living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

The Copernicus SAR Missions:
Sentinel-1 and ROSE-L

Malcolm Davidson (presenting), Lorenzo Iannini, Marcus Engdahl, Pierre Potin, Muriel Pinheiro, Antonio Valentino, Clément Albinet, Thibault Taillade

Tue, May 24, 2022

Other presentations on Sentinel-1 NG and ROSE-L

Thursday – 26.05.2022

08:30 am

B8.08.1 Copernicus Sentinel Expansion Missions - New capabilities for the Copernicus 2.0

Chair(s)

Dr. Craig James Donlon (ESA - ESTEC)
Dr. Mark Drinkwater (European Space Agency)

Room:
Geneva

Topic:
Advance Future Technology for Earth Observation Missions

Form of presentation:
Oral

Duration:
100 Minutes

09:45 am: The Copernicus ROSE-L (Radar Observing System for Europe at L-band) mission

10:40 am: Sentinel-1 Next Generation Mission: Delivering enhanced continuity with C-band SAR

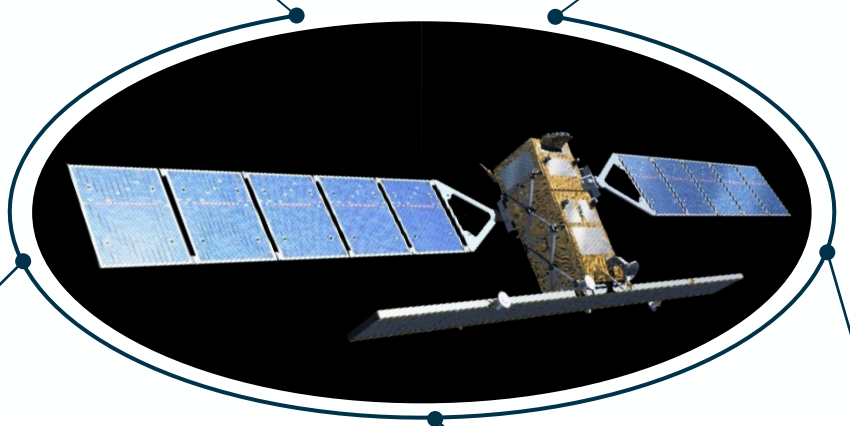
Sentinel-1 Mission in Brief

MISSION PROFILE

- Constellation of two identical SAR C-band (5.405 GHz) satellites: (A & B → C units)
- Near-Polar, sun-synchronous (dawn-dusk) orbit at 693 km altitude
- 7 years lifetime (consumables for 12 years)
- 12-day repeat cycle (each satellite), 6 days for the constellation

OPERATIONS

- Systematic SAR data acquisition using a predefined observation scenario
- Instrument duty cycle of max. 25 min/orbit in High Bit Rate modes (30 min outside eclipse) and 75 min/orbit in Low Bit Rate mode (Wave)



PROGRAMMATICS

- Sentinel-1C launch Q2 2023
- Sentinel-1D currently in storage to be launched as needed

PAYLOAD

- C-Band SAR
  - Centre frequency: 5.405 GHz
  - Polarizations: HH, VV, HH/HV, VV/VH
  - Incidence angle: 20º - 45º
  - Radiometric accuracy: 1 dB (3σ)
  - Radiometric stability: 0.55 dB (3σ), **0.45 (3σ) for S-1 C/D**
  - NESZ: -22 dB
  - DTAR: -22 dB
- **AIS Instrument marine surveillance (for S-1 C and D)**

IMAGING MODES

- Strip Map Mode: 80 km swath and 5x5 m (range x azimuth) resolution
- Interferometric Wide-Swath Mode: 250 km swath, 5x20 m resolution
- Extra-Wide-Swath Mode: 400 km swath and 20x40 m resolution
- Wave Mode: 5x5 m resolution, leap-frog sampled images of 20x20 km

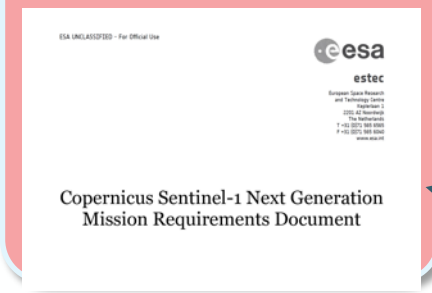
Sentinel-1 FG/NG and Copernicus Services

User Needs

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

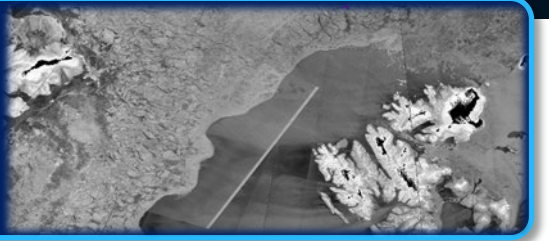
Sentinel-1 NG

Mission Requirements Document



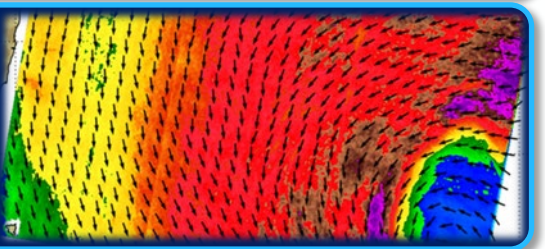
C3S

- 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

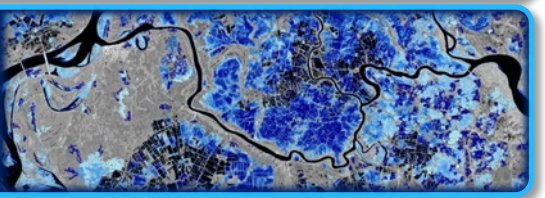
- Land use and land use change, including agriculture and forestry
- Ice sheets & glaciers velocity
- Wet snow extent
- Ground movement
- Soil moisture

EU-GMS

European Ground Motion Service

EMS

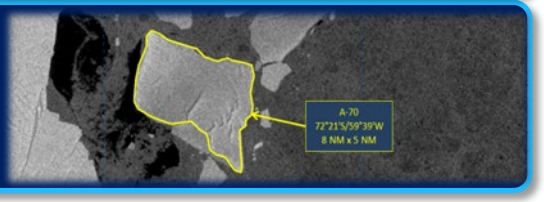
- Flooded area
- Ground movement
- Soil moisture
- Abrupt surface elevation changes



Security

EMSA / FRONTEX

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

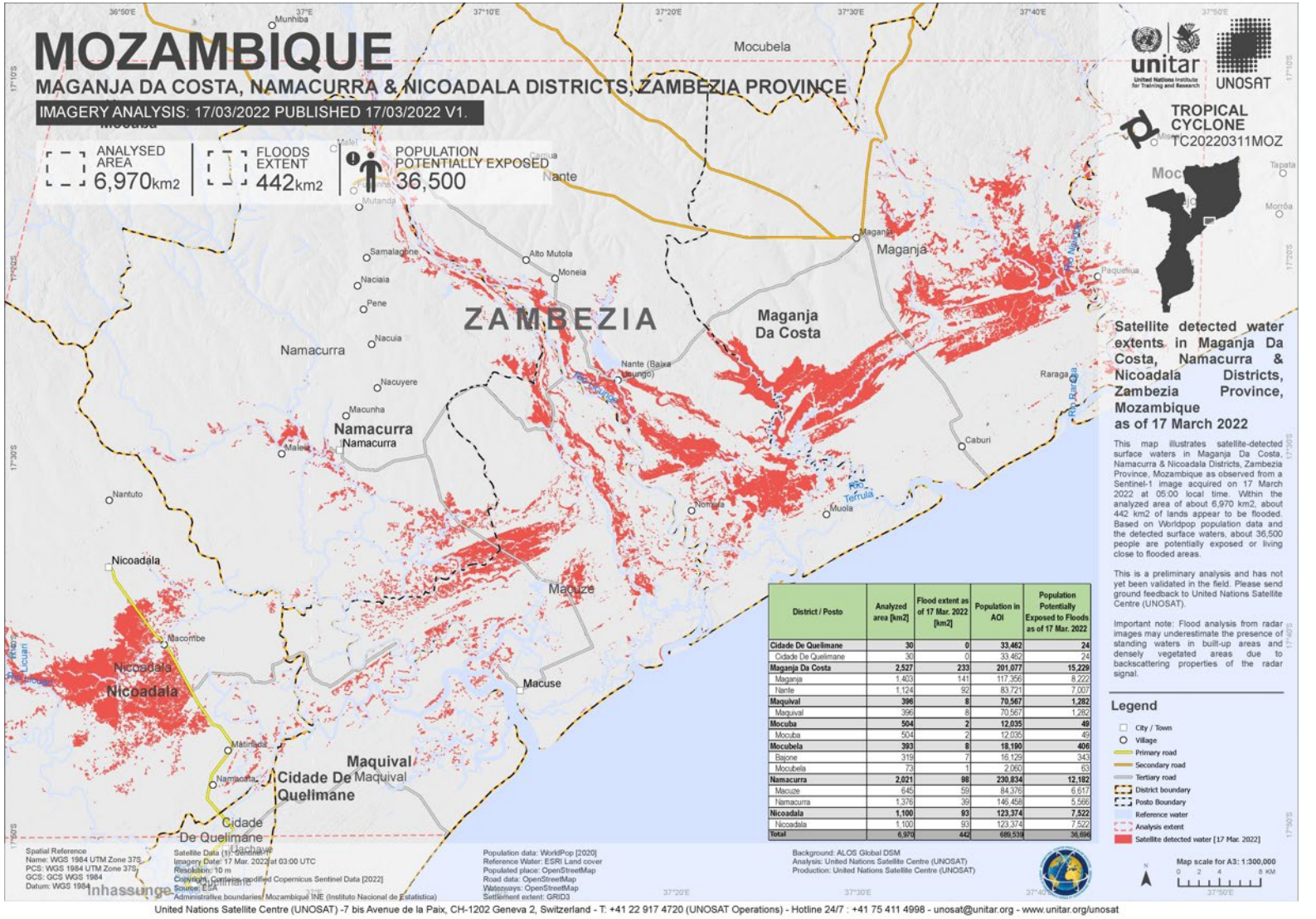


Sentinel-1 Success Stories

Recent example of flood monitoring by Sentinel-1

Call 866 from the International Charter Space and Major Disasters related to **floods in Mozambique**, due to the cyclone Gombe

Flood delineation map based on Sentinel-1A data acquired on 17 March 2022

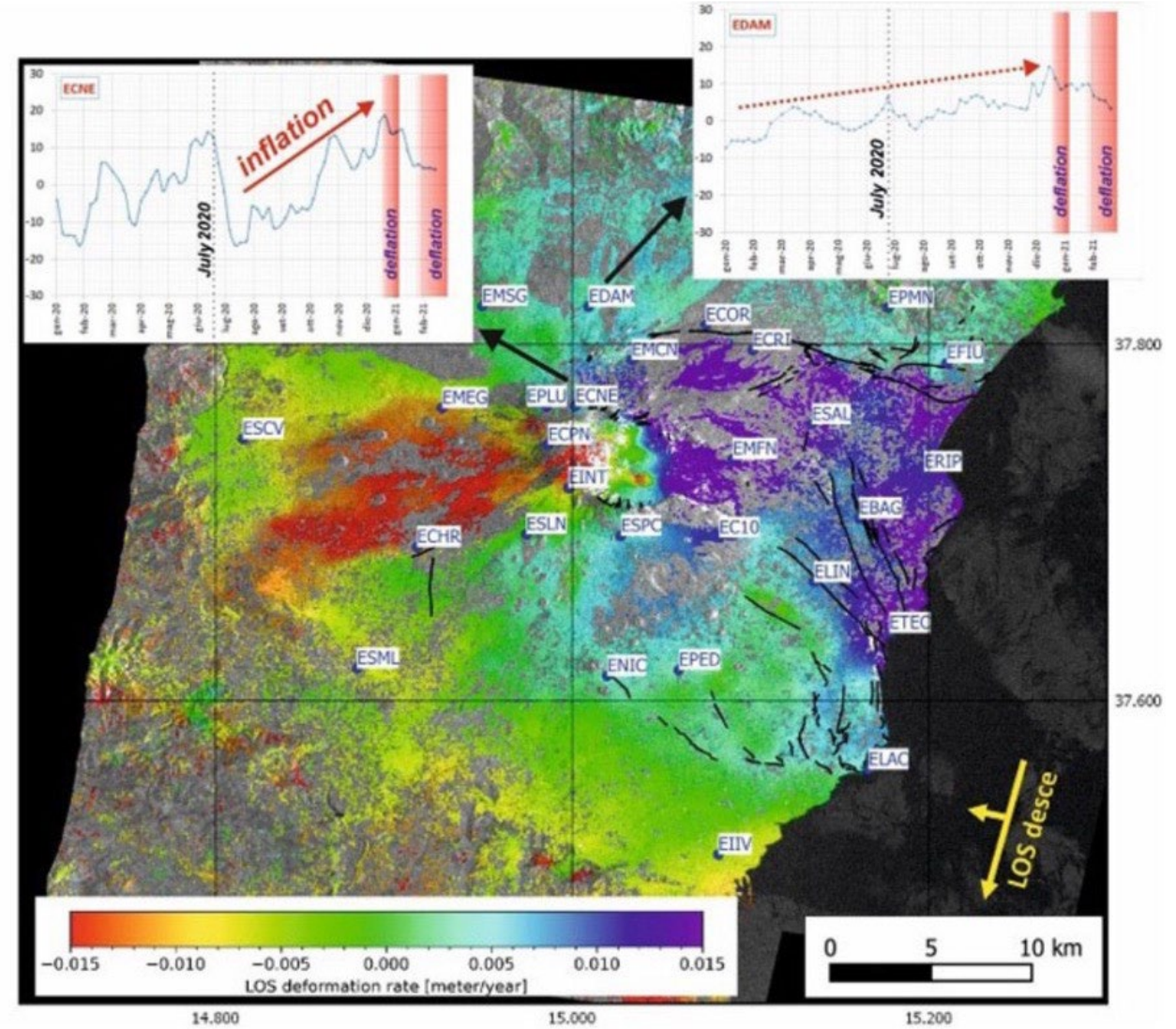


District / Posto	Analyzed area [km2]	Flood extent as of 17 Mar. 2022 [km2]	Population in AOI	Population Potentially Exposed to Floods as of 17 Mar. 2022
Cidade De Quelimane	**30**	**0**	**33,462**	**24**
Cidade De Quelimane	30	0	33,462	24
Maganja Da Costa	**2,527**	**233**	**201,077**	**15,229**
Maganja	1,403	141	117,356	8,222
Nante	1,124	92	83,721	7,007
Maquival	**396**	**8**	**70,567**	**1,282**
Maquival	396	8	70,567	1,282
Mocuba	**504**	**2**	**12,035**	**49**
Mocuba	504	2	12,035	49
Mocubela	**393**	**8**	**18,190**	**406**
Bajone	319	7	16,129	343
Mocubela	73	1	2,060	63
Namacurra	**2,021**	**98**	**230,834**	**12,182**
Macuze	645	59	84,376	6,617
Namacurra	1,376	39	146,458	5,566
Nicoadala	**1,100**	**93**	**123,374**	**7,522**
Nicoadala	1,100	93	123,374	7,522
Total	**6,970**	**442**	**689,539**	**36,696**

Copyright: Contains Copernicus Sentinel data (2022)/ processed by UNOSAT

Copernicus Sentinel-1 captures Etna's inflation

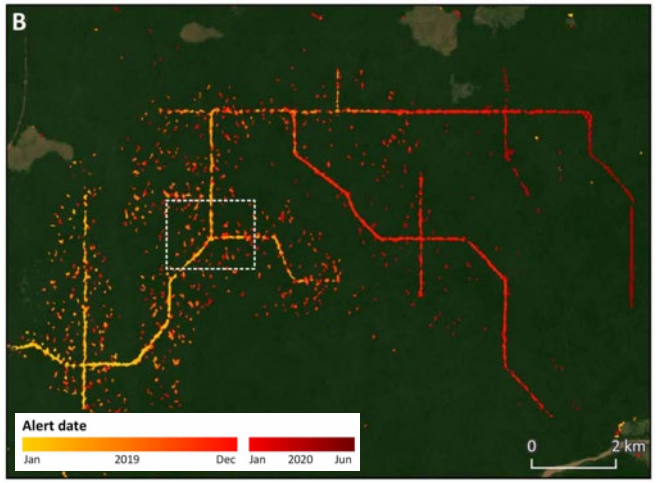
Details of the time evolution of the inflation are reported in the two plots. The East flank shows the deformation related to the persistent flank motion (green-purple area).

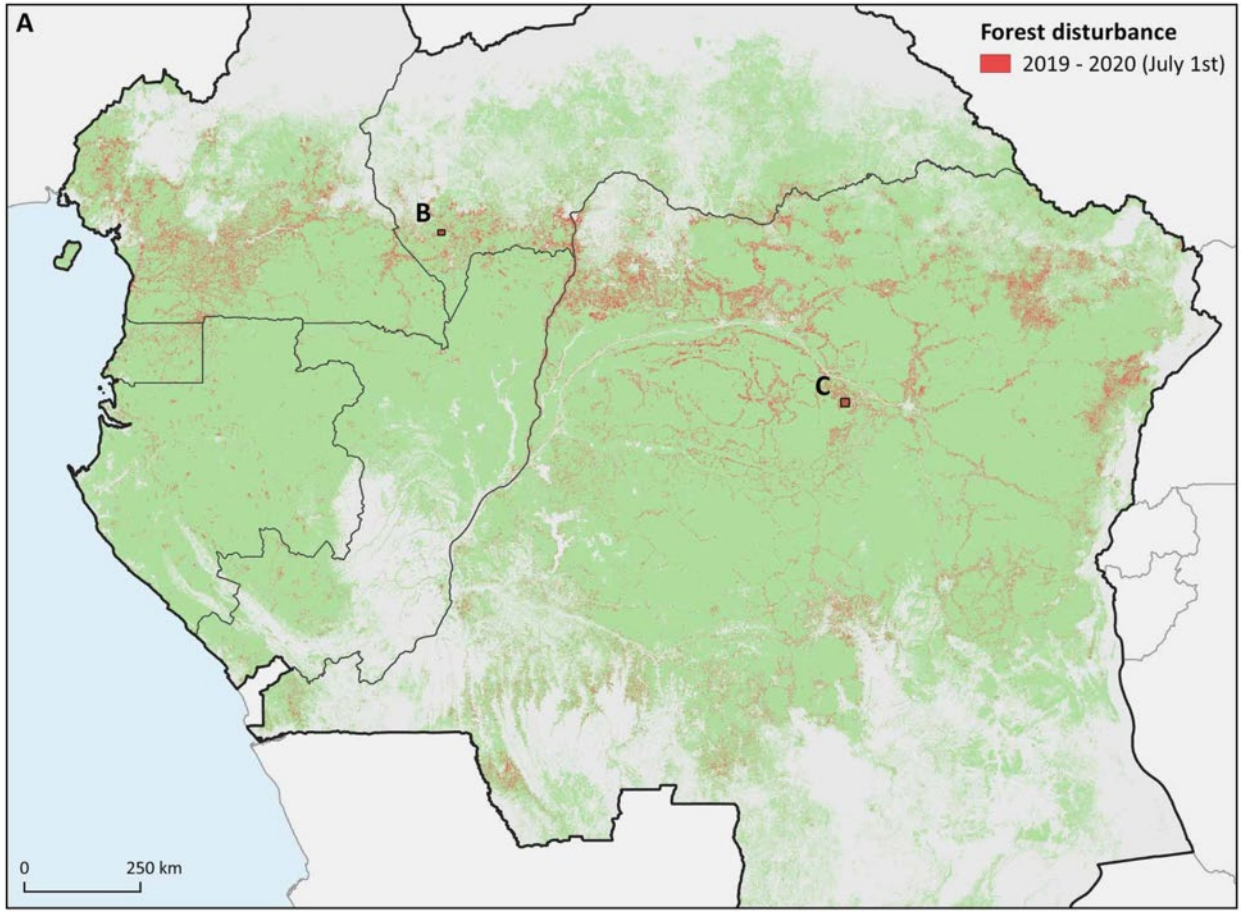


Sentinel-1 essential for forest monitoring

RADD (Radar for Detecting Deforestation)

The RADD alert system reveals forest disturbances caused by selective logging for the Congo Basin's tropical forest for the period 2019 through to 1 July 2020. The red colour marks logging roads and selective logging expansion in the Sangha-Mbaéré district, with tree canopy gaps alongside

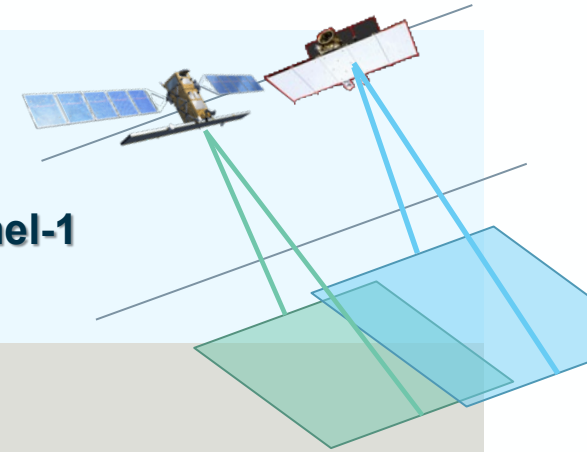




Copernicus SAR Timeline – current and future SAR missions

ROSE-L Mission Design – synergies with Sentinel-1

ROSE-L designed as a system of systems with Sentinel-1/ Sentinel-1 NG

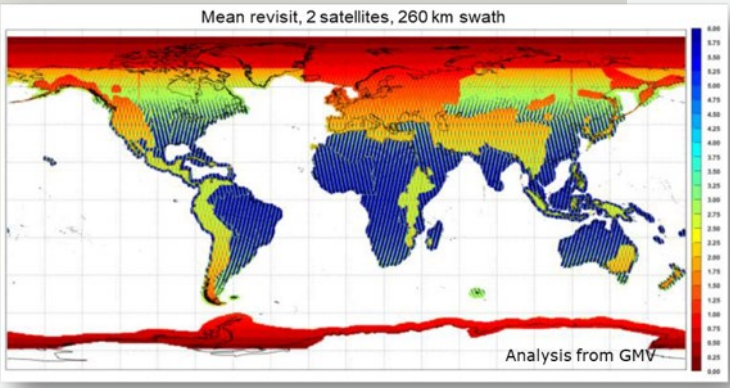


Collocation with Sentinel-1

- Same orbit configuration as Sentinel-1.
- Phasing of the orbital plane adjusted to allow ROSE-L to follow the **same ground track of Sentinel-1**
- Mission design supports option for optimized revisit or as convoy with Sentinel-1

Extensive Global coverage and consistent long-term archive

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



Performant Imaging

- Resolution 25 m2 • Low NESZ (-28 dB) • Dual-pol and Quad-pol capabilities
- On-ground DBF in azimuth open opportunities (e.g. ATI for moving target identification)

Free, full and open data policy

Enabling a **System of Systems approach** and enhanced information products beyond the missions taken in isolation

Geohazards Monitoring – Ground Motion

C-band: Sentinel-1 & Sentinel-1 NG

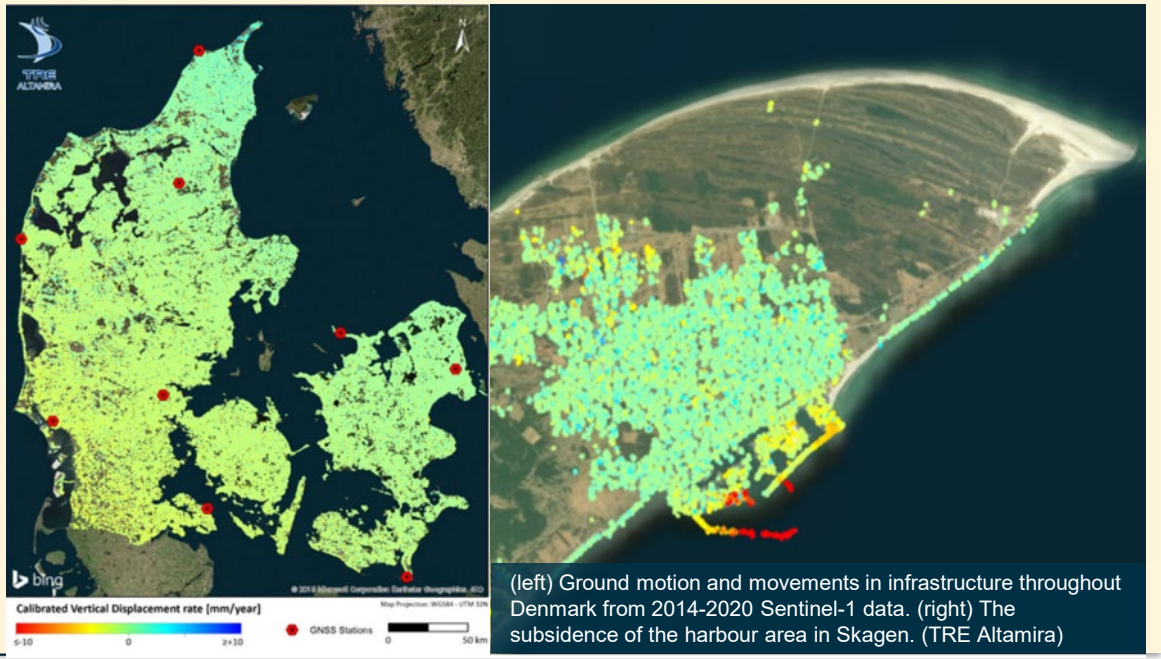
- **Precise mapping of** slow **deformation** thanks to the short wavelength
- High density of **PS in built-in areas**, further enhanced by Sentinel-1 NG resolution
- Established national motion ground services from Member States harmonized by EU-GMS

ROSE-L

- Availability of **motion information in vegetated areas** thanks to the capability of sensing the ground
- **Long term coherence** ensures robustness to canopy development and water/snow events through seasons
- **Robustness to phase unwrapping** in fast deformation scenarios due to the longer wavelengths

Opportunities and Challenges as Constellation

- **Precise, high resolution and robust mapping of deformation**
- **Improved density and characterization of the PS in built-in areas**
- **Opportunity to mitigate troposphere and ionosphere effects, especially when flying in close formation**
- **Sensitivity to 'ghost phases', e.g. from water in soil and canopy, to be considered**



(left) Ground motion and movements in infrastructure throughout Denmark from 2014-2020 Sentinel-1 data. (right) The subsidence of the harbour area in Skagen. (TRE Altamira)

Geohazards Monitoring - Flooding

C-band: Sentinel-1 FG & NG

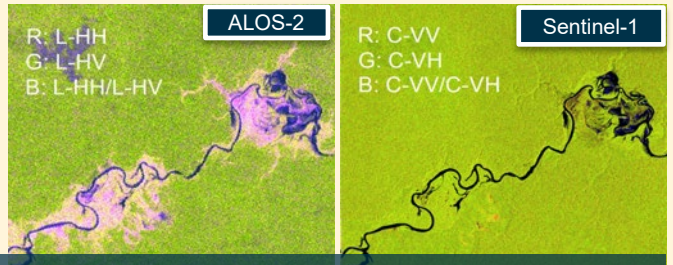
- **High resolution mapping of flood extent,** already exploited by the new Global Flood Monitoring (GFM) in the CEMS
- **Good sensitivity in bare and low vegetated terrains**
- **Enhancements** in delineation and characterization **expected from larger swath and short revisit by Sentinel-1 NG**

ROSE-L

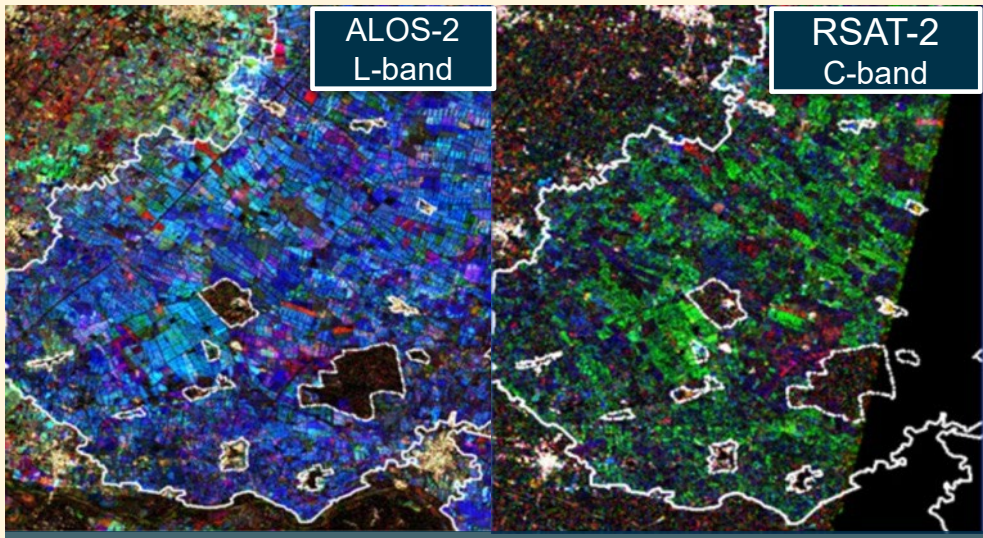
- **Improved sensitivity in densely vegetated terrains**, as longer wavelength can sense the water through the canopy
- **Augmented monitoring of wetlands** (swamp forests) inundation

Opportunities and Challenges as Constellation

- **Enhanced temporal monitoring of the flood thanks to shorter revisit**
- **Opportunity to combine coherences and DP/QP intensity from both wavelength to improve delineation and characterization in complex land cover environments**



Jaú river, Central Amazon Basin, Brazil (S1.90º, W61.70º). Seasonally inundated floodplain forest.
https://ceos.org/document_management/SEO/DataCube/Laymans_SAR_Interpretation_Guide_2.0.pdf



RGB color composite of multi-temporal double-bounce component in a rice field area in Vercelli (Italy). R: May 2015; G: June, 2015; B: July 2015. From Pierdicca et al. 2020. IGARSS

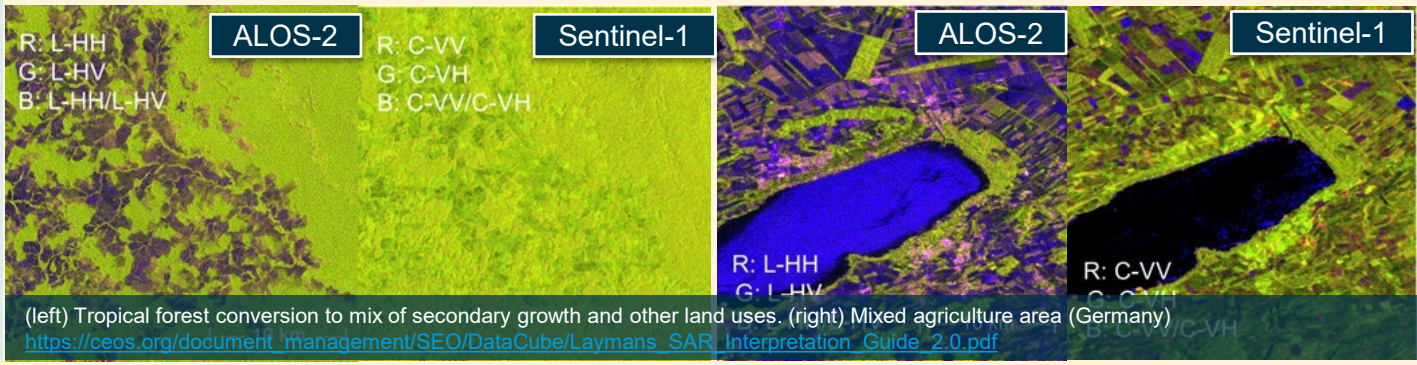
Biomass and LULC Mapping

C-band: Sentinel-1 FG & NG

- **Suitable for mapping crops and low canopy vegetation** with both intensity and coherence. The backscatter saturates and coherence is lost for medium biomass levels
- **Sensitivity to forest disturbances not excellent**, but facilitated by high revisit
- Currently S1 used or planned in several initiatives
  - CLMS HRL (Wetland, upcoming Vegetated and Non-Vegetated Land Cover Component…)
  - DG AGRI activities
  - ESA CCI+ Biomass
  - RADD (Radar for Detecting Deforestation)

ROSE-L

- L-band adding **information on forests with AGB up to 100-150 Mg/ha**, where it can sense the whole structure



(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

Opportunities and Challenges as Constellation

- **Enhanced continuity on deforestation monitoring,** including tropical forests. L-band and C-band are sensitive to changes/losses (e.g. by logging) and suited to map regrowth
- **New timely information on above ground biomass (AGB) and biomes structure/type**
- **Algorithms for LULC mapping and crop tracking, exploiting the complementary sensitivity and the short revisit**

Soil Moisture

C-band: Sentinel-1 FG & NG

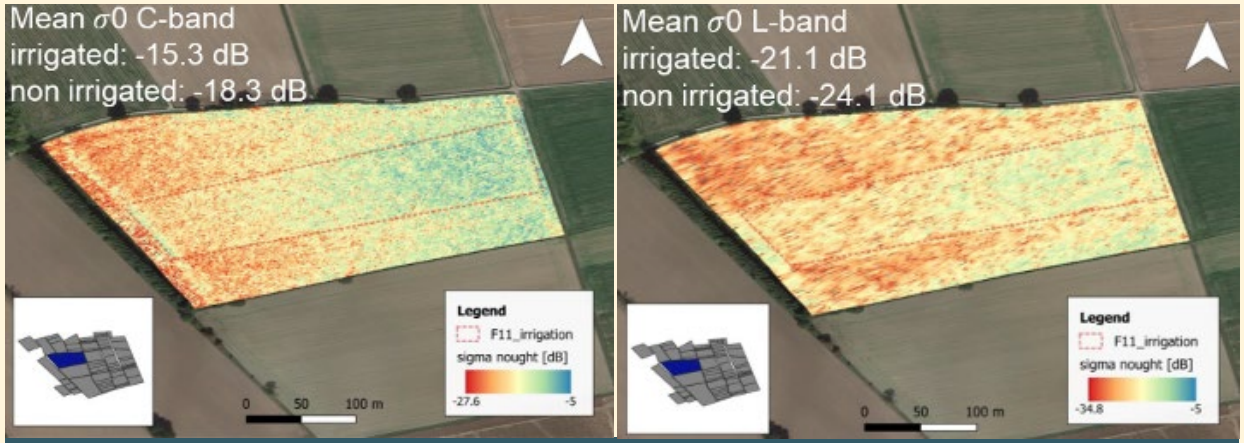
- **Suitable for bare soils and low vegetation areas,** currently exploited by Copernicus services in Surface Soil Moisture (SSM) and Soil Water Index (SWI) 1 km products
- **Sensitive to moisture in upper ~1 cm soil layer**
- **Sentinel-1 further increasing revisit and sensitivity**

ROSE-L

- **Suitable for a broad range of crops and vegetated land**, due to penetration capability of L-band
- Information of **Soil Moisture up to ~5 cm depth**
- **Hard requirement on NESZ**

Opportunities and Challenges as Constellation

- **More frequent high-resolution Soil Moisture information in a broad range of crops and vegetated land**
- **Assimilation of information from different sensors (including L-band radiometers) either on L1 or L2 level**



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

C-band: Sentinel-1 FG & NG

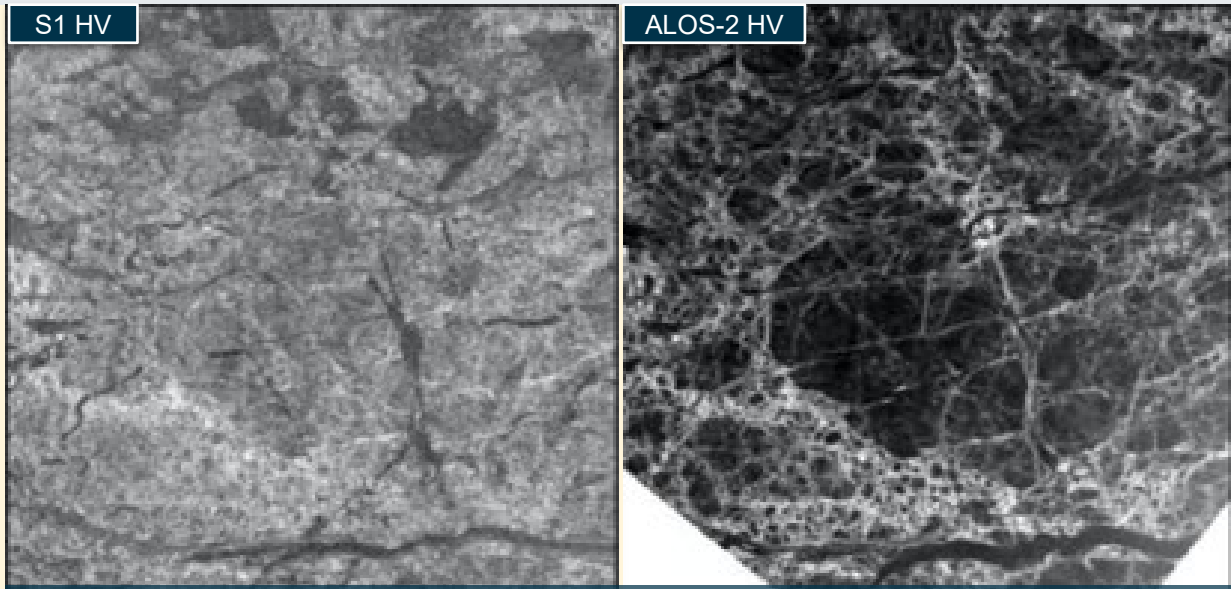
- **Good separability of thin ice types / open water. Beneficial for ice concentration**
- **Sensitive to surface roughness.** Poor sensitivity to larger ice structures, such as fractures or ridges

ROSE-L

- Suitable to **early detection of fractures and fast ice breakup**
- **Easy FY/MY discrimination** during the melt season,
- **Improved discrimination of deformed ice (ridges)** in high-resolution images
- **Less sensitivity to thin ice types and open water**

Opportunities and Challenges as Constellation

- **Daily high-resolution information on hazardous sea-ice and icebergs for navigation and weather/climate services**
- **Improved mapping of sea-ice type, concentration, thickness and drift by flying in formation/convoy**
- **Algorithms for automated assimilation**



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

Ice Sheets and Glacier Velocity

C-band: Sentinel-1 FG & NG

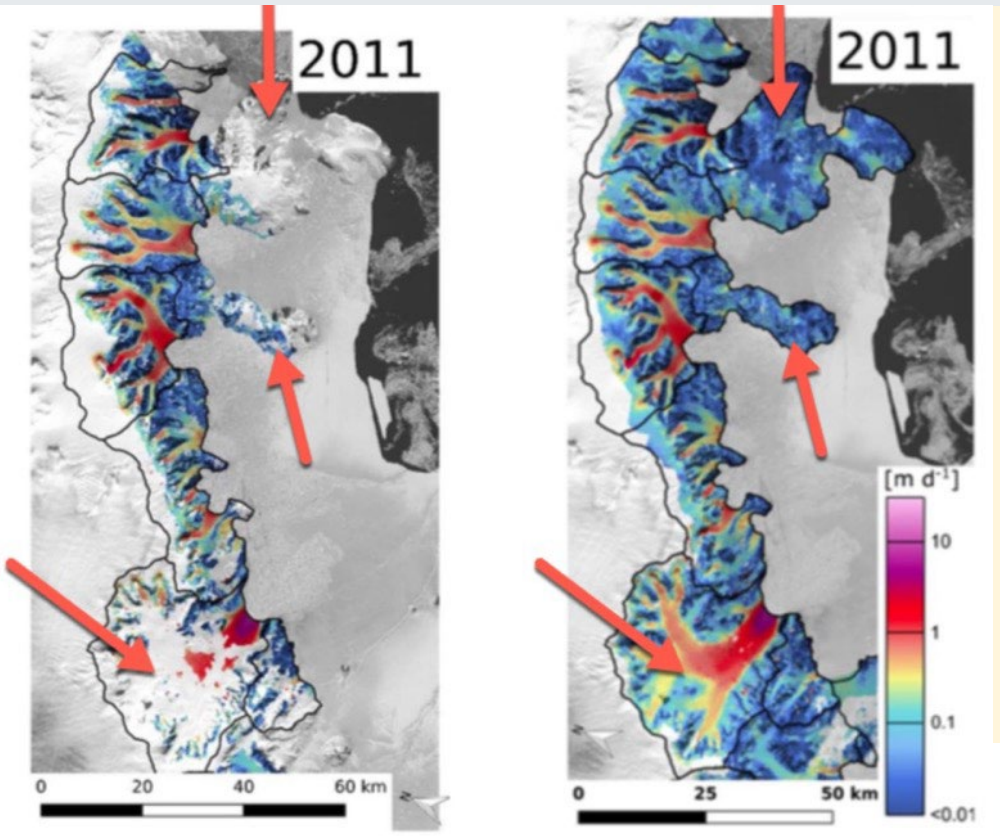
- **Ice displacement monitored with offset tracking**, as decorrelation is fast.
- **Sentinel-1 NG will make the use of InSAR easier than for S1-FG**

ROSE-L

- **More suitable for InSAR on ice sheets and glaciers,** thanks to a deeper and more stable signal
- **Impact of ionosphere on InSAR and on geo-location** accuracy (for offset tracking) is stronger than in C-band

Opportunities and Challenges as Constellation

- **Augmented sampling will benefit land ice motion estimates (L-band more robust to large changes, C-band less affected by ionosphere)**



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

C-band: Sentinel-1 FG & NG

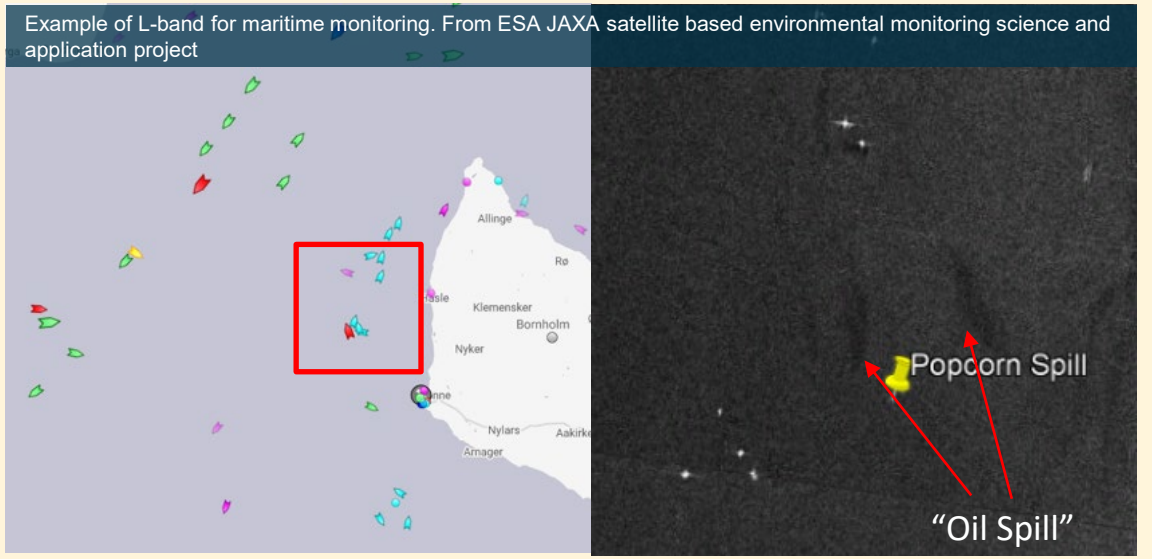
- **Currently FG well-established (and precious) at operational level** for maritime and marine monitoring, **NG enhanced swath and resolution will further augment capabilities**
- **Impact of sea state in vessel and iceberg detection**
- **Good sensitivity to oil spills**, also thanks to dual-polarization capability

ROSE-L

- **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

Opportunities and Challenges as Constellation

- **Assimilation addition enhances S1-based applications, especially on iceberg detection**
- **Consolidation of GMF in L-band needed for marine applications and for performance assessment maritime monitoring algorithms**



Agora seed questions

Regular C- and L-band SAR acquisitions in the same geometry are enormously powerful !

- For which applications can the use of Sentinel-1 (FG/NG) and ROSE-L measurements have an unprecedented scientific impact?
  - What would be the low-hanging fruits to address first?
- Where do we need to direct R&D activities in order to be ready?
- Any gridding requirements besides "on the same grid" at L1/L2/ARD?
- Which L2 products or applications require joint processing of dual-mission L1 data, for timeliness or other reasons?