The Copernicus Imaging Microwave Radiometer (CIMR)

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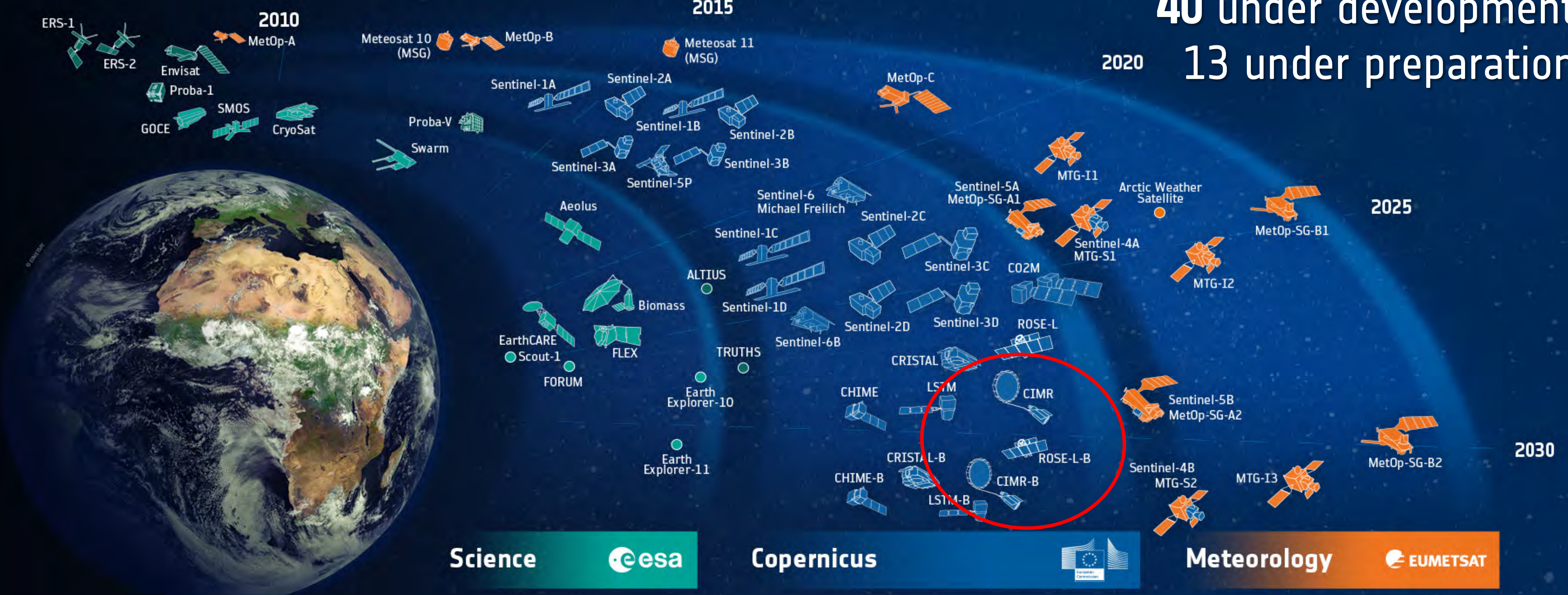
GSICS Microwave Subgroup, 28th February 2022

ESA-DEVELOPED EARTH OBSERVATION MISSIONS

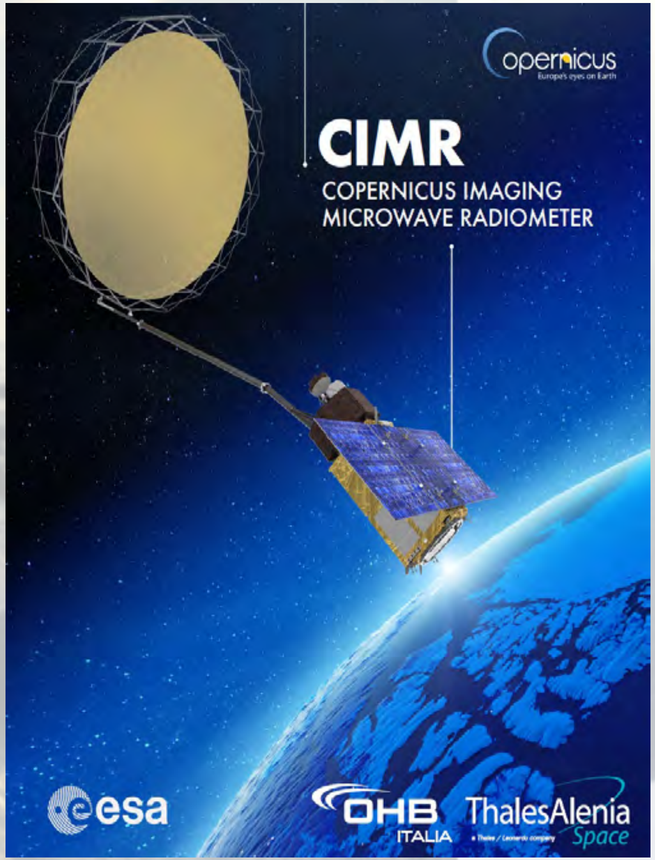
15 in operation
40 under development
13 under preparation



The Copernicus Imaging Microwave Radiometer (CIMR)

European Commission

The European Commission and the High Representative of the Union for Foreign Affairs and Security Policy issued to the European Parliament and the Council, on 27 April 2016, a joint communication that **proposed "An integrated European Union policy for the Arctic"**



Polar Oceans are fundamental to understanding the global environment

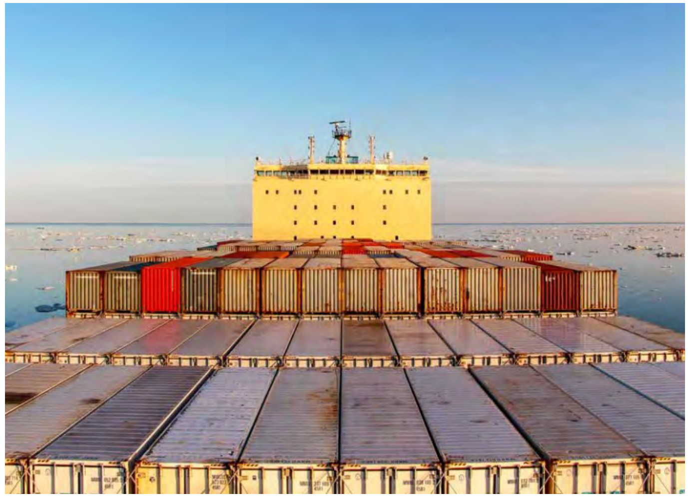
CIMR is designed to:

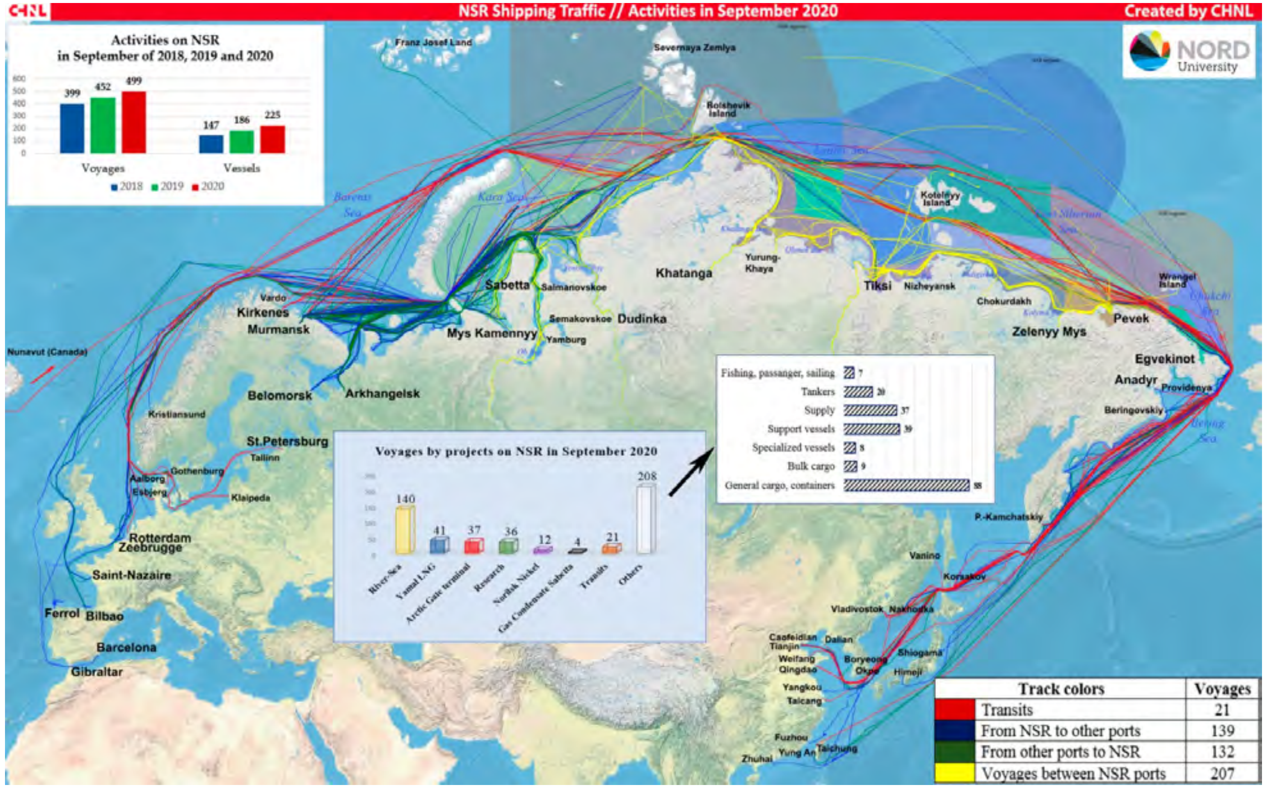
- **Prevent the anticipated Gap in capability**
- **Be "ready" for an ice free Arctic**
- **Key variables:** *Sea Ice Concentration, Sea Surface Temperature, thin Sea Ice Thickness, Sea Surface Salinity, Wind Speed, soil moisture…*
- Low frequency/High Spatial resolution (5–15 km)
- **Measurements every ~6 hours** in the Polar regions, no hole at the pole
- 95% global coverage every day for **application in all Copernicus Services**

- Directly addresses the EU Arctic Policy.
- **A 'Game Changer' for Copernicus**

Atmosphere (CAMS)
Marine (CMEMS)
Land (CLMS)
Climate (C3S)
Emergency (EMS)
Security

Opening of the Northern Sea Route



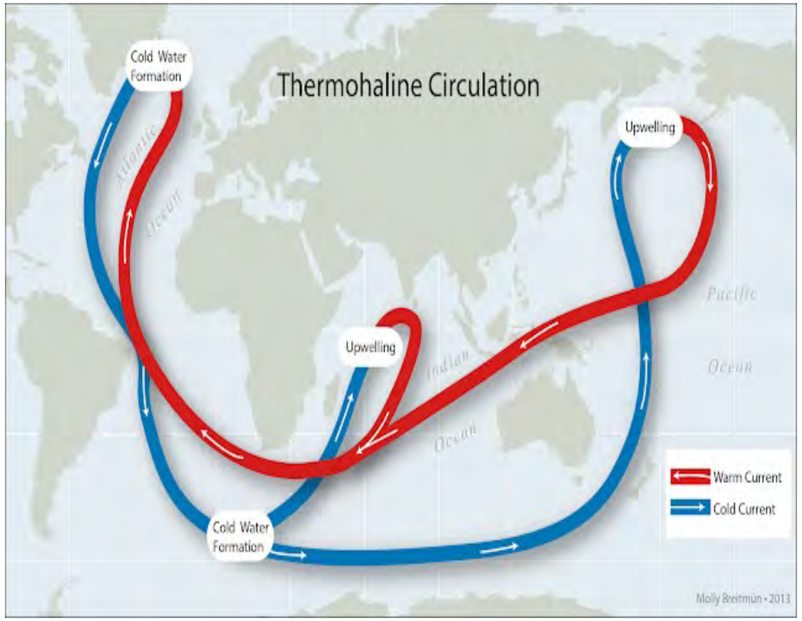


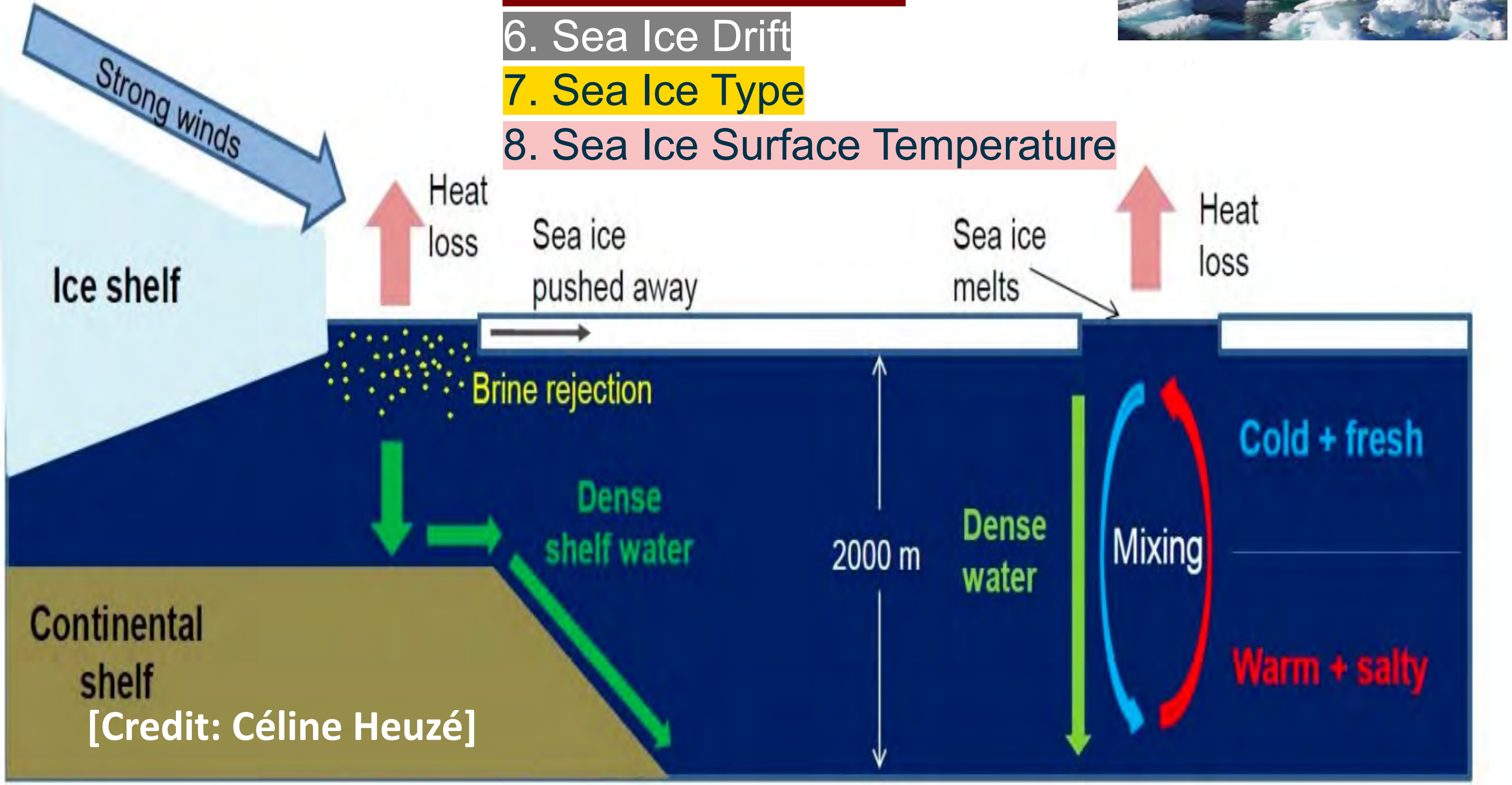
Credit: Center for High North Logistics Information Office at Nord University

“The emerging state of the Arctic Ocean features more fragmented thinner sea ice, stronger winds, ocean currents and waves. By the mid21st century, summer season sailing times along the route via the North Pole are estimated to be 13–17 days, which could make this route as fast as the North Sea Route”,
http://dx.doi.org/10.1016/j.marpol.2015.12.027

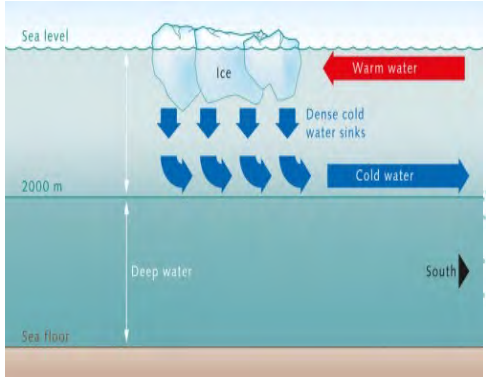
CIMR: Cryosphere-ocean-atmosphere processes

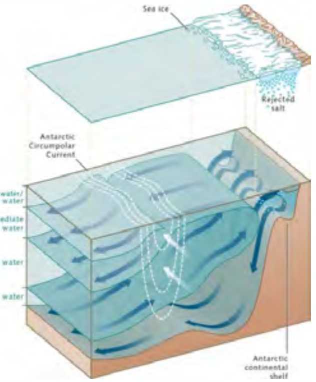
1. Sea Ice Concentration
2. Sea Surface Temperature
3. Sea Surface Salinity
4. Surface Winds
5. Sea Ice Thickness
6. Sea Ice Drift
7. Sea Ice Type
8. Sea Ice Surface Temperature





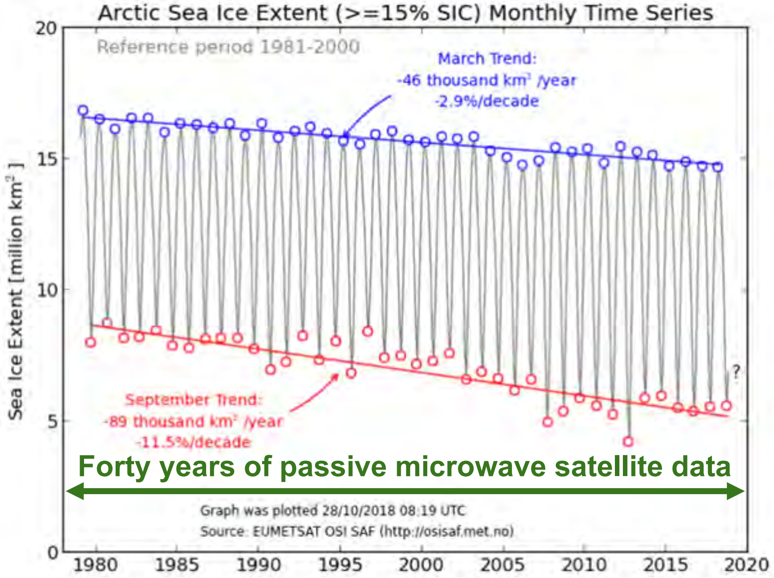
[Credit: Céline Heuzé]





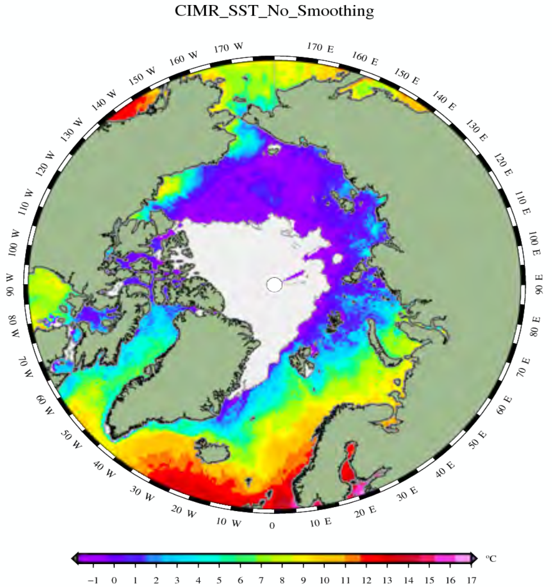
Level-2 Measurement Products

Sea Ice Concentration

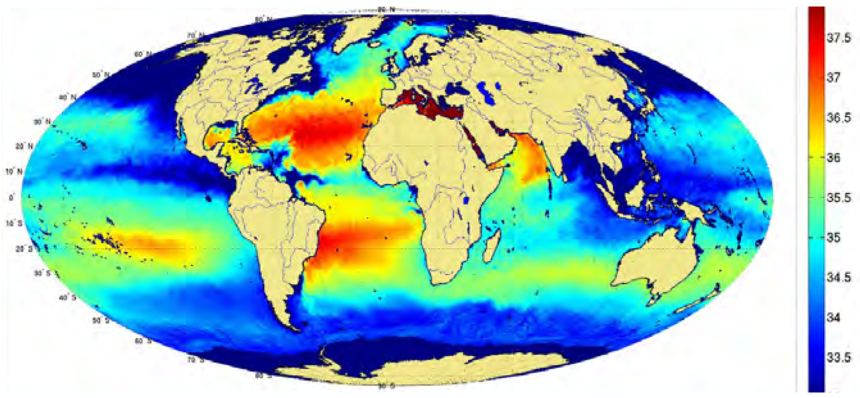


Forty years of passive microwave satellite data

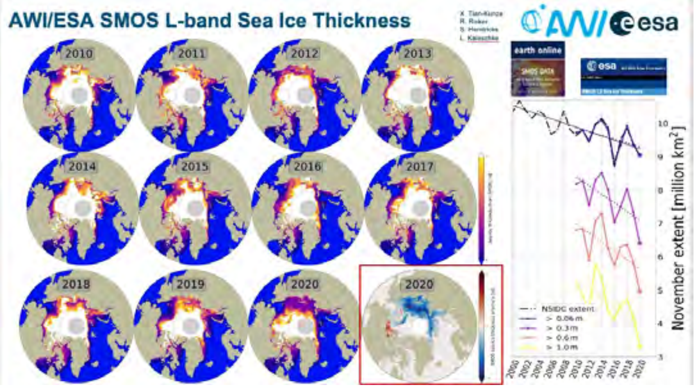
Sea Surface Temperature



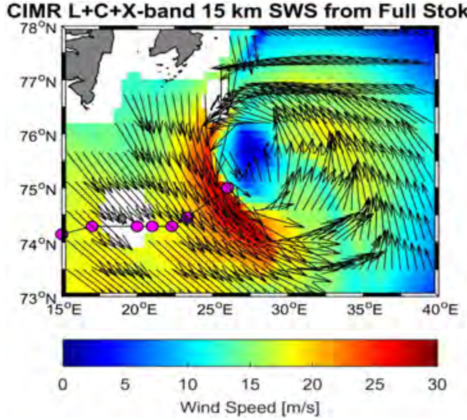
Sea Surface Salinity



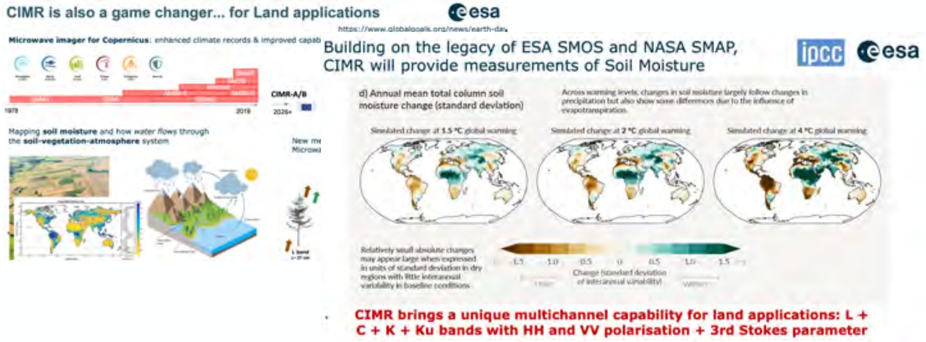
Thin Sea Ice thickness



Surface Wind over ocean



Sea Ice Drft, ice type, snow, Vegetation, soil moisture...



CIMR is also a game changer... for Land applications

Microwave imager for Copernicus: enhanced climate records & improved capab

Mapping **soil moisture** and how water flows through the **soil-vegetation-atmosphere** system

https://www.globalgoals.org/news/earth-day

Building on the legacy of ESA SMOS and NASA SMAP, CIMR will provide measurements of Soil Moisture

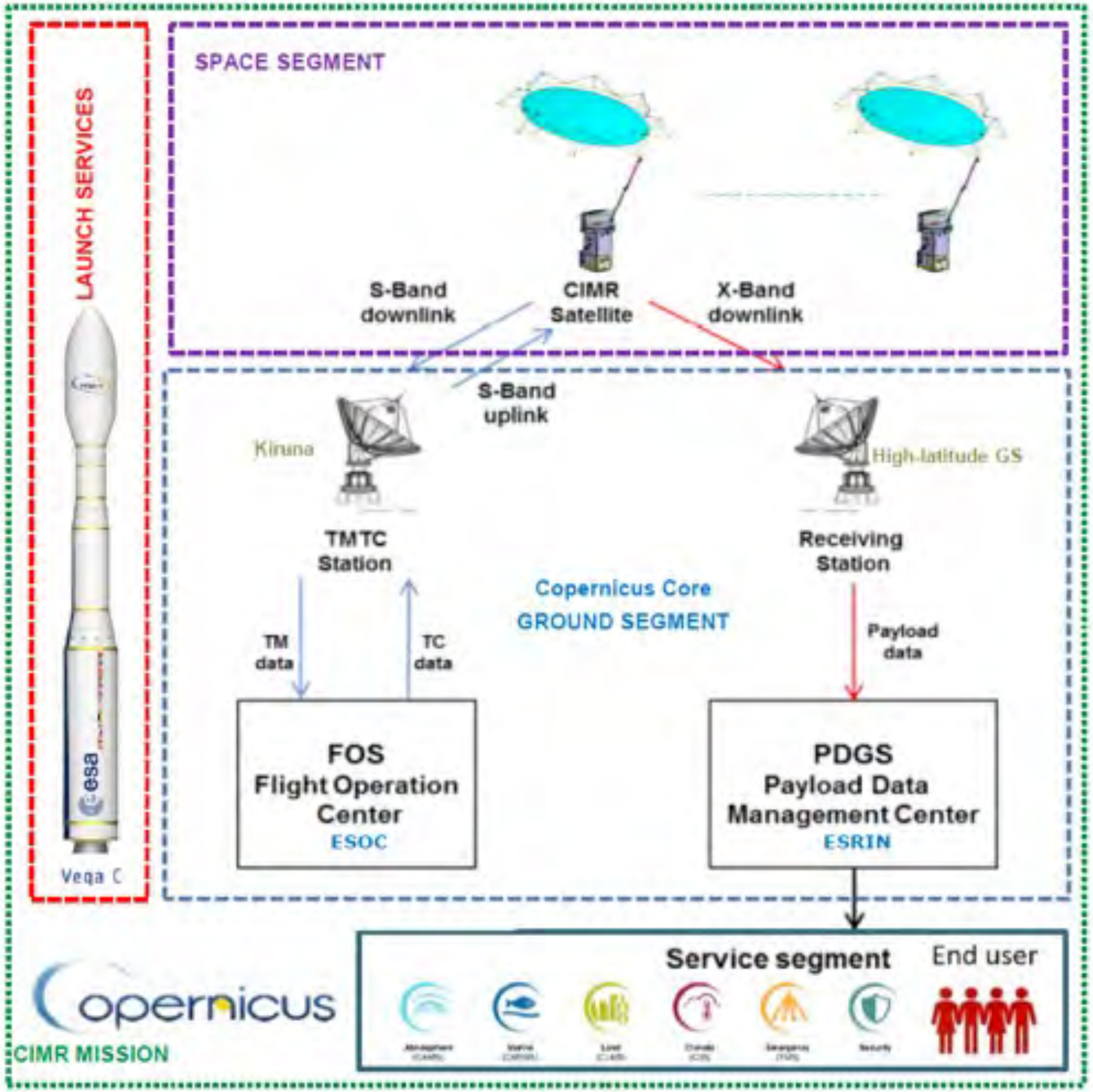
d) Annual mean total column soil moisture change (standard deviation)

Across warming levels, changes in soil moisture largely follow changes in precipitation but also show some differences due to the influence of evapotranspiration.

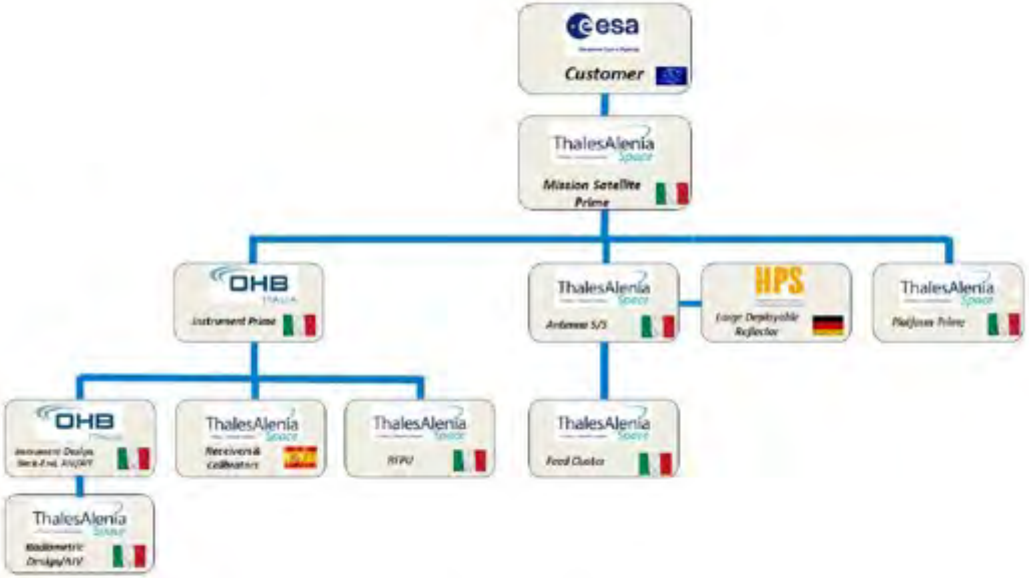
Relatively small absolute changes may appear large when expressed in units of standard deviation in dry regions with little interannual variability in baseline conditions

CIMR brings a unique multichannel capability for land applications: L + C + K + Ku bands with HH and VV polarisation + 3rd Stokes parameter

CIMR Mission Configuration



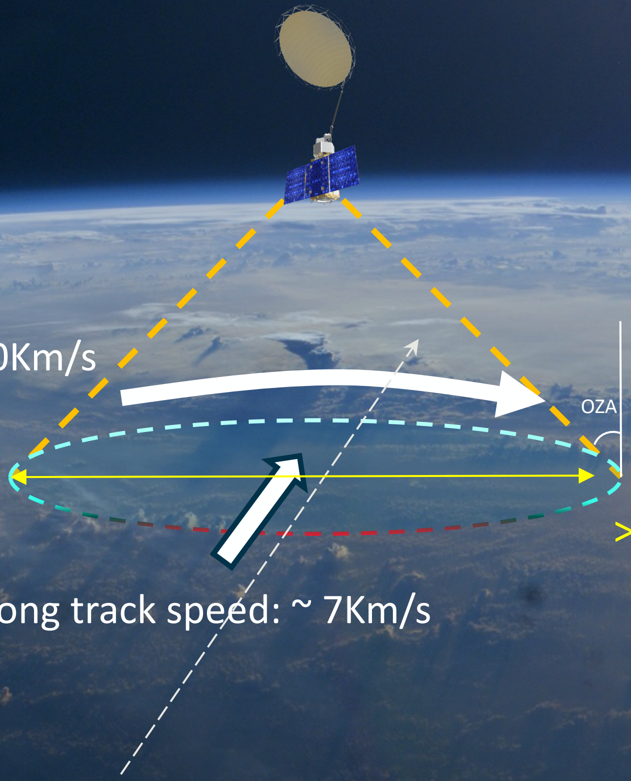
Industrial Team Led by Thales Alenia Italy



ThalesAlenia Space
a Thales / Leonardo company

OHB ITALIA
We.Create.Space.

The CIMR Payload Overview



Conical scan
Across track speed: ~ 770Km/s

>1900km Swath

Along track speed: ~ 7Km/s

- Reference altitude 817.5km
- OZA 55 ± 1.5 degrees
- Rotation speed 7.8rpm
  - Dictated by radiometric sensitivity requirements

- Antenna diameter 8.6 x 7.3 m
- Aperture: 7.1m
- f/D = 0.85

- 50 receiver channels in total (~11GHz total bandwidth), incuding dual linear polarisation

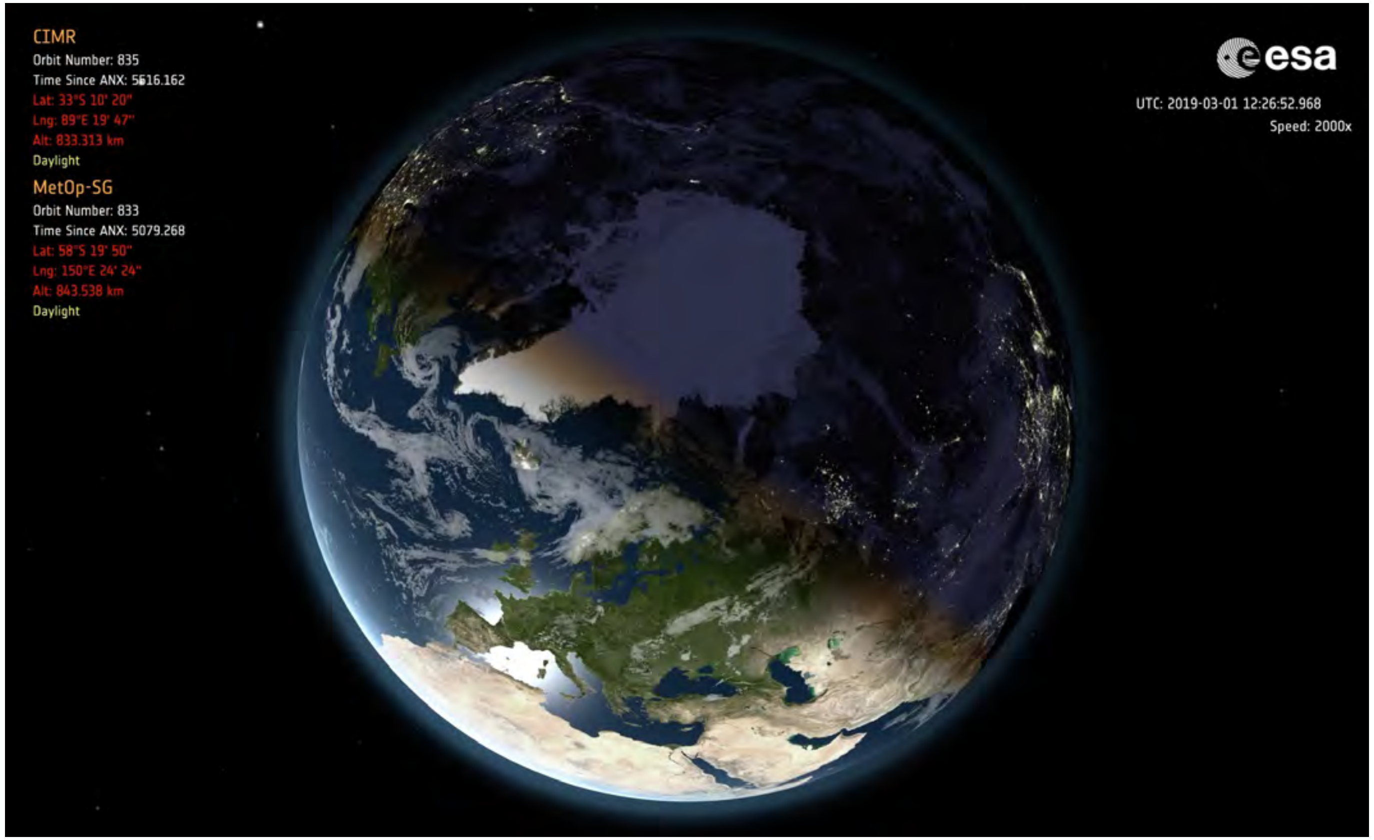
- Data ~ 7Mbps nominally

CIMR Orbit design

CIMR is to be placed in a 06:00 **sun synchronous dawn-dusk orbit**

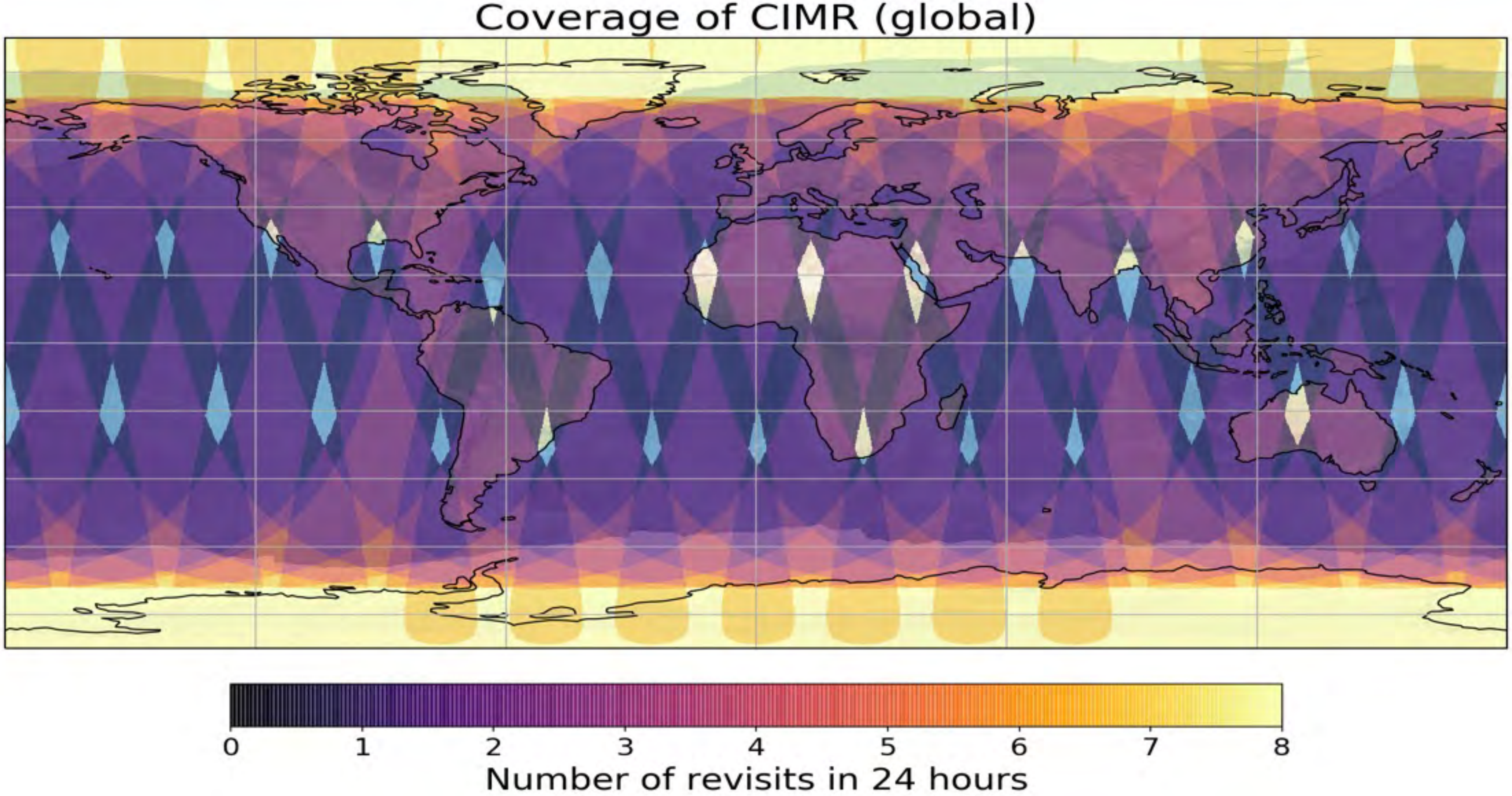
CIMR flies ‘ahead’ of MetOp-SG(1B)

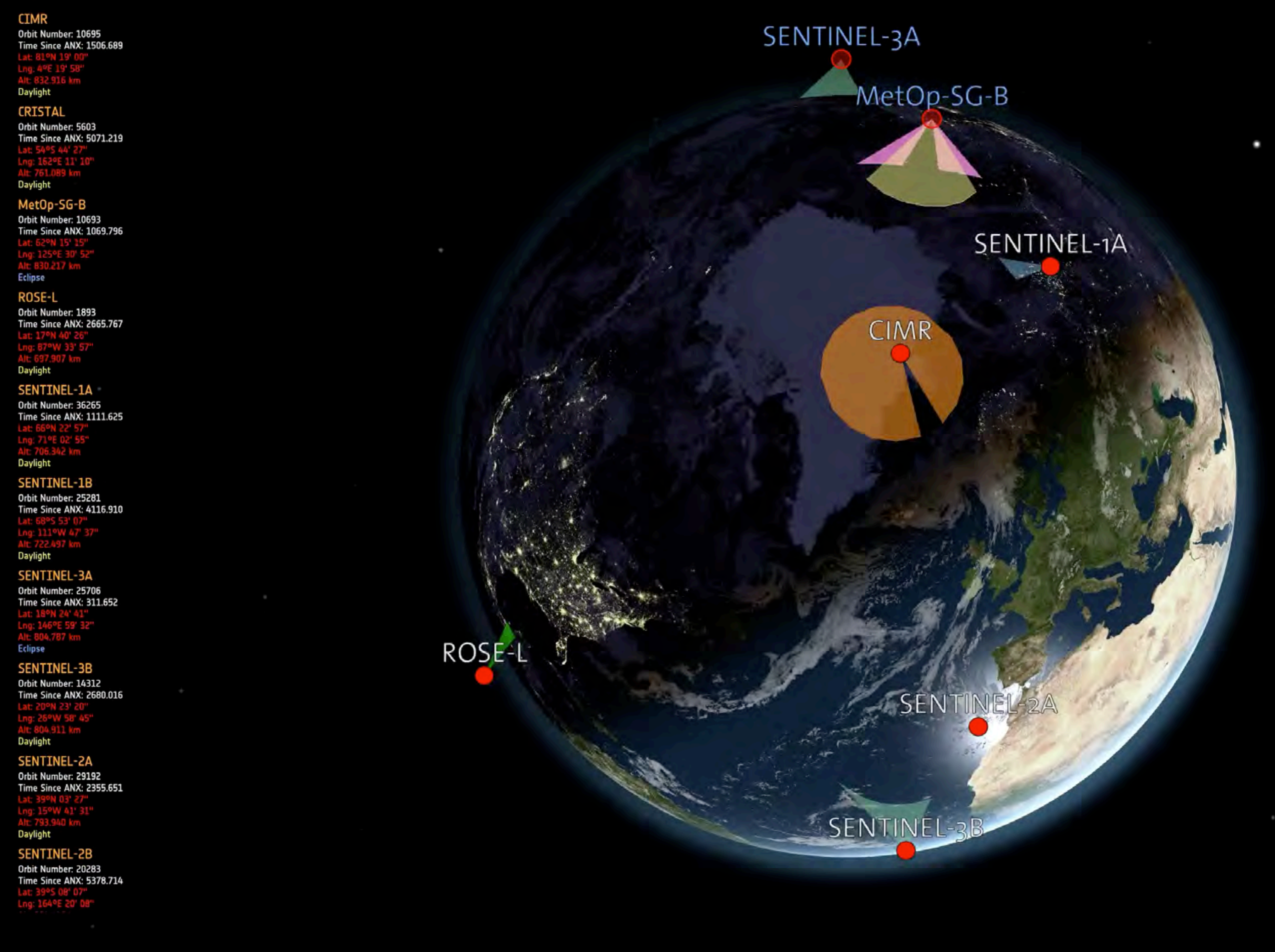
- +/- 10 mins difference in Arctic
- Focus on the Arctic region
- No “hole at the pole”
- Minimise daily eclipse periods and mitigate the impact of thermoelastic distortion,
- Maximise power generation,
- Minimise the complexity and size of the solar array.
- Maximise the colocation between CIMR measurements and MetOp-SG(B) within ±10 minutes in the polar regions



Coverage and Revisit

(~95%/day Global coverage, 1 satellite; 99% coverage after 1.5 days)





CIMR
Orbit Number: 10695
Time Since ANX: 1506.689
Lat: 81°N 19' 00"
Lng: 4°E 19' 58"
Alt: 832.916 km
Daylight

CRISTAL
Orbit Number: 5603
Time Since ANX: 5071.219
Lat: 54°S 44' 27"
Lng: 162°E 11' 10"
Alt: 761.089 km
Daylight

MetOp-SG-B
Orbit Number: 10693
Time Since ANX: 1069.796
Lat: 62°N 15' 15"
Lng: 125°E 30' 52"
Alt: 830.217 km
Eclipse

ROSE-L
Orbit Number: 1893
Time Since ANX: 2665.767
Lat: 17°N 40' 26"
Lng: 87°W 33' 57"
Alt: 697.907 km
Daylight

SENTINEL-1A
Orbit Number: 36265
Time Since ANX: 1111.625
Lat: 66°N 22' 57"
Lng: 71°E 02' 55"
Alt: 706.342 km
Daylight

SENTINEL-1B
Orbit Number: 25281
Time Since ANX: 4116.910
Lat: 68°S 53' 07"
Lng: 111°W 47' 37"
Alt: 722.497 km
Daylight

SENTINEL-3A
Orbit Number: 25706
Time Since ANX: 311.652
Lat: 18°N 24' 41"
Lng: 146°E 59' 32"
Alt: 804.787 km
Eclipse

SENTINEL-3B
Orbit Number: 14312
Time Since ANX: 2680.016
Lat: 20°N 23' 20"
Lng: 26°W 58' 45"
Alt: 804.911 km
Daylight

SENTINEL-2A
Orbit Number: 29192
Time Since ANX: 2355.651
Lat: 39°N 03' 27"
Lng: 15°W 41' 31"
Alt: 793.940 km
Daylight

SENTINEL-2B
Orbit Number: 20283
Time Since ANX: 5378.714
Lat: 39°S 08' 07"
Lng: 164°E 20' 08"

Synergy between Missions is important as we will have unprecedented coverage in 2028+

Channel selection

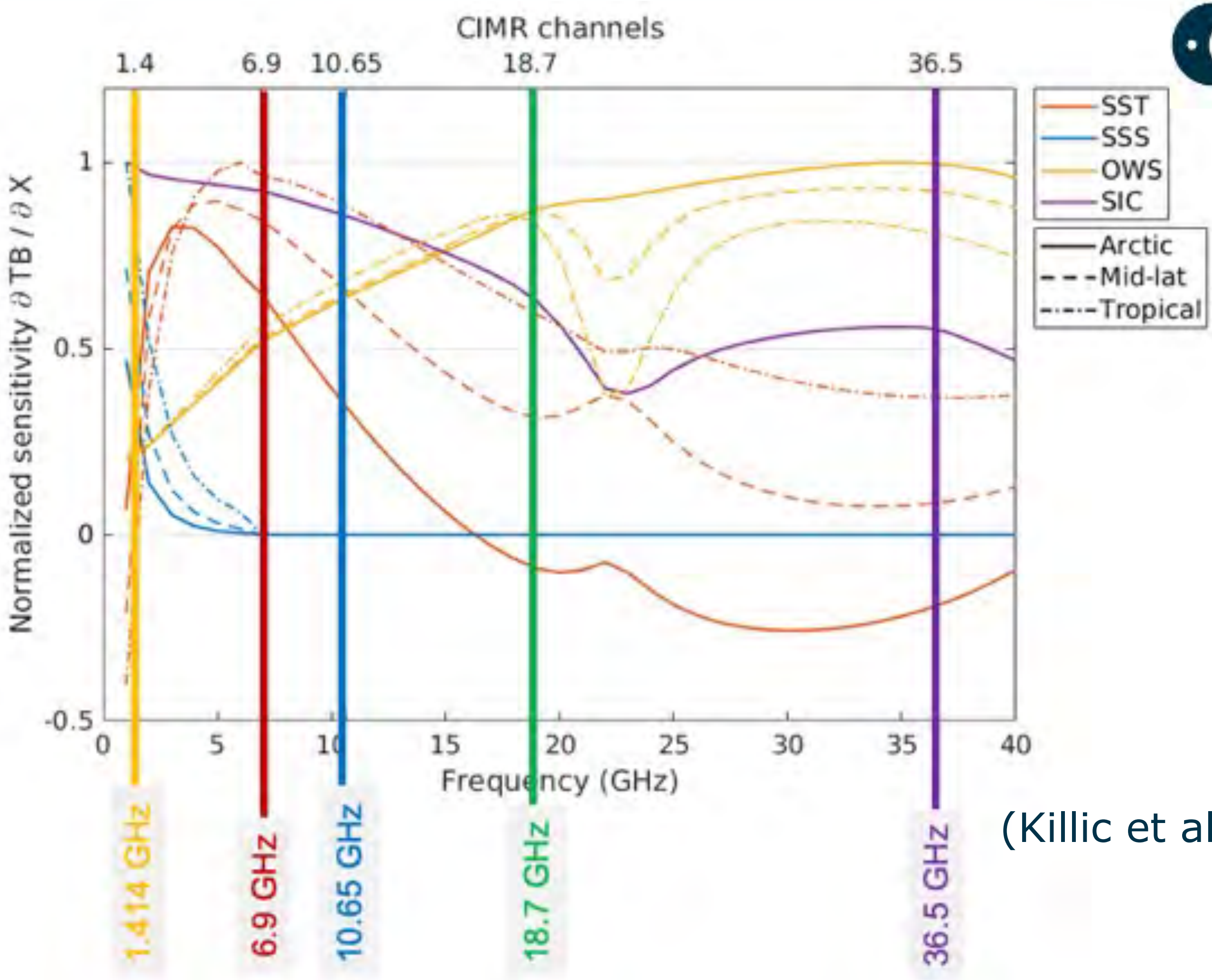
1.4135 GHz: SIT, SIC, SSS, WS, SM, SD

6.9 GHz: SIC, SST, SIT, IST, WS, SID, SM, SD

10.65 GHz: SST, PCP, WS, SD, SM

18.7 GHz: TCWV, LWP, PCP, SIC, SD, SM, SID

36.5 GHz: SIC, SST, LWP, TCWV, PCP, SIC, SWE, SD

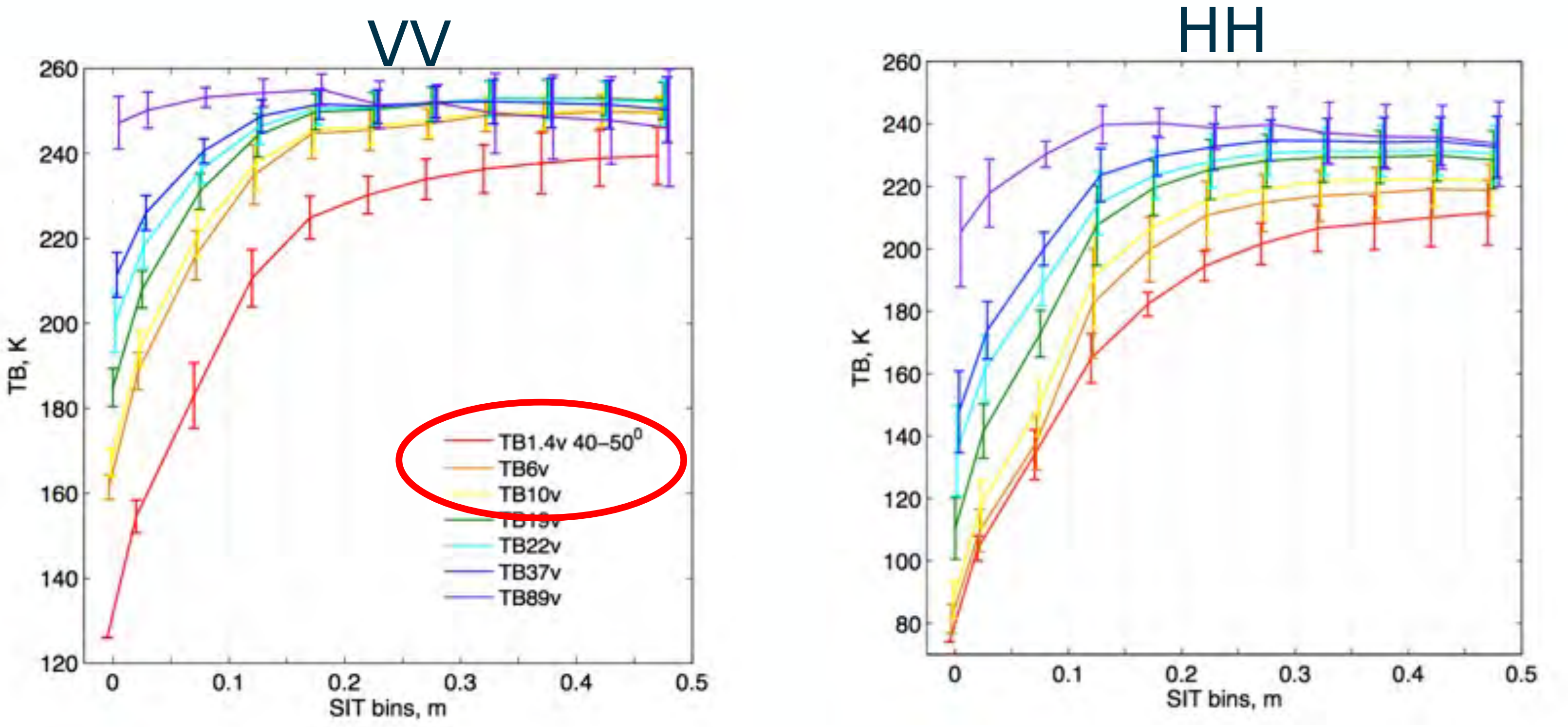


(Killic et al, 2020)

SIC = Sea Ice Concentration,
SST = Sea Surface Temperature, SIT = Sea Ice thickness,
SSS= Sea Surface Salinity,
WS = Wind speed,
LWP = Liquid Water Path,
TCWV = Total Column-liquid Water Vapour,
SD = Snow Depth,
SM = Soil Moisture,
SWE = Snow Water Equivalent,
SID = Sea Ice Drift,
PCP=precipitation

Channels (GHz, Full Stokes):	**1.4**	**6.9**	**10.65**	**18.7**	**36.5**
Resolution (km):	**<60**	**≤15**	**≤15**	**≤5.5**	**≤5 (g:4km)**
NEΔT (K @150K):	**≤0.3**	**≤0.2**	**≤0.3**	**≤0.4**	**≤0.7**
Tot. Standard Uncertainty(K):	**≤0.5**	**≤0.5**	**≤0.5**	**≤0.6**	**≤0.8**

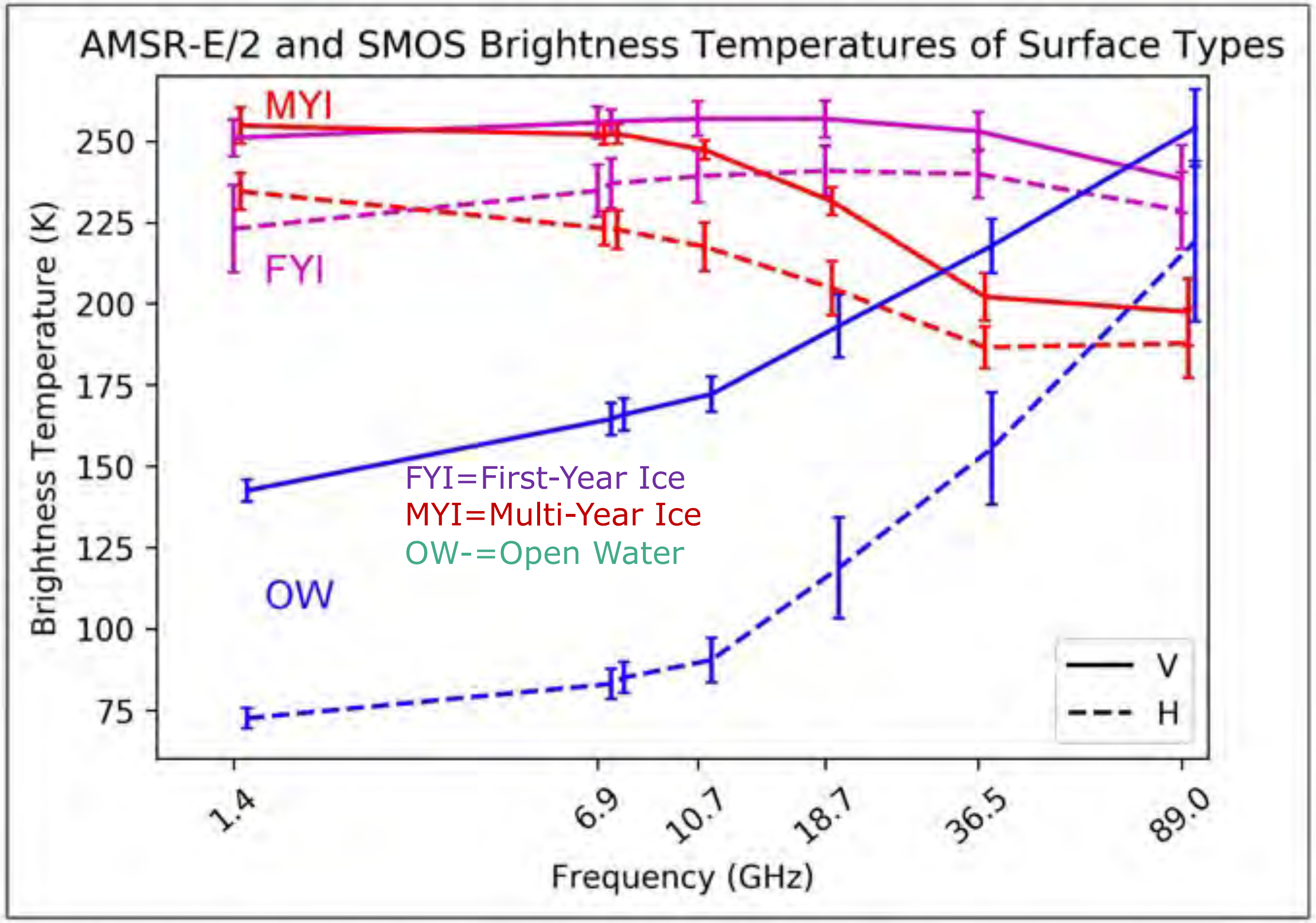
Sea Ice Thickness channel selection



Polarized brightness temperatures as function of sea ice thickness for various frequencies (from *Heygster et al*, 2014).

The best performing frequency for thin sea ice thickness determination is 1.4 GHz.

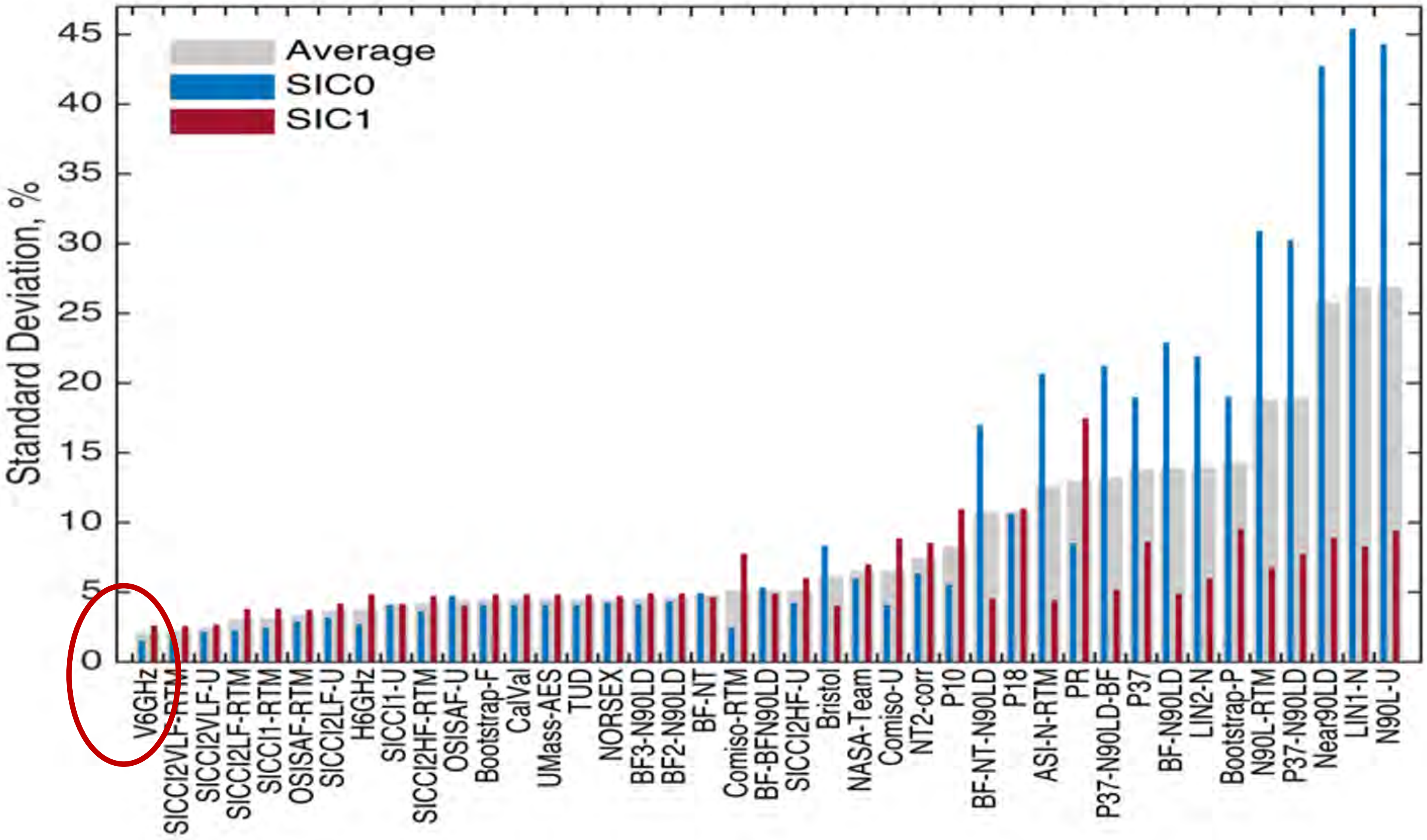
Sea Ice Concentration: the role of L-, C/X, K/Ka-bands



Lu, J. and Heygster, G.: AMSR-E/2 and SMOS Brightness Temperatures of Surface Types, , doi:10.6084/m9.figshare.7370261.v2, 2018.

- On a single-channel basis, we want to use low-frequencies because:
  - high dynamic range between Open Water and sea-ice.
  - limited dynamic range between Multiyear Ice and First-Year Ice.
- The best SIC algorithms involve Ka-band: high spatial resolution<5 km achievable

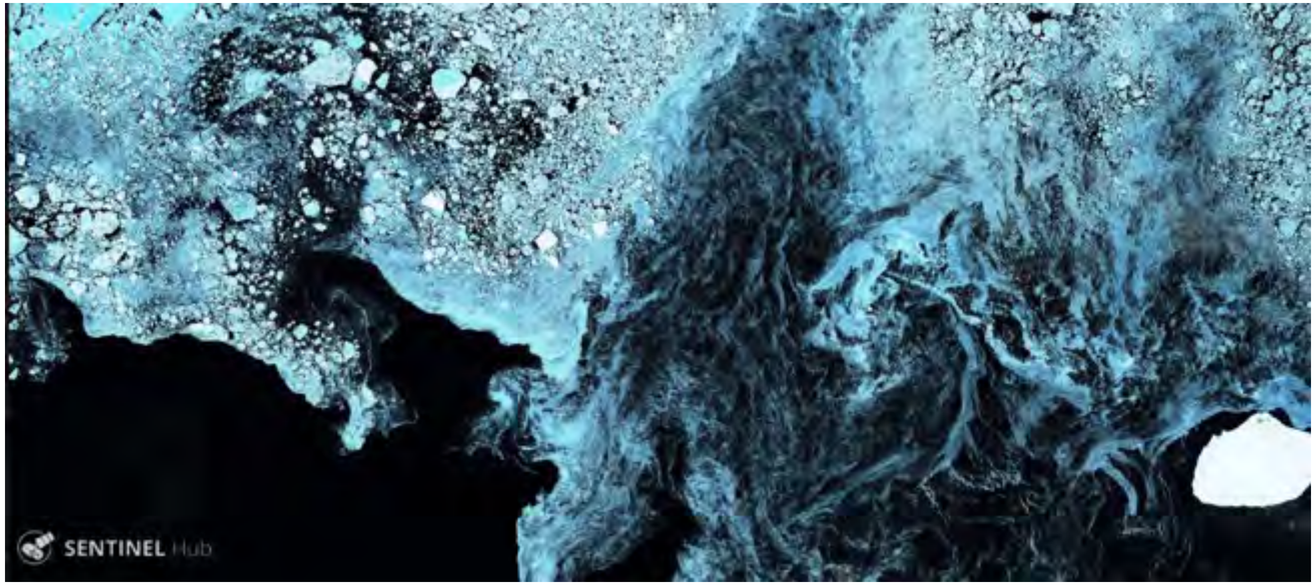
Sea Ice Concentration (SIC) algorithms

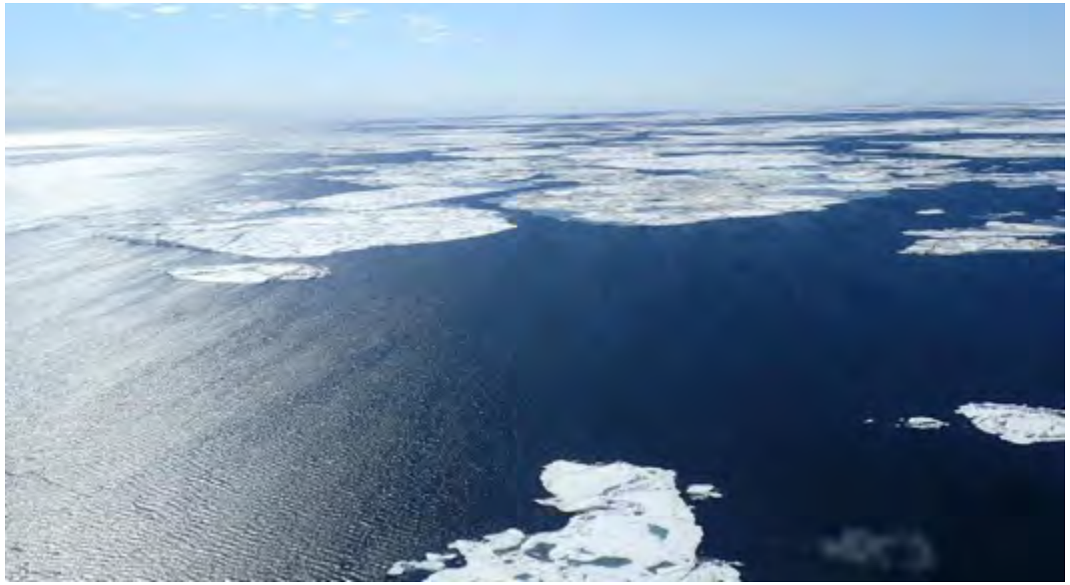


The best algorithm uses C-band

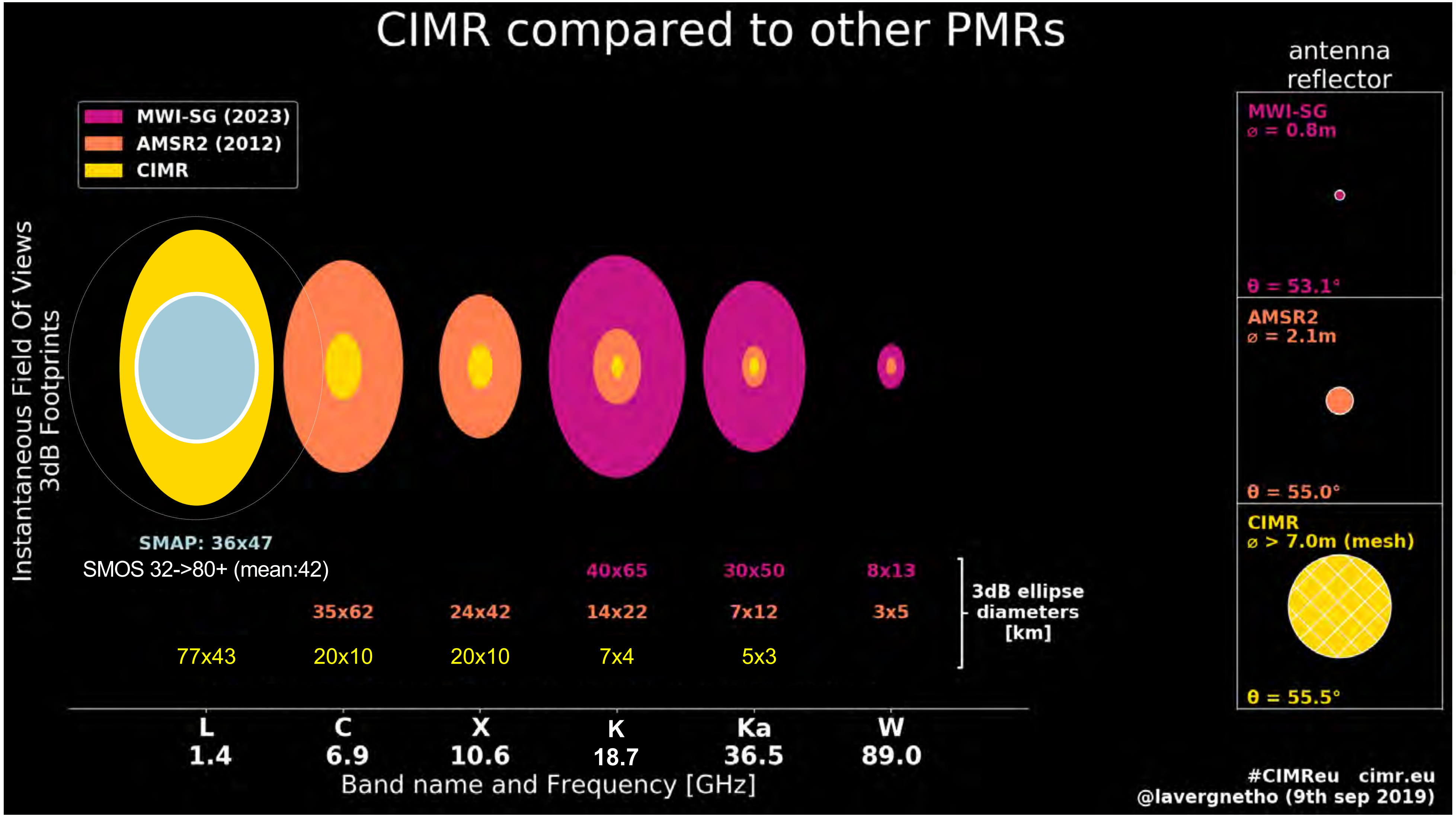
But…C-band has a large footprint…

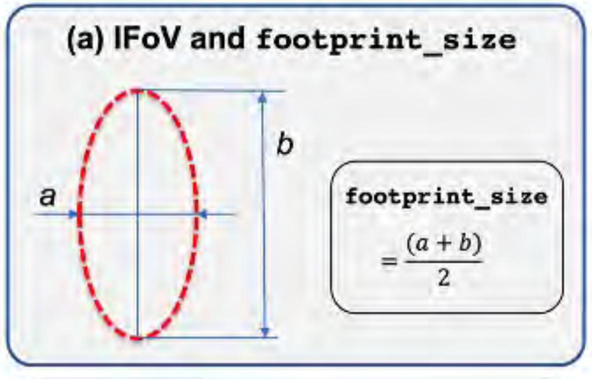
Sea Ice spatial characteristics are complex.





CIMR -3dB projected IFoV and `footprint_size`





`footprint_size`:

L: <60 km

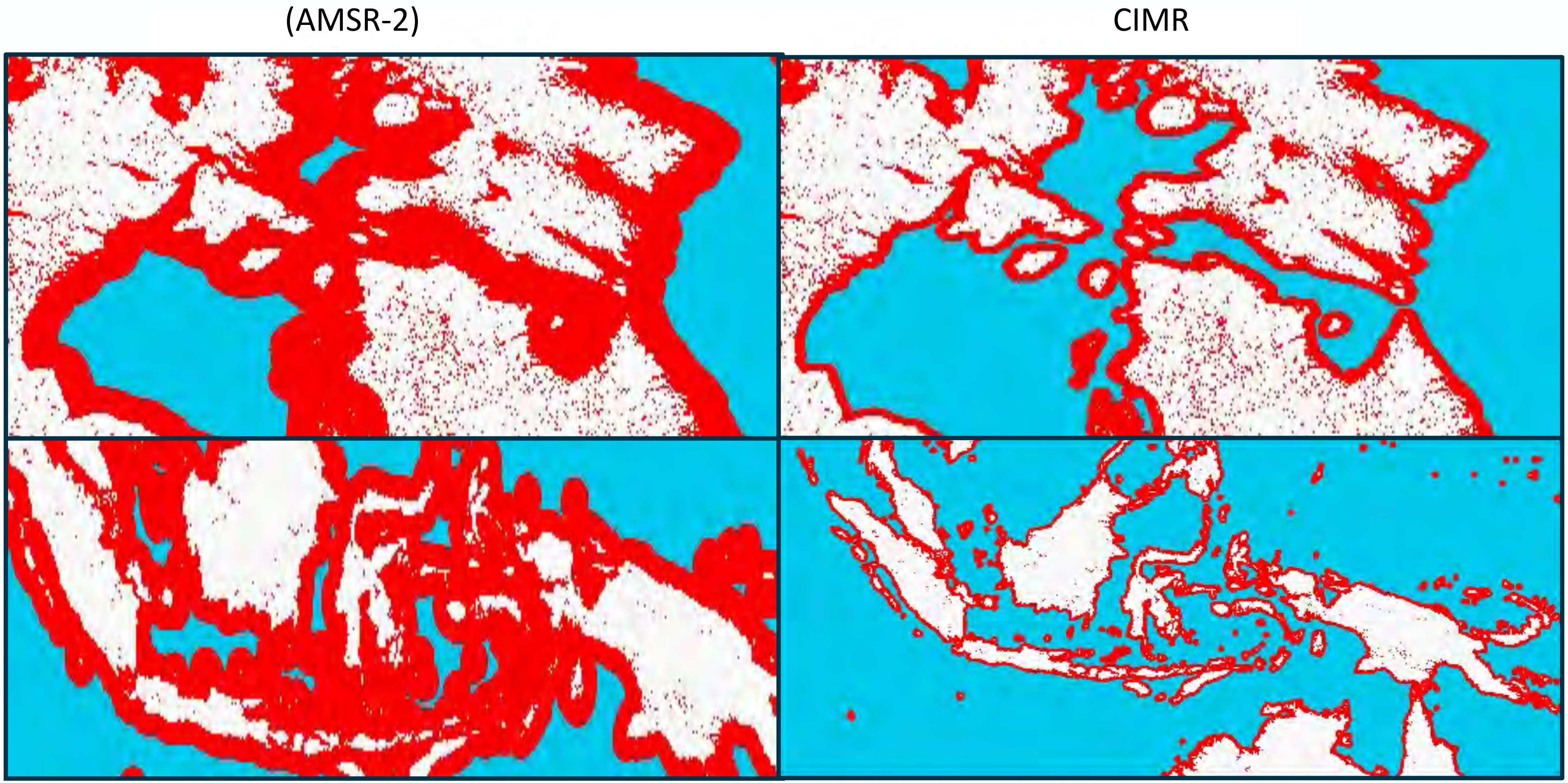
C: ≤15 km

X: ≤15 km

K: ≤ 5.5 km

Ka: ≤5 (g:4) km

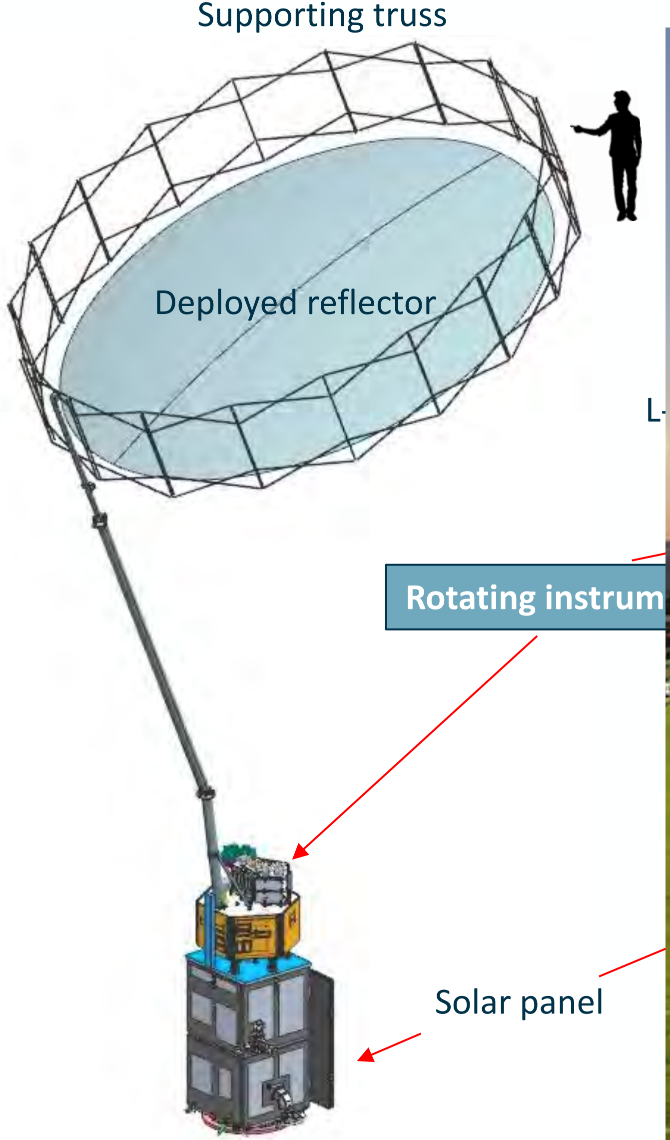
Impact of resolution on coverage



(AMSR-2)

CIMR

The CIMR Payload



Rotating instrument

- 50 receiver channels in total (~11GHz total bandwidth), incuding dual linear polarisation.
- Full Modified Stokes parameters provided.
- Each channel uses **internal calibration**.
  - Hot and Active Cold Load (ACL).
- Detection is done in digital domain.
- All channels have **onboard RFI processor**.
  - **To identify interferen**ce and remove it from the mesurement.
- All the above done in rotating part of the satellite (due to limitation in data transfer through the rotary joint to the fixed part).

Large Deployable Mesh antennas…

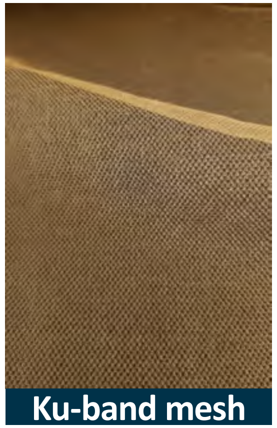
LEA-C5 EM 5m diameter („SCALABLE“, with ESA)

← Double Shifted Panthograph, Scalable from 1m to 20m, Low accommodation height

NASA SMAP 6m diameter test antenna in stowed configuration

photo: chris howell

L-band mesh



Ku-band mesh

Ka-band mesh

← Mesh density increases with frequency

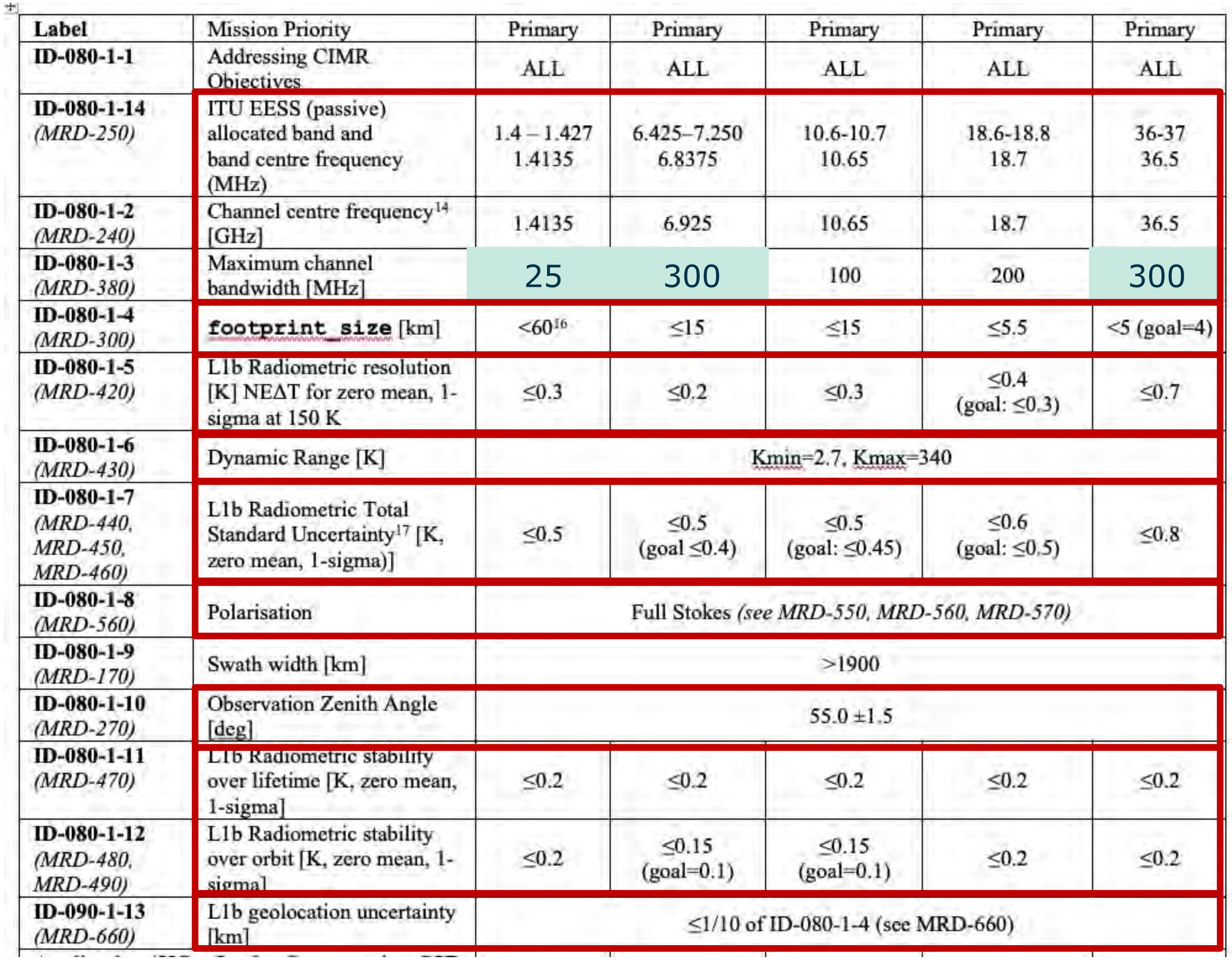
Engineering model of the 8m diameter antenna reflector

↑ *Antenna boom during deployment testing. © HPS GmbH*

← *First automatic motorised deployment test of the European LDR. © LSS GmbH*

https://phi.esa.int/automatic-unfurling-of-european-large-deployable-reflector-successfully-demonstrated/

CIMR Key Radiometric Performances

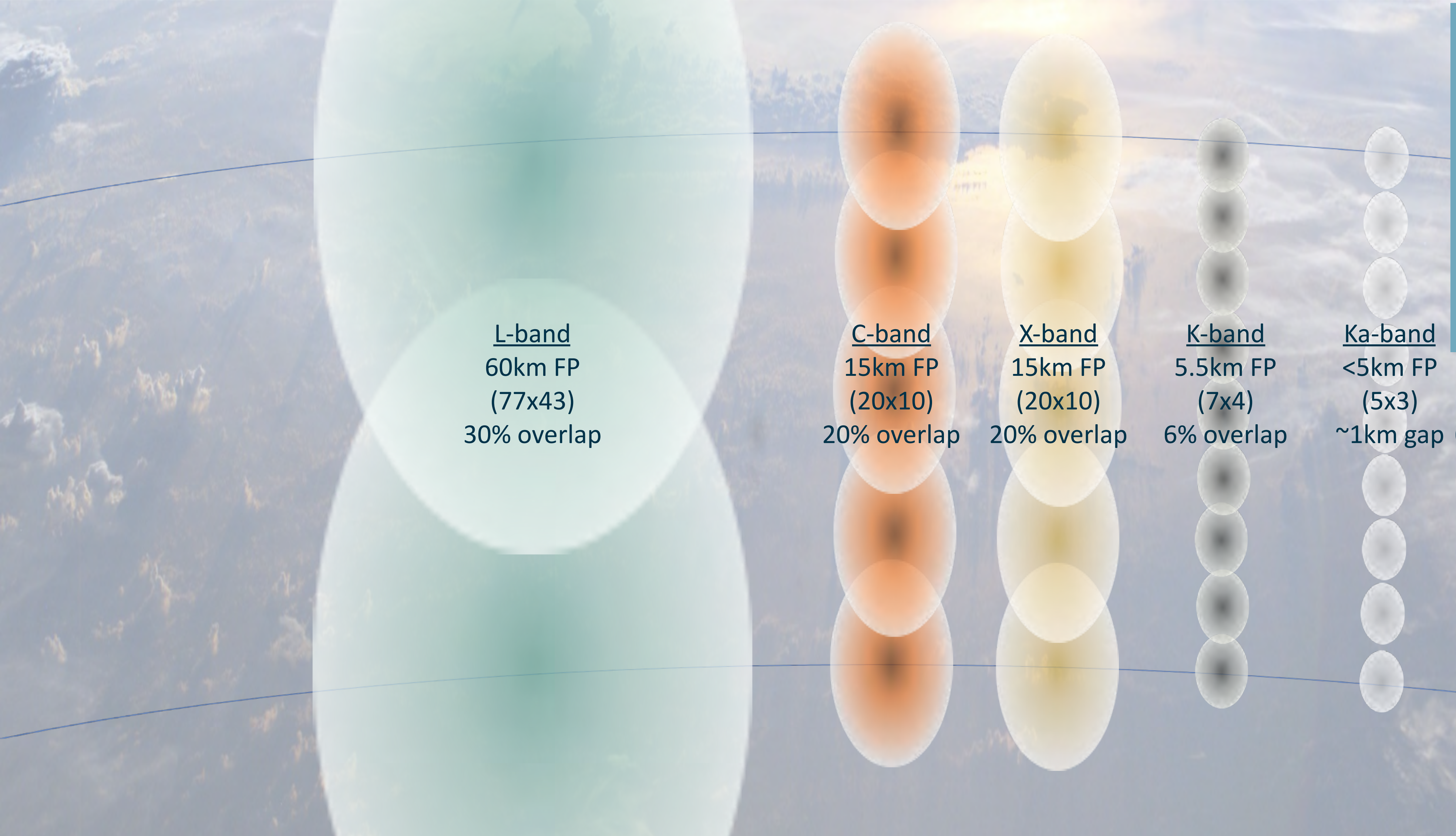


Label	Mission Priority	Primary	Primary	Primary	Primary	Primary
ID-080-1-1	Addressing CIMR Objectives	ALL	ALL	ALL	ALL	ALL
ID-080-1-14 *(MRD-250)*	ITU EESS (passive) allocated band and band centre frequency (MHz)	1.4 – 1.427 1.4135	6.425–7.250 6.8375	10.6-10.7 10.65	18.6-18.8 18.7	36-37 36.5
ID-080-1-2 *(MRD-240)*	Channel centre frequency[14] [GHz]	1.4135	6.925	10.65	18.7	36.5
ID-080-1-3 *(MRD-380)*	Maximum channel bandwidth [MHz]	25	300	100	200	300
ID-080-1-4 *(MRD-300)*	`footprint_size` [km]	<60[16]	≤15	≤15	≤5.5	<5 (goal=4)
ID-080-1-5 *(MRD-420)*	L1b Radiometric resolution [K] NEΔT for zero mean, 1-sigma at 150 K	≤0.3	≤0.2	≤0.3	≤0.4 (goal: ≤0.3)	≤0.7
ID-080-1-6 *(MRD-430)*	Dynamic Range [K]	Kmin=2.7, Kmax=340				
ID-080-1-7 *(MRD-440, MRD-450, MRD-460)*	L1b Radiometric Total Standard Uncertainty[17] [K, zero mean, 1-sigma)]	≤0.5	≤0.5 (goal ≤0.4)	≤0.5 (goal: ≤0.45)	≤0.6 (goal: ≤0.5)	≤0.8
ID-080-1-8 *(MRD-560)*	Polarisation	Full Stokes *(see MRD-550, MRD-560, MRD-570)*				
ID-080-1-9 *(MRD-170)*	Swath width [km]	>1900				
ID-080-1-10 *(MRD-270)*	Observation Zenith Angle [deg]	55.0 ±1.5				
ID-080-1-11 *(MRD-470)*	L1b Radiometric stability over lifetime [K, zero mean, 1-sigma]	≤0.2	≤0.2	≤0.2	≤0.2	≤0.2
ID-080-1-12 *(MRD-480, MRD-490)*	L1b Radiometric stability over orbit [K, zero mean, 1-sigma]	≤0.2	≤0.15 (goal=0.1)	≤0.15 (goal=0.1)	≤0.2	≤0.2
ID-090-1-13 *(MRD-660)*	L1b geolocation uncertainty [km]	≤1/10 of ID-080-1-4 (see MRD-660)				

https://esamultimedia.esa.int/docs/EarthObservation/CIMR-MRD-v4.0-20201006_Issued.pdf

The CIMR instrument remains on track to meet these performances

The CIMR Measurement Principle
Footprint sizes and overlap for all frequencies @ center of swath



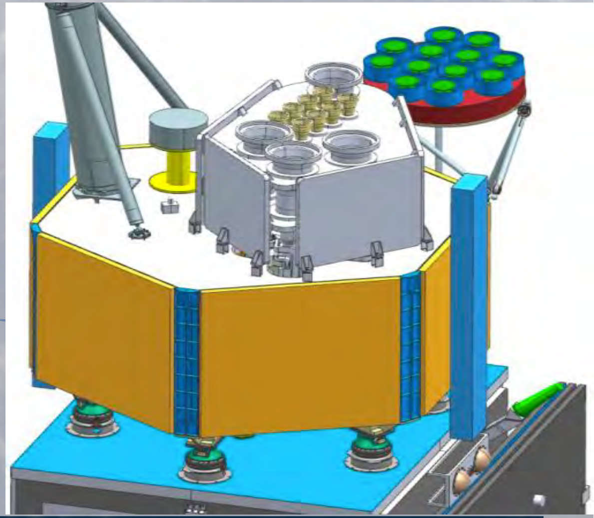
L-band	C-band	X-band	K-band	Ka-band
60km FP	15km FP	15km FP	5.5km FP	<5km FP
(77x43)	(20x10)	(20x10)	(7x4)	(5x3)
30% overlap	20% overlap	20% overlap	6% overlap	~1km gap (center of swath)

Instrument feed configuration:

1 L-band
4 C&X combined multifrequency
8 K&Ka combined multifrequency

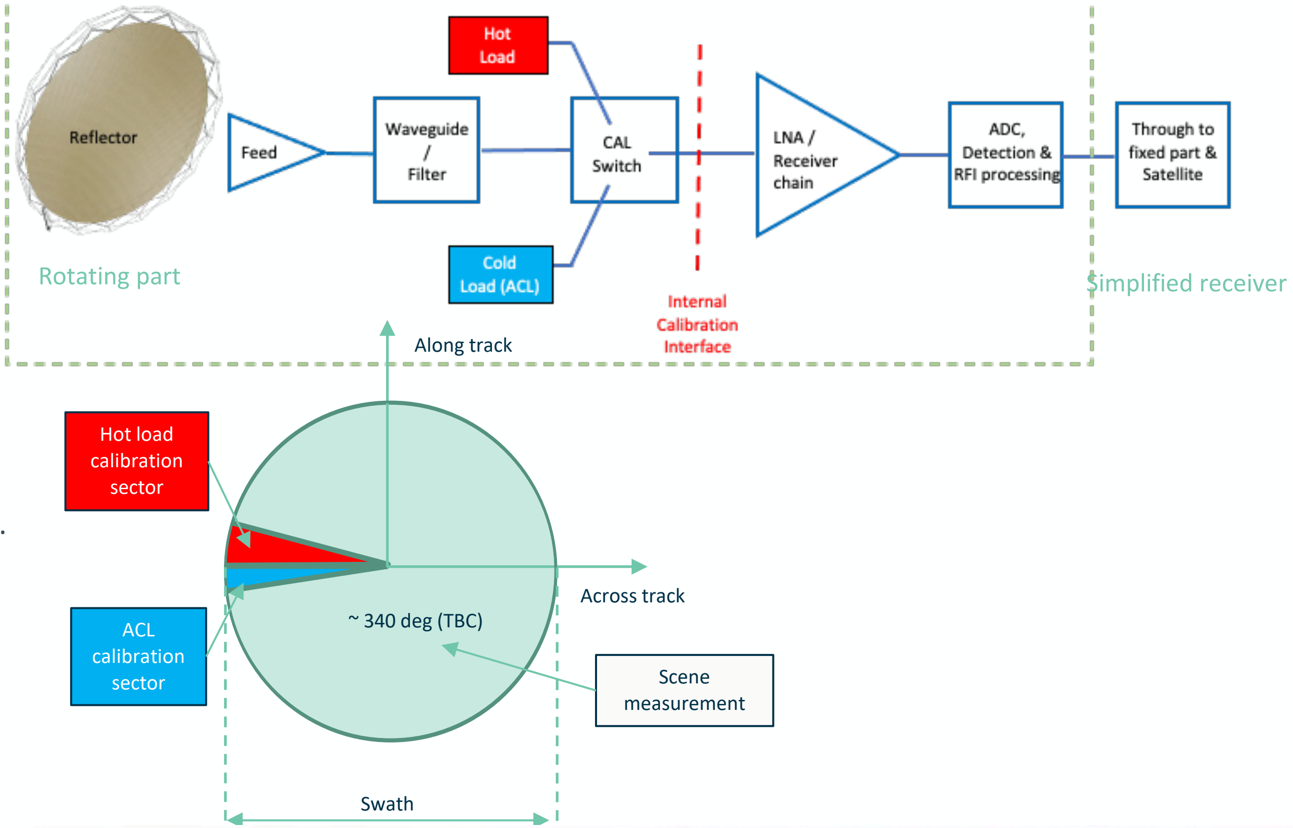
All feed are dual polarised

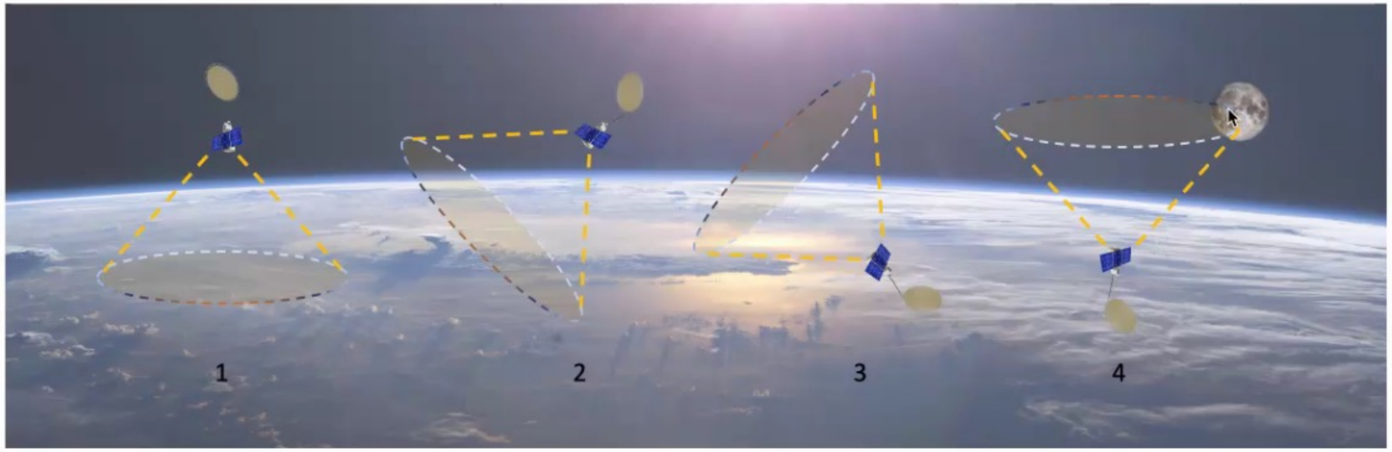
50 receiver channels in total



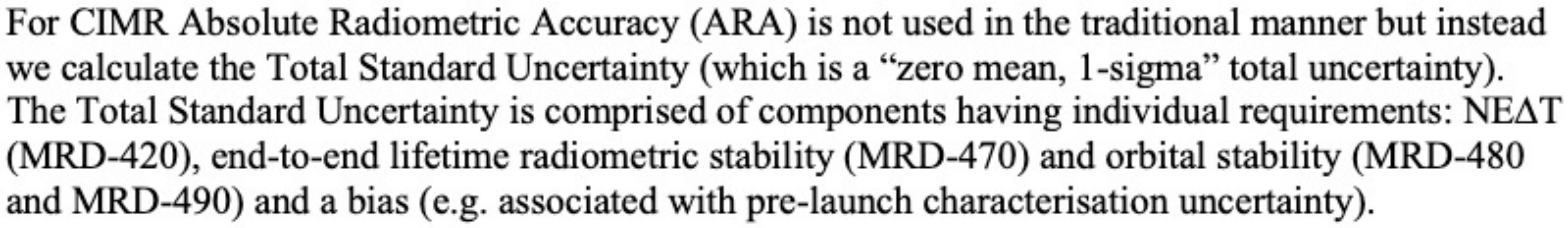
The CIMR calibration approach

- **Each CIMR channel will have a dedicated internal calibration subsystem**
  - 2 Point calibration: Hot load & Active Cold Load.
- Internal calibration is **performed every revolution**.
  - When, how long and how often is configurable.
  - **Complemented by thorough knowledge** on how instrument behaves
    - Extensive on-ground pre-launch characterization of the instrument.
    - On board temperature sensors.
    - Same approach as SMAP.
  - **Maintains radiometric sensitivity and orbital stability performance**.
- **Full end-to-end calibration achieved through maneuvers**
  - Cold sky view, nadir view, vicarious views (e.g open ocean, moon).
  - Performed regularly (Period TBC, depending on stability of internal calibration and receivers).
  - **Maintains lifetime stability** & channel consistency performance.





MRD Standard Total Uncertainty Allocations

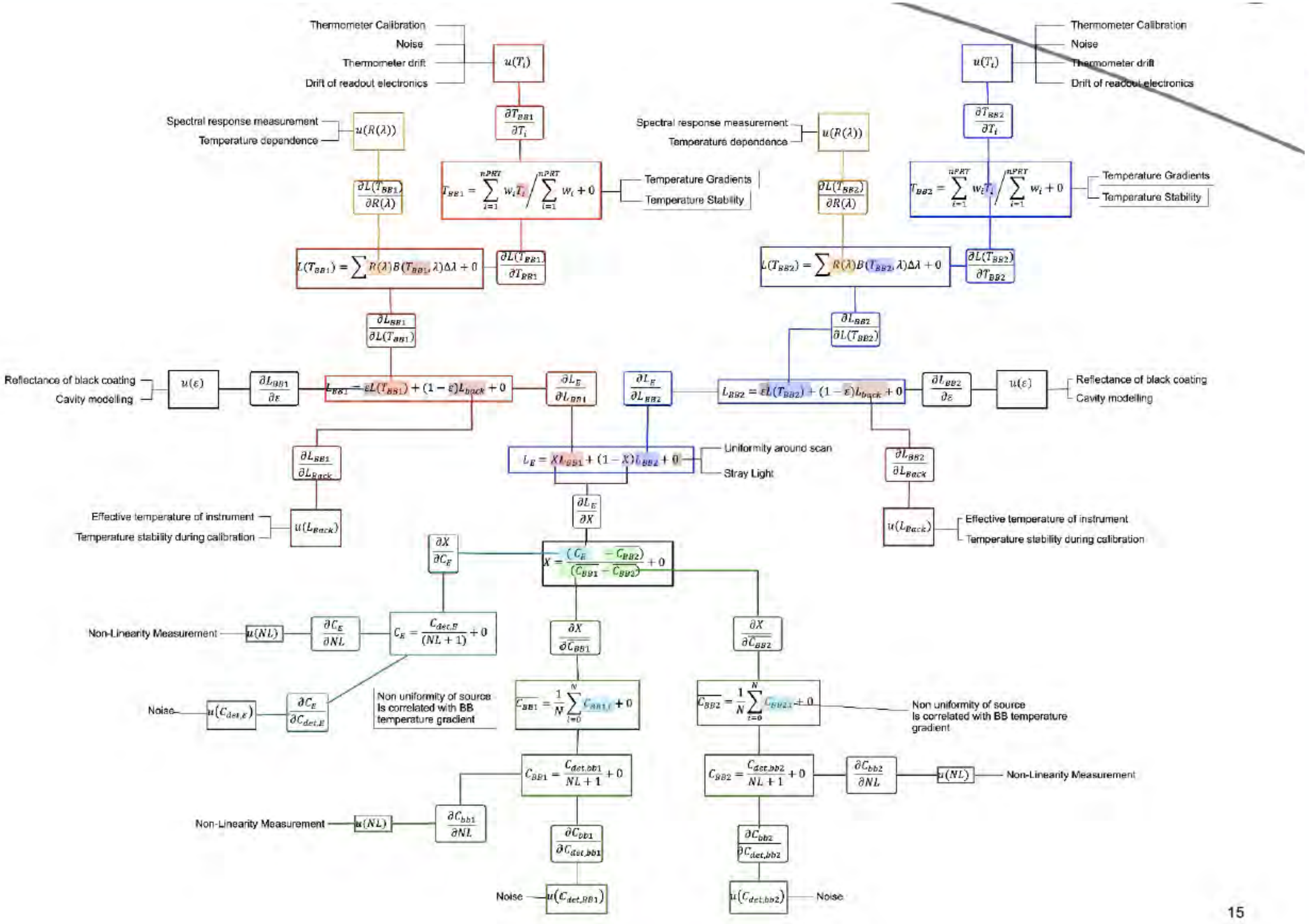


For CIMR Absolute Radiometric Accuracy (ARA) is not used in the traditional manner but instead we calculate the Total Standard Uncertainty (which is a “zero mean, 1-sigma” total uncertainty). The Total Standard Uncertainty is comprised of components having individual requirements: NEΔT (MRD-420), end-to-end lifetime radiometric stability (MRD-470) and orbital stability (MRD-480 and MRD-490) and a bias (e.g. associated with pre-launch characterisation uncertainty).

$$u_{total}^2 \cong u_{NE\Delta T}^2 + u_{orbit-stability}^2 + u_{lifetime-stability}^2 + u_{pl-cal}^2$$

GHz	U_{total} (K)	$u_{NE\Delta T}$ (K)	$u_{orbit-stability}$ (K)	$u_{lifetime-stability}$ (K)	u_{pl-cal} (K)
1.4135	≤0.5	≤0.3	≤0.2	≤0.2	≤0.2
6.9	≤0.5 (g:0.4)	≤0.2	≤0.15 (g:0.1)	≤0.2	≤0.2
10.65	≤0.5 (g:0.45)	≤0.3	≤0.15 (g:0.1)	≤0.2	≤0.2
18.7	≤0.6 (g:0.5)	≤0.4 (g:0.3)	≤0.2	≤0.2	≤0.2
36.5	≤0.8	≤0.7	≤0.2	≤0.2	≤0.2

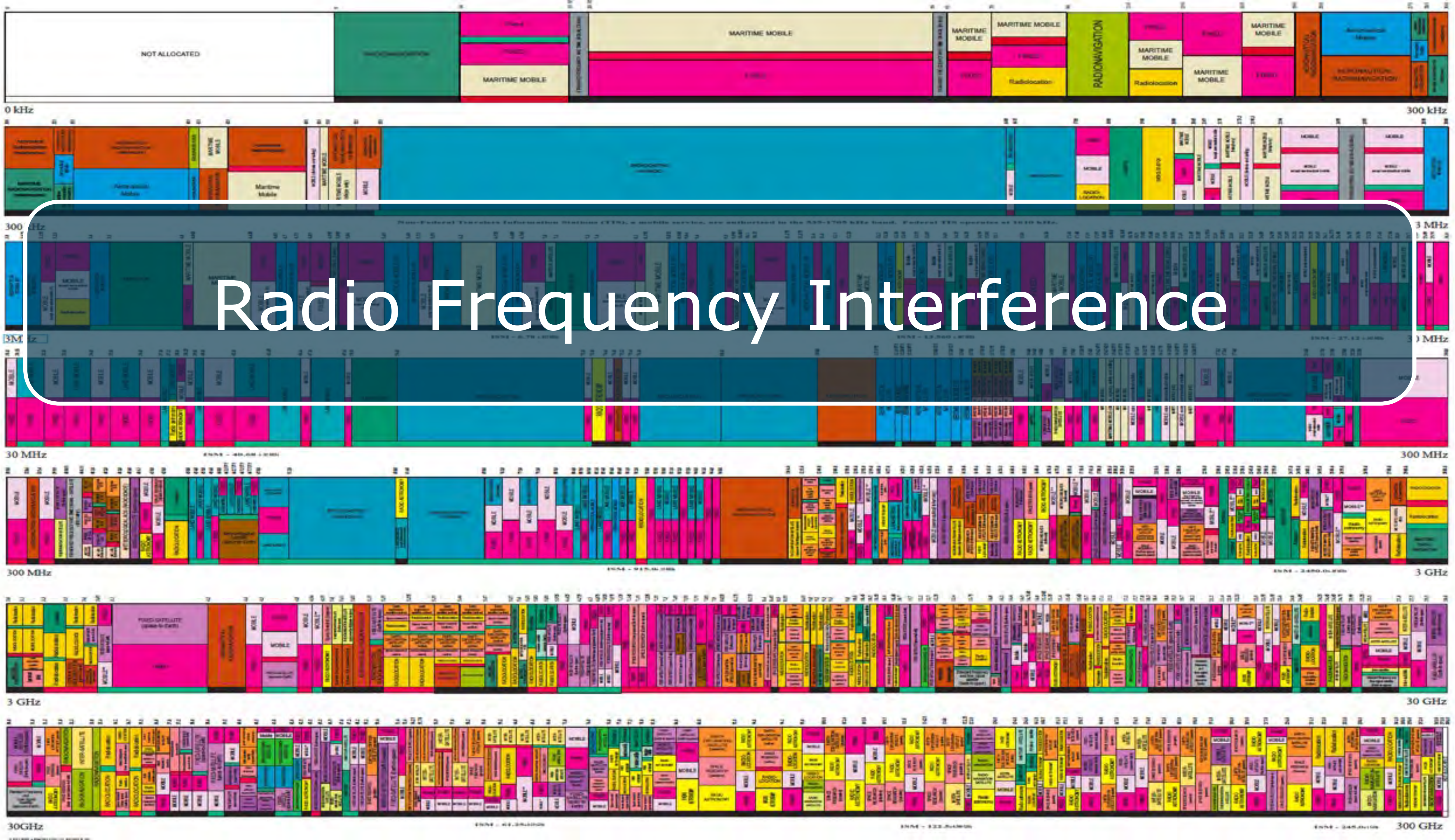
CIMR L1 uncertainty modelling



- Sentinel-3 SLSLTR Advanced approach to Level-1 uncertainty estimation
- Built on first principles
- Part of the FIDUCIO project
- **Same approach to be used by CIMR**

(D. Smith, RAL/STFC)

Radio Frequency Interference



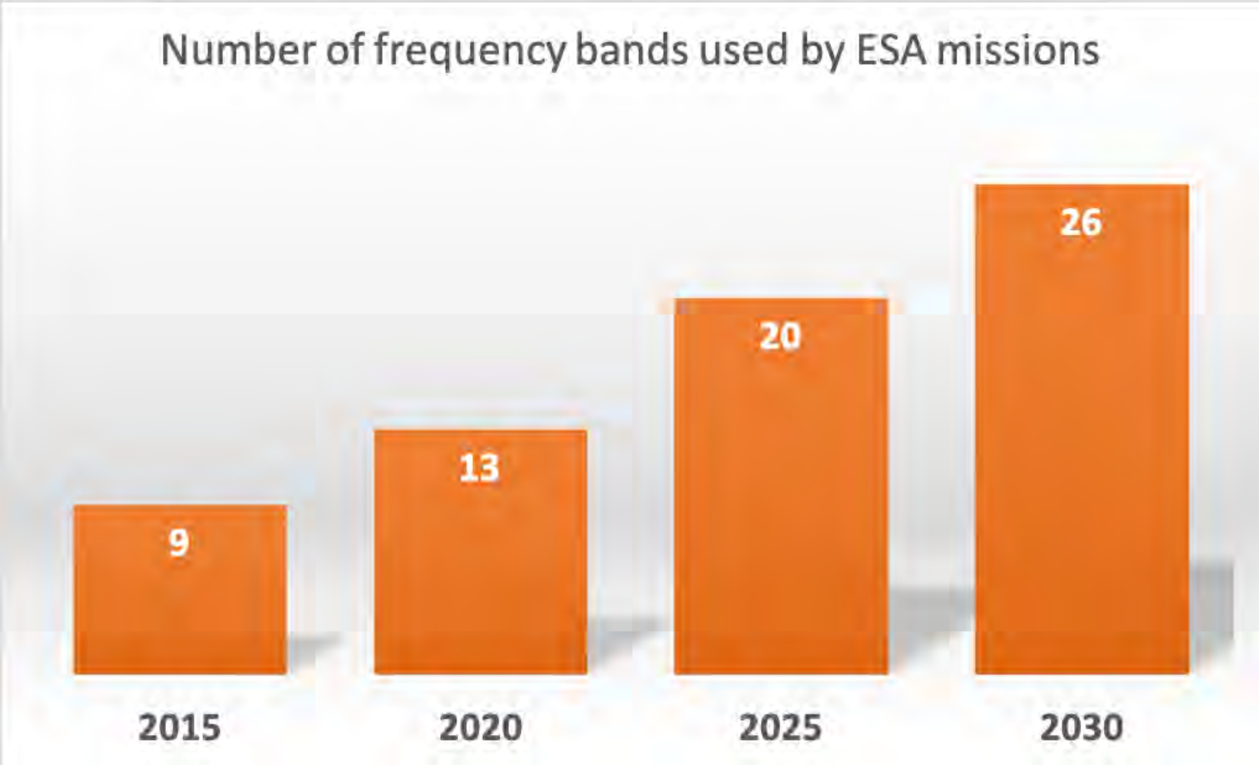
RFI Environment – How CIMR protects itself

- **IF RFI exists, THEN perfomance of CIMR is degraded:**
  - Potential physical damage to the instrument (end of mission…)
  - Data loss (hopeless numbers)
  - Increase in noise (NeDT → poor sensitivity important for SST and Salinity, must be managed well if RFI is mitigated)
  - Incorrect retrieval of geophysical parameters (if undetected and unflagged RFI)

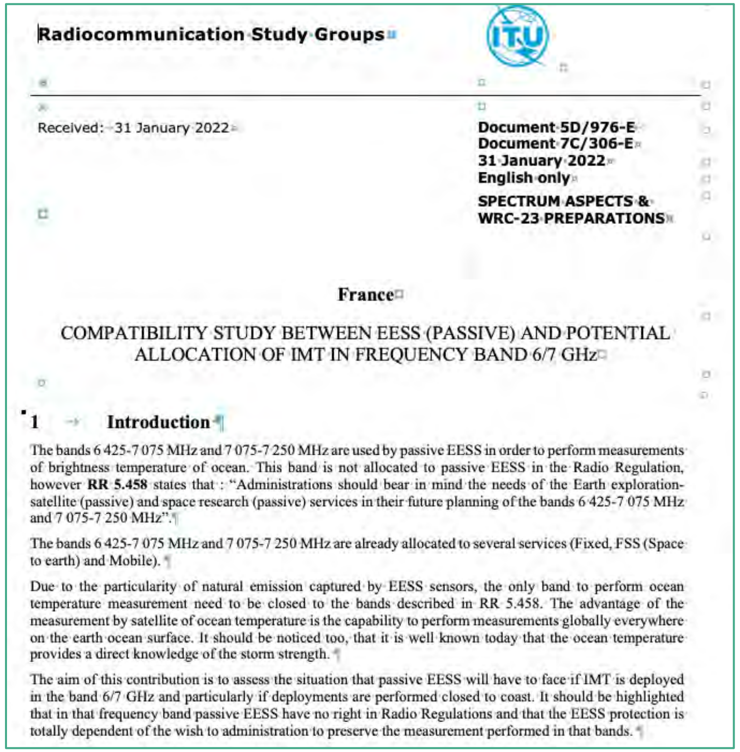
- **CIMR is threatened by 3 key issues:**
  - 1) **Protection from strong RFI** sources (**ground** or **space** sources)
  - 2) **Detection and mitigation of in-band RFI** sources from **ground**
  - 3) **Detection and mitigation of in-band RFI** sources from **space** (other satellites)

- **CIMR is designed to provide products within 3 hours of observation and thus an on-board RFI processor is required to minimise the impact of RFI:**
  - What can we salvage in NRT3H? What can we do on ground (what do we send to ground?)

Increasing use of the spectrum



This implies an **improved ability to observe the Earth system**.



Radiocommunication Study Groups

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Document 7C/306-E
31 January 2022
English only

SPECTRUM ASPECTS &
WRC-23 PREPARATIONS

France

COMPATIBILITY STUDY BETWEEN EESS (PASSIVE) AND POTENTIAL ALLOCATION OF IMT IN FREQUENCY BAND 6/7 GHz

1 Introduction

The bands 6 425-7 075 MHz and 7 075-7 250 MHz are used by passive EESS in order to perform measurements of brightness temperature of ocean. This band is not allocated to passive EESS in the Radio Regulation, however **RR 5.458** states that : “Administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the bands 6 425-7 075 MHz and 7 075-7 250 MHz”.

The bands 6 425-7 075 MHz and 7 075-7 250 MHz are already allocated to several services (Fixed, FSS (Space to earth) and Mobile).

Due to the particularity of natural emission captured by EESS sensors, the only band to perform ocean temperature measurement need to be closed to the bands described in RR 5.458. The advantage of the measurement by satellite of ocean temperature is the capability to perform measurements globally everywhere on the earth ocean surface. It should be noticed too, that it is well known today that the ocean temperature provides a direct knowledge of the storm strength.

The aim of this contribution is to assess the situation that passive EESS will have to face if IMT is deployed in the band 6/7 GHz and particularly if deployments are performed closed to coast. It should be highlighted that in that frequency band passive EESS have no right in Radio Regulations and that the EESS protection is totally dependent of the wish to administration to preserve the measurement performed in that bands.

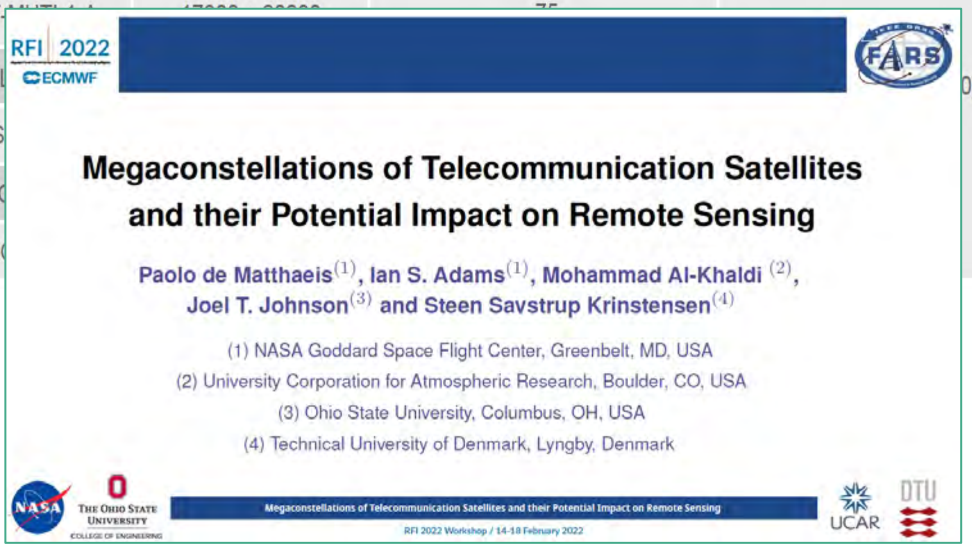
Because EO sensors operate outside allocations, it is **difficult to argue for their protection** in frequency management fora, and they **cannot claim protection** from the RFI they experience.

But it also implies **more RFI issues** and more involvement in frequency regulatory matters.

RFI environment: Satellite behind CIMR …

Space to Ground transmission through the CIMR reflector

RFI name	Operative frequency [MHz]	Power Level at RCA Input [dBm]	CIMR Impacted Band [MHz]
# LEO C	6875 ÷ 7075	-128	C [6775 - 7075]
# LEO D	6875 ÷ 7055	-115	
# LEO F	6875 ÷ 7075	-117	
# GSO C	10700 ÷ 10950	-167	X [10600 - 10700]
# GSO-VX	10700 ÷ 10950	-125	
# GSO F	18550 ÷ 18800	-105	0]
# BUSINESS VSAT	18550 ÷ 20200	-102	
# FSAT-			
# FI			
# GS			
# GS			
# LE			



RFI 2022
ECMWF

Megaconstellations of Telecommunication Satellites and their Potential Impact on Remote Sensing

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Megaconstellations of Telecommunication Satellites and their Potential Impact on Remote Sensing
RFI 2022 Workshop / 14-18 February 2022

Transparent mesh at High frequencies so we receive RFI from behind the reflector from other satellites

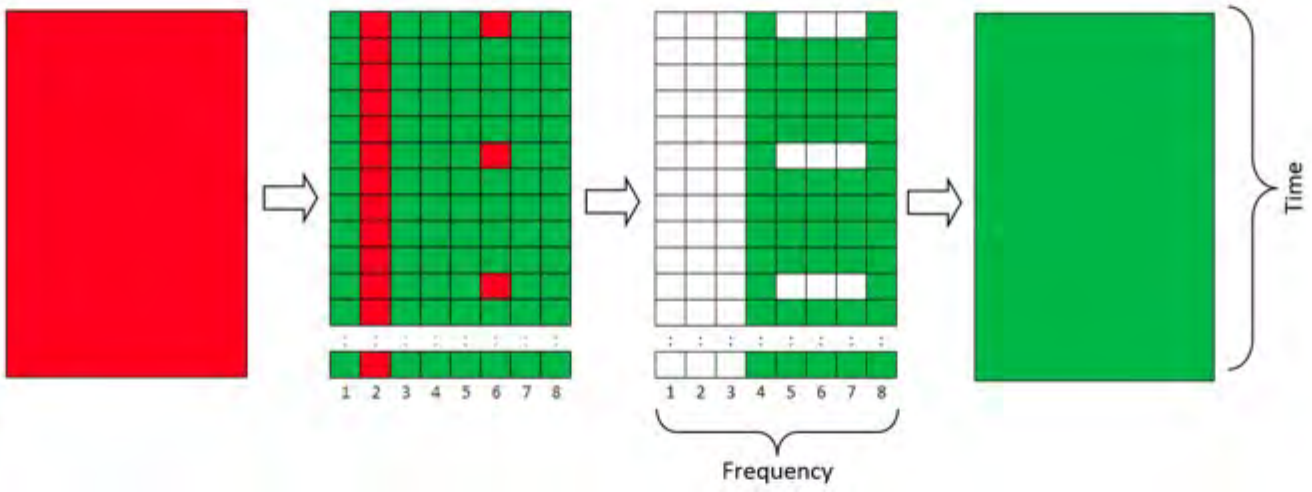
List shows list of satellites that are important

All RFI well attenuated – below the levels from ground – but still to be considered

CIMR on-board RFI mitigation approach

- For in-band interferers, **each CIMR channel will have dedicated RFI detection and mitigation processors with range of algorithms,** e.g. anomalous amplitude, kurtosis, glitch, polarimetry and cross-frequency.

- **CIMR architecture designed to accommodate tuning of algorithms and more/new algorithms with ease.**
  - Sub-banding to allow identification and removal of RFI and reconstruction of a useful measurement: **Increase in data rate**
  - Note: When RFI is mitigated by removing a sub-band **NeDT increases.**
  - Additional tests using **Kurtosis requires computation of Full Stokes**




Real-Time RFI Processor for the Next Generation Satellite Radiometers

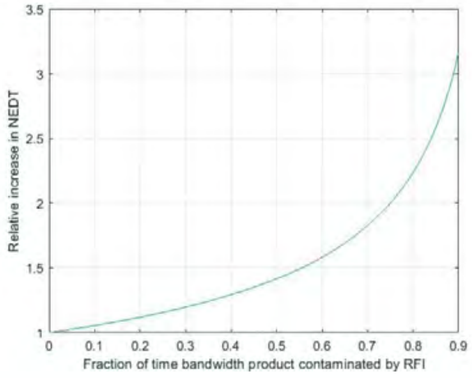
Publisher: IEEE

7 Author(s) Janne Lahtinen ; Arhippa Kovanen ; Kari Lehtinen ; Steen Savstrup Kristensen ; Sten Schmidl


Developments of RFI Detection Algorithms and Their Application to Future European Spaceborne Systems

Publisher: IEEE

Steen S. Kristensen ; Niels Skou ; Sten S. Søbjærg ; Jan E. Balling **All Authors**



- When RFI is detected the intent is to **send as much information to ground as feasible** (limit is the throughput of our rotating between the instrument and spacecraft and X-band downlink).

CIMR: 3 on-board RFI NRT detection and mitigation modes

- **Normal mode:** Operation Mode: RFI detection and mitigation on-board using DTU approach (next talk).
  - Output: **Native original data and RFI mitigated data sent to ground + number of removed time-frequency matrix cells** as an indicator of # sub-bands removed
  - But don't know which ones have been mitigated so we have challenges to reconstruct NeDT if there are frequency related issues
- **Diagnostic mode**: initiated by T/C (configurable for 1 feed horn of one frequency both H&V):
  - **Continuously** send_full_RFI_time_frequency_matrix_to_ground
  - Limited data take at this time…
- **On-Event Mode (OEM):** initiated by T/C (configurable for 1 feed horn of one frequency, both H&V):
  - IF (RFI) THEN **send_full_RFI_time_frequency_matrix_to_ground**

Final configuration and data type/flags/quantities (TBC) all being studied now in Phase B2.

CIMR Band	L	C	X	K	Ka
Accumulation Time [ms]	0,545	0,7	0,685	0,504	0,736
Rate [Hz]	1835	1429	1460	1984	1359
#Sub-Bands	18	215	72	143	215
#Time Bin	20	4	4	2	1
#Feed	1	4	4	8	8
#Parameters	6	6	6	6	6
Feed Id [bits]	8	8	8	8	8
Parameters Data Size [bits]	16	16	16	16	16
T-F bin Id [bits]	16		16	16	16
Spare [bits]	16	16	16	16	16
Single Feed Data Rate [Mbps]	3,96	36,87	12,61	34,06	35,06
Band Data Rate [Mbps]	3,96	147,47	50,46	272,50	280,50
Total Data Rate [Mbps]	754,89				

Data rate is obtained from Time-Frequency Matrix division:
Accumulation time: time length of a time bin
#Sub-bands: number of sub-bands of in a Band
Transferred data also includes Kurtosis parameter (KH, KV)

Current status – the path to reality

Thales Alenia Italy Italy signed contract to Prime CIMR mission Phase B2/C/D development (13/11/2020)

Preliminary Design Review (2022)

Mission Requirements Document available at https://esamultimedia.esa.int/docs/EarthObservation/CIMR-MRD-v4.0-20201006_Issued.pdf

Launch of CIMR-A in 2028+ (CIMR-B few years later)

RFI remains a major challenge for CIMR

We are addressing RFI issues as a core design element

Thank you
Any Questions?

Craig.Donlon@esa.int

RFI: ITU issues and approach

- **L-band:** Important to have a very well defined channel selectivity (bandpass and receiver) centered in the Earth Exploration Satellite Service(EESS) passive band 1400-1427 MHz (SMOS/SMAP experience show RFI from strong radars in adjacent bands).
- **C-band:** ***EESS(passive) is weak and we cannot claim protection (5G issues coming?)***. AMSR-xx shows significant RFI
- **X-band:** heavily used by the GEO/NGEO Fixed Satellite Service (FSS) on a primary basis and European video links (***5G issues coming?)***
- **K-band:** sharing regulatory constraints of EESS(passive) and the FSS downlinks. FSS (s-E) has allocation in the range 17.3 to 21.2 GHz, allocation to EESS(passive) falls in the middle.
- **Ka-band:** Powerful RADARS (e.g. KREMS) operating in the lower adjacent band. can blind, even damage, the receiver. The FSS(downlinks) operate above 37.5 GHz and are target for development of future LEO mega-constellations.
- **Solutions:**
  1. **Protect from damaging RFI**
  2. **Detect and mitigate using on-board processors in NRT3 Hours (Channel selectivity is important)**
  3. **Reprocess using on-ground data tools and techniques**

CIMR: RFI issues

- RFI is present in all CIMR frequency bands (as for most microwave radiometer instruments)
- **RFI issues are expected to increase**, as the use of the spectrum increases

- **In the design phase, it is important to take RFI into account to:**
  - Ensure **survivability** of the instrument;
  - Ensure high **rejection** levels outside the allocated band;
  - Develop RFI **detection** strategy;
  - Develop RFI **mitigation** approaches;
  - Develop RFI **monitoring** approach (evidence for ITU and spectrum pollution management)
  - In Phase E2 operations, it is important to implement **ground based RFI mitigation and monitoring techniques based on the CIMR data** → esach sensor 'sees' RFI in its own way
- RFI in some frequency bands can be reported to the ITU (e.g. in the bands where all emissions are prohibited by article 5.340 of the Radio Regulations). <u>This has decreased RFI in L-band!</u>
- Possible to **coordinate with other space agencies to report RFI**: now RFI in L-band are reported by SMOS and SMAP around the same time.

Cobra Dane radar…

https://en.wikipedia.org/wiki/Cobra_Dane#/media/File:Cobradane.jpg

RFI environment: Earth to CIMR …

RFI Name	CIMR Band	Frequency Range [MHz]	Frequency Distance [MHz]	Power Level at RCA Input [dBm]
SMOS RFI	L	-	In Band	-63,92
Radar A	L	1175 ÷ 1400	1	31,63
Radar A	L	-	In Band	22,7
ASR 4	L	1215 ÷ 1400	1	-6,78
FSS GES	C	5725 ÷ 7075	In Band	-64,2
Military Uplink (L)	C	5850 ÷ 6450	325	-24,02
Radar L	C	5350 ÷ 5850	925	1,23
Deep Space Station	C	7145 ÷ 7190	70	31,25
SBX	X	9000 ÷ 10000	600	26,61
Unknown (X)	X	9200 ÷ 10400	200	39,85
Haystack	X	9300 ÷10300	300	26,53
FSS GES	X	10700 ÷ 11700	0	-47,35
FSS GES	Ku	-	In Band	-100,31
BSS GES	Ku	17700 ÷ 18400	200	-63,53
Unknown (Ku)	Ku	17200 ÷ 17300	1300	20,67
FGAN	Ku	15900 ÷ 17500	1100	-5,43
KREMS	Ka	34000 ÷ 36000	350	25,3

- RADAR-A (Cobra Dane) **should be filtered**. This radar type may operate up to 1400MHz (edge of CIMR L-band channel), and even inside the CIMR band outside of Europe
- For the L-band channel, the operational characteristics of Radar A means that a **limiter diode** needs to be inserted in the receiver chain prior to the first amplification chain

- For C, X, K and Ka band, **filters will be employed to protect the receiver channels** from strong out of band RFI sources
- Note, C-band is TBD. A **limiter diode may be used intead/in combination with filters** in order to optimise mass/losses prior to the first ampification stage in order to optimise sensitivity of the receiver chain.
- **But…Filters add mass – and loss** so we may consider limiters as a mass saving solution (TBD)

- KREMS should be **filtered** as we have some separation

At the Receiver we can withstand ˜13 dBm for L- and C-band