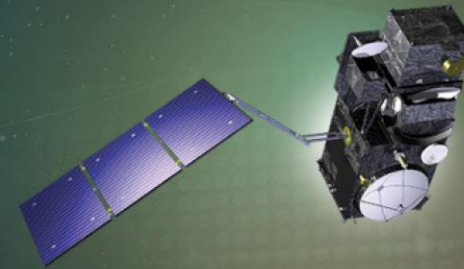




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18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

The new Sentinel-3 Thematic Products for LAND surfaces

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Introduction

ESA and MPC (Mission Performance Cluster) developed specialized delay-Doppler and Level-2 processing chains for Sentinel-3 STM over Inland-water, Sea-Ice, Land-Ice surfaces to generate dedicated thematic level-2 products with enhanced performances

1) Sentinel-3 Surface Topography Mission (STM) over Land:

- ❑ Evolution from Land Processor to three Thematic processors.

2) The new Sentinel-3 Thematic products:

- ❑ General overview and main product contents.

3) Processing Baseline evolutions:

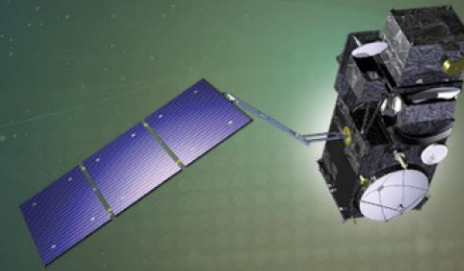
- ❑ Short-term and mid-term strategies to improve the level-2 processing and data quality.



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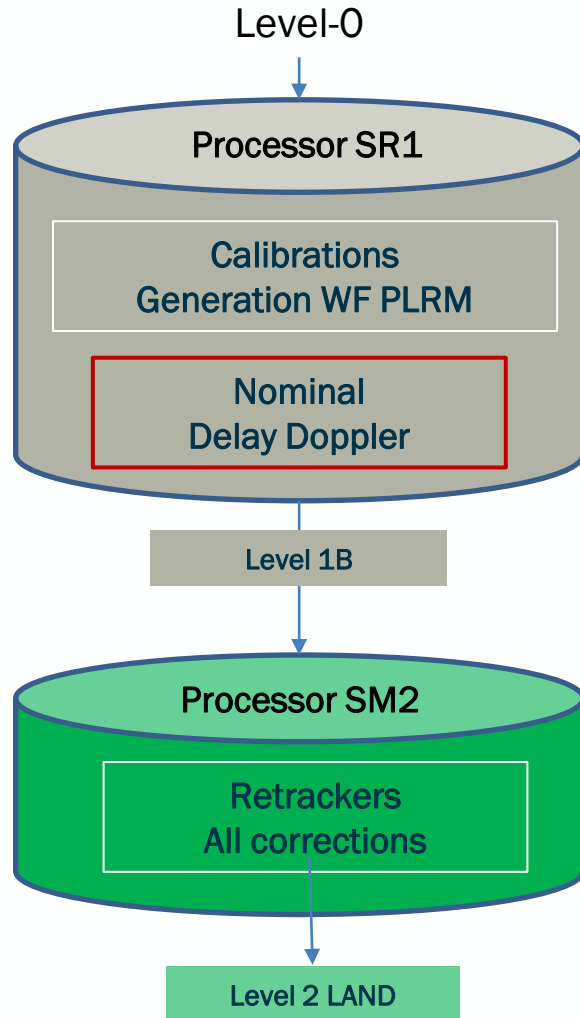
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1 – Sentinel-3 STM Land Processing Baseline: *Evolution towards Thematic Land processors*



Current operational processor



Level 1: **One** SR1 processor.

Level 2: **One** SM2 processor.

Nominal Delay Doppler applied at Level 1

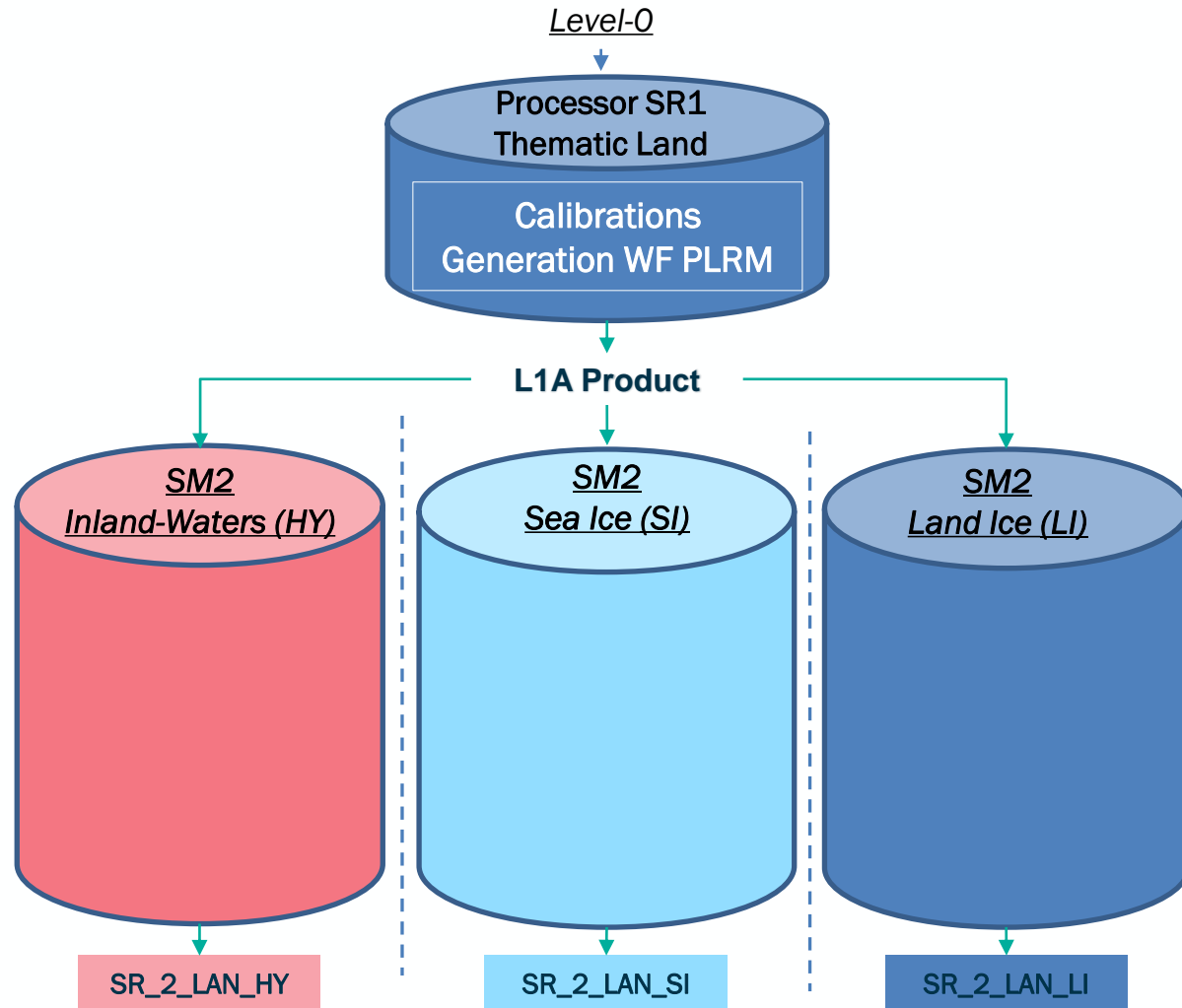
One global **user product** as L1 output:

Level 1B.

One **L2 LAND product**

- Standard_measurement** file, containing the main variables (geophysical estimations, geophysical and instrumental corrections),
- Enhanced_measurement**, which contains additional information for expert users (radar waveforms, MWR brightness temperatures),
- Reduced_measurement** file, containing a subset of the main 1-Hz variables.

New thematic processors for LAND surfaces



Level 1: One SR1 processor with one user product as L1 outputs:

- ❑ Level 1A.

Level 2: Three independent SM2 processors, with three L2 thematic product covering the surfaces:

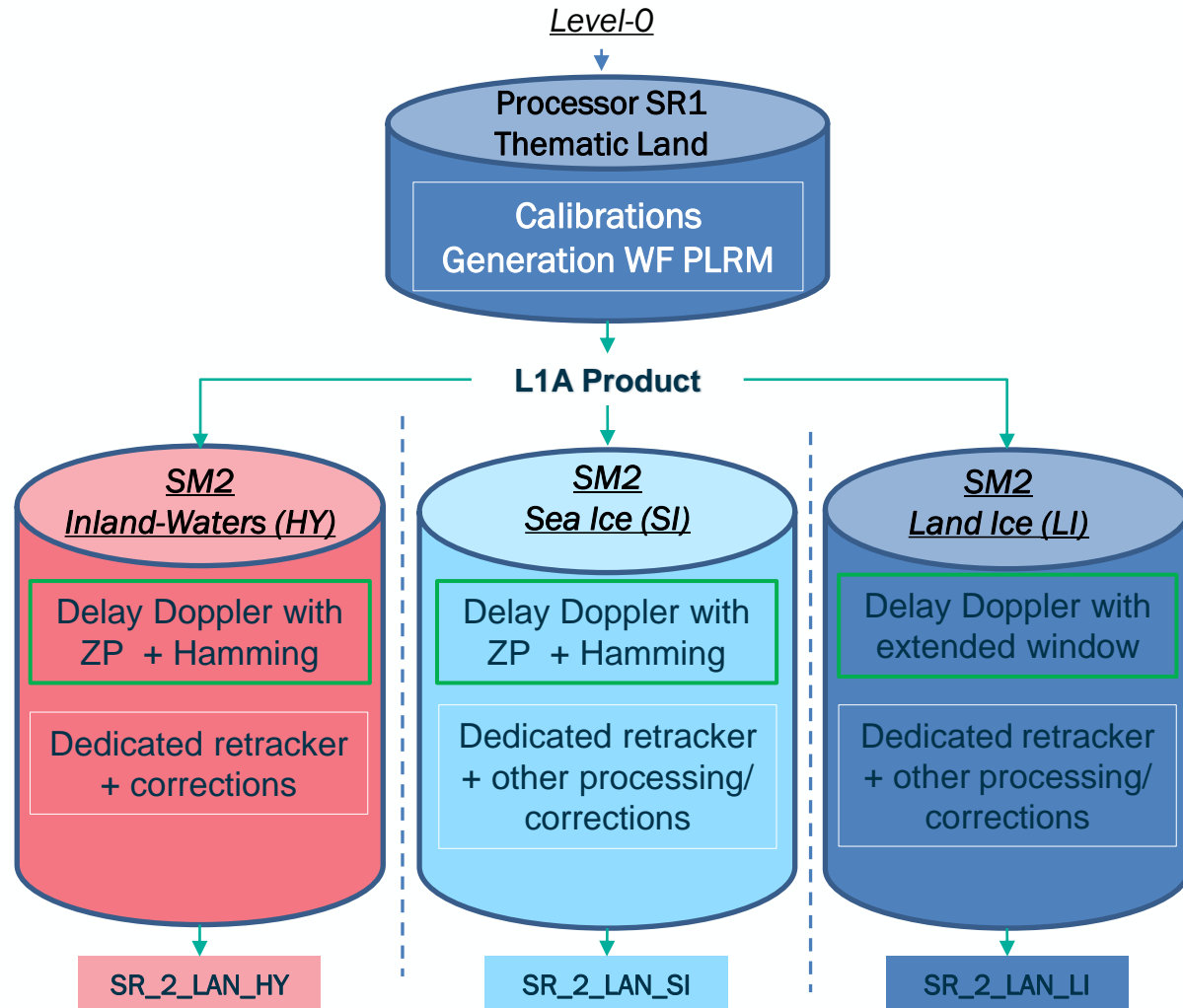
- ❑ Hydrology : S3*_SR_2_LAN_HY,
- ❑ Sea-Ice: S3*_SR_2_LAN_SI,
- ❑ Land-Ice : S3*_SR_2_LAN_LI.

Two NetCDF files for each thematic products:

- ❑ Standard_measurement,
- ❑ Enhanced_measurement.

The operational production is planned to start in Q2 2023, but S3 Land Altimetry Thematic products are anyway generated and available since July 2022 from the ESA Open Access Hub.

New thematic processors for LAND surfaces



Separated/dedicated delay-Doppler for each processor

- ❑ Better flexibility to upgrade each processing chain, to address the particularities of the three thematic surfaces
- ❑ The Sentinel-3 LAND thematic products will evolve and improve more efficiently over time.

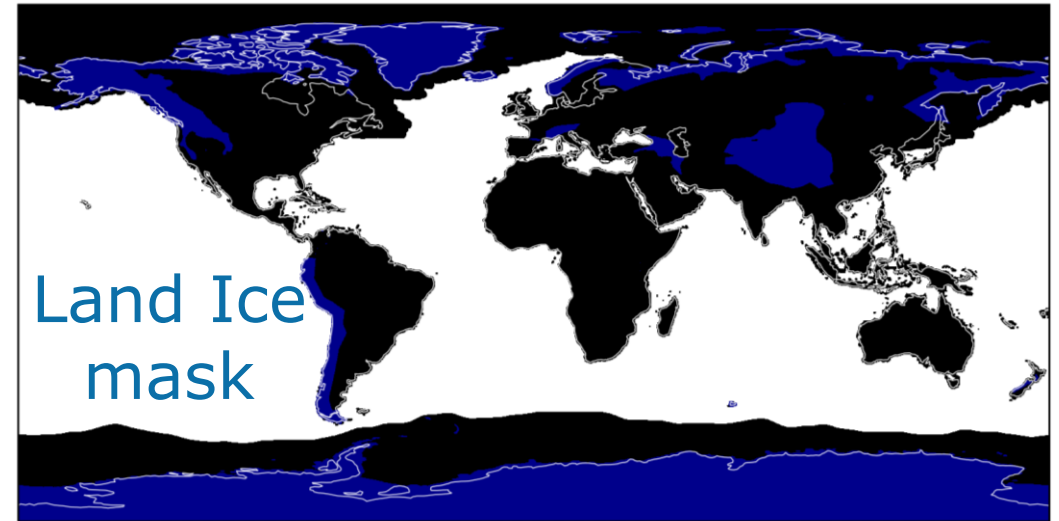
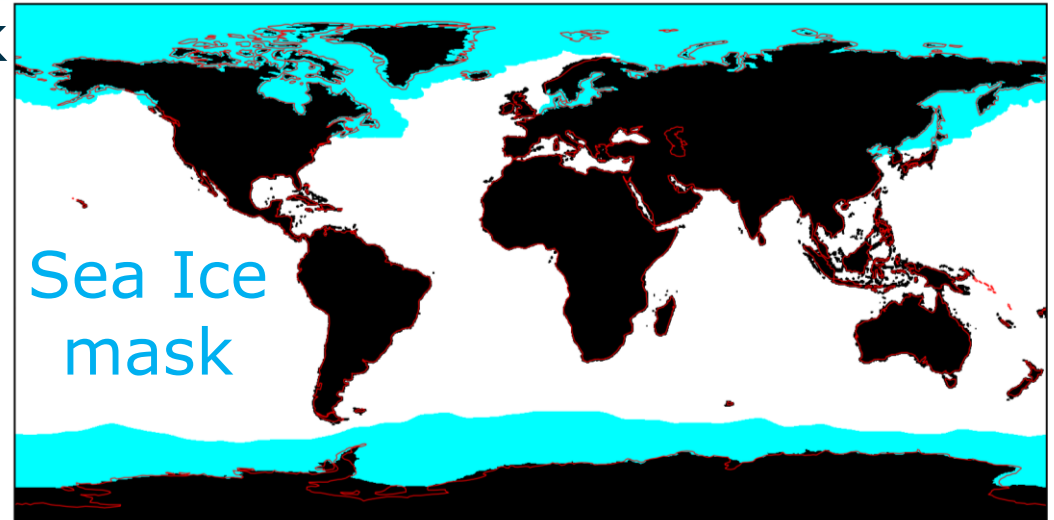
SI and HY include **Zero-Padding** and **Hamming filtering**,

- ❑ better sampling sharp leading edges, and
- ❑ reduces the effect of the side-lobes of the azimuth impulse response over specular surfaces.

LI includes a delay-Doppler processing with “**extended-window**”, to improve the data coverage over the ice margins.

Overview of the Sentinel-3 thematic mask

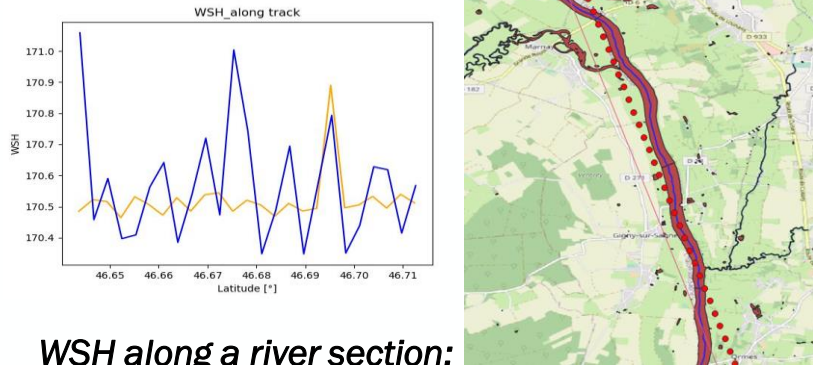
- ❑ Each Sentinel-3 Land Thematic products will cover their dedicated areas, defined in a Thematic Mask.
- ❑ While the tracks of the current global LAND products are processed and delivered “pole-to-pole”:
 - ❖ Sea Ice and Land Ice products will be “equator-to-equator” (to ensure data continuity over the poles).
 - ❖ Hydrology products will remain “pole-to-pole”.



Preliminary assessment of the Sentinel-3 STM thematic products

- At the beginning of 2022, **Test Data Set (TDS)** of the **new thematic products** were generated (information available in Sentinel-OnLine).
- First analyses performed by the MPC Expert Support Laboratories (ESL) show that **performances meet the expectations**, the data quality is **greatly improved** over the 3 surfaces (**=> more information available in the dedicated ESL talks**).

Hydrology



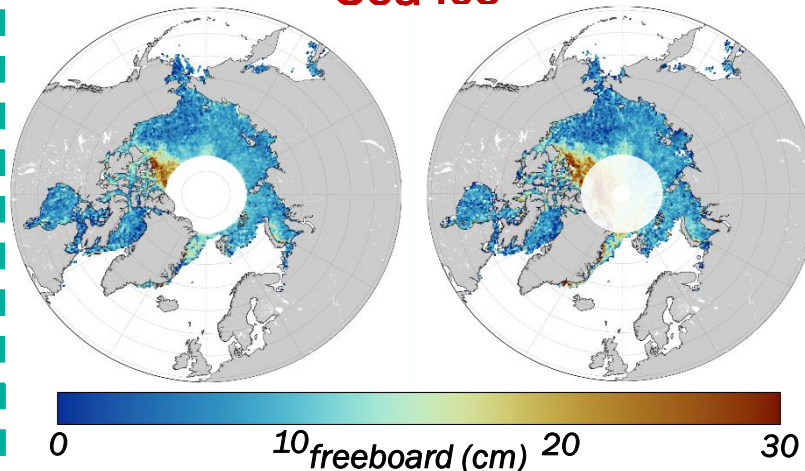
WSH along a river section:

blue = current LAND products

orange = new HY thematic products

Over lakes, average noise level of WSH decreases by about 15%. Precision over rivers strongly enhanced too

Sea Ice

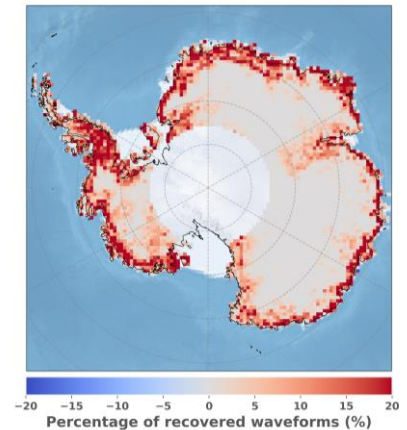


January/February 2020 gridded freeboard

Freeboard is now in overall agreement with CS-2 (CS2: ICE Baseline-D, limited to 81° here)

Land Ice

Maps showing the percentage of recovered valid waveforms*



*based on SNR and waveform quality flag

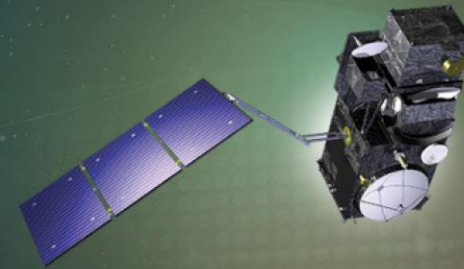
Significant amount of valid waveforms are recovered over the ice margins



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2 – The upcoming Sentinel-3 STM Land Thematic products

General overview and main product content

The new Sentinel-3 LAND Thematic products:

Product content

- ❑ Compared to the current operational Sentinel-3 Land products, **no main new parameters/variables were introduced, for now** (*see next slides, dedicated to Processing Baseline evolutions*).
- ❑ **The content of the current operational Sentinel-3 Land products was reviewed by the MPC**, to address the user's expectations. Only relevant parameters were selected and kept for each surface/thematic.
- ❑ **Nonetheless, many parameters/variables remain common to the 3 Thematic products** (*geolocation information, geophysical/instrumental corrections, auxiliary data... => more details in back-up slide*).
- ❑ **For Sea Ice and Hydrology products**, with the introduction of the zero-padding in the delay-Doppler processing, **SAR waveforms are now available in 256 samples**.



Sentinel-3 Hydrology Thematic product: main data contents

Main geophysical estimations from altimetry	Variable name	Algorithms
Surface topography for lakes and rivers	elevation_ocog_20_ku	OCO2/ICE-1 retracker Bamber et al. (1994)
Backscatter coefficient for lakes and rivers	sig0_ocog_20_ku	
Altimeter range dedicated to large lakes (<i>oceanic retracker</i>)	range_water_20_ku	SAMOSA retracker Dinardo et al. (2015)
Backscatter coefficient dedicated to large lakes (<i>oceanic retracker</i>)	sig0_water_20_ku	
Additional variables from altimetry	Comments	
Geophysical estimations from the sea-ice retracker	=> See next slide dedicated to Sea Ice products	
Auxiliary data	Comments	
Geoid estimation	EGM 2008 model	
Sea Ice concentration	From the OSI SAF data product "OSI-430-a"	



Sentinel-3 Sea Ice Thematic product: main data contents

Main geophysical estimations from altimetry	Variable name	Algorithms
Sea Ice classification (open_ocean / floes / lead / unclassified)	surf_type_class_20_ku	Freeboard processing chain from MSSL , documented in an upcoming Handbook Retracking: over leads: Giles retracking method; over floes: a threshold first maximum retracker. Tilling et al. (2018) Sea Ice classification based on the sea ice concentration and waveform peakiness
Sea Ice Surface Height (over leads and floes)	sea_ice_ssha_20_ku	
Interpolated Sea Ice Surface Height over the floes	int_sea_ice_ssha_20_ku	
Radar freeboard	freeboard_20_ku	
Additional variables from altimetry	Comments	
Sea Ice surface type derived from altimetry and MWR measurements	6-states ocean/sea-ice flag indicating open water or sea-ice type (i.e. first-year ice, multiyear ice, wet ice...). References: Tran et al. (2009)	
Geophysical estimations from OCOG/ICE-1 and SAMOSA , in SAR and P-LRM	/	
Auxiliary data	Comments	
Sea Ice concentration	From the OSI SAF data product "OSI-430-a"	



Sentinel-3 Land Ice Thematic product: main data contents

Main geophysical estimations from altimetry	Variable name	Algorithms
Surface topography	<i>elevation_ocog_20_ku</i> <i>elevation_ice_sheet_20_ku</i>	OCOG/ICE-1 retracker Bamber et al. (1994)
Backscatter coefficient	<i>sig0_ocog_20_ku</i> <i>sig0_ice_sheet_20_ku</i>	UCL ice sheet retracker Wingham and Wallis (2010)
Latitude and Longitude of relocated elevations	<i>lon_cor_20_ku</i> <i>lat_cor_20_ku</i>	Using slope models derived from auxiliary DEM generated by Helm et al. (2014)
Additional variables from altimetry	Comments	
Outputs from ICE-2 retracker , only applied to P-LRM waveforms	Range, Sigma-0, Leading edge width, First Trailing edge slope, Second Trailing edge slope. Reference: Legresy and Remy (1997)	
Waveform quality flag dedicated to land ice measurements	Parameter " <i>waveform_qual_ice_20_ku</i> ", providing results in different tests performed on the waveform: power, thermal noise, variance, presence of leading edge, high/low peakiness	
Ice-sheet snow facies derived from altimetry and MWR measurements	14-states flag " <i>ice_sheet_snow_facies_flag_01_ku</i> ", indicating the type of the ice-sheet snow facies. References: Tran et al. (2008)	



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3 – Processing Baseline evolutions

Short-term and mid-term strategies to improve the level-2 processing and data quality

One of the main scope of the MPC is to ensure that the products meet the user requirements, therefore:

- ❑ **The Sentinel-3 LAND Processing Baselines will evolve over time based on different inputs/drivers:** *keep the products as close as possible to the state-of-the-art, account for studies/assessments performed by the MPC ESL, account for user requirements, solve any anomalies detected in the processing.*
- ❑ **ESA and the Sentinel-3 MPC particularly listen to the feedbacks/recommendations provided during S3VT and QWG meetings.** These recommendations are documented and traced (*as reported in ESA/P.Féménias talk*).
- ❑ **The products evolution is under the MPC responsibility.** In co-operation and discussion between the Expert Support Laboratories (ESL) the ESL Co-ordinator, Service Manager (SM) and ESA Technical Officer.
- ❑ **A clear process is established to ensure traceability and rationality in the implemented evolutions.** A Roadmap document contains all the potential evolutions envisaged for Sentinel-3, with associated maturity and priority levels. The document is routinely discussed and updated by the MPC team.

Short-term evolutions

Processing Baseline evolutions under technical feasibility assessment

	Brief Description	Impact in L2 products	Recom.	Surface
OLTC information in the HY products	To inform users if the OLTC was “fine-tuned” for a dedicated target	New dedicated variable(s) in L2 product	S3VT/ QWG	HY
Pekel information in the HY products	To provide “Pekel’s occurrence” in L2 products, giving a probability of water at nadir location (Pekel et al., 2016)	New dedicated variable(s) in L2 product	MPC ESL	HY
Towards Sea ice Thickness estimation	To provide Sea Ice Thickness estimations, using the Sentinel-3 radar freeboard (more a “mid-term” evolution => see next slides)	SIT estimations (+ <i>snow depth & ice type</i>)	S3VT/ QWG	SI
TFMRA retracker	To estimate the altimeter range in the first leading edge of the waveform (Helm et al., 2014)	New range and surface elevation estimates	S3VT/ QWG	LI
Antarctica and Greenland surface flag	A dedicated surface flag for Antarctica and Greenland in L2 products to discriminate between ice sheet / ice shelf / land From BedMachine data set (Morlinghem et al., 2020)	New surface flag in L2 products + improved elevations over ice shelves	MPC ESL	LI
Waveform classification from Neural Network	A waveform classification, based on a Neural Network algorithm using different waveform parameters (geometrical and/or geophysical when possible) (Poisson et al., 2018)	New variables in L2 products, giving information about waveform shape	S3VT/ QWG	All

Mid-term evolutions of Hydrology Thematic products:

Key evolutions (2024 and beyond)

UnFocused-SAR at 80 Hz

To increase the posting rate for improving the data sampling, especially valuable for small targets. Preliminary investigations in studies funded by ESA / CNES showed improvements on L3 derived products. In addition, several FRM sites currently being defined in St3tart are over <300m rivers.

Retracking improvements

*Need of retrackers adapted to the target characteristics (size, roughness). Assessments/benchmarks are required to review the possible current solutions (SAMOSA+/++, numerical retracker with mean square slope, sinus cardinal retracker, others ?...). Besides, **how to run a processing such as CNES Lake Processing Prototype (LPP) given operational constraints ?***

River information from external data (slope, width, mask ...)

Slope correction is critical to build L3 time series and for validation activities. River width will be complementary information to Pekel's occurrence.

Mid-term evolutions of Sea Ice Thematic products:

Key evolutions (2024 and beyond)

Towards Sea Ice Thickness (SIT) computation

with S3 radar freeboard as input, and snow depth + sea ice type from Auxiliary Data (or MWR/SRAL)

The computation of the SIT will have to be done step by step, by evaluating the different options available for snow depth and sea ice type.

Upgrade of the freeboard processing chain

Along-track filtering and smoothing to improve the precision, and recover more data ? Better discrimination between leads and floes ?

Retracking improvements

Towards a common physical retracker for leads and floes. Solutions from SAMOSA+/, CLS fast-Adaptive, NOAA retracker... to be tested/evaluated. Analysis of roughness and snow penetration effects.

Mid-term evolutions of Land Ice Thematic products:

Key evolutions (2024 and beyond)

Improved relocation method

to reduce the so-called "slope induced error"

- State of the art is Roemer et al. (2007), directly searching for closest range in DEM. New approaches with simulation coupled to HR DEM are promising (see talk from Aublanc et al.)*
- These methods are challenging regarding operational constraints (CPU time, memory usage...)*

Retracking improvements

- R&D studies are needed to develop such a retracker (especially in snow modelling)*
- Land Ice ESL first envisage to characterise and discriminate effects from surface topography and volume scattering in the waveform shape*

Relocated estimations over additional ice caps and glaciers

(and not only Antarctica / Greenland)

Other mid-term evolutions envisaged

- **Common: Unfocused SAR processing at 80 Hz**, to provide a finer sampling of surface topography
- **Common: FF-SAR**, over specular surfaces (hydro, sea ice) there are issues due to closed-burst chronogram (replicas), but there are still perspectives to use FF-SAR over small hydrological targets. Over ice sheet, dedicated L2 processing are needed to exploit the high resolution
- **Common: Uncertainties** provided in the products, based on work/studies performed by the MPC ESL
- **Hydrology: Lake Ice Thickness (LIT) estimation** (*on-going studies in the frame of ESA S6-JTEX project*)
- **Hydrology: Better processing of multi-peak waveforms** (*=> long term evolution, studies needed*)?
- **Sea Ice**: Potential improvement of the **multi-state ocean/sea-ice flag** indicating sea ice type
- **Land Ice: New surface topography information** provided in L2 products, extracted from **auxiliary DEM**
- **Land Ice: A quality flag** dedicated to the estimated surface elevation

The new Sentinel-3 LAND Thematic products: Useful information

- ❑ The Sentinel-3 LAND Thematic products are already being generated routinely since June 2022, for **S3A and S3B**, as **pilot products**, NTC timeliness (*in parallel of the current operational LAND products*).
<https://sentinels.copernicus.eu/fr/web/sentinel/-/copernicus-sentinel-3-stm-land-thematic-products-operationa-release-of-pilot-data-set/1.6>
- ❑ These pilot products can be downloaded in the **Copernicus Data Hub**: <https://scihub.copernicus.eu/>
- ❑ The document describing the **Product Data Format Specifications (PDFS)** is available at this link:
<https://sentinels.copernicus.eu/documents/247904/2753172/Sentinel-3+Product+Data+Format+Specification+L2+Land.pdf>
- ❑ More general information related to Sentinel-3 is available in **Sentinel OnLine**:
<https://sentinels.copernicus.eu/fr/web/sentinel/missions/sentinel-3>
- ❑ A **Product Handbook** is coming soon to describe the new Sentinel-3 LAND Thematic products



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BACK-UP



Many variables remain common to the 3 level-2 Thematic products:

- **Geolocation information:** latitude, longitude, altitude at nadir. Altimeter tracker range (*in SAR mode + P-LRM + C band*)
- **Geophysical corrections:** to account from delays due to troposphere and ionosphere, to correct for effects due to tides (oceanic, solid earth, pole tide)
- **Instrumental corrections:** internal path delay, USO drift, antenna-COG distance...
- **Distance and angle to the coast** from GSHHG v2.3.7
- **Two different surface flags**
- **Brightness temperatures from radiometer** (238°K and 365°K)
- **Waveform peakiness:** from 2 different methods
- **Radar waveforms** in SAR, P-LRM and C band + the Range Integrated Power (RIP) of delay-Doppler stack
- **Scale factors for the Sigma-0 computation**
- **Ocean Depth or Land Elevation from ACE2 model** (Berry et al., 2010)
- **Delay-Doppler Stack parameters:** STD, Skewness, Kurtosis, look angles....

New Sentinel-3 STM LAND thematic



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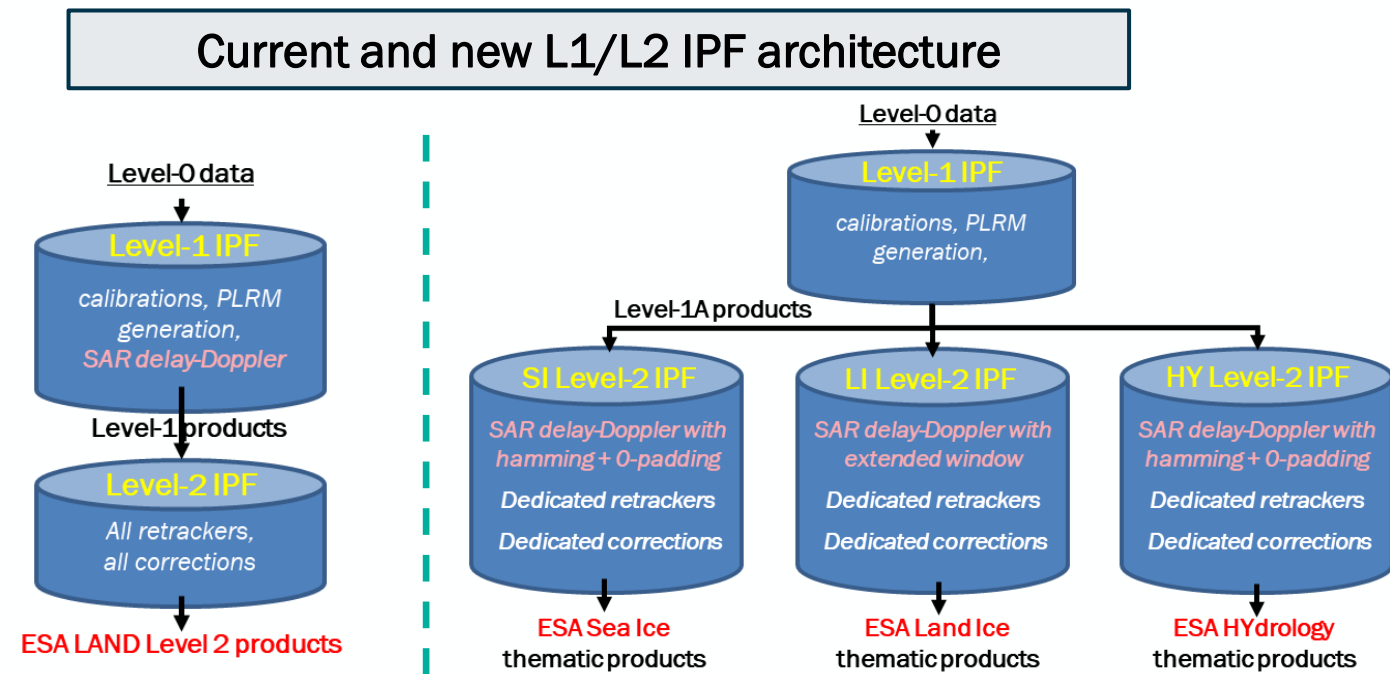
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- ESA and the MPC developed specialized delay-Doppler and Level-2 processing chains for Sentinel-3 STM over Hydrology, Sea-Ice, and Land Ice, to generate dedicated thematic level-2 products with enhanced performances

- New specific processing are already implemented in the upcoming Processing Baseline for optimizing the performances over the 3 surfaces.

(mainly Hamming and zero-Padding over sea-ice and hydrology; delay Doppler with extended-window over land ice)



With new dedicated delay-Doppler and level-2 processing chains, the Sentinel-3 LAND thematic products will evolve and improve more efficiently over time.



Overview of Sentinel-3 thematic mask over hydrology areas



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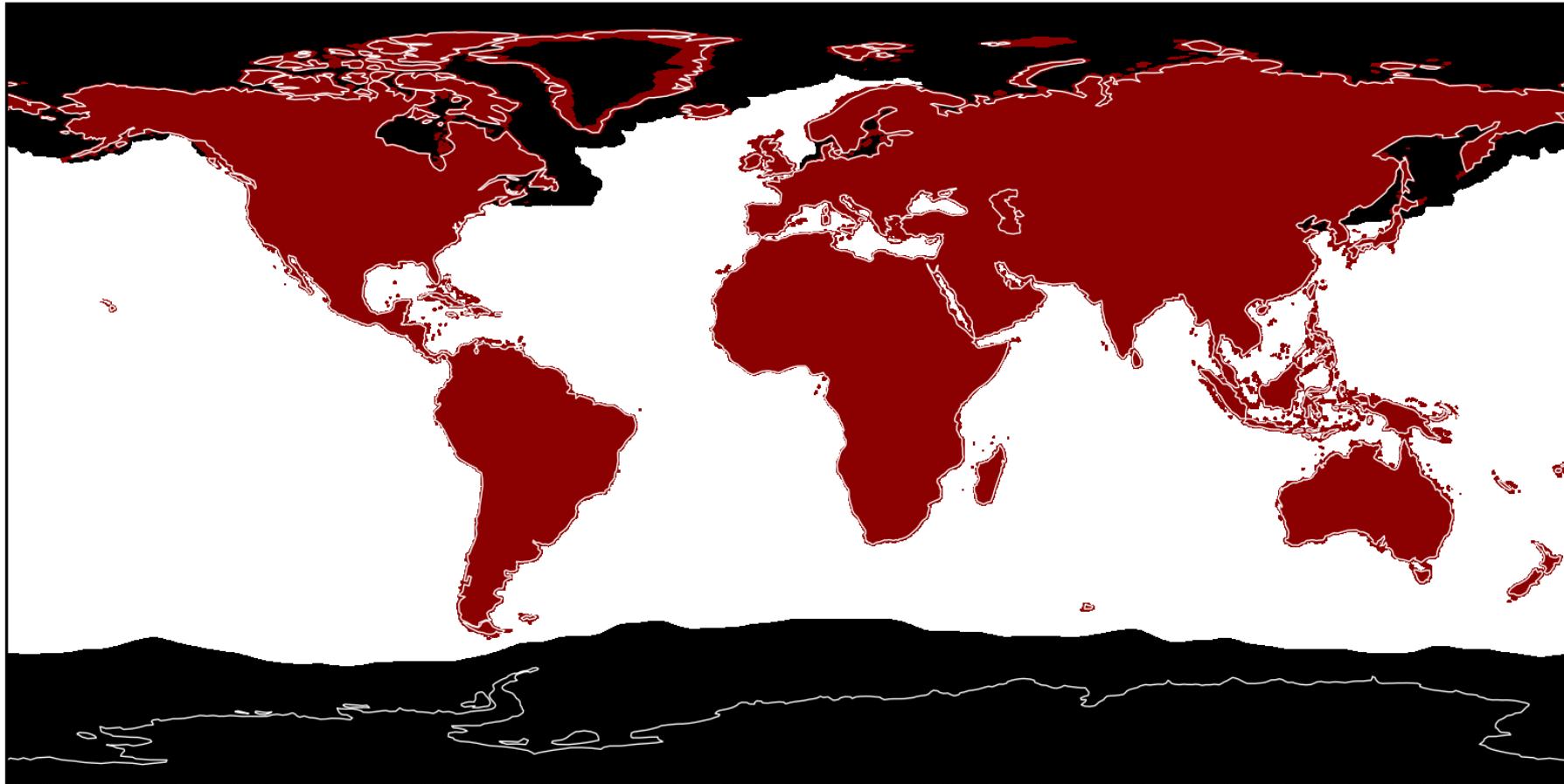


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Sentinel-3 Land thematic mask, binary view of hydrology areas (in red)



Overview of Sentinel-3 thematic mask over sea ice areas



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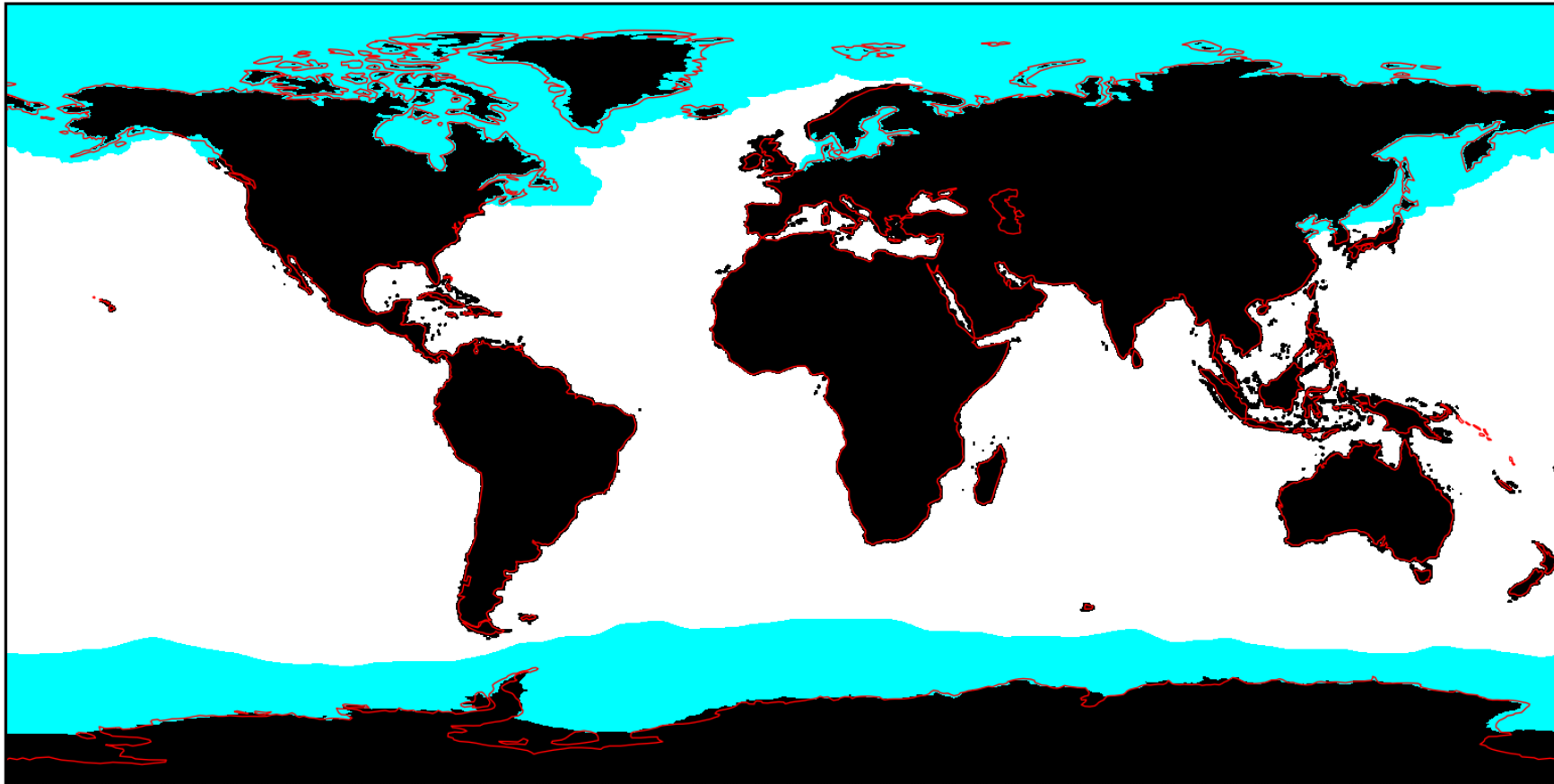


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Sentinel-3 Land thematic mask, binary view of sea ice areas (in cyan)



Overview of Sentinel-3 thematic mask over **land ice areas**



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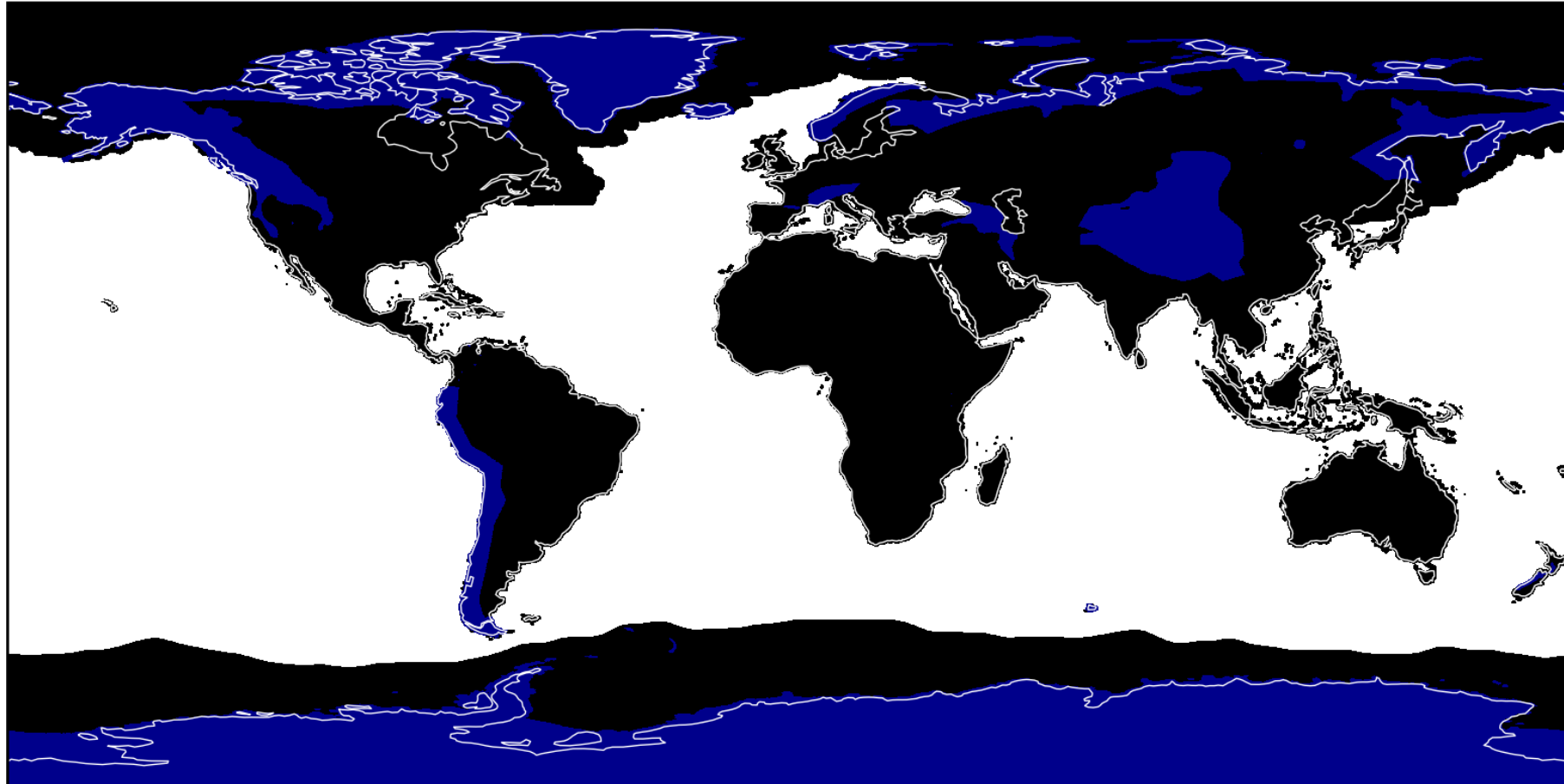


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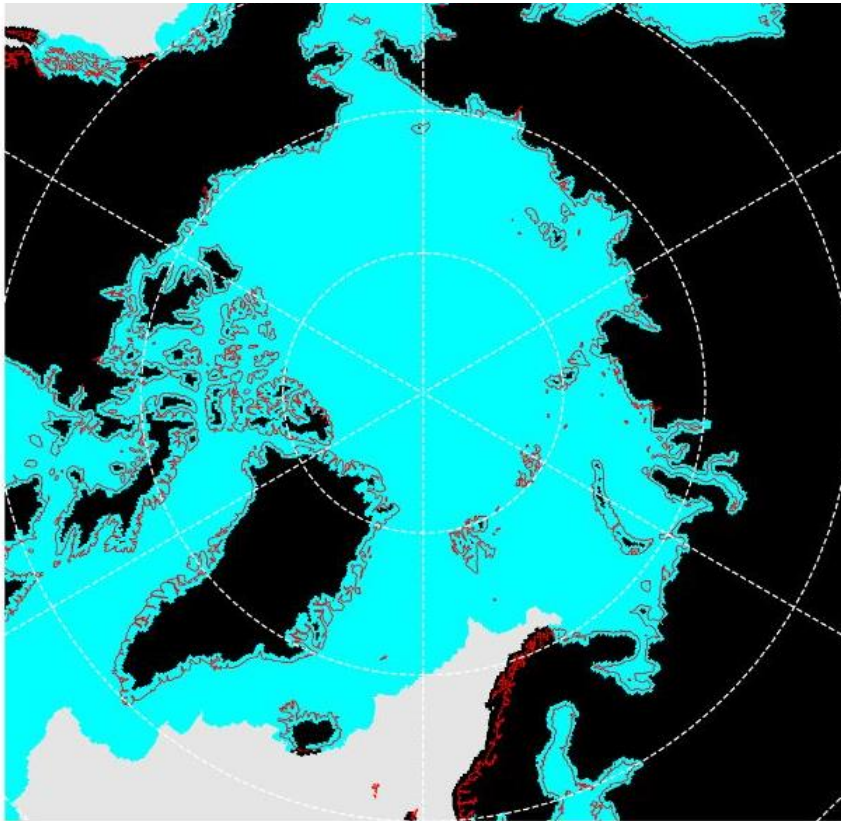
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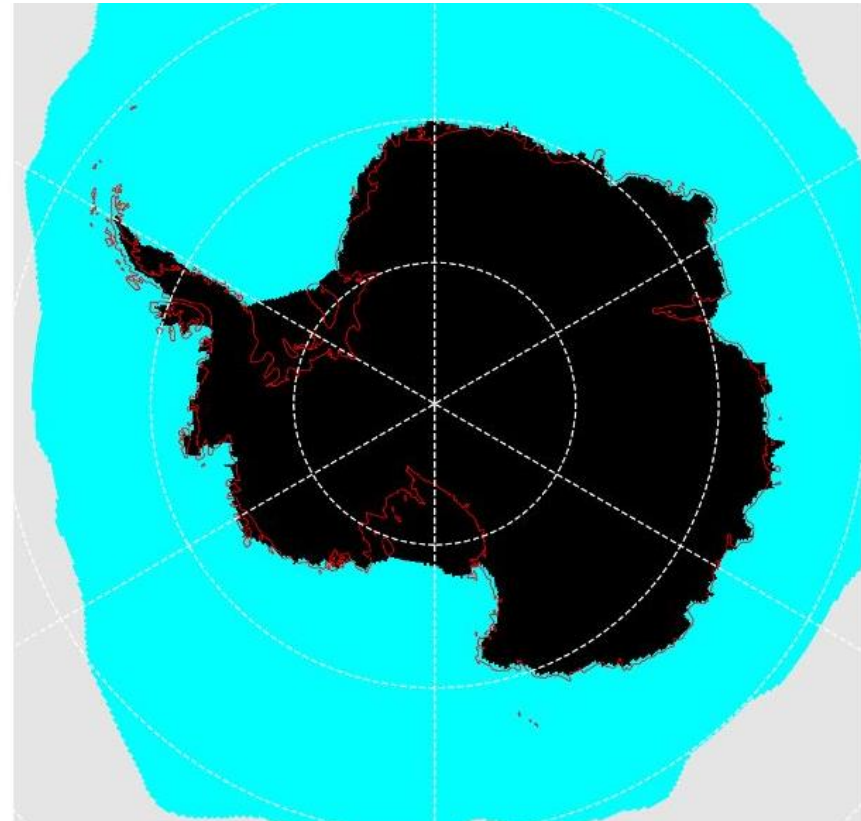
Sentinel-3 Land thematic mask, binary view of land ice areas (in blue)



Sentinel-3 Land thematic mask, binary view of **Sea Ice** areas in North/South stereographic projection



Northern Hemisphere



Southern Hemisphere