Copernicus ROSE-L
Radar Observing System for Europe in L-Band

Lorenzo Iannini, Malcolm Davidson
7th Advanced Training Course on Radar Polarimetry, Toulouse, France

16/06/2023

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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**)

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

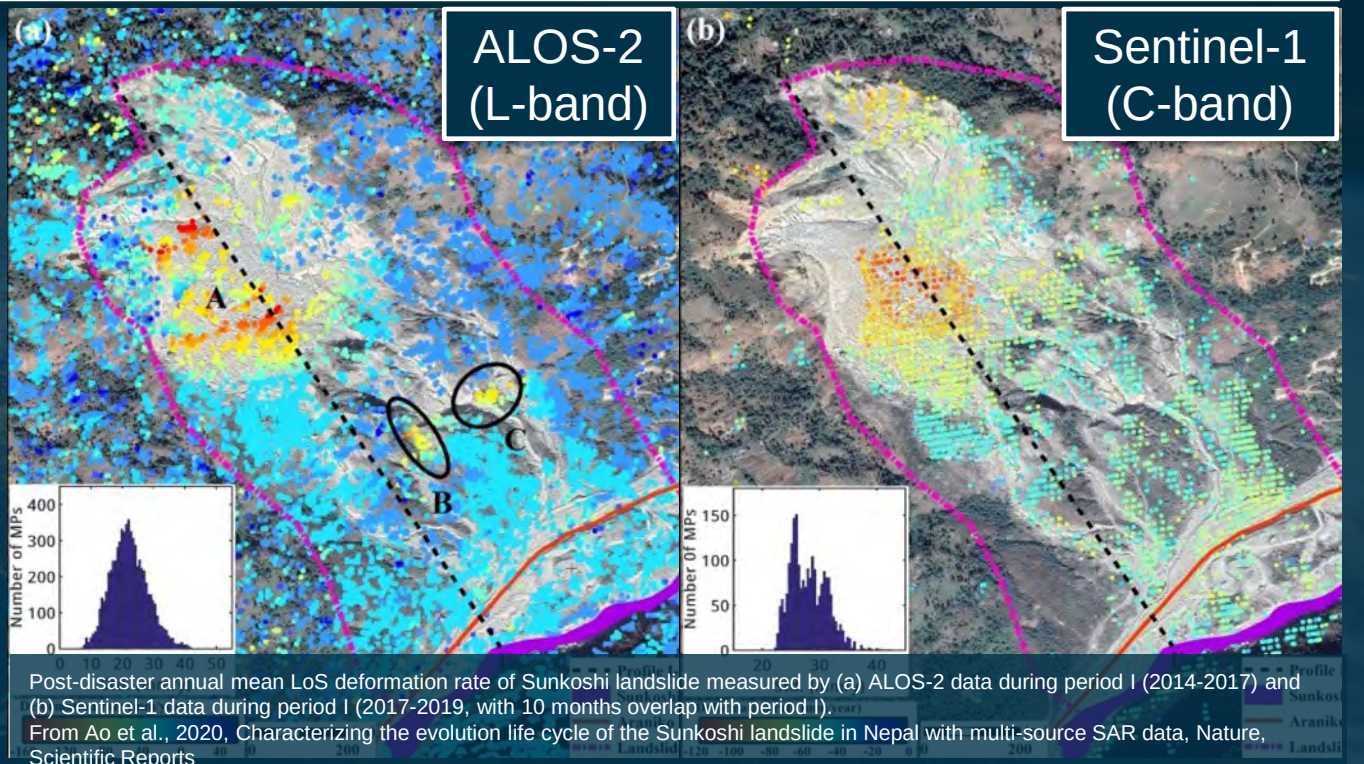
Maritime Monitoring

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

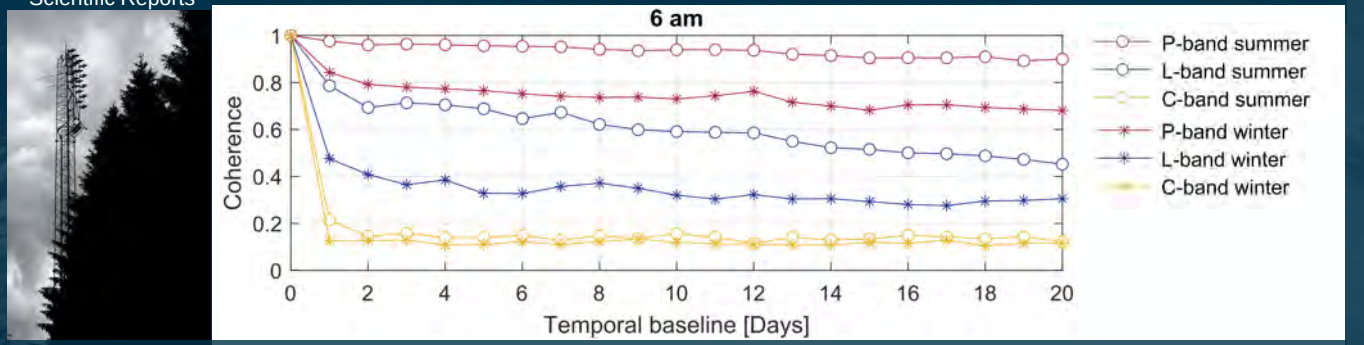
EMSA FRONTEX

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

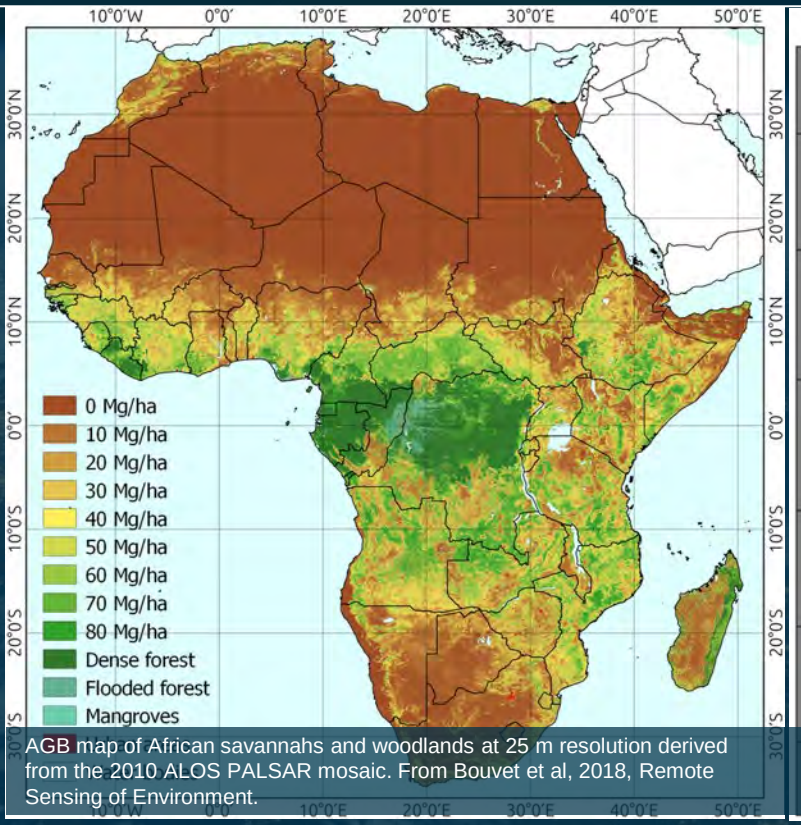
- 6 days repeat pass with two satellites
- 50 m2 Resolution for localized displacement
- ASC and DESC acquisitions for EW motion
- Low latency for rapid mapping after event

Biomass and LULC Mapping

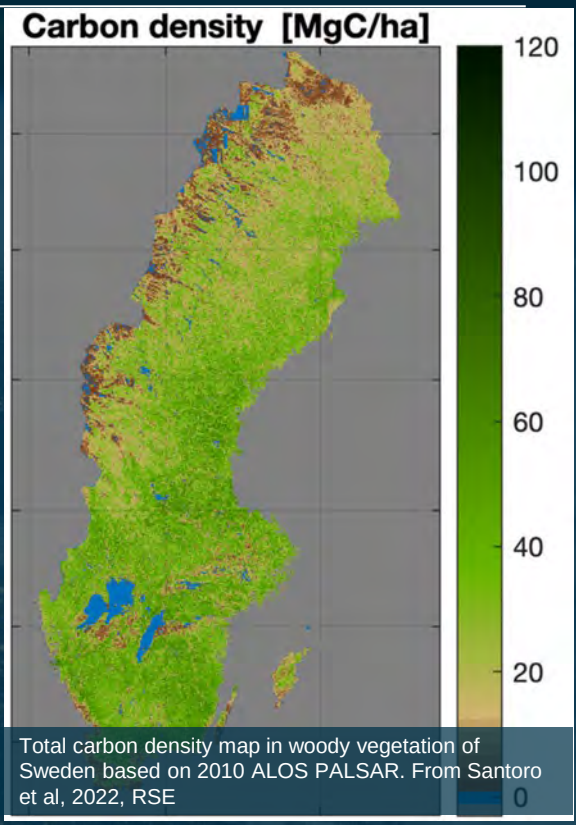
- **New timely information on above ground biomass (AGB) and biomes structure/type.** L-band is suitable to forests with AGB up to 100-150 Mg/ha, where it can sense the whole structure
- **Enhanced continuity on deforestation monitoring,** including tropical forests. L-band is sensitive to changes/losses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

REQUIREMENTS

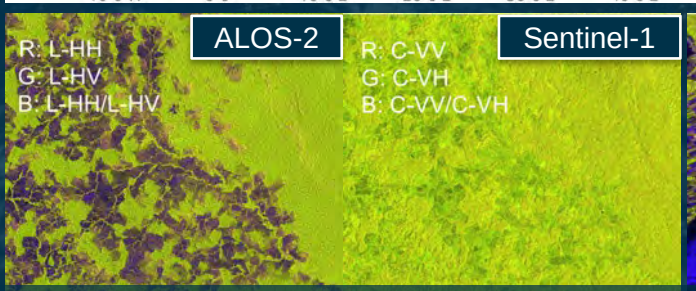
- Revisit (6 days Global, 3 days Europe)
- High resolution
- Companion friendliness to support option for forest height retrieval

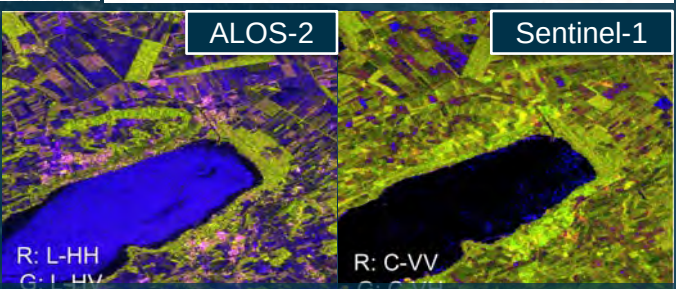


AGB map of African savannahs and woodlands at 25 m resolution derived from the 2010 ALOS PALSAR mosaic. From Bouvet et al, 2018, Remote Sensing of Environment.



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





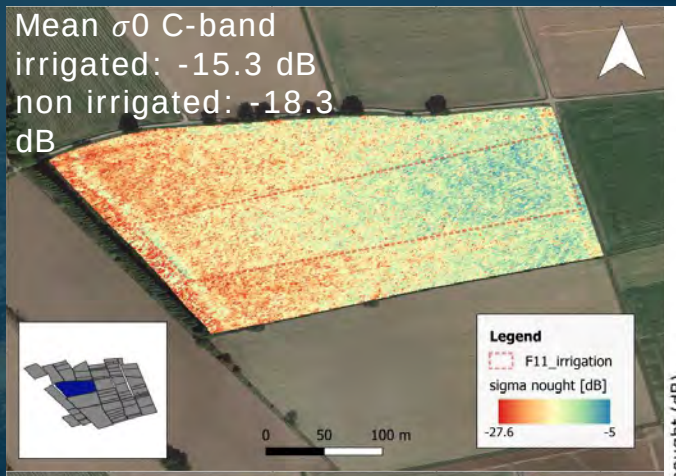
(left) Tropical forest conversion to mix of secondary growth and other land uses. (right) Mixed agriculture area (Germany)
https://ceos.org/document_management/SEO/DataCube/Laymans_SAR_Interpretation_Guide_2.0.pdf

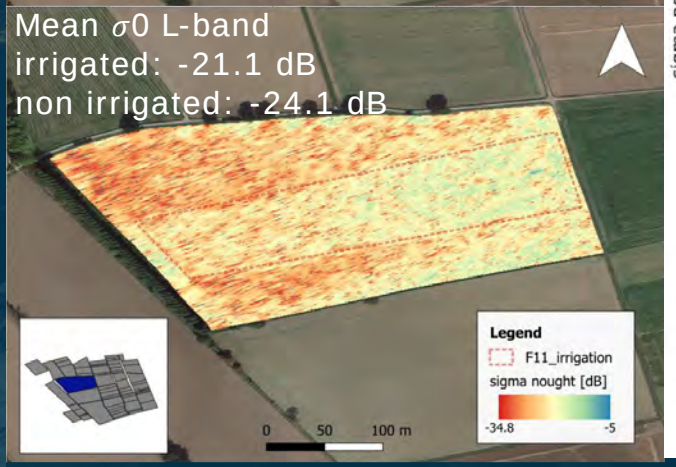
Soil Moisture

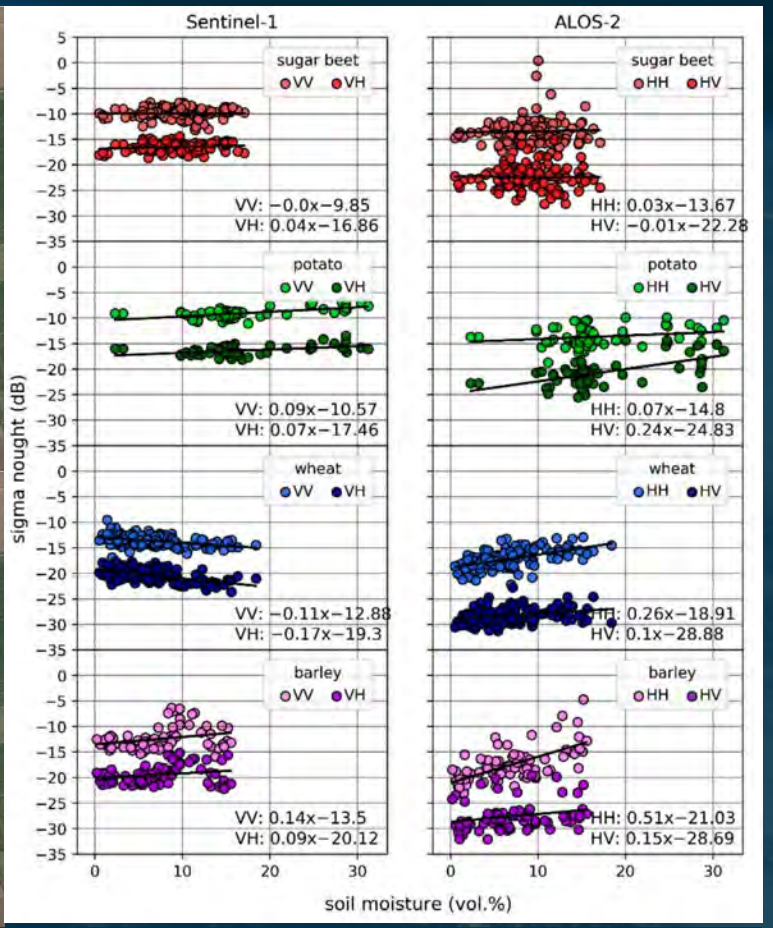
- **High-resolution Soil Moisture tracking in a broad range of crops and vegetated land,** complementing Sentinel-1 SSM products that are mainly suitable for bare soils and low vegetation areas.
- Information of **Soil Moisture up to ~5 cm depth** that shall be combined with upper 1 cm layer SSM from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







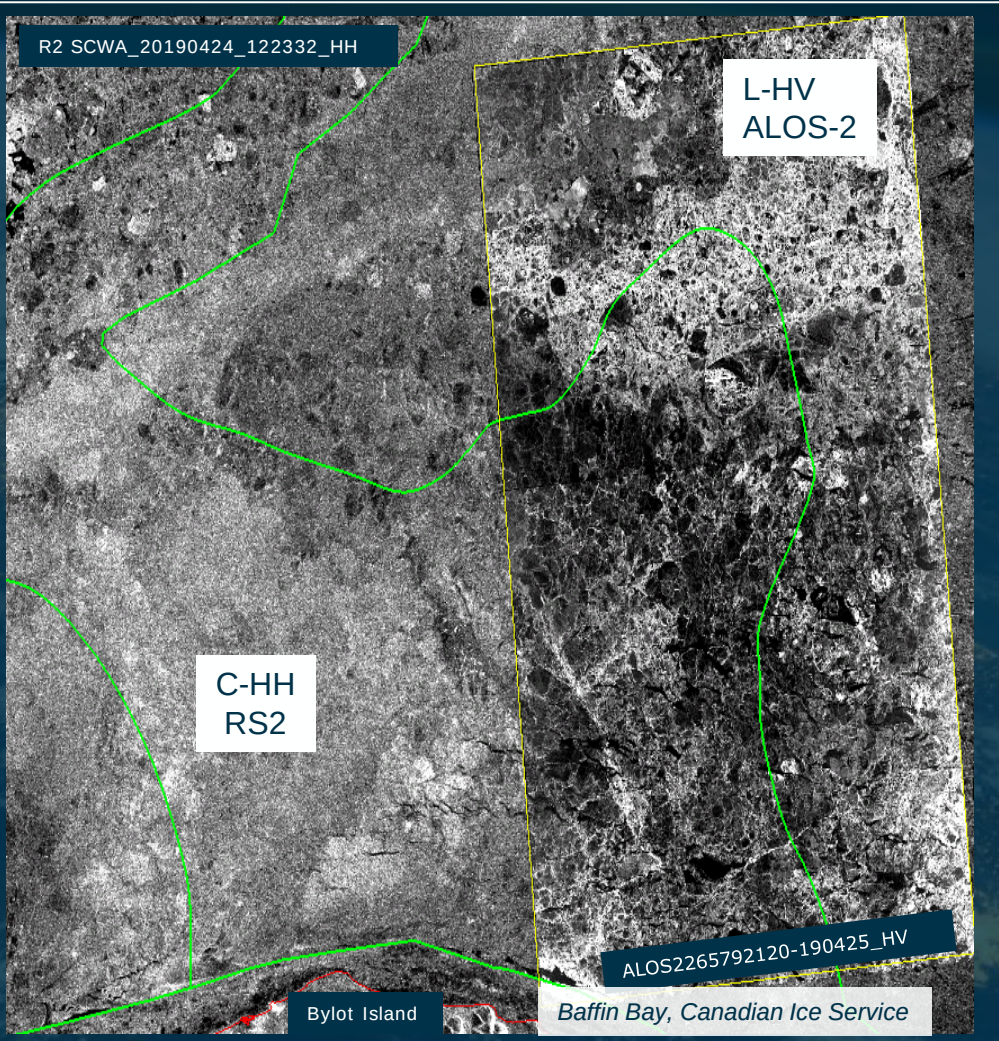
Results from ESA SARSense air- and space- borne campaign. Acquisitions over Selhausen (DE).
(left) Change in backscatter observed in C- and L-band for irrigated and non-irrigated area (F11), but also range dependent.
(Right) Scatter plots between soil moisture and backscattering signal from co- and cross-polarized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

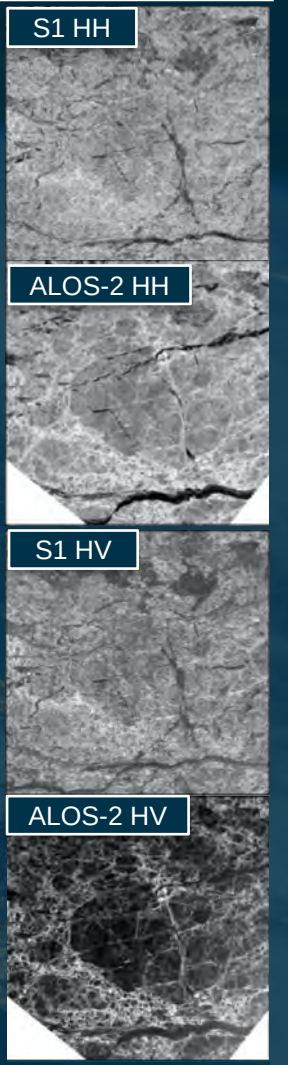
Sea Ice Monitoring

- **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

Land Ice and Seasonal Snow

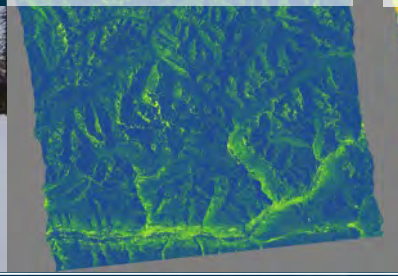
- **Enhanced ice velocity retrieval (ice sheets and glaciers)** thanks to a deeper and more stable signal
- **New seasonal snow modeling capability** through retrieval of **Snow Water Equivalent (SWE)**, enabled by to penetration till the ground in dry snow

REQUIREMENTS

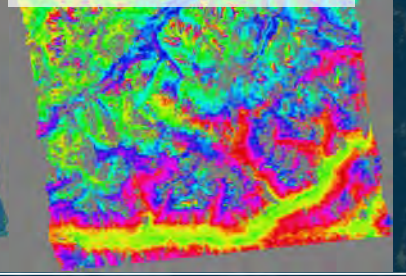
- 6 days repeat pass for ice velocity and SWE
- Low noise level (NESZ and ambiguities)
- High-resolution and wide swath
- Close acquisition to Sentinel-1 for wet snow detection

Ongoing assessment of SWE in Engadin (CH), Eastern Alps. By ENVEO

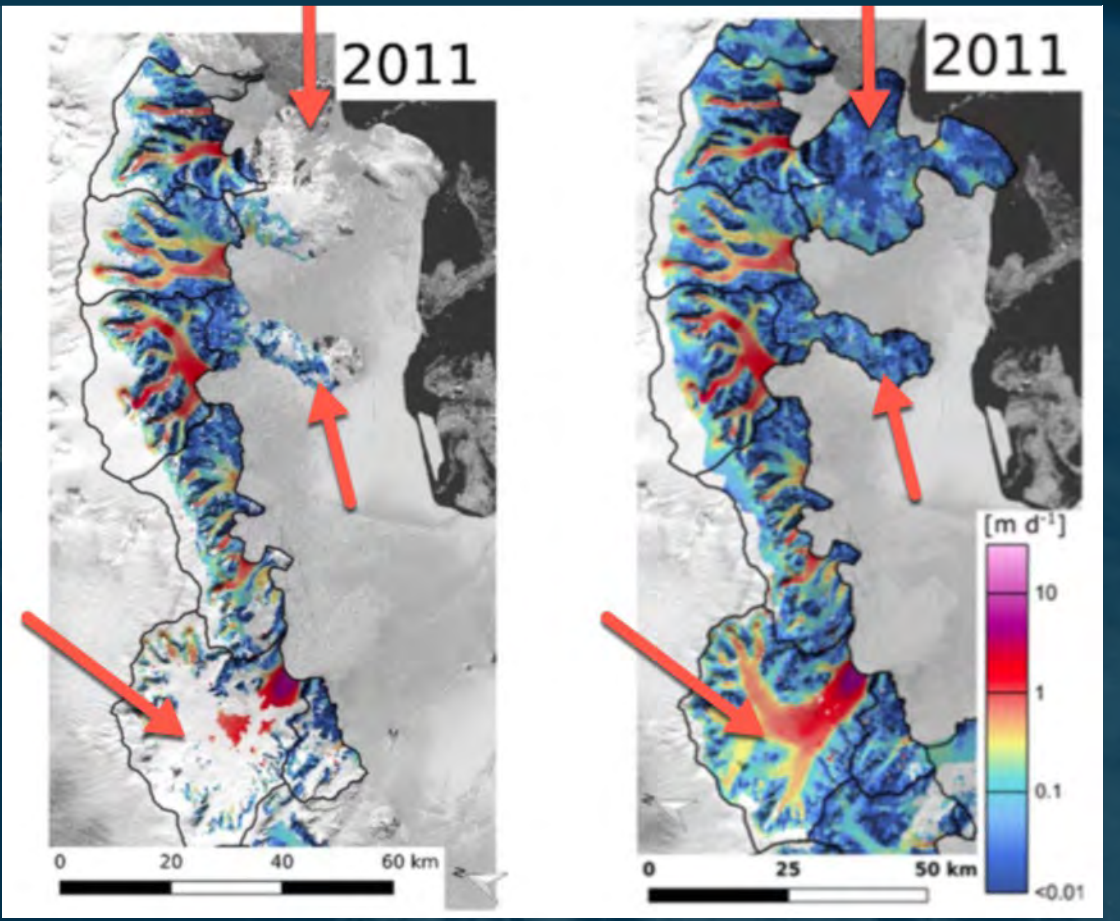
InSAR Frame 910 17/12/2019 – 31/12/2019
Coherence



InSAR Frame 910 17/12/2019 – 31/12/2019
InSAR phase

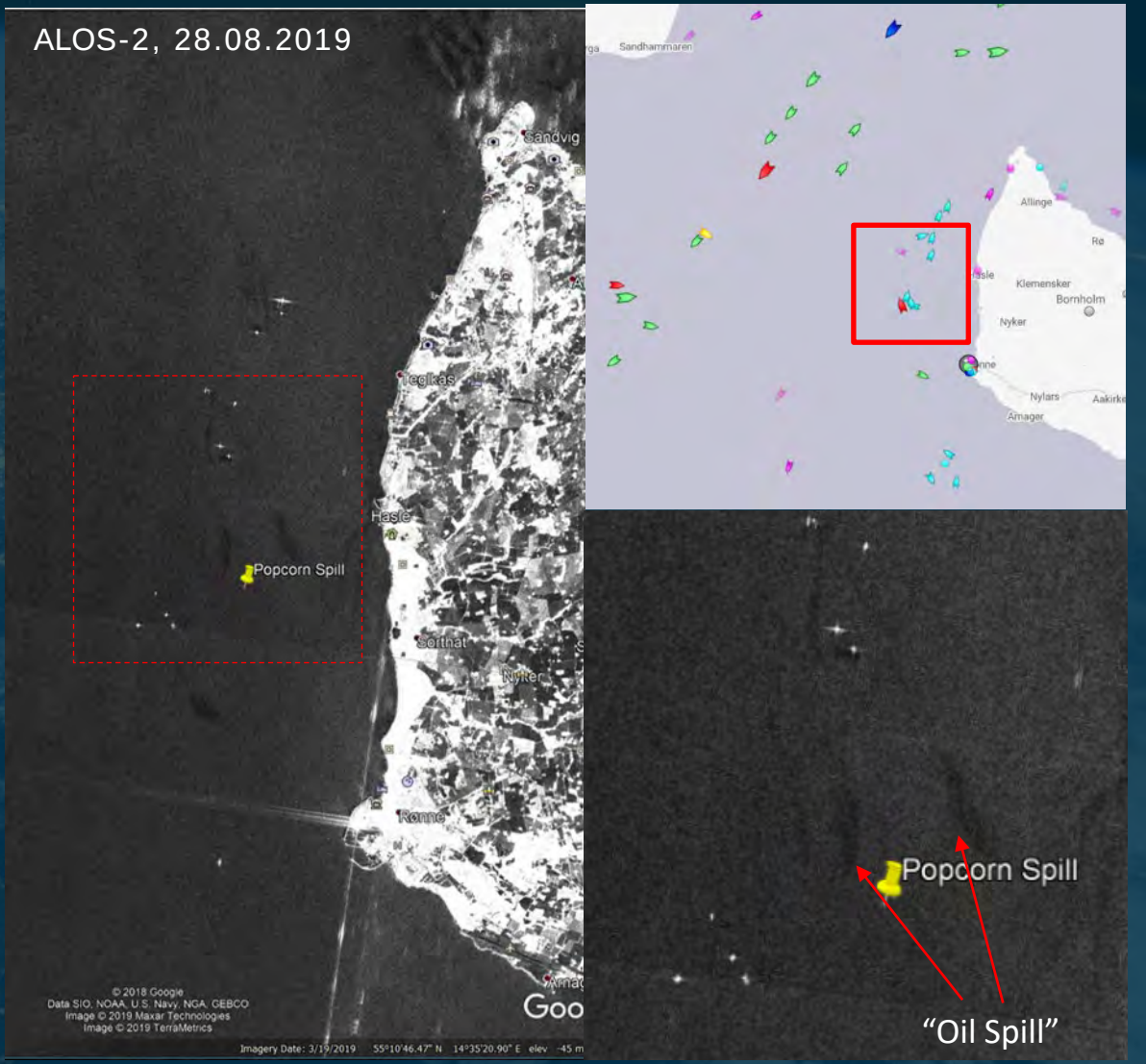


Maps of ice velocity on glaciers of Larsen-A embayment. Left: derived from TerraSAR-X repeat-pass SAR data by offset tracking. Right: Gaps in TerraSAR-X velocity map filled by means of PALSAR (L-band) velocity data. Note the areas indicated by the red arrows where L-band SAR has contributed and filled gaps with ice velocity information.



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)

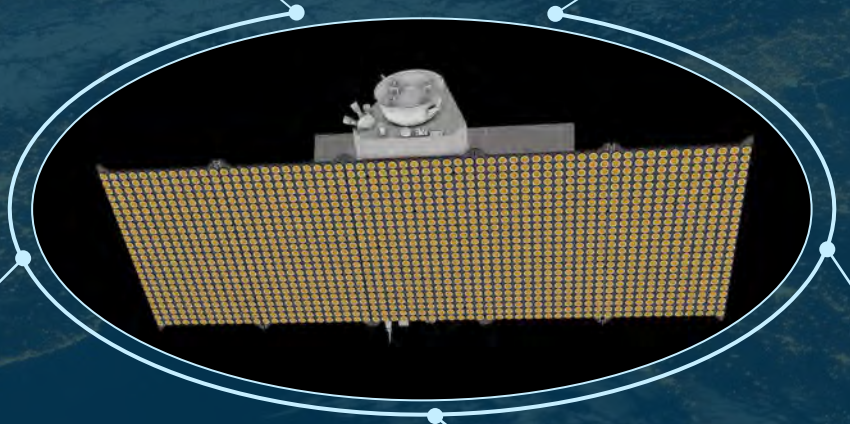
ROSE-L Mission in Brief

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)

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

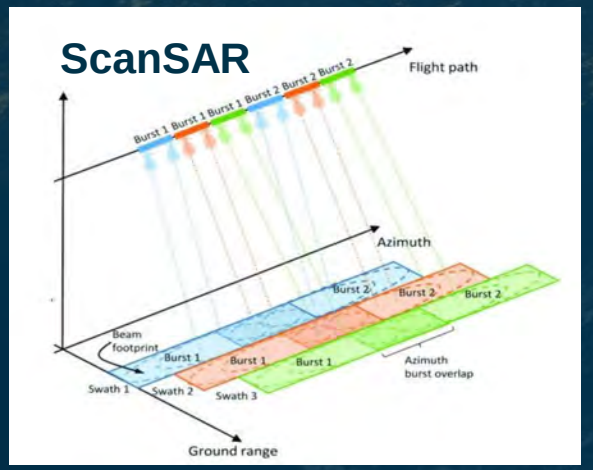
PROGRAMMATICS

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

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***

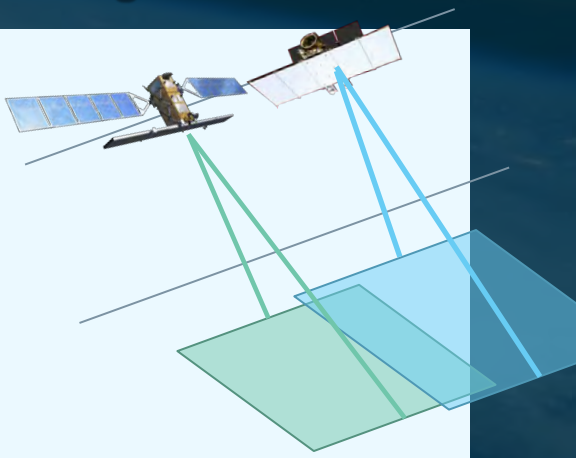
ROSE-L ***continuous operations*** capability per sliding orbit time window:

- 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

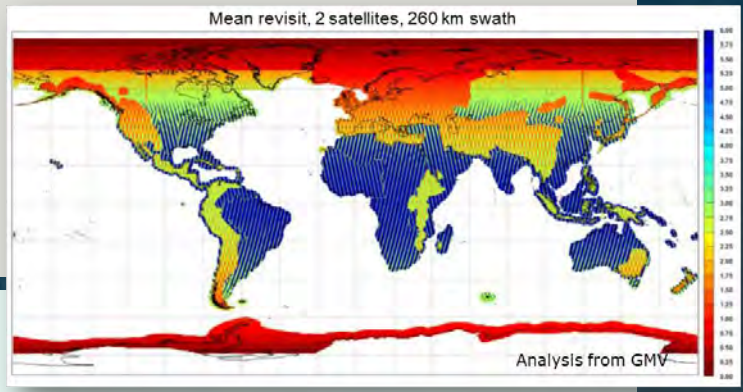
ROSE-L will augment Sentinel-1 by means of a **synergic acquisition plan and mission design**

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

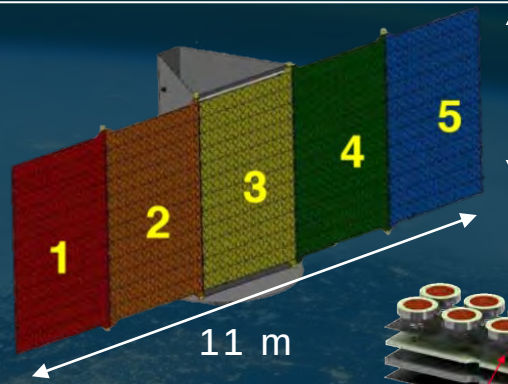
- Deployable **planar active array antenna** of 11m x 3.6m with **5 panels**
- Antenna consists of **5 (az)** x **12 (el) sub-arrays** = (analog) **60 phase centers**
- Each phase center is fed by an individual dual-pol TRM of ~150W peak

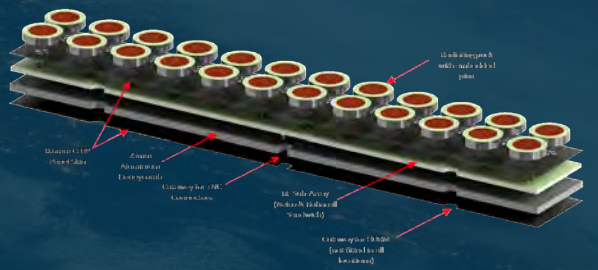
⇒ Radiated **peak** power **~9kW**

- 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

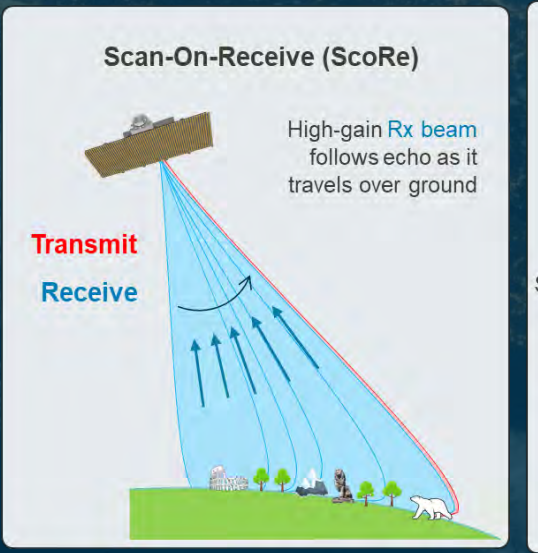
  ⇒ resulting **4 digital channels** (V&H) used to form **"Scan-on-Receive"** beams in **real-time on board**
  - **5 digital channels** in **azimuth "MAPS",** all down-linked and then **combined on-ground**

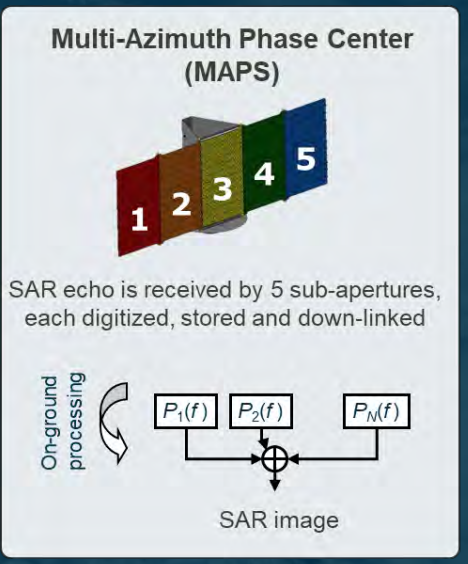
⇒ Total of **20 (V) + 20 (H) digital channels**





sub-array with 2x12 radiating elements





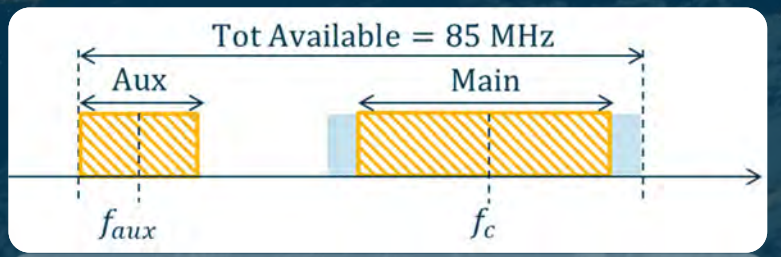
Ionosphere

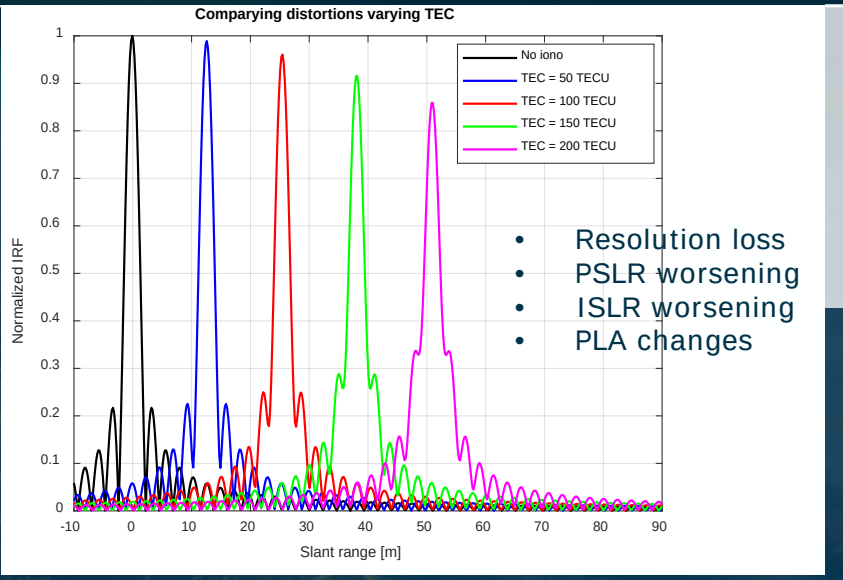
Effects of Ionosphere on L1 Products

- Errors in Pixel Localization Accuracy (PLA) due to absolute range and azimuth shifts
- Distorsion of Impulse Response Function (IRF) and degradation of resolution
- Polarimetric channel mixing due to Faraday rotations
- Disturbances on InSAR phases

Split Band Transmission Capability

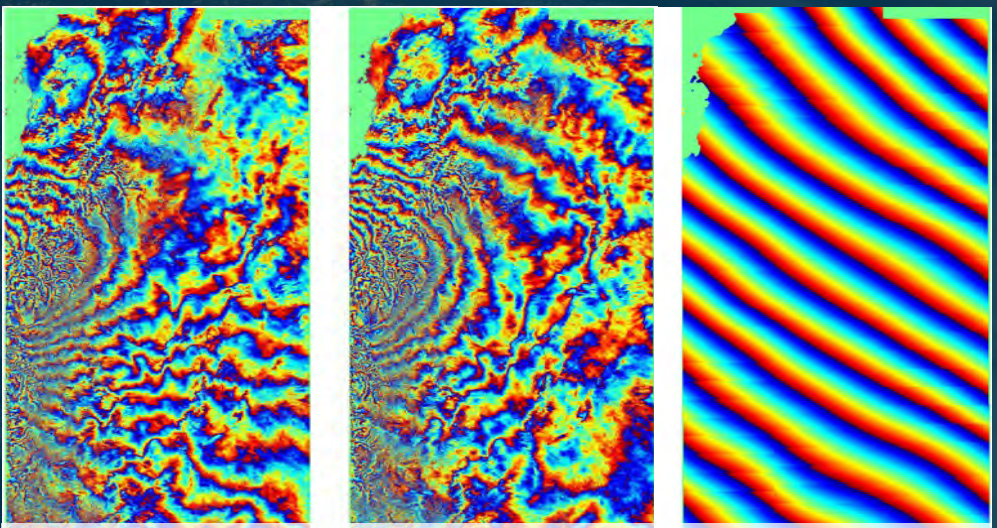
- The transmission of an auxiliary bandwidth of up to 8 MHz at one end of the spectrum is implemented to enhance the Split-Spectrum accuracy
  - Impact on data rate and NESZ
  - Need to handle the additional data at L0 and L1 product level





- Resolution loss
- PSLR worsening
- ISLR worsening
- PLA changes

Source: Thales Alenia Space Italia, ARSI KEO 2022



S1 Interferogram before (left) and after (centre) ionosphere correction and ionosphere phases (right) derived by split-spectrum technique. Chile Earthquake September 2015 From (Gomba, 2018)

Science Activities and Collaborations

Ongoing activities contributing to maturing the SRL of ROSE-L products

- Campaigns aimed at investigating the potential of L-band (e.g. TomoSense, LuxScat, LC-ICE, SnowLab-NG)
- Projects funded by ESA under different sources/initiatives (e.g. CCI, DUE, STSE)
- Newly funded activities as part of the ROSE-L science plan, starting from this year (2023)
- Joint Research Activities carried out with other space agencies (in addition JAXA, NASA and CONAE participate as observers in ROSE-L MAGs)

ESA-JAXA SATELLITE BASED ENVIRONMENTAL MONITORING SCIENCE and APPLICATION

- Around 28 sites and 16 topics
- ALOS-2 and S1 providing excellent coverage of all agreed areas
- ESA trying to support activities that make use of collaboration data sets to secure scientific output
- Ad-hoc acquisitions in context of extreme weather (hurricanes) and disaster (oil spill close to Mauritius)
- Dedicated campaigns including RS-2, TSX and CSK data, as well as ground based measurements
- Joint conference sessions (see LPS 2022, Fringe 2023) to present and collect results of the cooperation

ROSE-L Science Plan

- Plan covers mission development phases and Phase E1 (2028/2029 → end of commissioning phase)
- Expected KO of first projects: Q2/Q3 2023

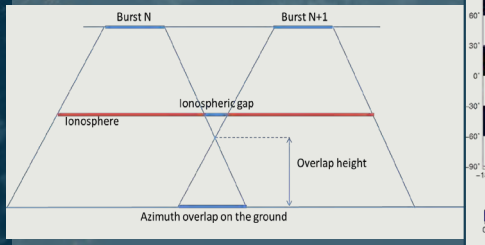
AfriSAR-2 Airborne Campaign

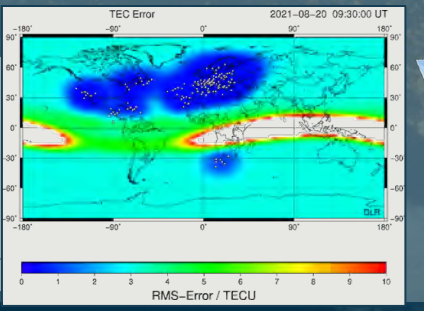
Acquisitions: May-June 2023

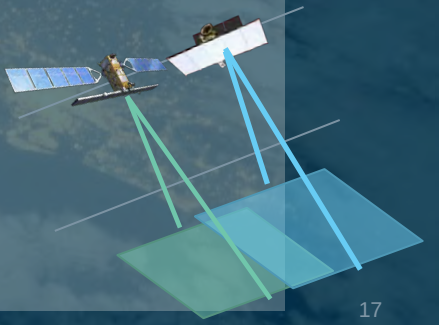
- Relate the temporal changes in P- and L-band polarimetric and interferometric radar signatures with respect to AfriSAR-1 to changes in the forest structure.
- Document the sensitivity of BIOMASS and ROSE-L signals to forest conditions
- Provide feedback on validation and retrieval methods

Ionosphere Mitigation Algorithms

- Consolidate the algorithms for the correction or/and annotation of ionospheric disturbances as a pre-processing step on both single images and on stacks of images
- To support the relevant mission design trade-offs by quantifying benefits of Quad-pol, burst overlap, short baseline with Sentinel-1, etc..







Moving to ARD

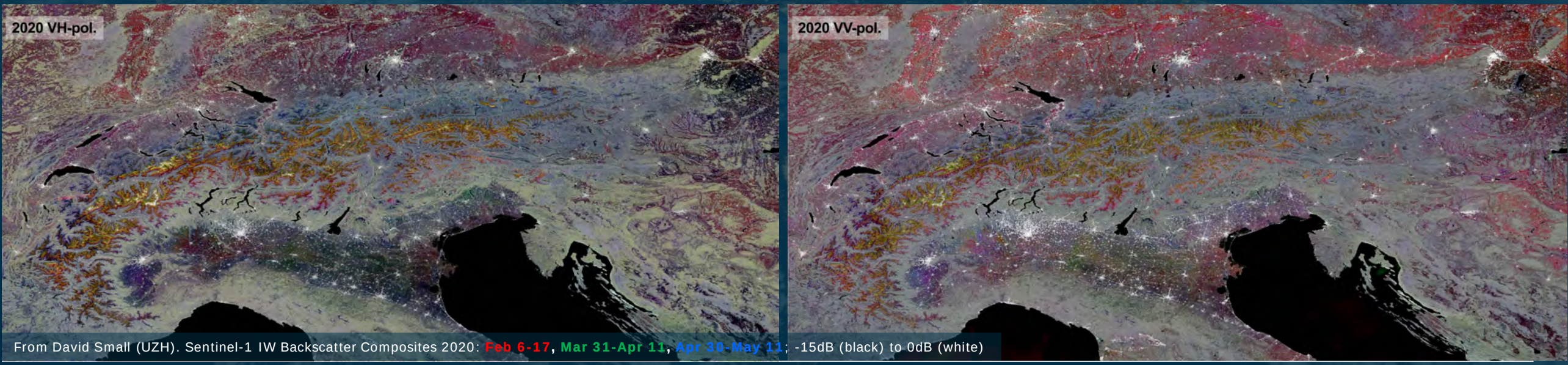
In order to broaden user community on the use of dense time-series

- Provide data products that do not require expert knowledge
- Move from radar geometry (slant & ground range) to map coordinates

GRD product likely to be replaced in the CopEx / Next Gen mission processors by ARD data, including for instance the RTC product (Radiometric Terrain Correction).

RTC: Product family specification of Normalized Radar Backscatter (NRB) is formulated by the CEOS-ARD initiative (https://ceos.org/ard/)

- Backscatter normalized using local scattering area, not incident angle
- Facilitates multi-sensor data integration



Conclusions

ESA with industry and together with EC preparing “expansion” of Copernicus SAR missions

- ROSE-L Mission at L-band as a Copernicus Expansion mission *to address information gaps* and provide new information not yet available through current Sentinel missions

ROSE-L bring new and enhanced capabilities

- High resolution (50m2 for ROSE-L RIWS)
- Low NESZ e.g. -28 dB for ROSE-L
- Wide swath and frequent revisit capability

Sentinel-1, ROSE-L and Sentinel-1 NG shall be addressed as a system (not in isolation)

- ROSE-L same orbit, swath and acquisition geometry as Sentinel-1 (IWS) providing an operational dual-frequency system
- Synergies between C- and L-band expected to lead to enhanced and new information beyond what can be achieved for each mission taken in isolation
- Synergies with other missions such as Earth Explorer Biomass @P-band also need to be further investigated

Work still required to prepare for uptake of ROSE-L by user community (e.g. ionospheric correction, interferometric error budgets, C- and L-band synergies)