beam width (spatial resolution)
6.925 7.3	H/V	350	< 0.34 K	1.8 ° (34km x 58km)
10.25	H/V	500	< 0.34 K	1.2 ° (22km x 39km)
10.65	H/V	100	< 0.70 K	1.2 ° (22km x 39km)
18.7	H/V	200	< 0.70 K	0.65 ° (12km x 21km)
23.8	H/V	400	< 0.60 K	0.75 ° (14km x 24km)
36.42	H/V	840*	< 0.70 K	0.35 ° (7km x 11km)
89.0 A/B	H/V	3000	< 1.20 K	0.15 ° (3km x 5km)
165.5	V	4000	< 1.50 K	AZ=0.23 ° / EL=0.30 ° (4km x 9km)
183.31±7	V	2000×2	< 1.50 K	AZ=0.23 ° / EL=0.27 ° (4km x 8km)
183.31±3	V	2000×2	< 1.50 K	AZ=0.23 ° / EL=0.27 ° (4km x 8km)

Red: Changes from AMSR2 including additional CHs

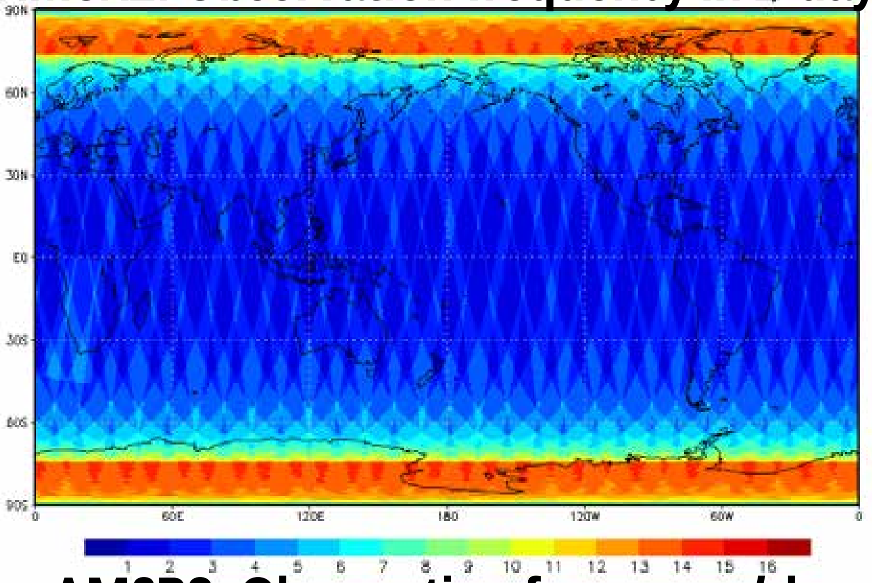
* Changed the specification of Ka-band passband to reduce the future risk of RF interference from 5-G mobile communication system

① Additional 166 & 183 GHz channels to enable monitoring of global precipitation (rain & snow) and contribute to water vapor analysis in NWP

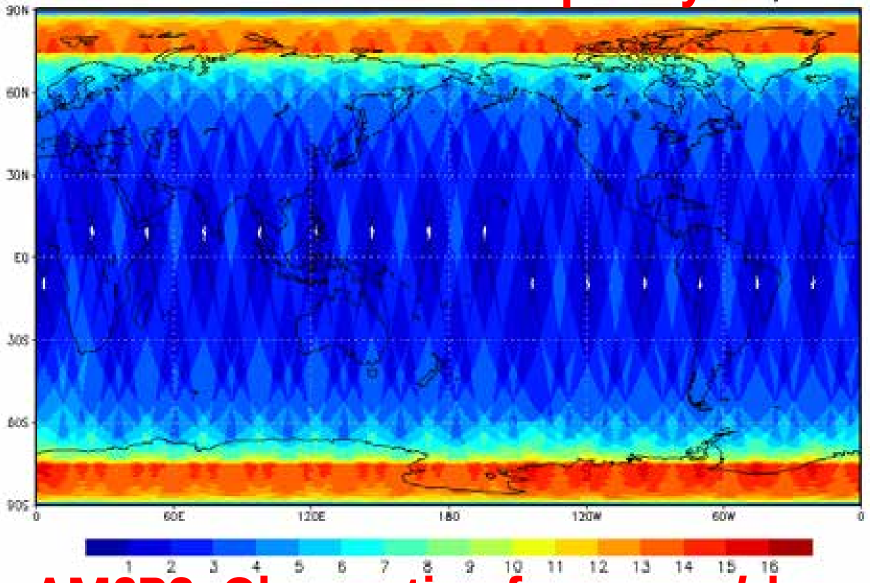
② Additional 10 GHz channels with improved NEDT to enable robust SST retrievals in higher spatial resolution

AMSR3 Observation Frequency

AMSR2: Observation frequency in 2-day

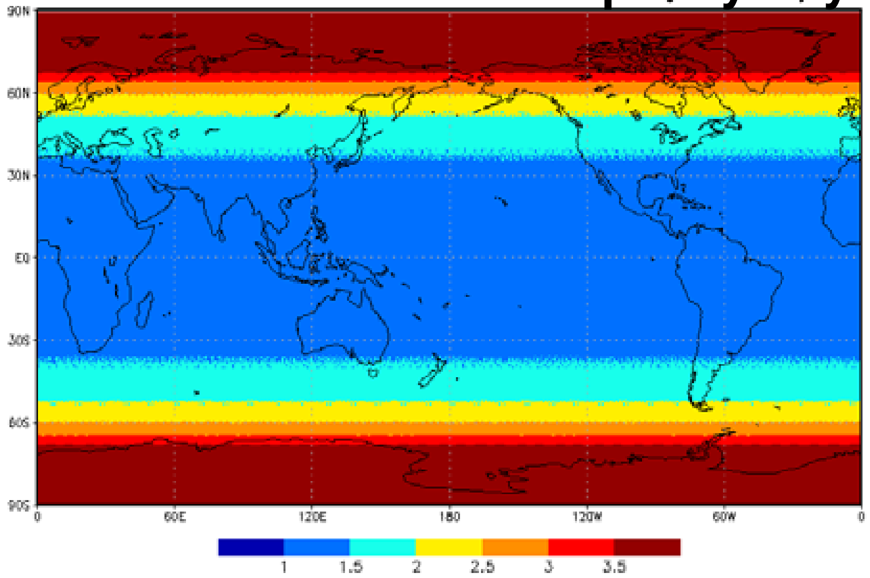


AMSR3: Observation frequency in 2-day

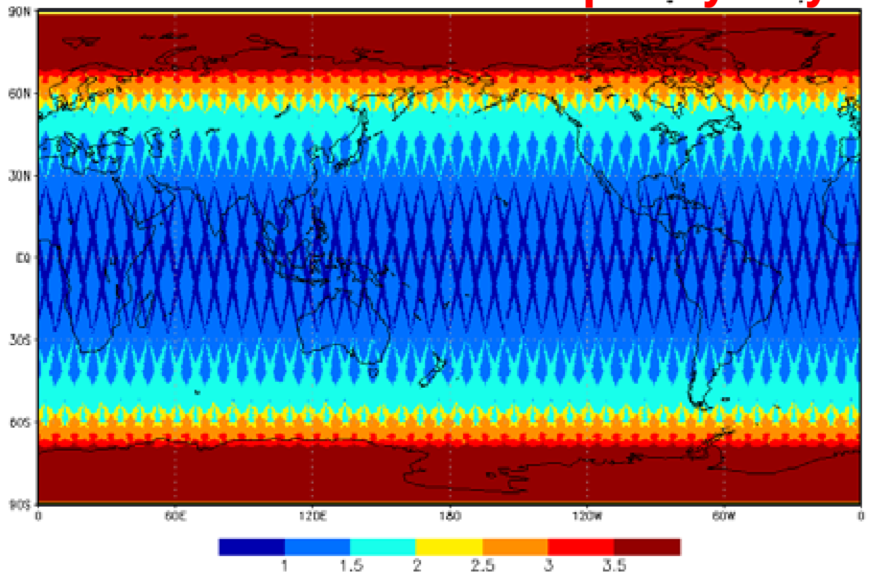


Unlike AMSR2, **AMSR3 cannot cover global area within 2-day** and small missing areas (white) are remained.

AMSR2: Observation frequency/day



AMSR3: Observation frequency/day



Observation frequency of AMSR3 is **NOT homogeneous** for every longitude and there are fixed areas less than 1 observation/day (blue).

AMSR3 Follow-On Discussions

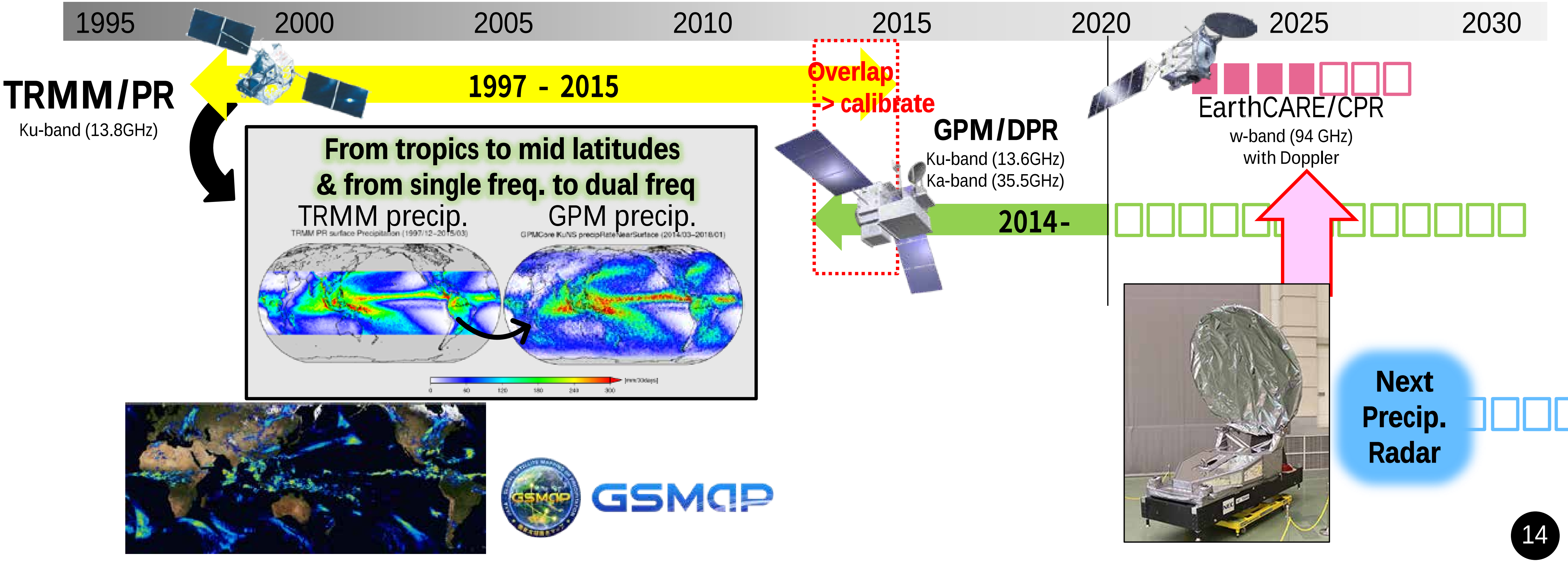
- Discussions on AMSR3 follow-on mission has started since Mar. 2021 within the AMSR user committee (domestic) and science team (international), and following points are raised during early discussions
  - Continuation of AMSR series observation is base-line
  - Directions of hardware evolution are different among observation requirements of atmosphere, earth surface & sea ice
  - Common requirements
    - Improvement of temperature resolution (noise reduction)
    - Improvement of measures against RFI (on-board, ground)
  - Atmospheric observations (18-183GHz)
    - Addition of new frequency channels (50GHz, sub-millimeter band) (air temperature, cloud ice, etc.)
    - Expansion of swath width (global coverage within a day)
    - Downsizing (enable future option to mount on small satellites under collaboration of commercial companies)
    - More frequent observation (geostationary satellite, in future)
  - Earth surface observations (6-36GHz)
    - Higher spatial resolution for 6-10GHz
    - Addition of new frequency channels (1GHz) (sea surface salinity)
  - Sea ice observations (18-36GHz (89GHz))
    - Low Earth Orbit (NO geostationary satellite)
    - Higher spatial resolution for 6-10GHz (can be used if it is higher resolution)
    - Addition of new frequency channels (1GHz) (sea ice thickness)
- Feasibility study of hardware based on above requirements is ongoing before mission definition

More frequent!

Higher resolution!

Precipitation and Cloud Profiling Radar developed and planned in JAXA

- JAXA has large heritage of the TRMM/PR and GPM/DPR, and the data record of spaceborne precipitation radars is more than 20 years.
- JAXA and NICT are developing Cloud Profiling Radar (CPR) with doppler capability, onboard the Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) jointly with ESA.



Future Missions: EarthCARE (Earth Clouds, Aerosol and Radiation Explorer) (2024)

EarthCARE

Earth Clouds, Aerosol and Radiation Explorer

EarthCARE is an earth observation satellite that Japan and Europe have been jointly developing to observe clouds, aerosols and radiation (Illingworth et al. 2015, Wehr et al. 2023).

Observation Instruments on EarthCARE

CPR	Cloud Profiling Radar	NICT JAXA
ATLID	Atmospheric Lidar	esa
MSI	Multi-Spectral Imager	esa
BBR	Broadband Radiometer	esa

CPR instrument @ JAXA Tsukuba Space center (Sep. 2015)

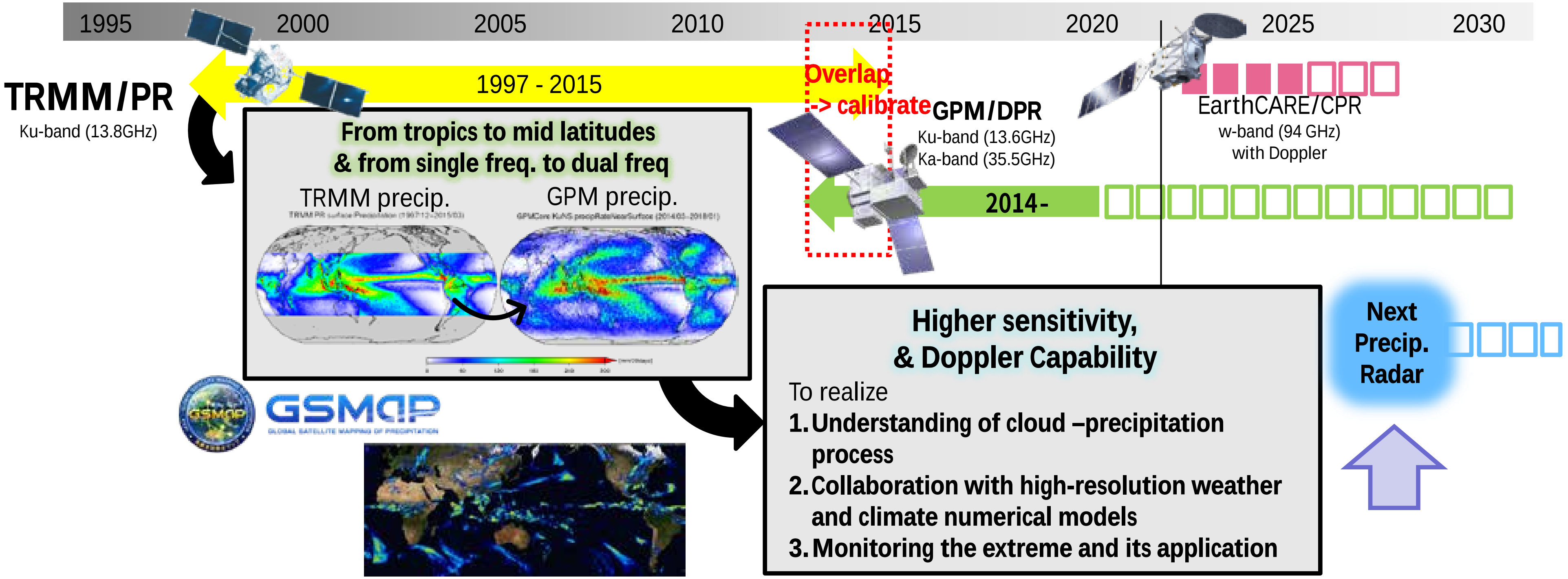
EarthCARE@Airbus (April.2021)
©Airbus

Orbit	Sun-synchronous sub-recurrent orbit Altitude: approx. 400km Inclination angle: 97.05 ° Local Sun Time at Desc.: 14:00 Revisit time: 25 days
Instruments	**- Cloud Profiling Radar (CPR)** by NICT & JAXA - Atmospheric Lidar (ATLID) by ESA - Multi-Spectral Imager (MSI) by ESA) - Broad-Band Radiometer (BBR) by ESA
Mass	Approx. 2.2 tons at launch
Designed lifetime	3 years

- The Cloud Profiling Radar (CPR) will provide observations of not only cloud but also snowfall and light rainfall.
- Measuring Doppler velocities by the CPR is very challenging, but it is expected to advance cloud/precipitation science.

Future Missions: JAXA's Next-generation Precipitation Radar Project (PMM)

- The JAXA has studied a feasibility of a **next generation precipitation radar** with Japanese science team and user community.
  - Ø The EarthCARE will have the first Cloud Profiling Radar (CPR) with a **Doppler capability in space**.
- Our targets for the next generation precipitation radar in the **Precipitation Measuring Mission (PMM)** will be **Doppler Observations**, **Higher sensitivity measurements with scanning capability.**
  - ü JAXA has participated **in NASA's Atmosphere Observing System (AOS)** Pre-Phase A activities.



Future Missions: JAXA's Next-generation Precipitation Radar Project (PMM)

- In January 2022, JAXA's Precipitation Measuring Mission (PMM) Pre-Project Team was established on for the Spacecraft carrying the Ku-band Doppler Precipitation Radar.
- Target launch: JFY2028 (=April 2028 to March 2029)

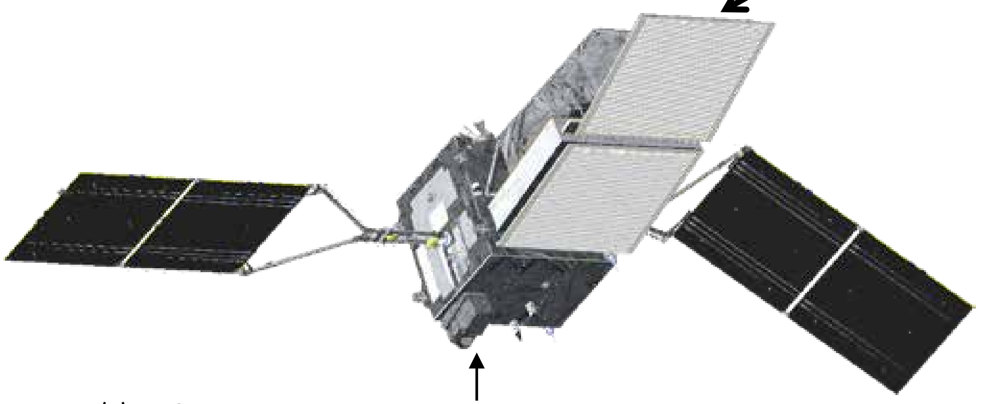
The Ku-band Doppler Precipitation Radar (KuDPR) will be two-antenna system that adopts Displaced Phase Center Antenna (DPCA) approach (Durden et al. 2007, Tanelli et al. 2016).

à The DPCA approach can lead to **more accurate Doppler measurement.**

Major characteristics

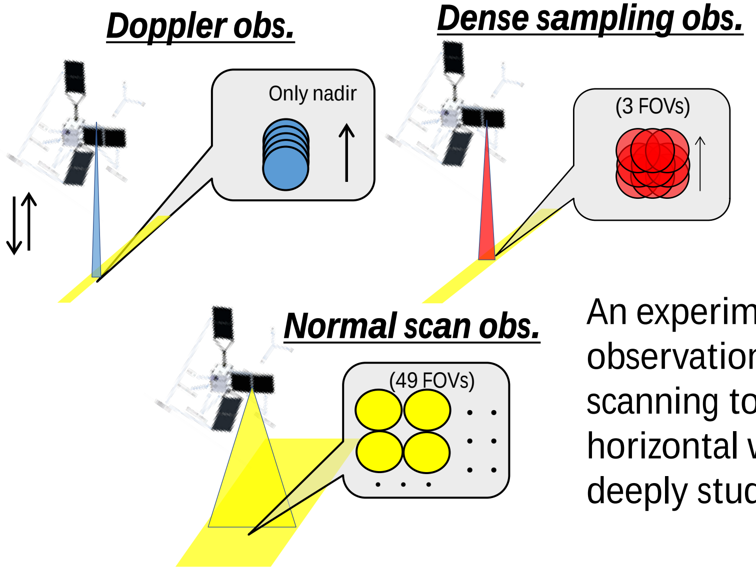
Frequency	13.6 GHz
Observation modes	• Doppler obs. mode • Dense sampling obs. mode • Normal scan obs. mode

Ku-band Doppler Precipitation Radar (KuDPR)



(c) NEC

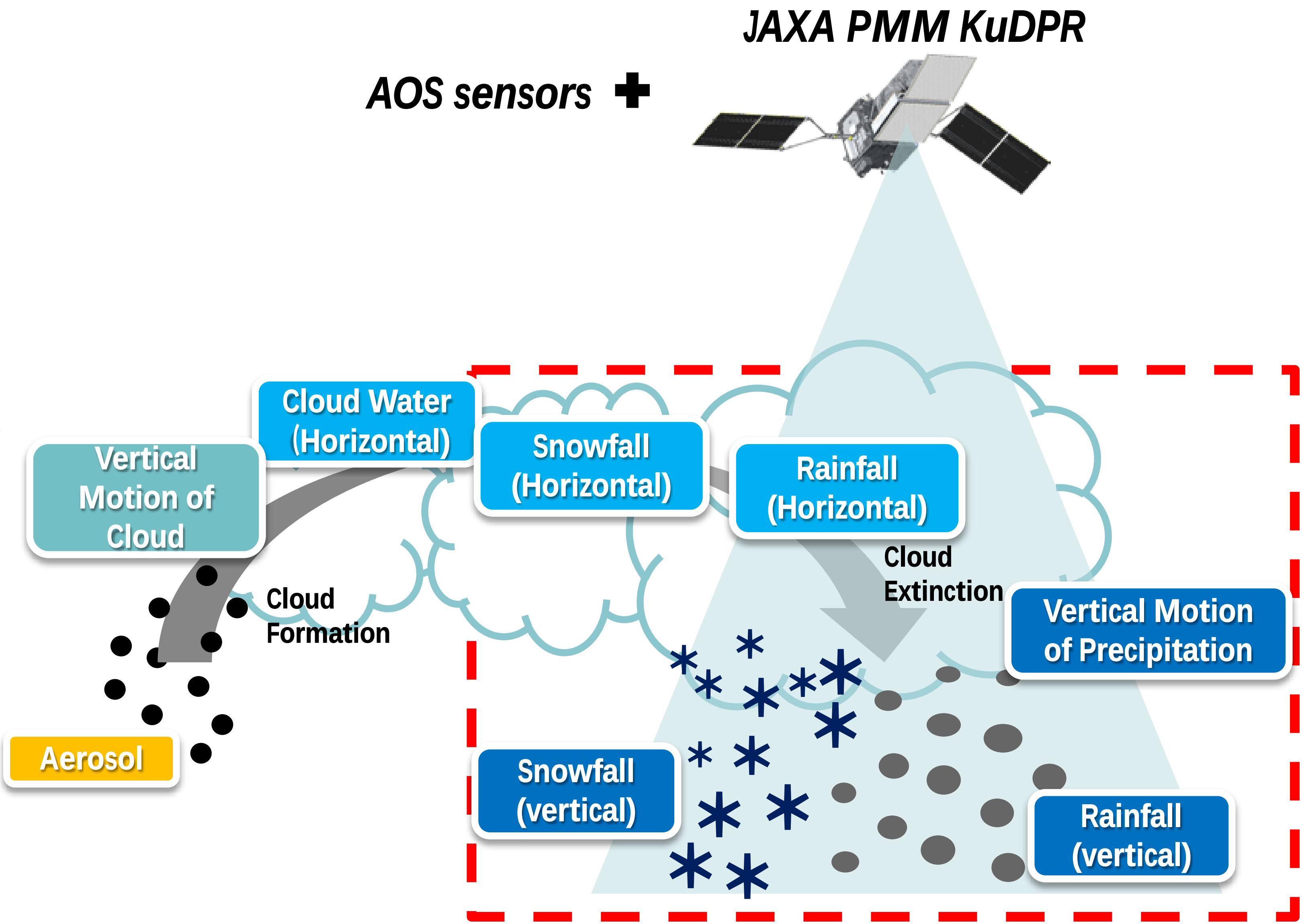
CNES radiometer



An experimental observation of doppler beam scanning to measure horizontal winds has been deeply studied in the Japan.

Precipitation Radar in Synergy with Aerosols and Cloud Science

- Japan's next precipitation radar satellite (PMM), carrying the Ku-band Doppler Precipitation Radar (KuDPR), focuses on advanced observation of precipitation
  - Doppler velocity observation
  - Higher sensitivity
- International collaboration with NASA AOS missions will bring us integrated understanding of Aerosol~Cloud~Precipitation processes
- It also enhances the mission value for improving weather/climate models in the context of international collaboration.



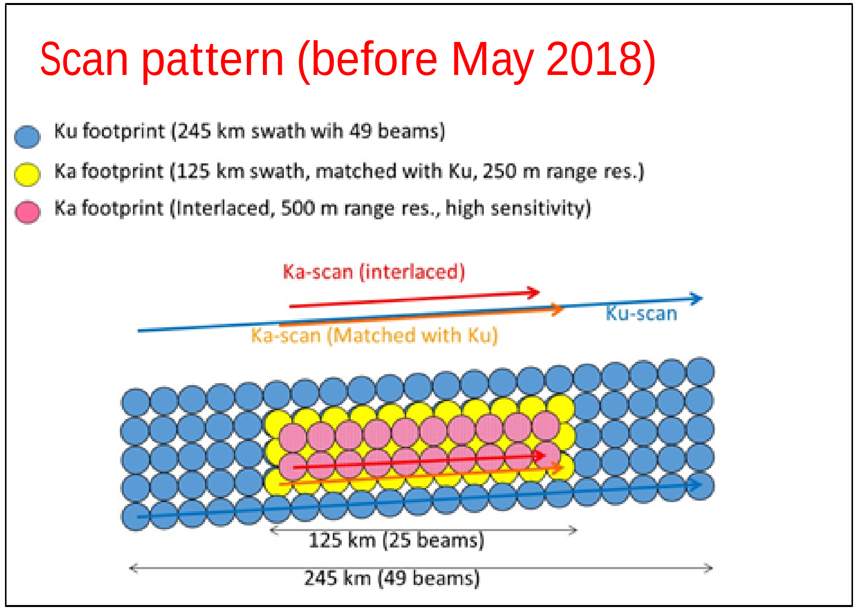
Concluding Remarks

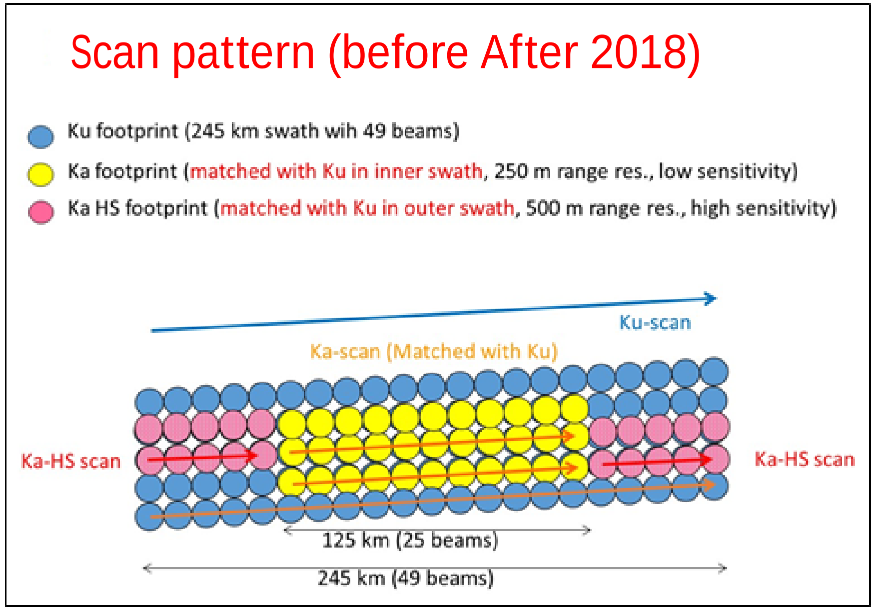
- JAXA has long history and big heritage of satellite-based precipitation observation by both passive and active microwave sensors.
- Passive microwave sensor
  - Since 2002 to present, AMSR series with large-sized antenna and C-band frequency channels contributes largely to water cycle observations, including GSMaP merged rainfall products.
  - Future AMSR3 on board the GOSAT-GW will have additional high-frequency channels for snowfall retrievals to be launched in JFY 2024 (Apr. 2024 – Mar. 2025).
  - Discussions of AMSR3 follow-on mission are underway -- variety of requirements from various fields -- Continuity VS New capability, More frequent VS High resolution, etc.
- Active microwave sensor
  - Since 1997 to present, TRMM/PR and GPM/DPR are only reliable references to passive microwave radiometers for precipitation observation.
  - In January 2022, JAXA's PMM Pre-Project Team was established on for the Spacecraft carrying the Ku-band Doppler Precipitation Radar. Target launch: JFY2028.
  - The CPR with doppler capability in the EarthCARE is planned to be launched in 2024.

Dual-frequency Precipitation Radar (DPR) status

All data collection is nominal and instruments are in good condition.

In Dec. 2021, JAXA and NASA started to release the DPR V07, corresponding to the KaPR scan pattern change.





- By the scan pattern change in May 2018, dual-frequency technique can be applied in a full swath, which can enable us more accurate estimates.
- In Dec. 2021, JAXA and NASA started to release the DPR V07 (standard product).
  - V07 is the first standard product, corresponding to the scan pattern change. All GPM/DPR observations were reprocessed in V07.