The future Copernicus SAR mission constellation ROSE-L and Sentinel-1 NG

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Copernicus SAR Context

CURRENT GENERATION SENTINELS

Sentinel-1 A + B C-Band Radar	**Sentinel-1 C + D** C-Band Radar
Sentinel-2 A + B High Res Optical	**Sentinel-2 C + D** High Res Optical
Sentinel-3 A + B MR Optical + Altimeter	**Sentinel-3 C + D** MR Optical + Altimeter
Sentinel-4 A Atm. Chemistry (GEO)	**Sentinel-4 B** Atm. Chemistry (GEO)
Sentinel-5P Atm. Chemistry (LEO)	**Sentinel-5 A** Atm. Chemistry (LEO)
Sentinel-6 A Altimeter	**Sentinel-6 B** Altimeter

NEXT GENERATION SENTINELS

Sentinel-1 NG
C-Band Radar

Sentinel-2 NG
High Res Optical

Sentinel-3 NG
MR Optical + Altimeter

COPERNICUS EXPANSION MISSIONS

ROSE-L
L-Band Radar for Arctic and Crysphere Monitoring, Land and Emergency Mapping, Ground Motion, Soil Moisture

CO2M
Carbon Dioxide Monitoring

CRISTAL
Polar Ice & Snow Topography Altim.

CHIME
Hyperspectral Imaging

LSTM
Land Surface Temperature

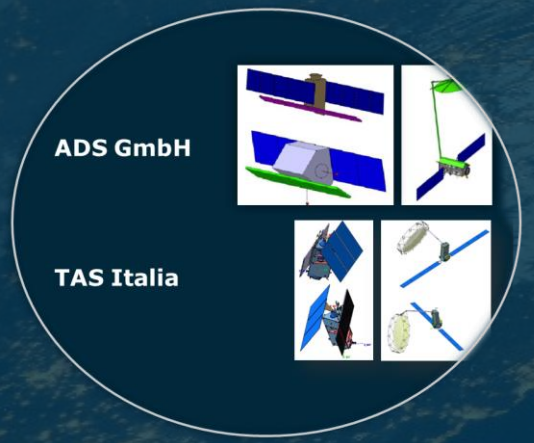
CIMR
Imaging Microwave Radiometer

Copernicus Timeline – Current and Future SAR Missions

Copernicus Expansion missions

- **Provides new information not yet available (Gaps)**
- Provides enhanced information in combination with current Sentinel missions (**Enhanced continuity**)

Sentinel-1 NG Objectives and Driving Requirements



OBJECTIVES

- *Ensure continuity* and expansion of services and applications relying on Sentinel-1
- *Enhance* existing services and applications
- *Enable* new application developments building on improved performance and observation gaps (e.g. resolution, revisit and others)

MISSION AND SYSTEM REQUIREMENTS

- Performance shall be equal or better than Sentinel-1 FG
- Revisit: 3 days Global, 0.5 days Arctic and sea ice
- Resolution ≤ 25 m^2
- NESZ ≤ -26 dB
- Full continuity in Dual-Pol and Quad-Pol capability
- Use of a dedicated Mission Mode to cover the North Pole region
- **Same orbit of S1FG / ROSE-L in constellation of two satellites**

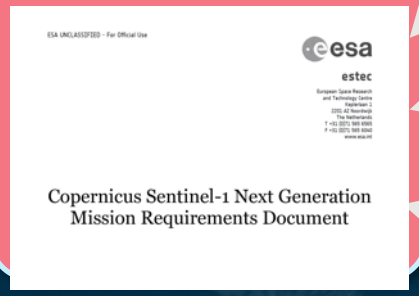
Sentinel-1NG and Copernicus Services

User Needs

- EC
- Polar Expert Group
- REDD+
- UNFCCC
- ….

Sentinel-1 NG

Mission Requirements Document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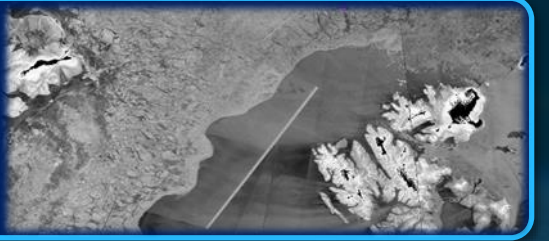
Copernicus Sentinel-1 Next Generation
Mission Requirements Document

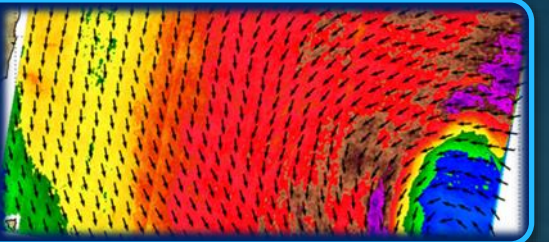
C3S

- Sea ice type, concentration and motion
- Ice sheets & glaciers velocity, Grounding line
- Ground movement
- Ice sheets margins and glacier surface height
- Ice sheet melt/freeze extent



CMEMS

- Sea ice type, concentration and motion
- Iceberg location, size and drift
- Ocean surface currents
- Ocean surface wind vectors
- Swell properties



CLMS

- Land use and land use change, including agriculture and forestry
- Ice sheets & glaciers velocity
- Wet snow extent
- Ground movement
- Soil moisture

EU-GMS

European Ground Motion Service

EMS

- Flooded area
- Ground movement
- Soil moisture
- Abrupt surface elevation changes

Security

EMSA

FRONTEX

- Iceberg location, size and drift
- Vessel location, size and velocity
- Oil spill location and morphology

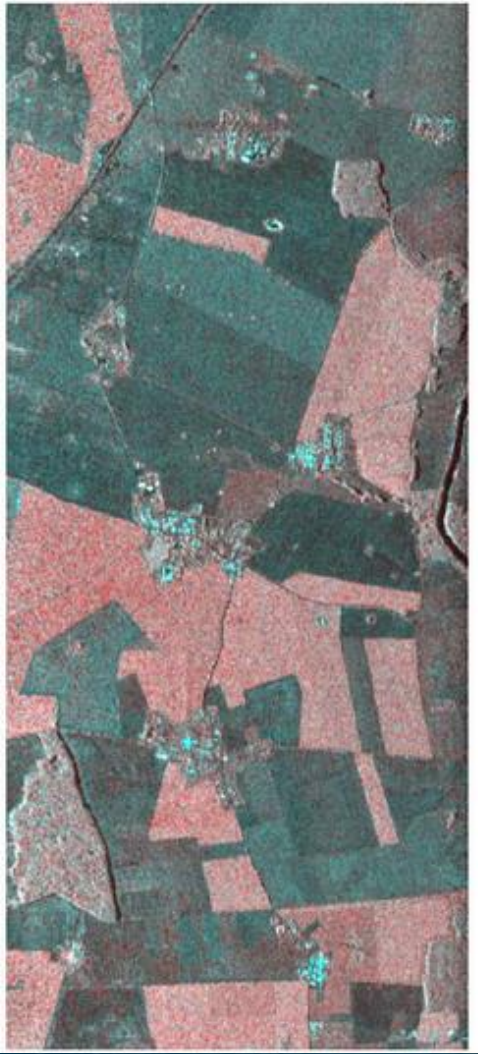
Sentinel-1 NG Requirements

Performance Requirements	Sentinel-1 NG	Sentinel-1
Latitude coverage	**-80 to +90 deg**	North-pole gap
Revisit	Goal: **3 days** Global Goal: **0.5 days** Arctic and Sea Ice	Up to 12 days
Latency	**10 min** European Waters **120 min** Global	10 min RT, 1 h NRT emergency, > 3 h Global
Repeat pass InSAR	**6 / 12 days** (S1 & ROSE-L orbit)	6 / 12 days
Incidence angle access	**Better than 20 – 45 deg**	20 – 45 deg
Swath width	**Larger than 400 km**	250 IW – 400 EW
Resolution	**25 m²**	~100m2 IW - ~800m2 EW
NESZ	**-26 dB**	-22 dB
Polarization capability	**SP, DP and QP**	SP and DP
Duty cycle	**43% (˜43 min/orbit) with 53min any orbit**	25min/orbit

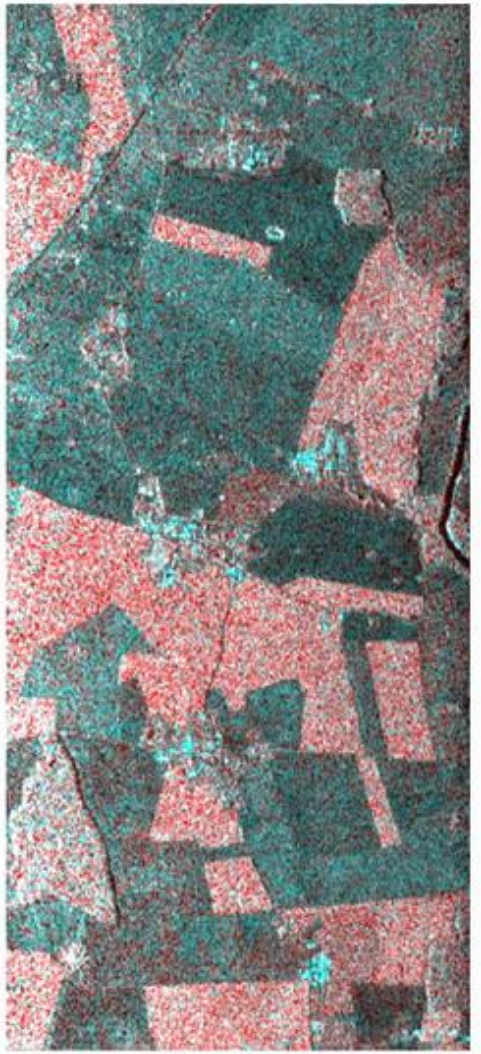
Other Mission Requirements
Enhanced operations through the **potential integration of additional satellites**
Automatic Identification System (AIS) payload to augment maritime services
Over open oceans the mission shall support the generation of **wave mode products**

S1NG – benefits of higher resolution

E-SAR standard (8 looks)



S1NG 5m resolution



S1 IWS (4 looks)

Lower NESZ (-26 dB)

will further enhance mapping and characterization of weak scatterers (benefits in soil moisture, oil spills, sea ice mapping, etc…)

E-SAR data for ESA AgriSAR campaign with Sentinel-1 simulation in stripmap and IWS mode. Color coding is RGB: HV-HH-HH. Stripmap resolution is the same as S1-NG, although with higher NESZ (DLR)

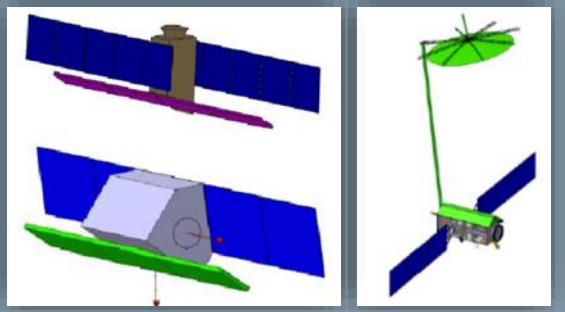
Sentinel-1NG Programme Aspects

- Phase 0 (Mission Identification) carried out in 2019-2020
- Phase A/B1 in two years 2021-2023 – two parallel studies with European industry
  - PRR carried out in February/March 2022 for both consortia
  - ISRR concluded in Q2 2023 for both consortia
- ITT for Development Phase (Phase B2/C/D/E1) to be issued by November 2023
- Expected launch > 2032

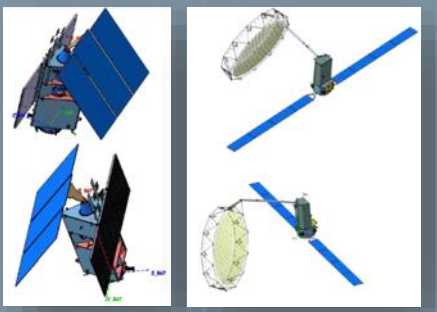
Phase A Candidate Concepts

Two contracts kicked-off in May 2021

ADS GmbH



TAS Italia

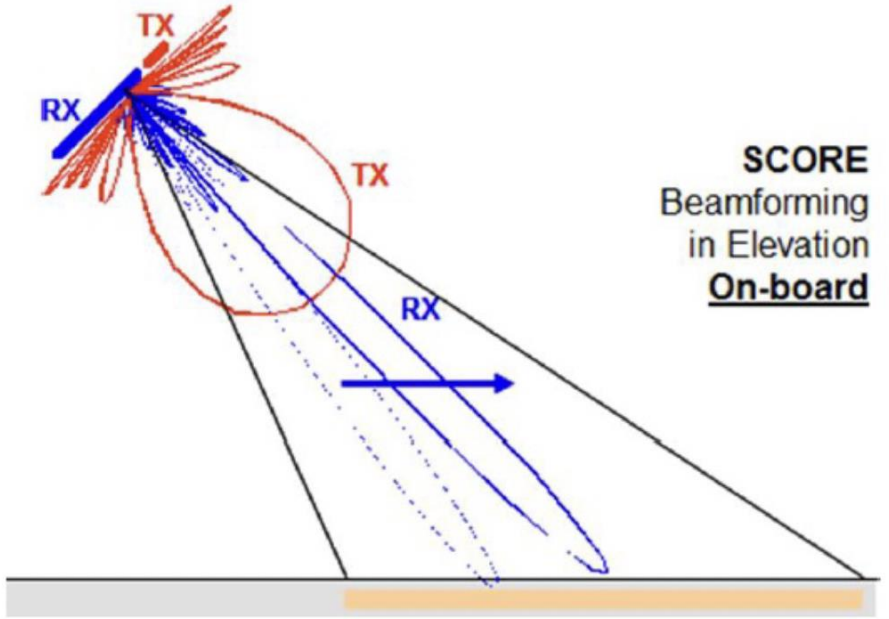


- Constraints:
  - Launcher (VEGA-C)
  - Technology readiness
- Concepts with both **Planar Array Antennas** and **Reflector Antennas** were studied
  - Planar array antennas were selected by both consortia at the end of Phase A (PRR)
- The instrument is based on SCORE (DBF in elevation) and MAPS (DBF on-ground in azimuth)
- Both ScanSAR and Stripmap modes are proposed
- AIS instrument providing continuity with the S1C & S1D payloads

Sentinel-1NG use of SCORE and MAPS

Scan on Receive in Elevation (SCORE)

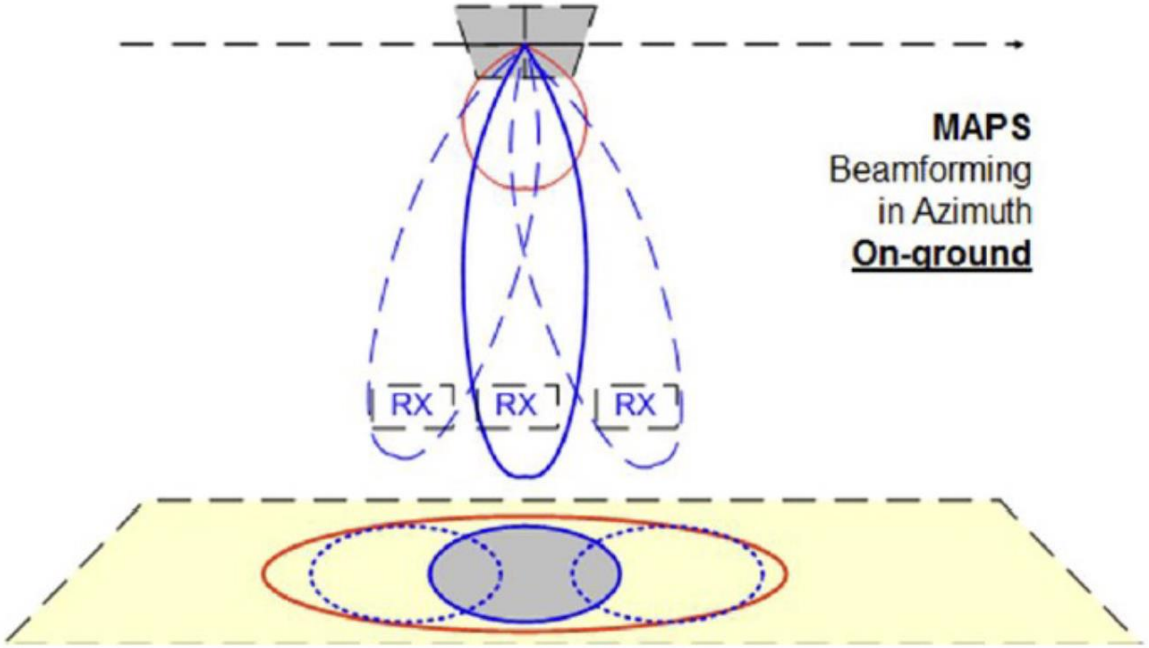
SCORE combines the signals of the various elevation channels in a way that the direction of maximum receive gain follows the reflection of the radar pulse on the ground.



- Wide swaths (wide angular range) up to SM with 229 km
- Good RgDTAR suppression performance for polar incidence angles of 59° (dual pol) and for >45° (quad pol) mode,

Multiple Apertures in Azimuth (MAPS)

The phased array acquires multiple directions simultaneously. On-ground processing allows to shape and steer the virtual antenna beams individually.



- Large instantaneous Doppler bandwidth with moderate scalloping for ScanSAR modes IW and EW
- Low PRF operation with good AzDTAR performance for wide SM-DP and SM-QP

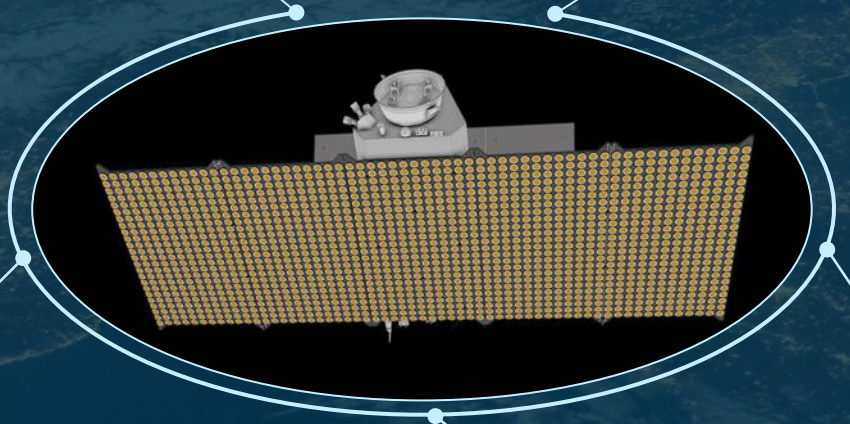
ROSE-L Mission in Brief

GENERAL

- Constellation of 2 satellites (PFM & FM2) + options under study
- Consortium led by Thales Alenia Space Italy (TAS-I), involving 29 companies from 15 countries
- Service continuity with Sentinel-1 FG and NG

IMAGING

- L-Band – 85 MHz ITU allocated band (1.215-1.300 GHz)
- Dual-Pol and Quad-Pol modes
- Wave mode capability
- Resolution < 50 m2 (RIWS mode)
- NESZ < -28 dB
- DTAR < -23 dB
- Swath width > 250 km



COVERAGE

- Coverage of Global Land (excl. Antarctica) and Arctic
- Revisit with 2 satellites :
  - 6 days Global Land
  - 3 days Europe
  - 1 day Arctic
- Repeat cycle of 6 days over Global Land (2 satellites)

PROGRAMMATICS

- Currently at the beginning of Phase C
- Science Plan activities start in 2023
- Launch of PFM expected in 2028
- FM2 delivery expected in 2030

SYSTEM

- Synergic acquisitions with Sentinel-1: co-located swaths and support to convoy configuration
- Low latency
  - 10 min Europe coastal waters
  - 200 min Global
- Companion friendliness for Single-Pass Interferometry

ROSE-L Objectives and Services

CLMS

C3S

CMEMS

EMS

Security

METEO

Meteorology and Hydrology Services

National and Local Authorities

Geohazards Monitoring

- Deformation
- Landslides
- Urban subsidence
- Flooding

EU-GMS

Land Use, Agriculture and Forestry

- Forest biomass and structure
- Land over and land cover change
- Agriculture

Soil Moisture

- High-resolution soil moisture

METEO

Cryosphere and Arctic

- Sea ice characterization
- Ice sheets and glacier velocity
- Grounding line
- Snow water equivalent
- Permafrost thawing and extent

METEO

Marine Monitoring

- Ocean surface wind vectors
- Swell properties

METEO

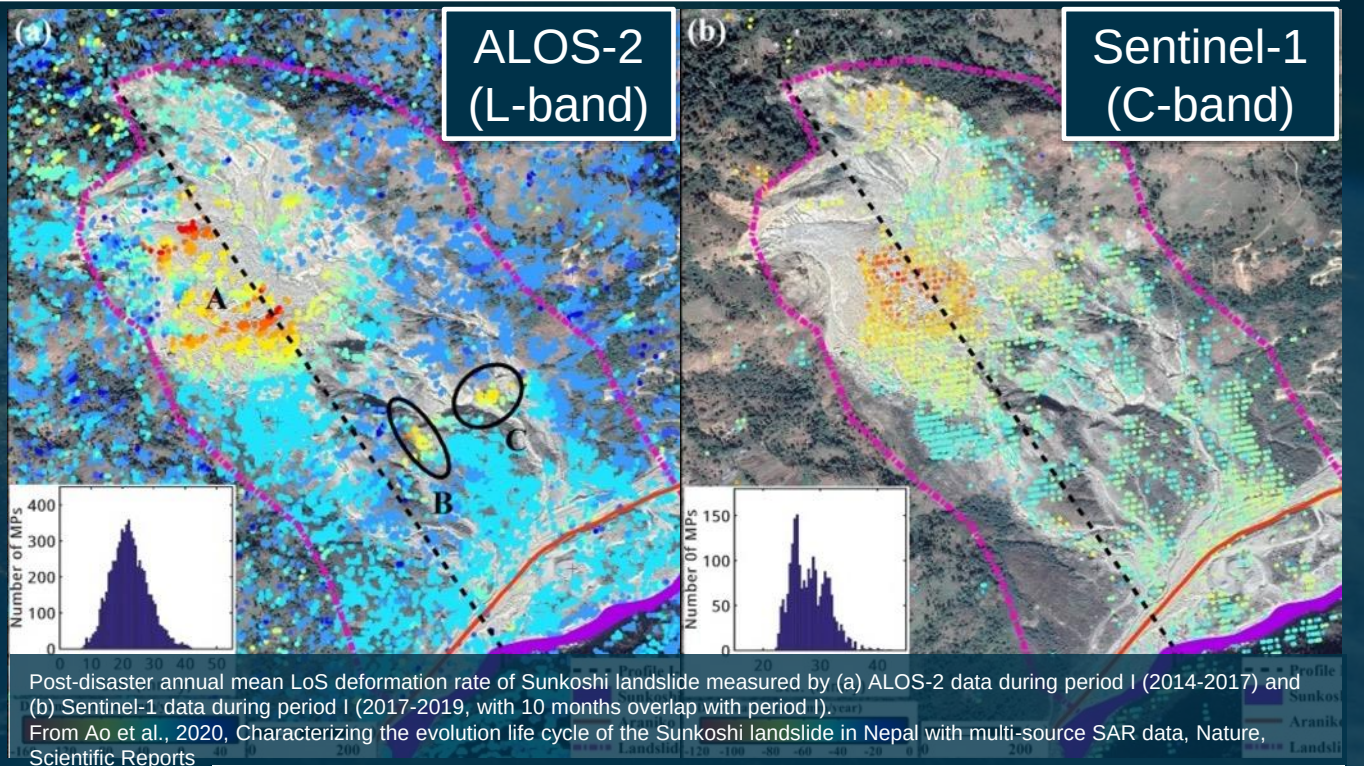
Maritime Monitoring

- Iceberg location, size and drift
- Vessel location, size and velocity
- Oil spill location and morphology

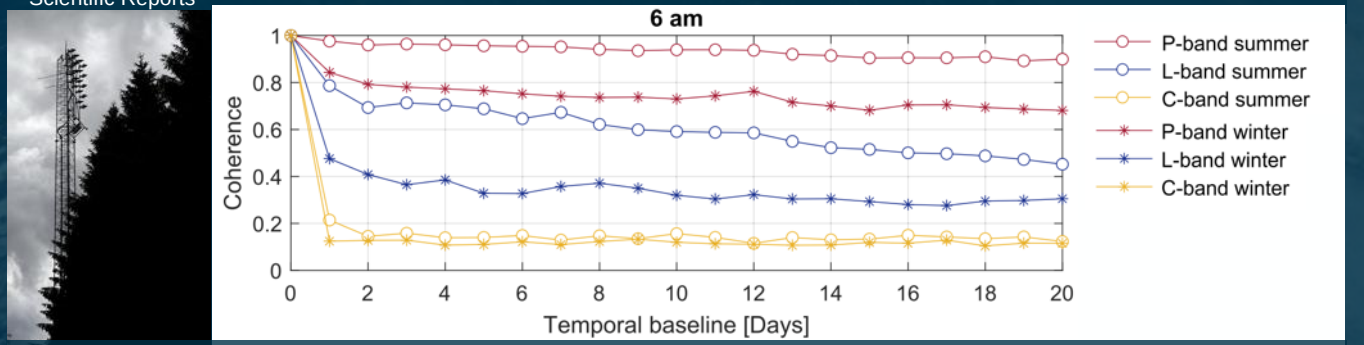
EMSA FRONTEX

Geohazards Monitoring – Ground Motion

- **Improved coverage** and availability of motion information in **vegetated and snow covered areas**, compared to C-band, mainly due the capability of sensing the ground
- **Enhanced robustness to phase unwrapping** in fast deformation scenarios due to longer wavelengths



Post-disaster annual mean LoS deformation rate of Sunkoshi landslide measured by (a) ALOS-2 data during period I (2014-2017) and (b) Sentinel-1 data during period I (2017-2019, with 10 months overlap with period I).
From Ao et al., 2020, Characterizing the evolution life cycle of the Sunkoshi landslide in Nepal with multi-source SAR data, Nature, Scientific Reports



ESA BorealScat experiment. Median temporal coherence over temporal baselines of multiples of one day.
From Monteith and Ulander, TGRS, 2021

REQUIREMENTS

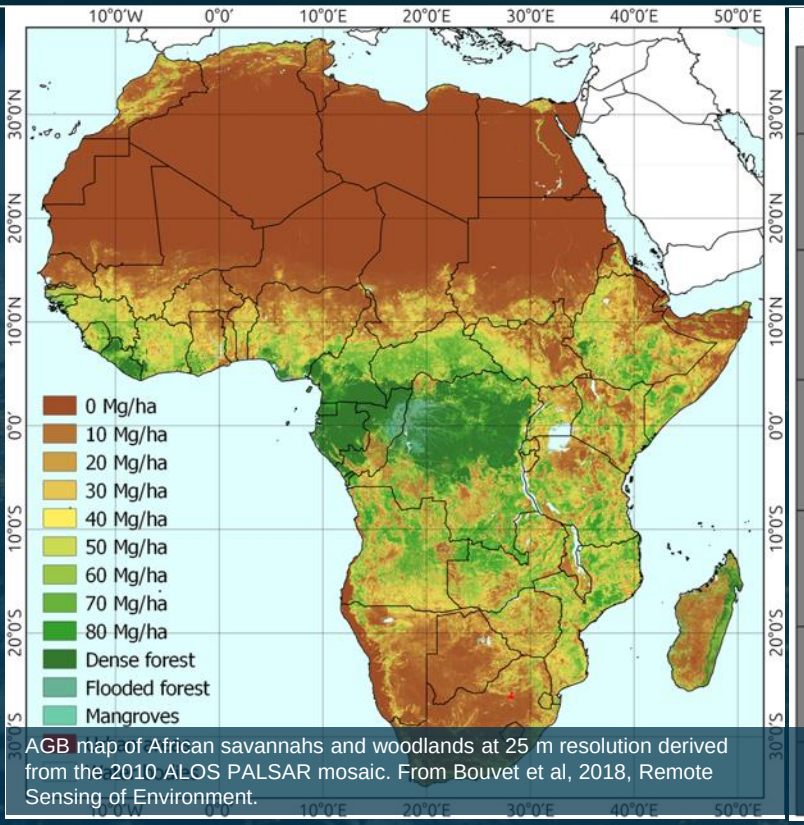
- 6 days repeat pass with two satellites
- 50 m2 Resolution for localized displacement
- ASC and DESC acquisitions for EW motion
- Low latency for rapid mapping after event

Biomass and LULC Mapping

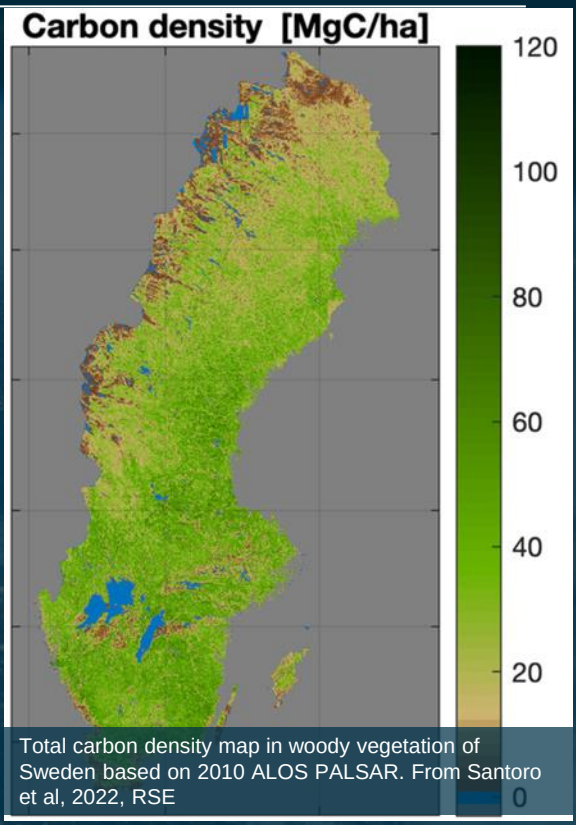
- **New timely information on above ground biomass (AGB) and biomes structure/type.** L-band is suitable to forests with AGB up to 100-150 Mg/ha, where it can sense the whole structure
- **Enhanced continuity on deforestation monitoring,** including tropical forests. L-band is sensitive to changes/losses (e.g. by logging)
- **Improved Land Use / Land Cover mapping** in combination with Sentinel-1, exploiting the complementary sensitivity.

REQUIREMENTS

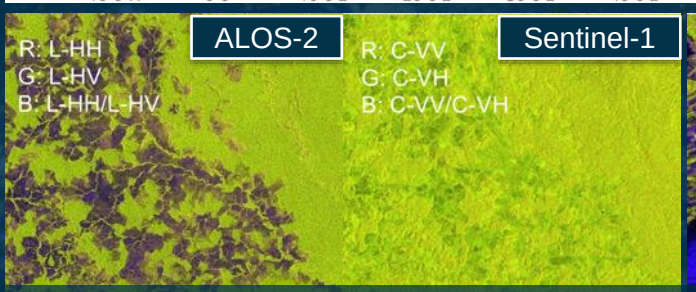
- Revisit (6 days Global, 3 days Europe)
- High resolution
- Companion friendliness to support option for forest height retrieval

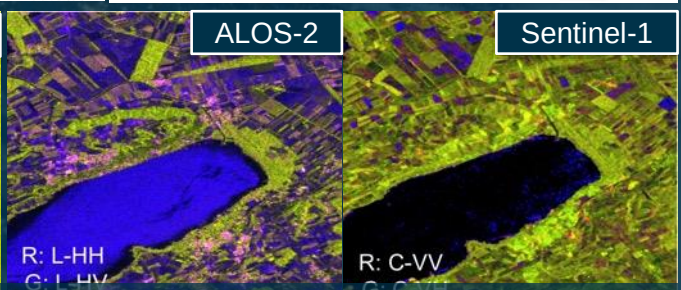


AGB map of African savannahs and woodlands at 25 m resolution derived from the 2010 ALOS PALSAR mosaic. From Bouvet et al, 2018, Remote Sensing of Environment.



Total carbon density map in woody vegetation of Sweden based on 2010 ALOS PALSAR. From Santoro et al, 2022, RSE





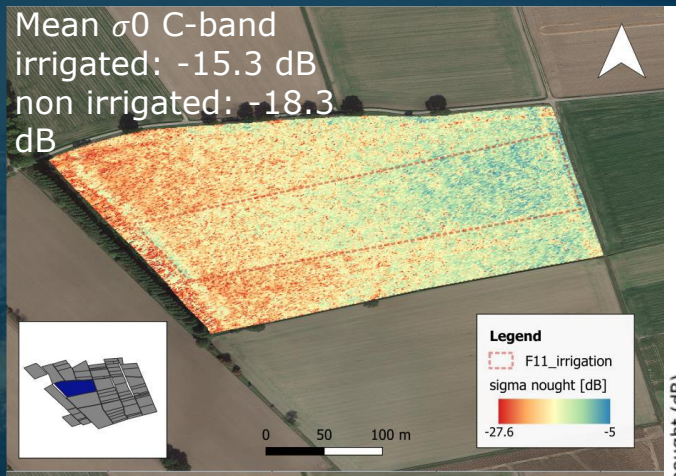
(left) Tropical forest conversion to mix of secondary growth and other land uses. (right) Mixed agriculture area (Germany)
https://ceos.org/document_management/SEO/DataCube/Laymans_SAR_Interpretation_Guide_2.0.pdf

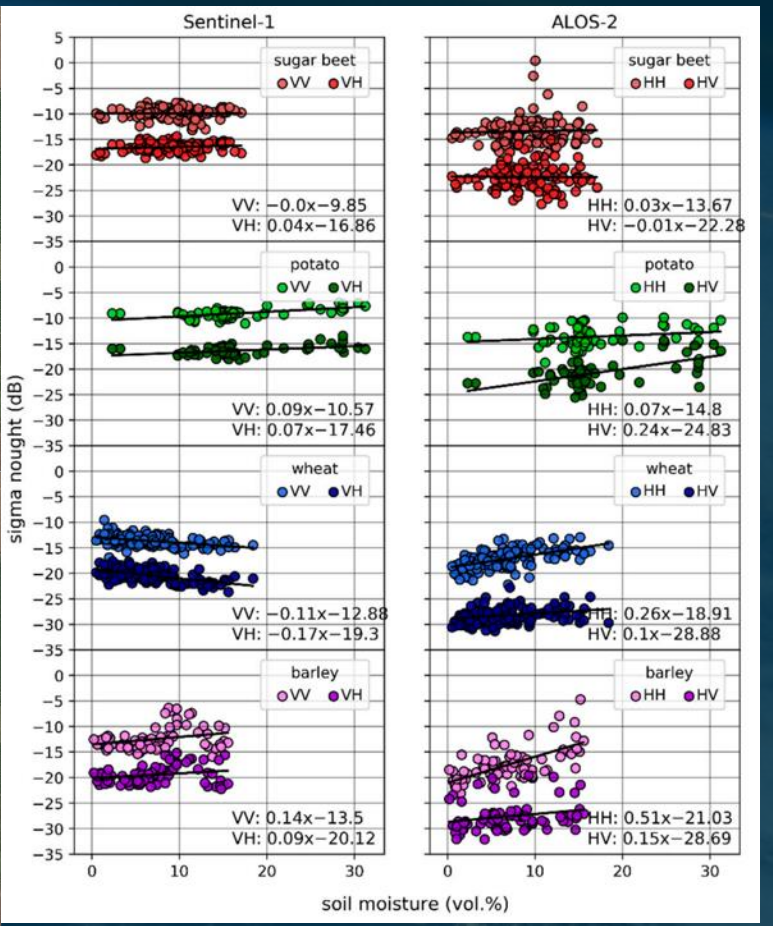
Soil Moisture

- **High-resolution Soil Moisture tracking in a broad range of crops and vegetated land,** complementing Sentinel-1 SSM products that are mainly suitable for bare soils and low vegetation areas.
- Information of **Soil Moisture up to ~5 cm depth** that shall be combined with upper 1 cm layer SSM from Sentinel-1

REQUIREMENTS

- Revisit (6 days Global, 3 days Europe)
- High resolution
- Low noise level (NESZ, ambiguities)
- Integration (downscaling) with Scatterometers and L-band Radiometers for temporal revisit and accuracy





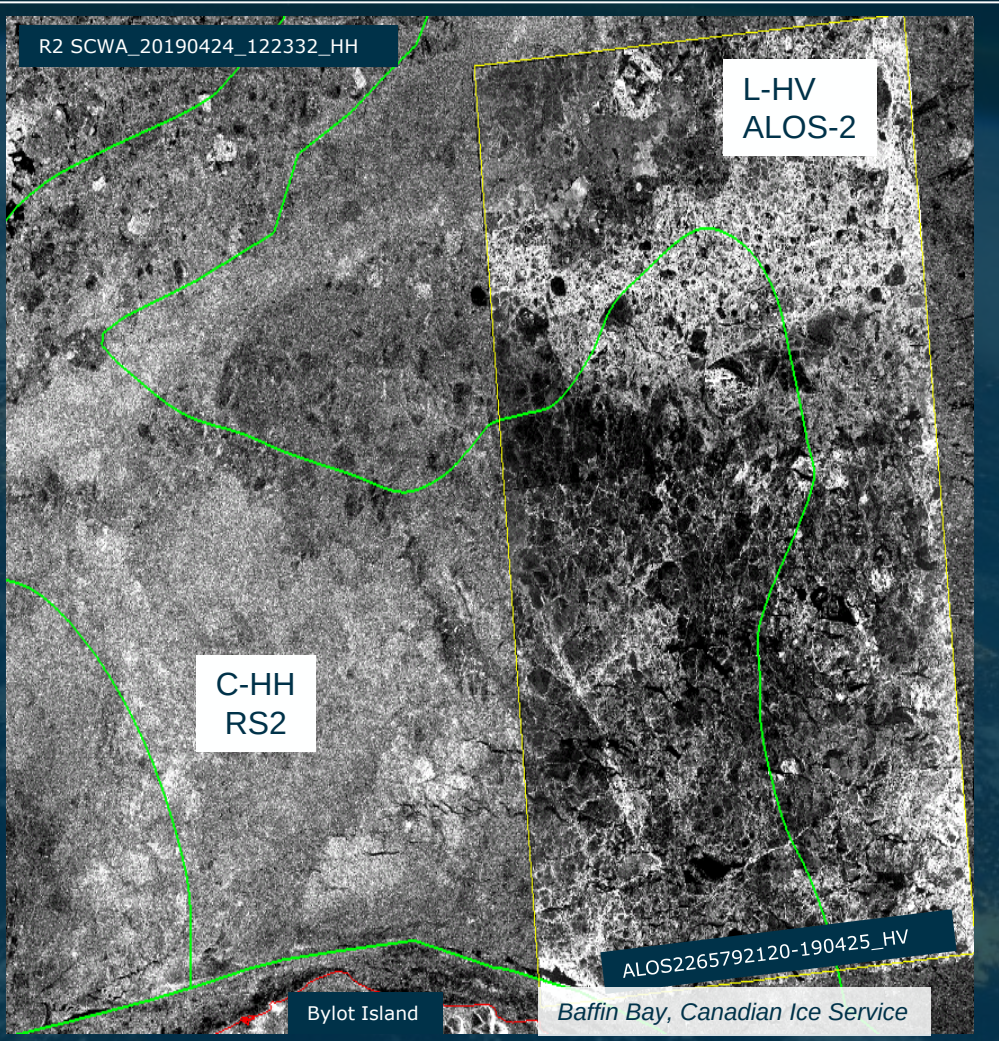
Results from ESA SARSense air- and space- borne campaign. Acquisitions over Selhausen (DE).
(left) Change in backscatter observed in C- and L-band for irrigated and non-irrigated area (F11), but also range dependent.
(Right) Scatter plots between soil moisture and backscattering signal from co- and cross-polarized channels of C- and L-band satellite data. From Mengen et al., 2021, Remote Sensing

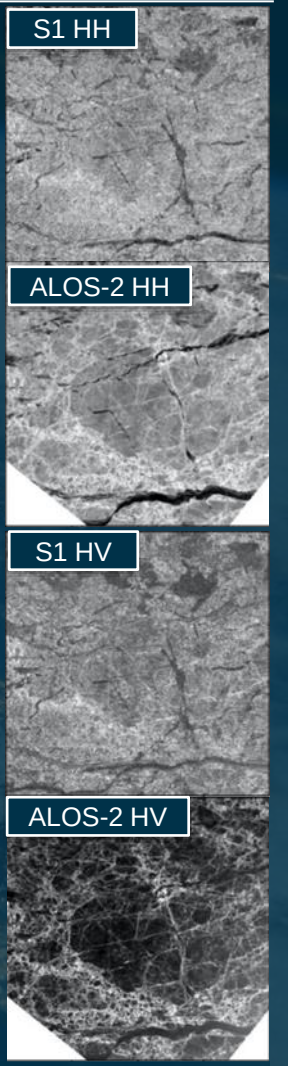
Sea Ice Monitoring

- **Daily high-resolution information on hazardous sea-ice and icebergs** for navigation and weather/climate services
- **Enhanced mapping of sea-ice type and concentration,** adding to C-band the L-band sensitivity to large ice structures (e.g. fractures and ridges)
- **Improved mapping of sea-ice drift** by flying in a close formation with Sentinel-1

REQUIREMENTS

- Revisit (1 day Arctic, 3 days Europe, 6 days Global)
- Low noise level (NESZ, ambiguities)
- High-resolution and wide swath
- Simultaneous acquisitions with Sentinel-1 for sea ice mapping

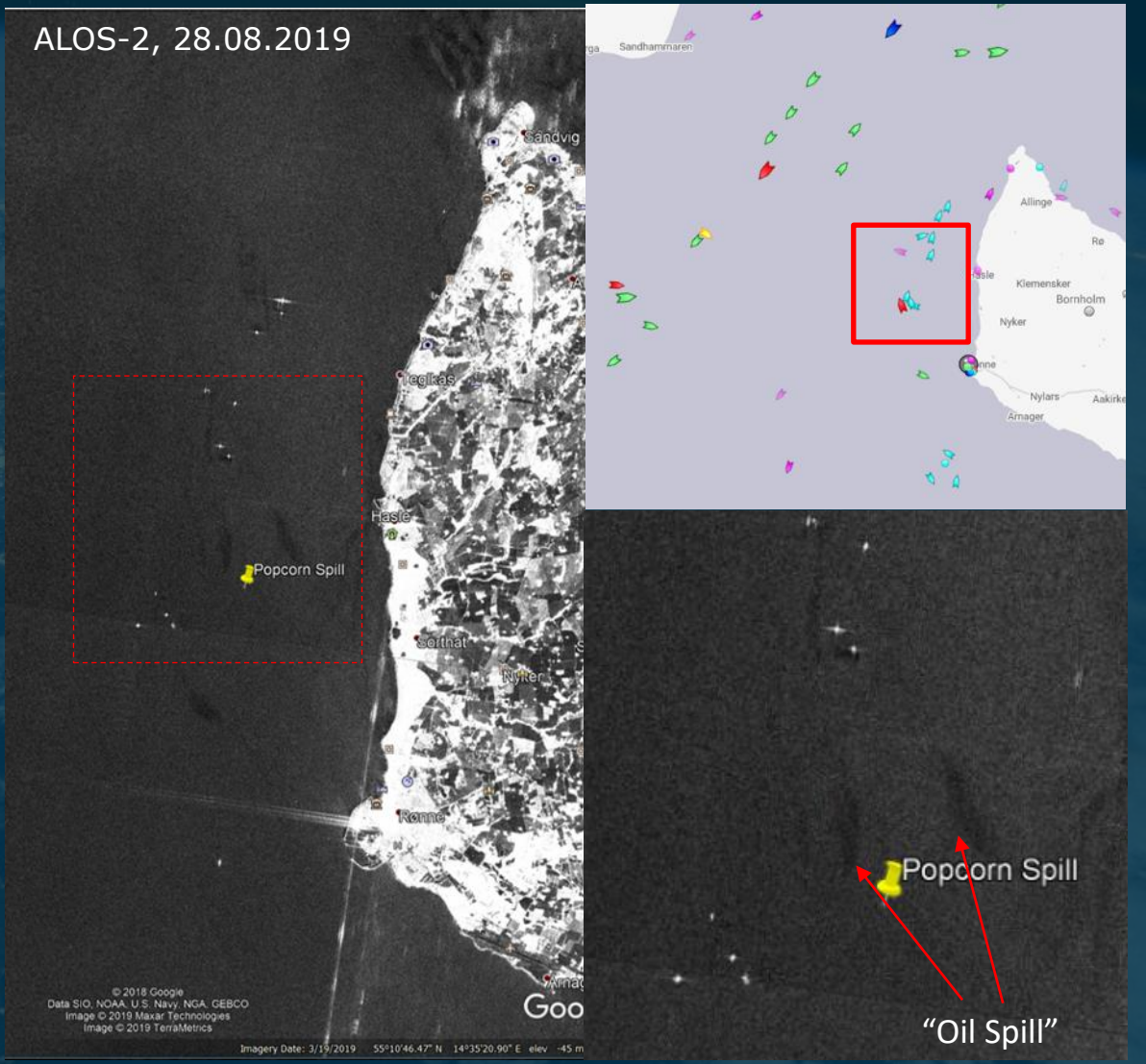




Sentinel-1 Extra Wide Swath and ALOS-2 PALSAR-2 Wide Beam images acquired at HH- and HV polarization over Fram Strait, on Dec. 9, 2019. The PALSAR-2 images were aligned to the Sentinel images. By courtesy of Johannes Lohse, UiT. From Dierking et al., 2022, IGARSS

Maritime and Marine Monitoring

- **Added value in vessel detection** for maritime surveillance due to reduced sensitivity of sea backscatter at lower wind
- **Improved detection of icebergs** thanks to a better sensitivity of L-band to large ice structures
- **Added value in extreme events (e.g. tropical cyclones)** as high winds do not saturate the signal



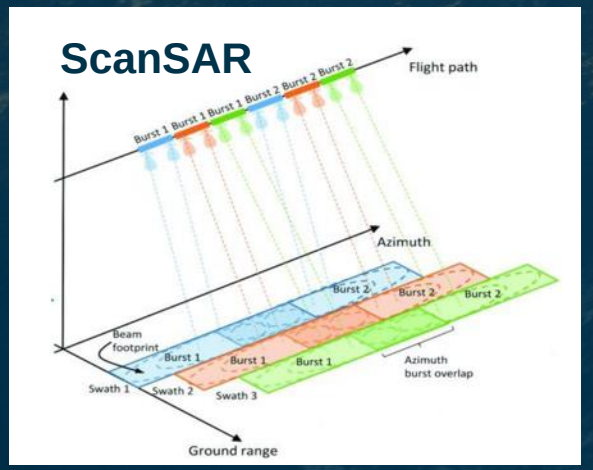
REQUIREMENTS

- Wave mode
- Revisit (1 day Arctic, 3 days Europe, 6 days Global)
- Low latency for European waters (< 10 minutes)
- Low noise level (NESZ and ambiguities)
- High-resolution, wide swath
- ATI capabilities (MAPS)

ROSE-L SAR Imaging and Systematic Acquisitions

As current baseline the instrument provides ***2 ScanSAR Wide Swath modes*** and a **Wave Mode** over open ocean

ROSE-L SAR Modes	**RIWS** ROSE-L Interferometric Wide Swath	**QWS** Quad-pol interferometric Wide Swath	**Wave Mode**
Polarization	Dual-Pol (HH-HV or VV-VH)	Quad-Pol (HH-HV-VH-VV)	Single-Pol
Incidence angle access	29 – 46 deg Full overlap with S1 IWS swath at all latitudes	Fixed swath within 20 – 45 deg (e.g. 25 – 42.3 deg)	Variable
Swath	260 km	260 km	20 x 20 km
Resolution	50 m^2	100 m^2	50 m^2
NESZ	< -28 dB	< -28 dB	< -28 dB
DTAR	< -23 dB	< -23 dB	< -23 dB



ROSE-L Sizing Requirements:

a) "Always on" over ***Europe***, ***Arctic***, ***coastal Antarctica*** and ***global Tectonic areas*** in dual or quad-pol SAR mode

b) Full coverage of ***remaining landmass*** (not included in a)) within *12-day* revisit time , i.e. *6-day* revisit time for entire *constellation* in dual or quad-pol SAR mode

c) Wave mode over ***Open Ocean***

ROSE-L ***continuous operations*** capability per sliding orbit time window:

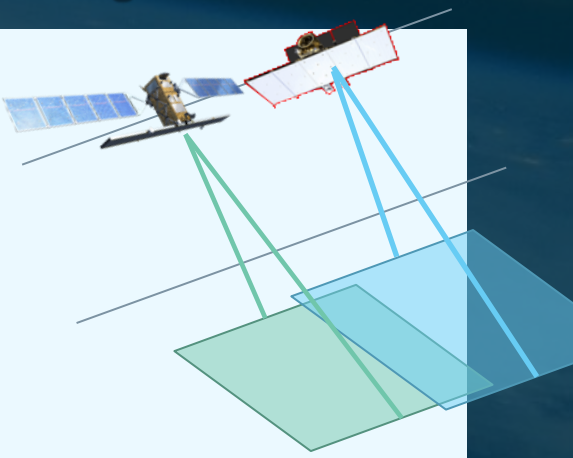
- 35 min in ***dual- pol SAR mode*** or
- 20 min in ***quad-pol SAR mode***, and
- for the remaining time in ***Wave Mode***

ROSE-L Mission Design Highlights and Constellation

ROSE-L will augment Sentinel-1 by means of a **synergic acquisition plan and mission design**

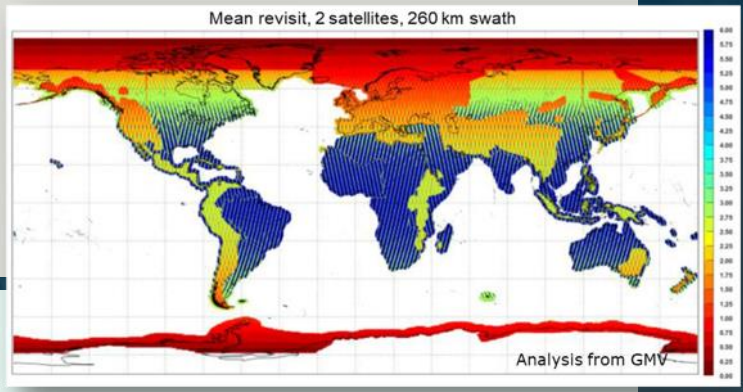
Collocation with Sentinel-1

- Same orbit configuration of Sentinel-1.
- Phasing of the orbital plane adjusted to follow the **same ground track of Sentinel-1**
- **RIWS mode guarantees full swath overlap with S1 IWS**
- Mission design supports options for: 1) different orbit phasing for optimized revisit
  2) convoy with Sentinel-1 (up to a minimum 1min baseline)



Extensive Global coverage and consistent long-term archive

- Coverage of Global land (except for South pole). **~ 38 min/orbit duty cycle**
- Consistent acquisitions through years for **long-term coherent data stacks**



Free, full and open data policy

Moving towards a **System of Systems concept** and enhanced information products

ROSE-L SAR Instrument – Main Characteristics

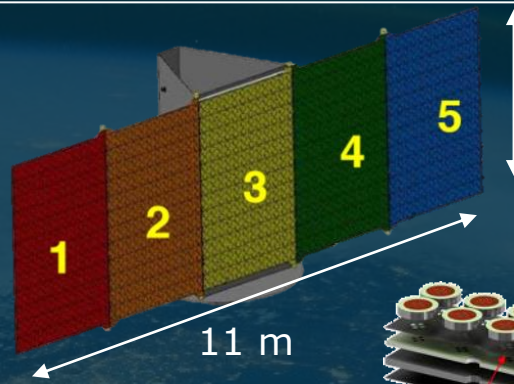
- Deployable **planar active array antenna** of 11m x 3.6m with **5 panels**
- Antenna consists of **5 (az)** x **12 (el) sub-arrays** = (analog) **60 phase centers**
- Each phase center is fed by an individual dual-pol TRM of ~150W peak

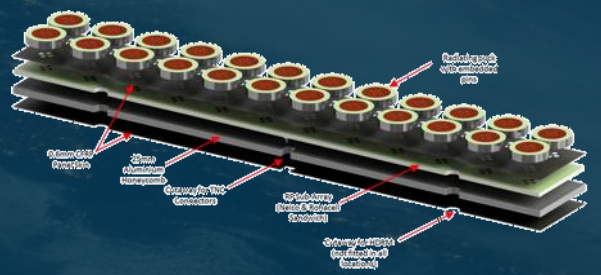
⇒ Radiated **peak** power **~9kW**

- Each sub-array consists of 2 x 12 radiating elements
- **Digital beamforming (DBF)**: 12 channels in Elevation
  - 3 adjacent elevation channels combined (V&H) and then digitized

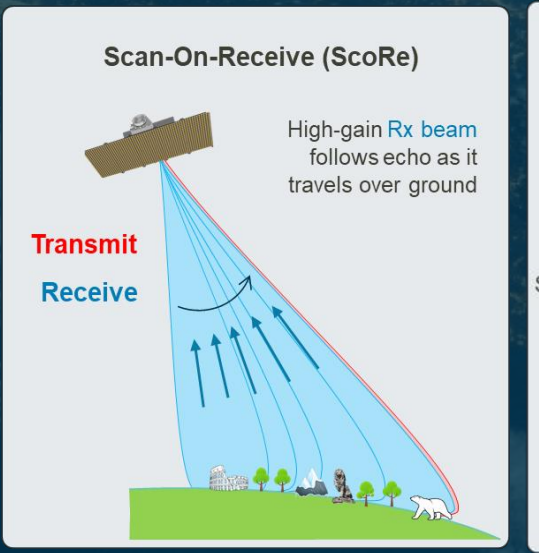
  ⇒ resulting **4 digital channels** (V&H) used to form **"Scan-on-Receive"** beams in **real-time on board**
  - **5 digital channels** in **azimuth "MAPS",** all down-linked and then **combined on-ground**

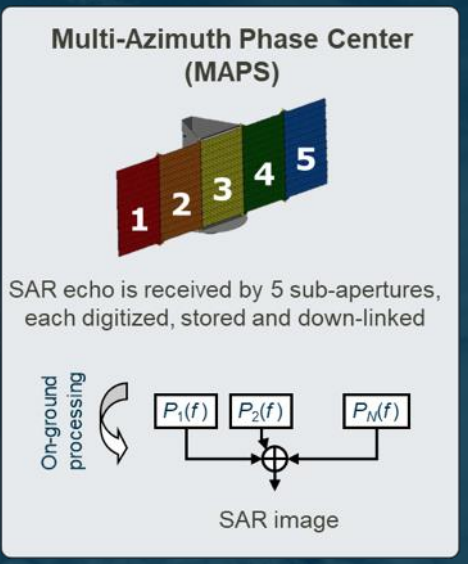
⇒ Total of **20 (V) + 20 (H) digital channels**





sub-array with 2x12 radiating elements





Conclusions

- Sentinel-1 Next Generation at C-band to
  - *ensure continuity* and expansion of services and applications relying on Sentinel-1
  - *enhance* existing services and applications
  - *enable* new application developments building on improved performance and observation gaps (e.g. resolution, revisit and others)
- Sentinel-1 NG will bring new and enhanced capabilities
  - Higher resolution (25m^2 for S1NG)
  - Low NESZ (-26 dB for Sentinel-1 NG)
  - Wide swath (400km) and frequent revisit capability and greatly enhanced duty cycle
- ROSE-L bring new and enhanced capabilities
  - *to address information gaps* and provide new information not yet available through current Sentinel missions
  - High resolution (50m^2 for ROSE-L RIWS)
  - Low NESZ e.g. -28 dB for ROSE-L
  - High duty cycle, wide swath & frequent revisit capability => Mapping machine
- Sentinel-1, ROSE-L and Sentinel-1NG are addressed as a system (not in isolation)