Passive Microwave and sub-mm wave imaging missions at EUMETSAT

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Presentation outline

- Introduction: Clouds in a (MW) nutshell
- EPS-SG Microwave and sub-mm wave imaging missions
- Microwave Imaging (MWI) mission
- Ice Cloud Imaging (ICI) mission
- New L1 products features: opportunities and challenges
- Summary

Passive Microwave Measurements

- Main Applications:
  - Global Numerical Weather Prediction (NWP), Regional NWP
  - Atmospheric state and surface monitoring, precipitation and cloud properties
  - Oceanography and Hydrology
  - Nowcasting
  - Climate monitoring
- Timeliness:
  - **1h15 min.** for global L1, 2h for global L2 **EPS**
  - **Direct readout to 30 min.** (EARS) for local **EPS** data
  - **60 min.** for global L1, **80 min.** for global L2 **EPS-SG**
  - **20 min.** for regional L1, **40 min.** for regional L2 **EPS-SG**
  - **30 min. for GMI**
- Coverage:
  - Global (through LEO missions)
- Outstanding Characteristics:
  - Measurements available in day- and night-time conditions
  - “All weather” measurements, providing information in clear and cloudy conditions

Atmospheric spectrum

Imaging channels in the "windows"

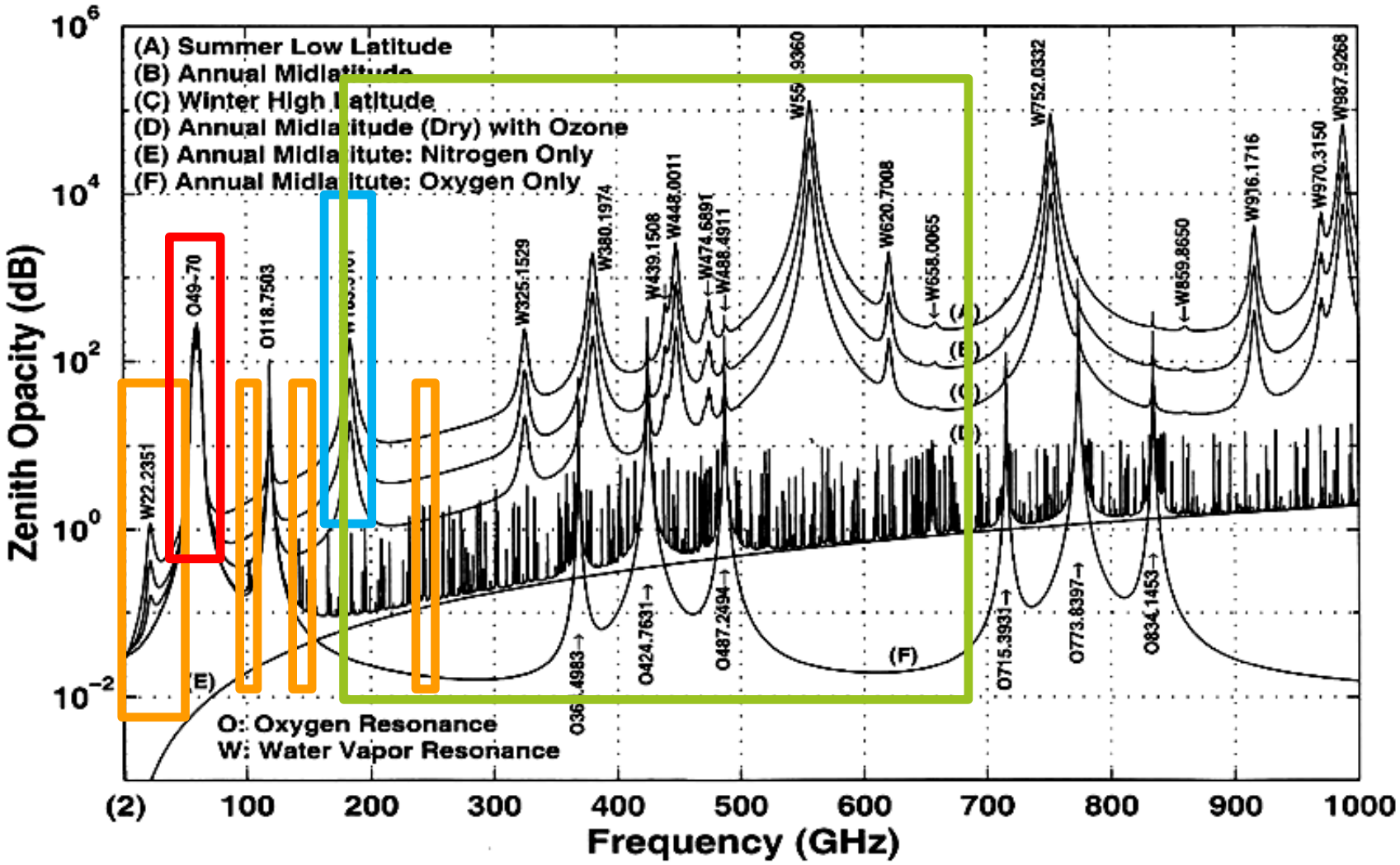
Temperature sounding in the 60 GHz line (MWS)

Humidity sounding in the 183 GHz line

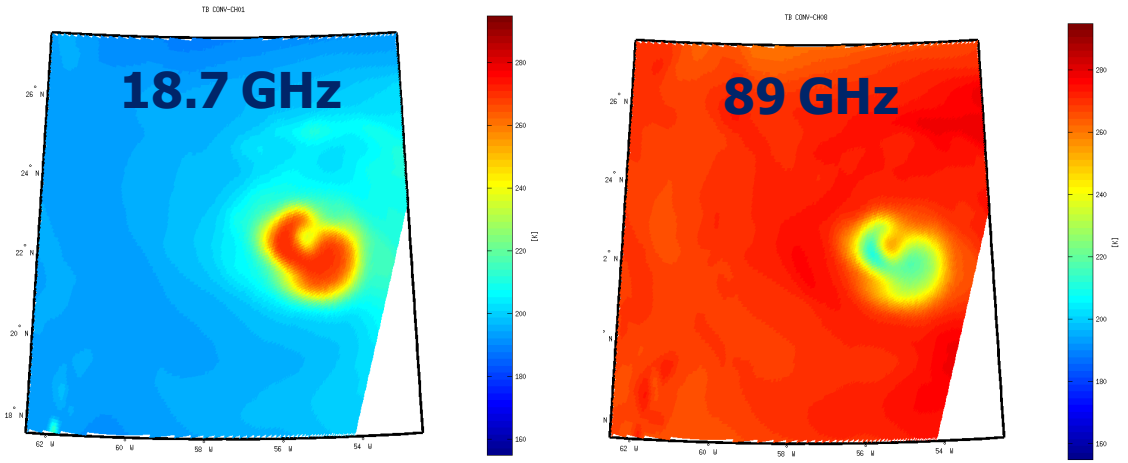
..and beyond: Ice Cloud Imager (ICI)

30 GHz ↔ 10mm wavelength (λ)

Atmospheric spectrum in the MW/Sub-mm range (*Klein and Gasiewski, 2000*)



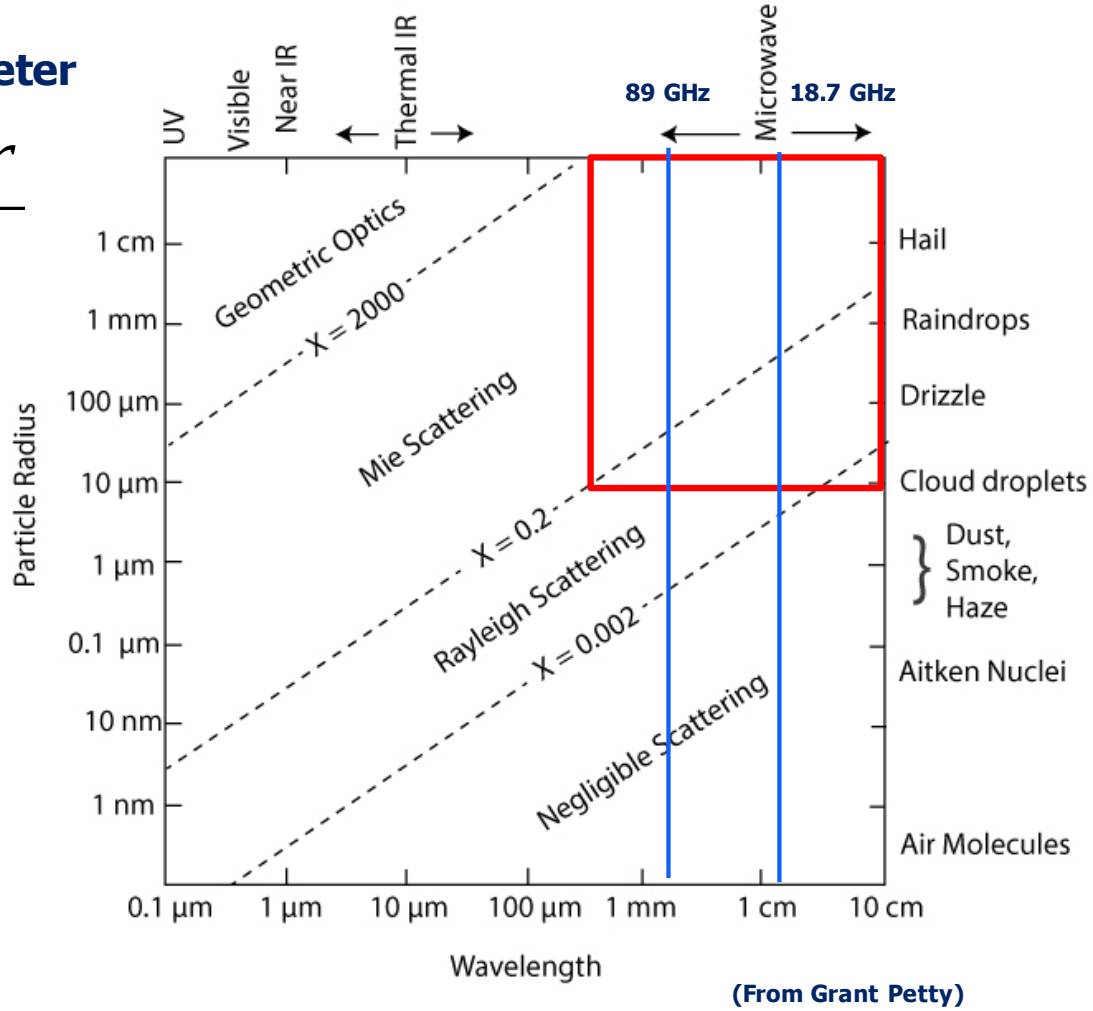
Clouds in a (MW) nutshell



Size Parameter

$$x = \frac{2\pi r}{\lambda}$$

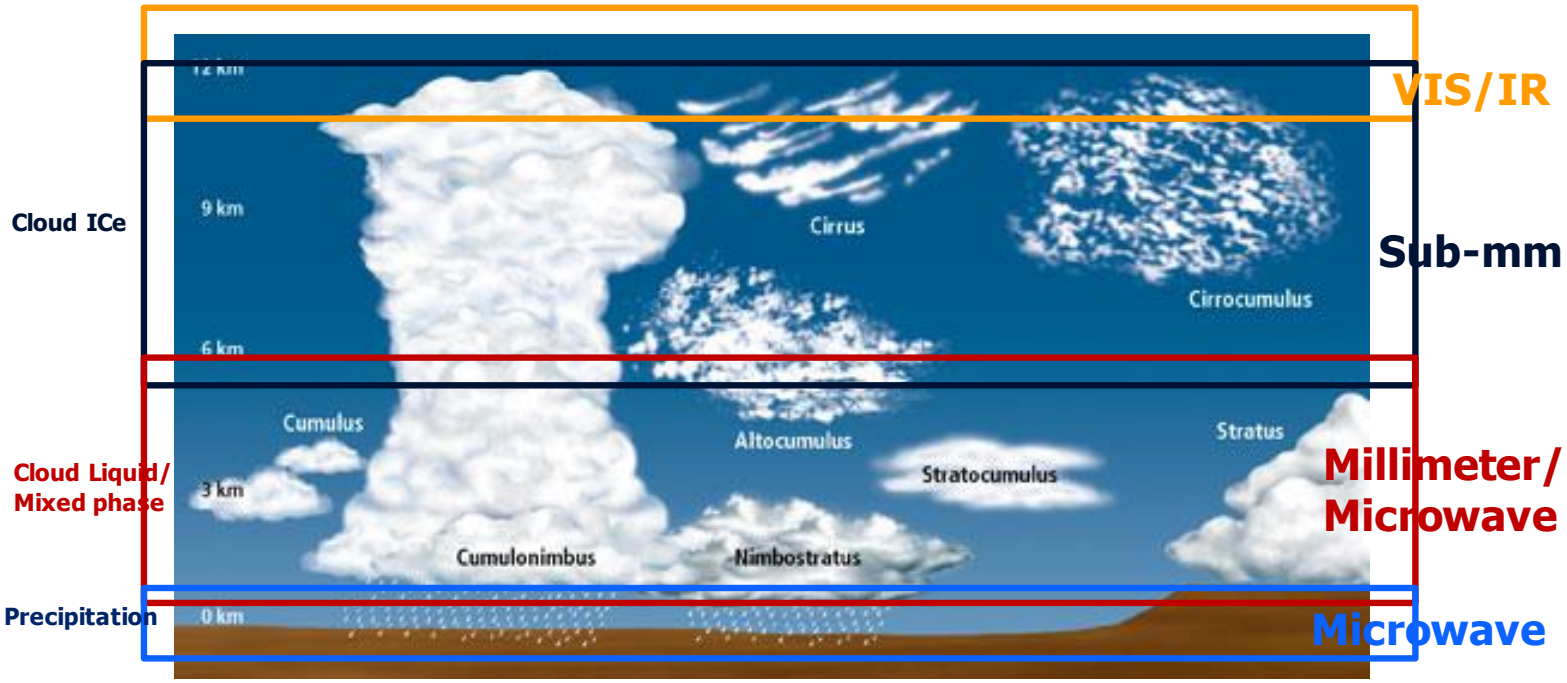
Hydrometeor	dimension [mm]	Size parameter, x 18.7 GHZ	Size parameter, x 89 GHZ	Scattering regime
Cloud droplets	0.025	0.0098	0.046	Rayleigh
Drizzle	0.1	0.039	0.186	Rayleigh
Rain drop	1	0.39	1.86	Mie
Ice crystals	0.1	0.039	0.186	Rayleigh
Snow	10	3.9	18.6	Mie
Hail	10	3.9	18.6	Mie

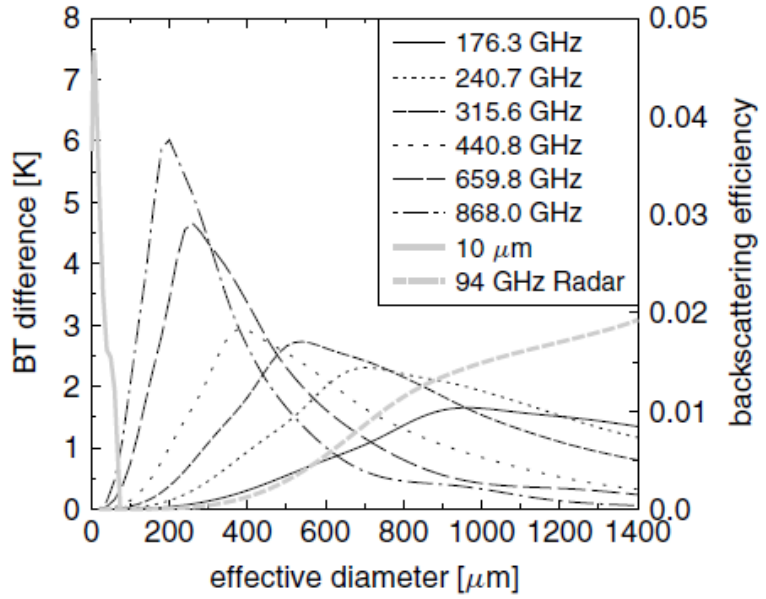


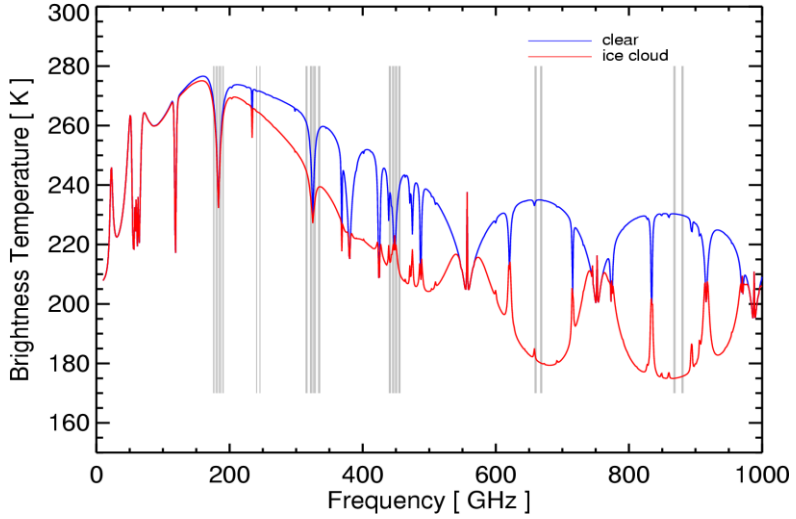
(From Grant Petty)

Sub-mm channels for ice cloud observations

The sensitivity of measurements at different frequencies to particle size *







*: Buehler, S. A., Jiménez, C., Evans, K. F., Eriksson, P., Rydberg, B., Heymsfield, A. J., Stubenrauch, C. J., Lohmann, U., Emde, C., John, V. O., Sreerekha, T. R., and Davis, C. P., 2007: A concept for a satellite mission to measure cloud ice water path, ice particle size, and cloud altitude", *Q. J. Roy. Meteorol. Soc.*, 133, 109–128.

EPS-SG Microwave Imager (MWI)
&
Ice Cloud Imager (ICI)

EPS-SG: EUMETSAT Polar System - Second Generation

•The EUMETSAT Polar System (EPS) in Low Earth Orbit (LEO) will be followed by a second generation system (EPS-SG). European contribution to the Joint Polar System set up with NOAA.

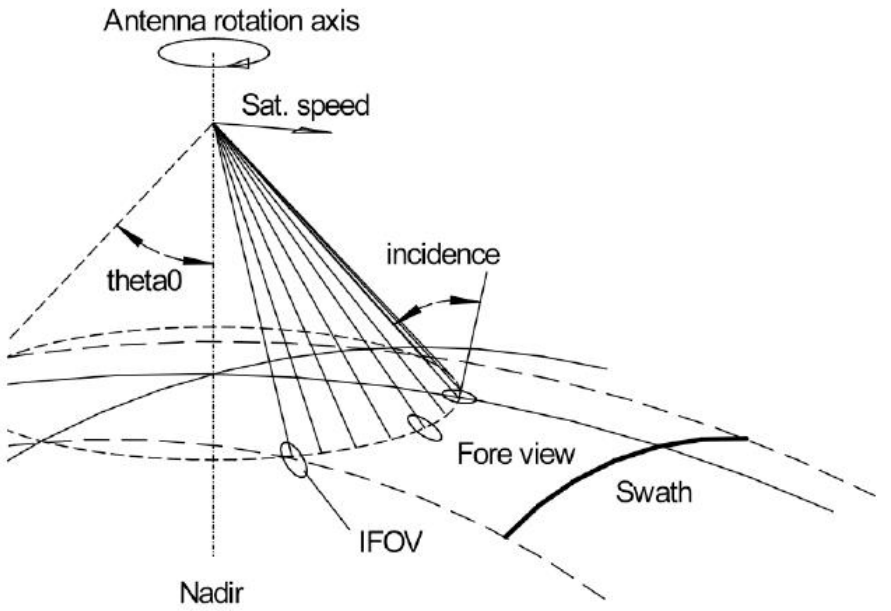
• Same orbit as Metop (sun-synchronous, 832 km mean altitude, 09:30 local time of the descending node).

• Payload distributed between the two parallel satellites Metop-SG A and B. Nominal lifetime of 7.5 years/spacecraft for an operational lifetime of the programme over 21 years.

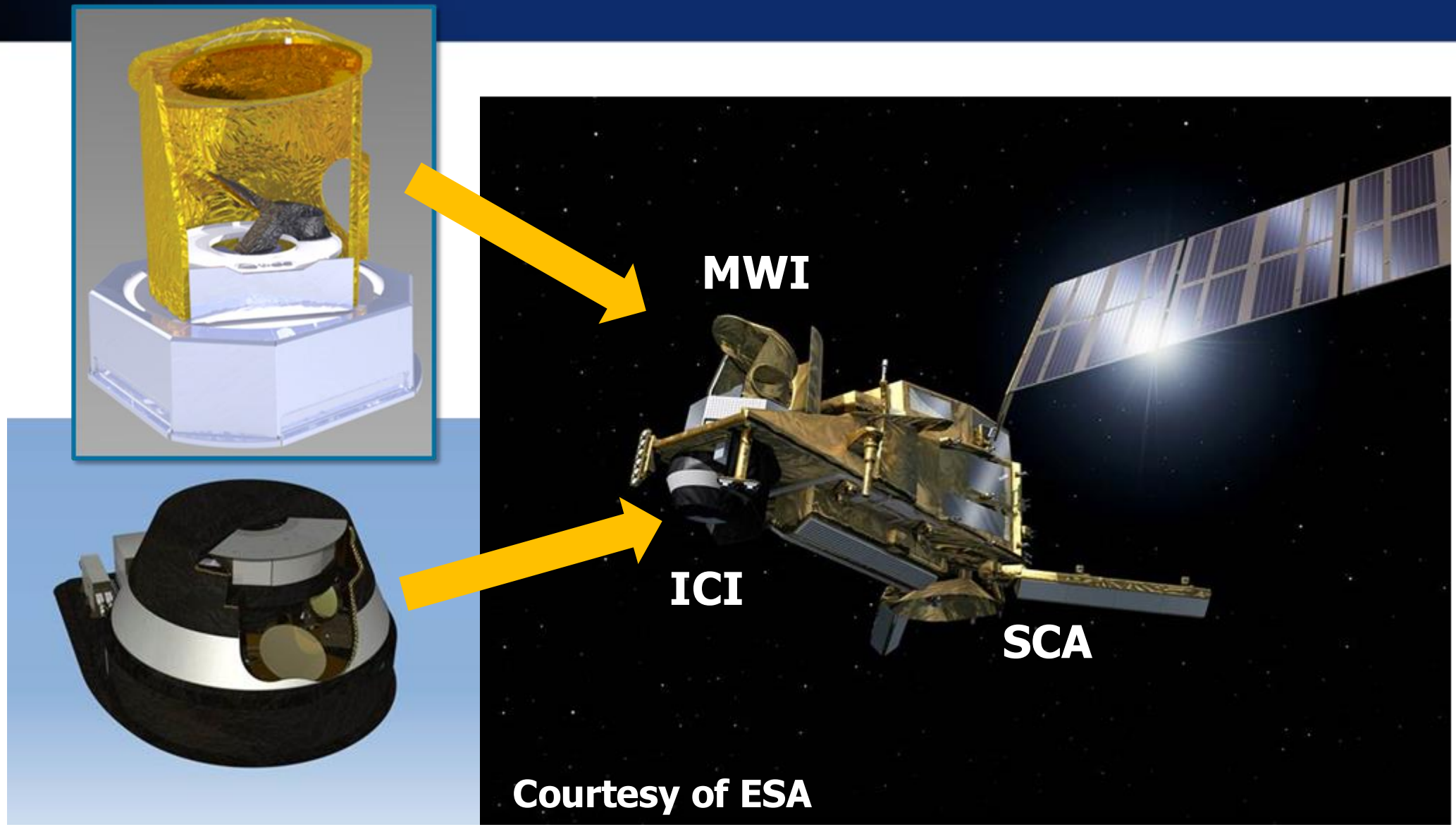
Metop payload	Metop-SG payload	Metop-SG satellite
Infrared Atmospheric Sounding Interferometer (IASI)	Infrared Atmospheric Sounding Interferometer – New Generation (IASI-NG)	A
Advanced Very High Resolution Radiometer (AVHRR)	Visible-Infrared Imager (METimage)	A
–Advanced Microwave Sounding Unit A (AMSU-A1/A2), Microwave Humidity Sounder (MHS)	**Micro-Wave Sounder (MWS)**	**A**
Global Ozone Monitoring Experiment 2 (GOME-2)	UV-VIS-NIR-SWIR Sounder (Sentinel-5)	A
Advanced Scatterometer (ASCAT)	Scatterometer (SCA)	B
Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS)	Radio Occultation (RO)	A and B
-	**Micro-Wave Imager (MWI)**	**B**
-	**sub-mm wave Ice Cloud Imager (ICI)**	**B**
-	Multi-viewing, -channel, -polarisation Imager (3MI)	A

MW and Sub-mm Wave Imaging missions (MWI & ICI)

- **ICI and MWI are conically scanning passive imagers**
- **MWI ranging from 18 to 183 GHz**
- **ICI ranging from 183 GHz to 664 GHz**
- **Incidence angles within 53°±2°**
- **Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath)**



The MWI and ICI instruments on EPS-SG Satellite B



The Microwave Imager (MWI)

•Continuity of key microwave imager channels for weather forecast (e.g. SSM/I, AMSR-E, GMI).

•All MWI channels up to 89 GHz measured with both vertical (V) and horizontal (H) polarisations.

• Innovative set of channels in the oxygen absorption band near 50–60 GHz and 118 GHz. Enabling the retrieval of information on weak precipitation and snowfall.

• Channels MWI-13 to MWI-18 provide information on water vapour profiles and snowfall. Less sensitive to surface, more usable globally and enabling cloud slicing.

•Few data:
- mass: 250 kg
- height: 1.8 m
- reflector diameter: 80 cm

Channel	Frequency (GHz)	Bandwidth (MHz)	NE∆T (K)	Polarisation	Footprint Size 3dB (km)
MWI-1	18.7	200	0.8	V, H	50
MWI-2	23.8	400	0.7	V, H	50
MWI-3	31.4	200	0.9	V, H	30
MWI-4	50.3	400	1.1	V, H	30
MWI-5	52.610	400	1.1	V, H	30
MWI-6	53.24	400	1.1	V, H	30
MWI-7	53.750	400	1.1	V, H	30
MWI-8	89.0	4000	1.1	V, H	10
MWI-9	118.7503±3.20	2x500	1.3	V	10
MWI-10	118.7503±2.10	2x400	1.3	V	10
MWI-11	118.7503±1.40	2x400	1.3	V	10
MWI-12	118.7503±1.20	2x400	1.3	V	10
MWI-13	165.5±0.75	2x1350	1.2	V	10
MWI-14	183.31±7.0	2x2000	1.3	V	10
MWI-15	183.31±6.1	2x1500	1.2	V	10
MWI-16	183.31±4.9	2x1500	1.2	V	10
MWI-17	183.31±3.4	2x1500	1.2	V	10
MWI-18	183.31±2.0	2x1500	1.3	V	10

MWI expected performance

The Ice Cloud Imager (ICI)

ICI is the first radiometer of this type designed with the objective of remote sensing of cloud ice, providing good cloud penetration capability and sensitivity to a significant portion of particle size range that not covered either in the optical/thermal IR or in the mm-wave range

- **Novel mission**

- **In support of a synergetic use of ICI and MWI, both instruments carry common spectral channels at 183 GHz.**

- **Set of channels providing information related to total vertical column of cloud ice and ice particles size**

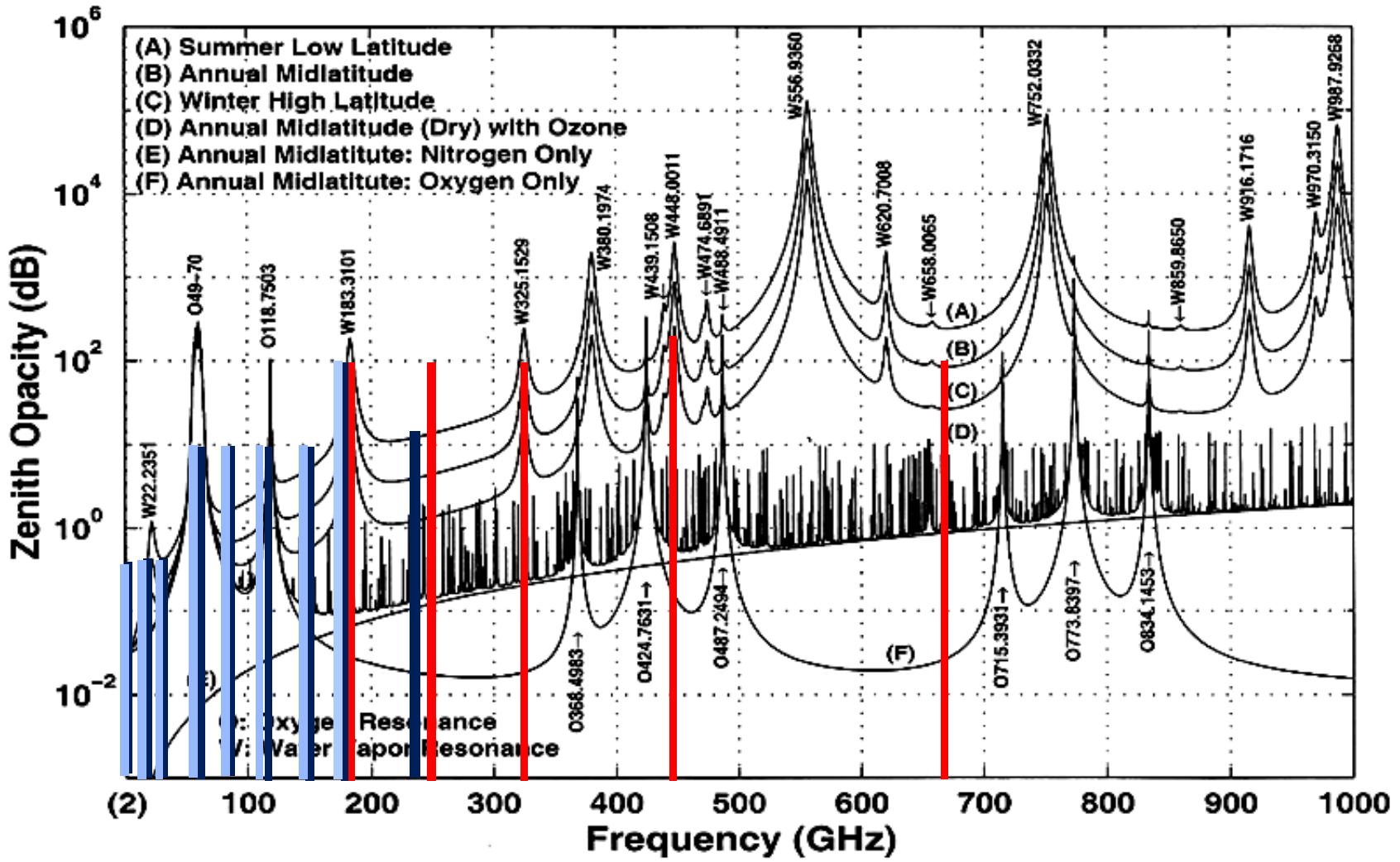
- **Use of channels around weak absorption lines (around 325.15 GHz and 448 GHz) allows performing cloud slicing**

•Few data:
- **mass: 170 kg**
- **height: 1.3 m**
- **reflector diameter: 30 cm**

Channel	Frequency (GHz)	Bandwidth (MHz)	NE∆T (K)	Polarisation	Footprint Size 3dB (km)
ICI-1	183.31±7.0	2x2000	0.8	V	16
ICI-2	183.31±3.4	2x1500	0.8	V	16
ICI-3	183.31±2.0	2x1500	0.8	V	16
ICI-4	243.2±2.5	2x3000	0.7	V, H	16
ICI-5	325.15±9.5	2x3000	1.2	V	16
ICI-6	325.15±3.5	2x2400	1.3	V	16
ICI-7	325.15±1.5	2x1600	1.5	V	16
ICI-8	448±7.2	2x3000	1.4	V	16
ICI-9	448±3.0	2x2000	1.6	V	16
ICI-10	448±1.4	2x1200	2.0	V	16
ICI-11	664±4.2	2x5000	1.6	V, H	16

ICI expected performance

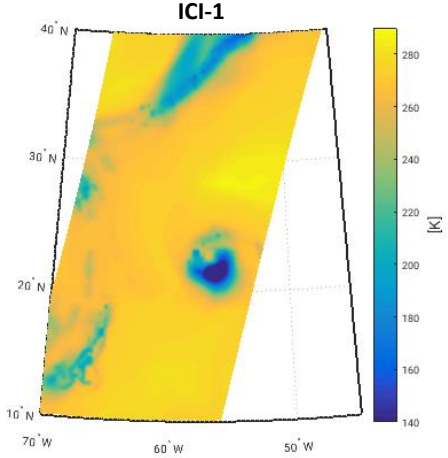
Main channels of EPS-SG passive missions in spectrum



Simulations of hurricane “IKE” , sept 2008

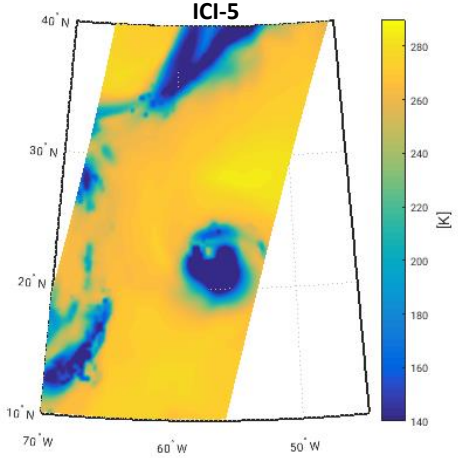
183.3 ± 7 GHz

ICI-1

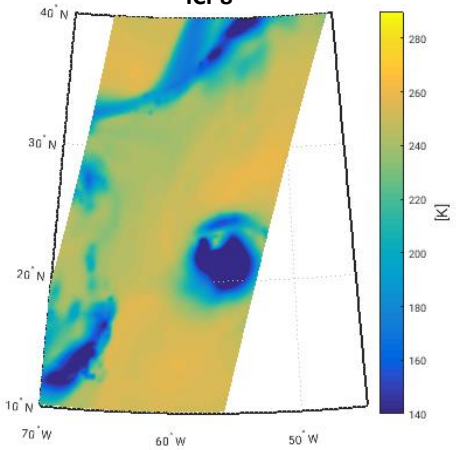


325.15 ± 9 GHz

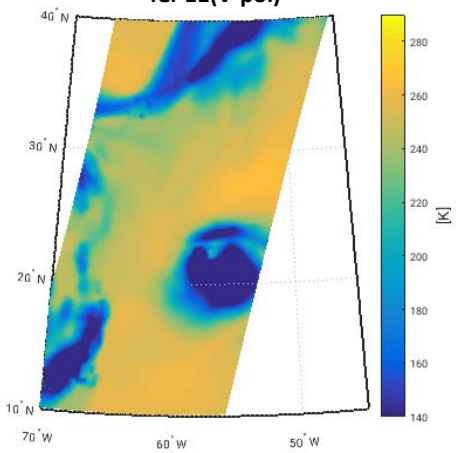
ICI-5



ICI-8



ICI-11(V-pol)

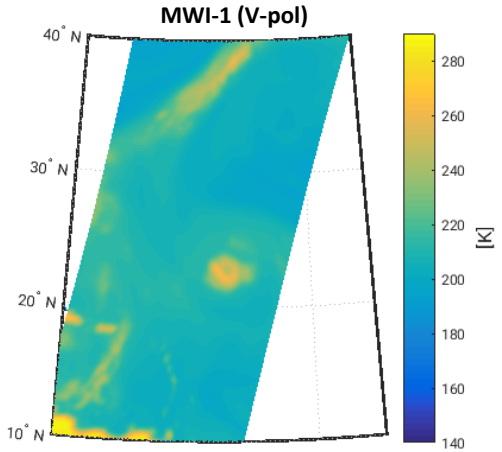


448 ± 7 GHz

664 ± 4 GHz

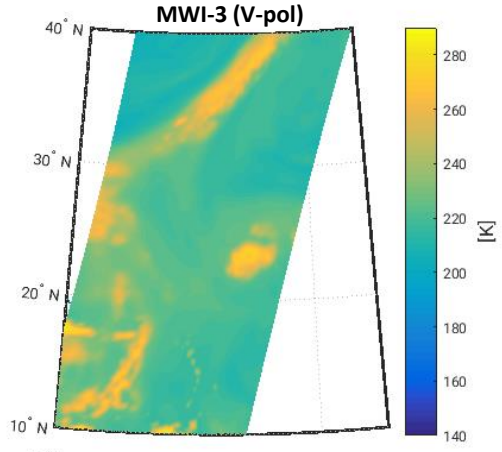
18.7 GHz

MWI-1 (V-pol)

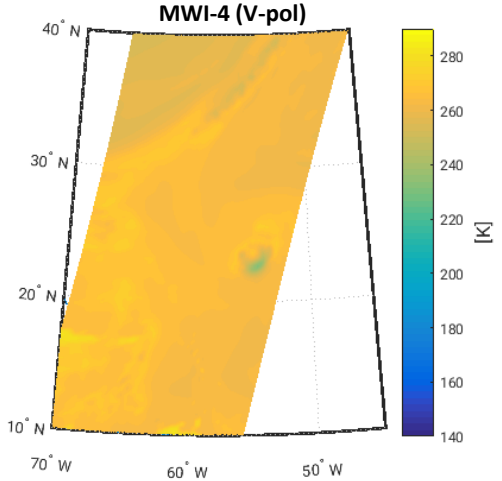


31.4 GHz

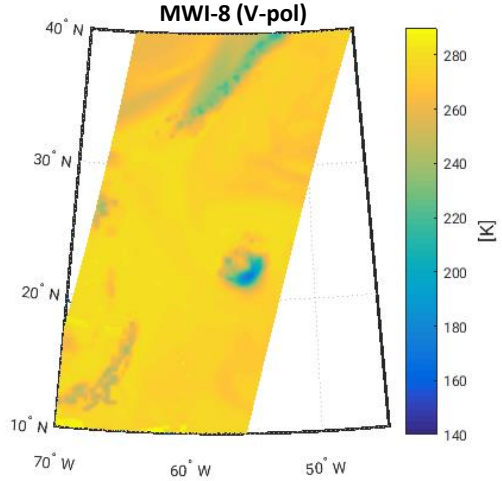
MWI-3 (V-pol)



MWI-4 (V-pol)



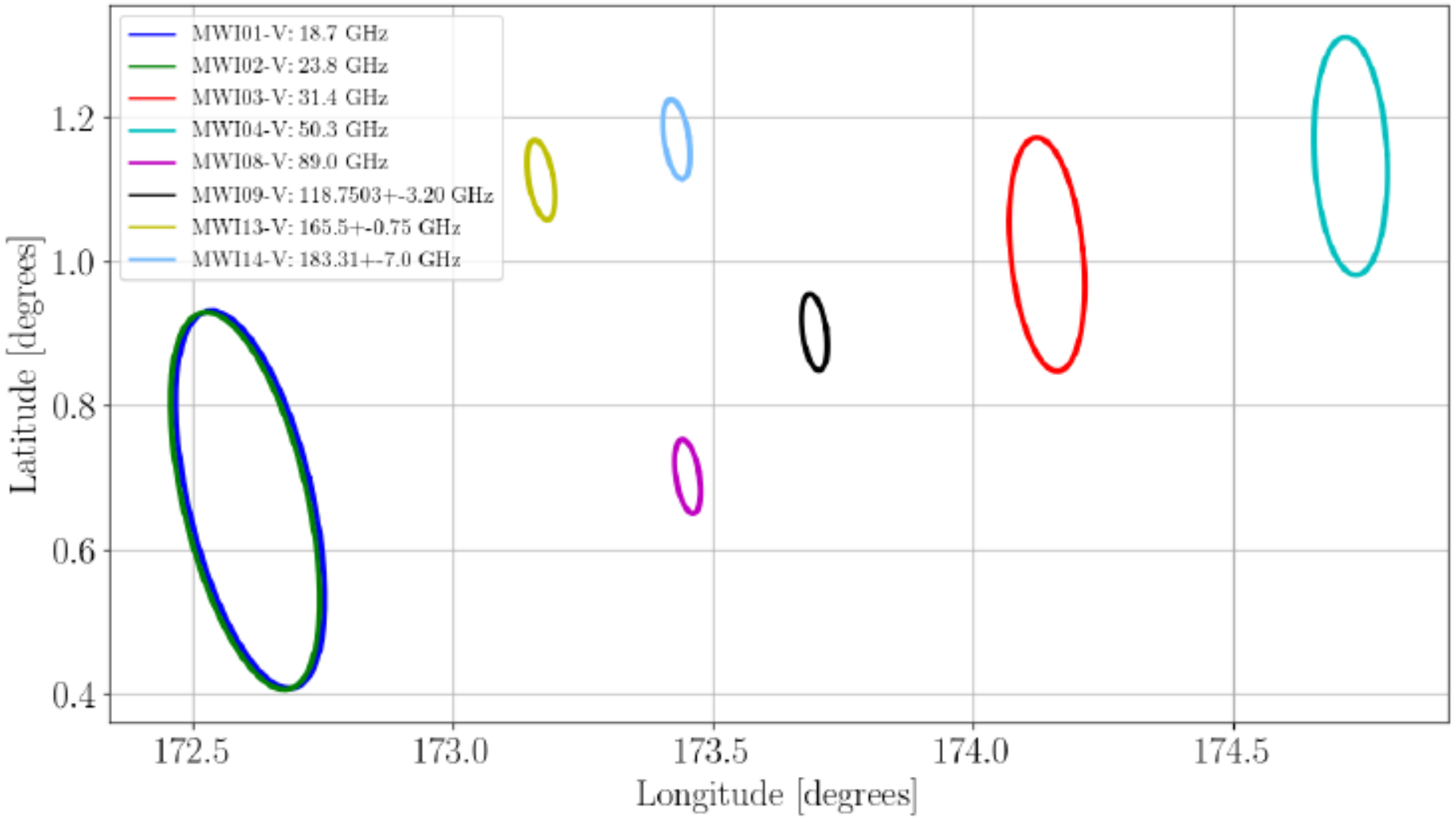
MWI-8 (V-pol)



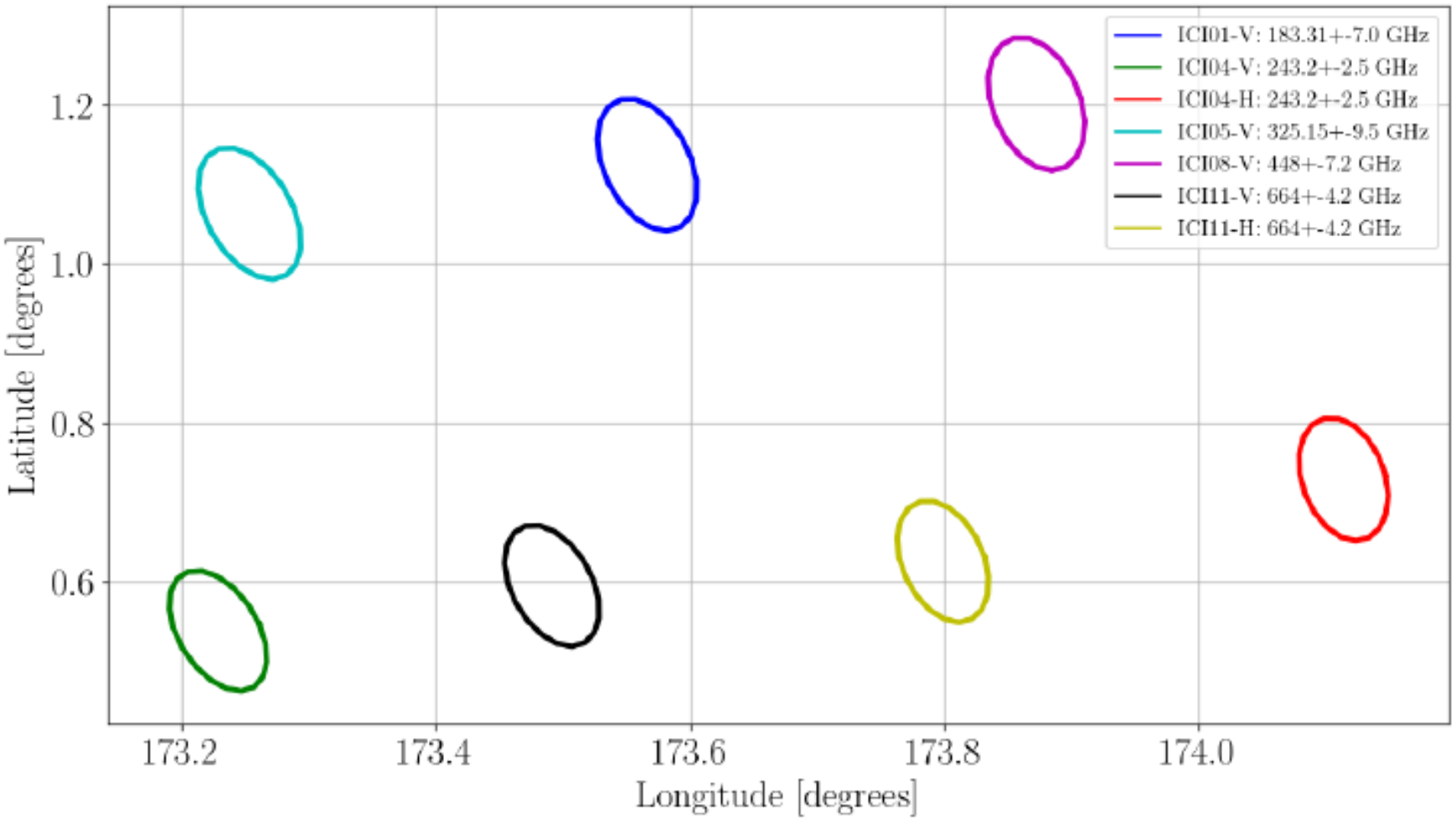
50.3 GHz

89 GHz

MWI - IFOVs


MWI01-V: 18.7 GHz
MWI02-V: 23.8 GHz
MWI03-V: 31.4 GHz
MWI04-V: 50.3 GHz
MWI08-V: 89.0 GHz
MWI09-V: 118.7503+-3.20 GHz
MWI13-V: 165.5+-0.75 GHz
MWI14-V: 183.31+-7.0 GHz
Latitude [degrees]
1.2
1.0
0.8
0.6
0.4
172.5
173.0
173.5
174.0
174.5
Longitude [degrees]

ICI - IFOVs


ICI01-V: 183.31+-7.0 GHz
ICI04-V: 243.2+-2.5 GHz
ICI04-H: 243.2+-2.5 GHz
ICI05-V: 325.15+-9.5 GHz
ICI08-V: 448+-7.2 GHz
ICI11-V: 664+-4.2 GHz
ICI11-H: 664+-4.2 GHz
Latitude [degrees]
1.2
1.0
0.8
0.6
173.2
173.4
173.6
173.8
174.0
Longitude [degrees]

Mission products

ICI

- Level 1B Radiances (NetCDF, BUFR)
- Level 2 products: Cloud ice water path, mean ice particle size by mass and mean mass height, snowfall

MWI

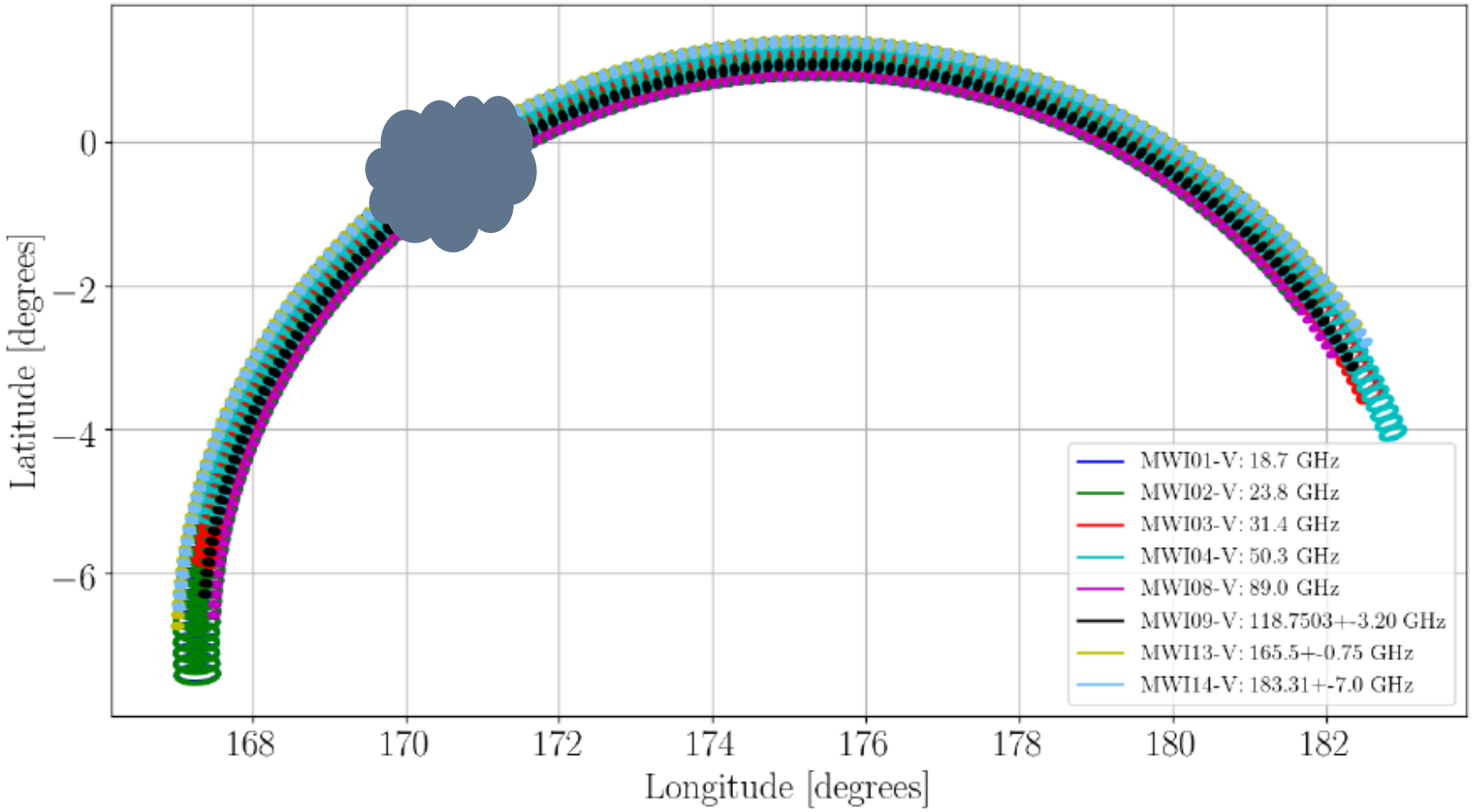
- Level 1B Radiances (NetCDF, BUFR)
- Level 2 products:
  - ✓ Cloud and precipitation including bulk microphysical variables
  - ✓ Total column water vapour over ocean
  - ✓ Water vapour and temperature gross profiles capability
  - ✓ All weather surface imagery including: sea ice coverage (and type), snow coverage and water equivalent, sea surface wind speed (complementary to the scatterometer - SCA)

Several L2 products are developed by the EUMETSAT Satellite Application Facilities (SAFs) like the Hydrology SAF, Nowcasting SAF, Climate Monitoring SAF, Ocean and Sea Ice SAF

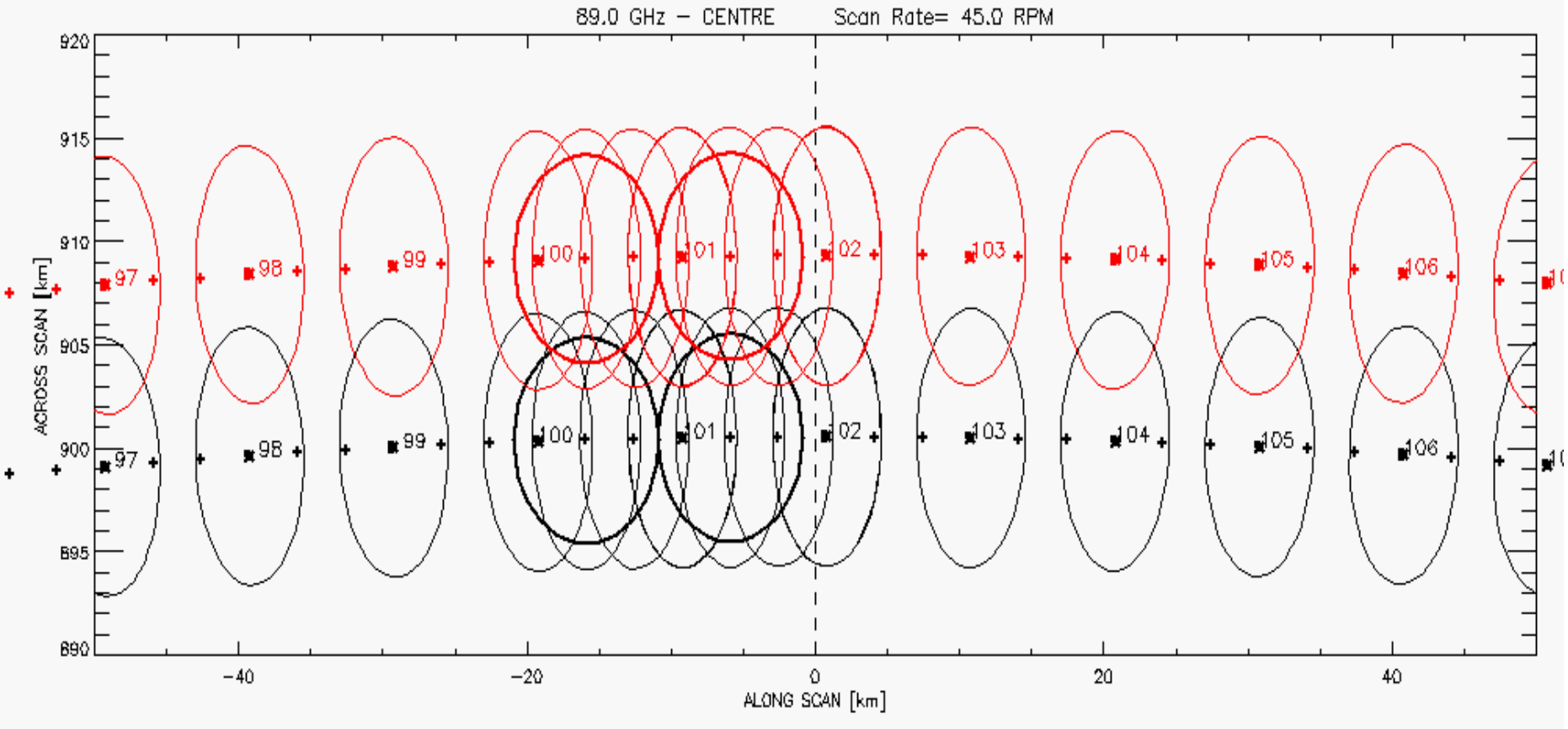
All very nice, but we want more…

Or: New L1 products features: opportunities and challenges

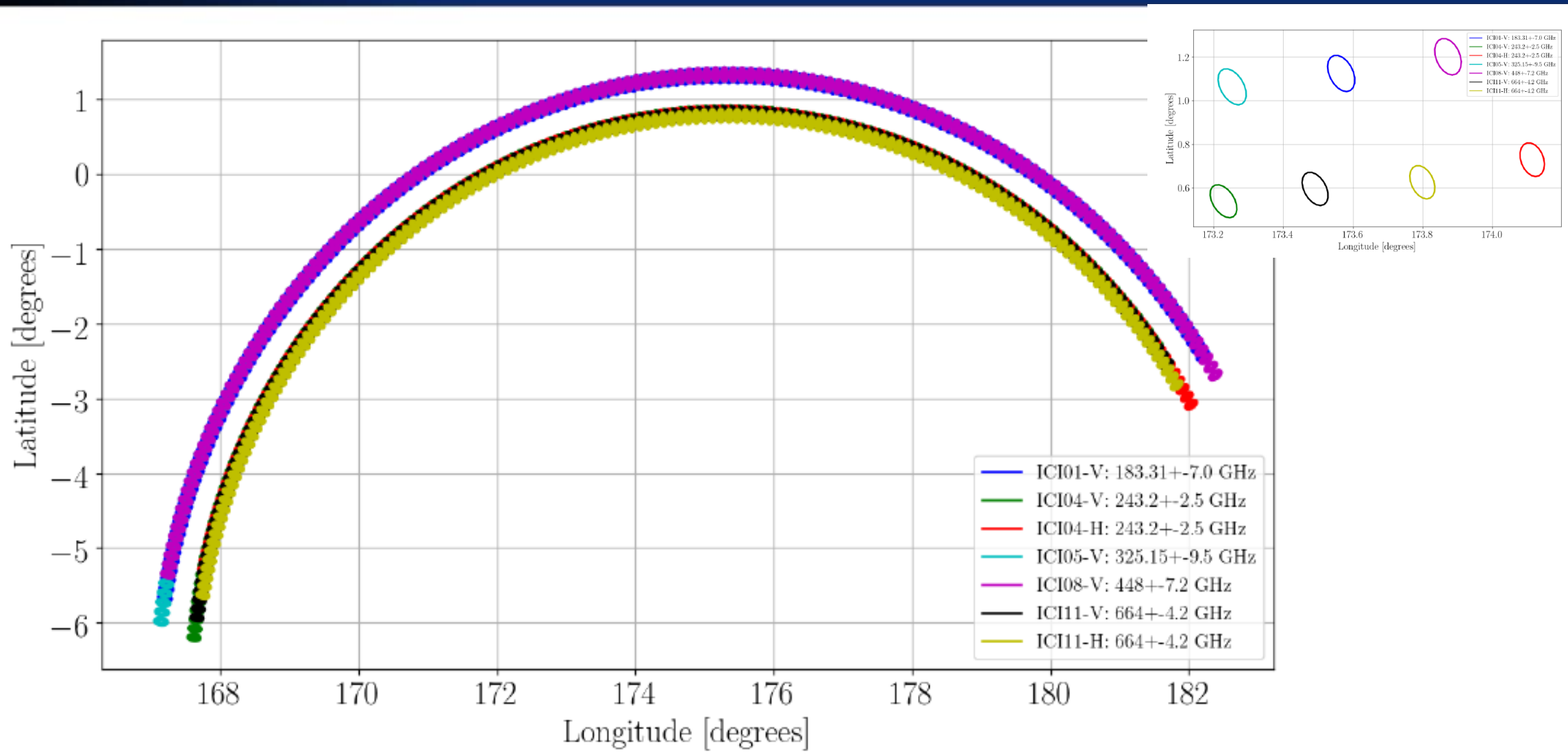
MWI Swath - 1 scan: about 1400 samples



Oversampling along scan



ICI Swath 1 scan: about 800 samples



New opportunities

- **Many samples available, a lot of information to deal with**
- **New possibilities: new thinning strategies could be applied to select the most homogeneous areas in the scan: MW and sub-mm wave adaptive thinning, sub-footprint homogeneity assessment?**
- **Samples have a higher NEΔT w.r.t. aggregated L1B footprints since there is oversampling along scan: it could be anyway an advantage for precipitation retrievals, or even for DA?**
- **On the other hand, super-obbing might be preferable to reduce the NEΔT for assimilation. Assessment of super-obbing vs NEΔT could be interesting**
- **Synergy between MWI and ICI (on the same platform!)**

New challenges

- **Many samples available, a lot of information to deal with !**
- **New channels, new combinations possible, especially for light precipitation and snowfall (50-54 GHz, 118 GHz) and of course ICI.**
- **ICI is a new mission, first imager covering the sub-mm wave spectral range**
- **ICI will not observe the surface often (challenging for Cal/Val)**
- **Scientific studies to prepare for ICI:**
- **Scattering properties of frozen hydrometeors at MW and sub-mm wavelengths:** https://www.eumetsat.int/website/home/Data/ScienceActivities/ScienceStudies/ScatteringpropertiesoffrozenhydrometeorsatMWandsubmmwavelengths/index.html **AKA ARTS, Eriksson et al. 2018.**
- **Optimal interpolation methods for MWI and ICI: dependency on incidence angle**
- **Geolocation study for ICI & MWI - ongoing**

Benefits for the users (ICI)

ICI

- **provision of ice cloud products for climate monitoring. IWP is an essential climate variable that is highly uncertain. Current observations are not able to derive accurate global estimates**

- **support the validation of the presentation of ice clouds in weather and climate models**
  - **cloud microphysical schemes**
  - **cloud radiation interaction**

- **fill observational gap: provide information on non-precipitating ice that are neither accessible in the micro-wave region nor in the infrared domain. ICI sub-mm channels sense different altitudes of cloud depending on wavelength and fill gap between IR and radar.**

- **Further objectives include the measurement of water-vapour gross profiles and snowfall distributions in support of numerical weather prediction and nowcasting.**

Benefits for the users (MWI)

MWI

- Provision of cloud and precipitation products including bulk microphysical variables, and all weather surface imagery
- Support Numerical Weather Prediction at regional and global scales: all-weather direct assimilation into NWP systems, information related to the integrated total column water vapour as well as near-surface wind speed derived from MWI data is considered crucial
- MWI has to be viewed as part of an international partnership for global precipitation observations (Global Precipitation Measurement – GPM – like constellation)
- Continuity of measurements of key microwave imager channels as observed by SSM/I, TRMM TMI, SSMIS, AMSR-E, GMI, in support of long-term climate records
- The availability of high quality retrievals of cloud, precipitation and all weather land surface variables would also contribute to fulfil other key requirements common to Nowcasting and very short-range forecasting (VSRF) at regional scales
- MWI observations of sea-ice extent and other sea ice variables in Arctic and Antarctic Oceans possible via microwave imaging instruments, as polar nights and persistent cloud cover prevent complete coverage by optical imagers

Summary (I)

- **The ICI radiometer provides an unprecedented set of microwave passive measurements from 183.3 GHz up to 664 GHz.**

- **The MWI (on the same platform with ICI) will continue and enhance important measurements of cloud and precipitation. Synergy among missions.**

- **The MWS mission ensures continuity of existing MW sounding instruments.**

These missions will:

- **Provide continuation and enhancement of EUMETSAT service from polar orbit in 2021 – 2042.**
- **Expand by 20+ years the EUMETSAT contribution to climate data records.**
- **Contribute to GPM constellation.**

Passive Microwave missions @ EUMETSAT

WHAT WE NEED TO DO:

EPS

- **Assure and continue operations**: AMSU/MHS on Metop-A and NOAA-19 (up to 2021/22), on Metop-B (up to 2023/24), and on Metop-C (up to 2025/26)
- Support Metop-A End of Life (EOL) testing (2019/2020)

EPS-SG (short term)

- **Prepare** EPS-SG MWS L1, L2 and take ownership of product processing chains (Metop-SGA-1 to be launched in 2022) **and ensure** MWS continuous operations
- **Prepare** EPS-SG MWI/ICI L1, L2 and take ownership of product processing chains (Metop-SGB-1 to be launched in 2023) **and ensure** MWI/ICI continuous operations

EPS-SG (> 5 years):

- **Prepare** EPS-SG Metop-SGA-2 MWS, and Metop-SGB-2 MWI/ICI
- **Assure simultaneous operations** of EPS-SG MWS Metop-SGA-1, Metop-SGA-2, and MWI/ICI Metop-SGB-1, Metop-SGB-2

- **Prepare for the future…**