BIG SAR ANALYSIS READY DATA: REALISING THE ESA-DLR SENTINEL-1 NORMALISED RADAR BACKSCATTER PRODUCT

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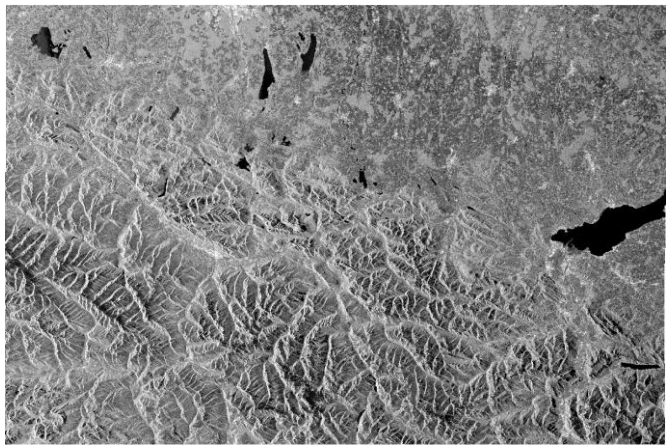
DLR

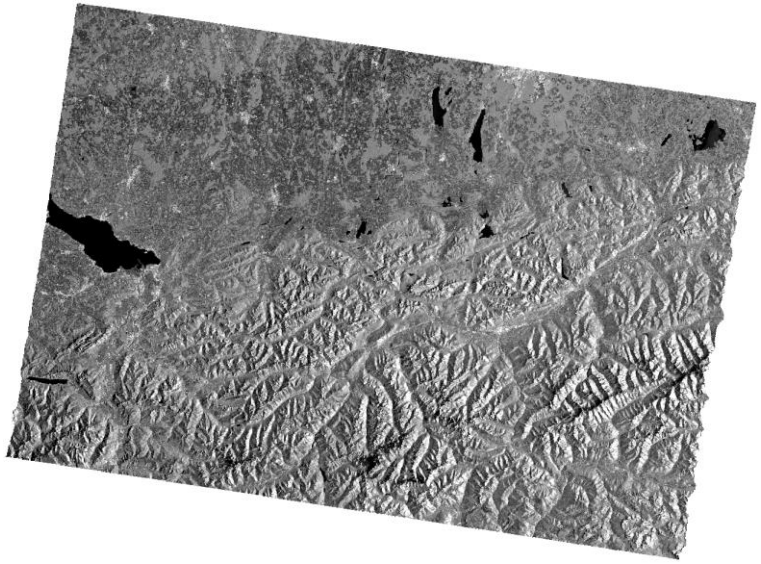
Sentinel-1

- Synthetic Aperture Radar (SAR) mission of the Copernicus programme
- Operated by ESA
- Free and open data policy
- Application examples:
  - Marine monitoring: ship traffic, ice, sea state
  - Land monitoring: flood mapping, ground deformation
- Revisit time: 12 days (6 with two satellites)
- Satellites:
  - Sentinel-1A: 2014-04-03 –
  - Sentinel-1B: 2016-04-25 – 2022-08-03
  - Sentinel-1C: 2023
- Total data volume as of Sept. 2022:
  - Ground Range Detected (GRD): 2 PB
  - Single Look Complex (SLC): 10 PB

SAR Image Processing

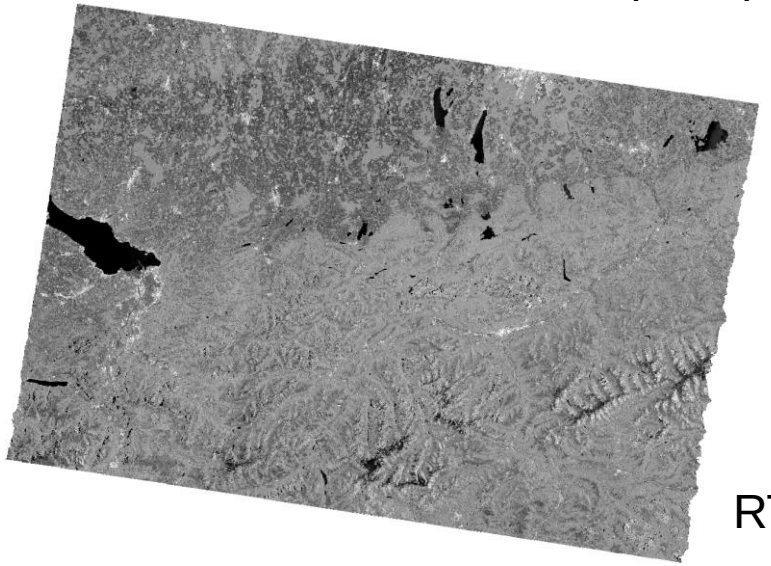


Calibration
Noise removal
geocoding



Ellipsoid-based sigma nought

+ radiometric terrain correction (RTC)



RTC gamma nought

CEOS Analysis Ready Data

Current Product Family Specifications

PFS	Type	Version	Download	Metadata Spec	Last Updated
Surface Reflectance	Optical	5.0	PDF | Word	-	8 June 2020
Surface Temperature	Optical	5.0	PDF | Word	-	8 June 2020
Normalised Radar Backscatter	Radar	5.5	PDF | Word	XLSX	13 May 2022
Polarimetric Radar	Radar	3.5	PDF | Word	XLSX	13 May 2022
Aquatic Reflectance	Optical	1.0	PDF | Word	-	23 February 2022
Ocean Radar Backscatter	Radar	1.0	PDF | Word	XLSX	21 September 2022
Nighttime Lights Surface Radiance	Optical	1.0	PDF | Word	-	2 October 2022

https://ceos.org/ard/

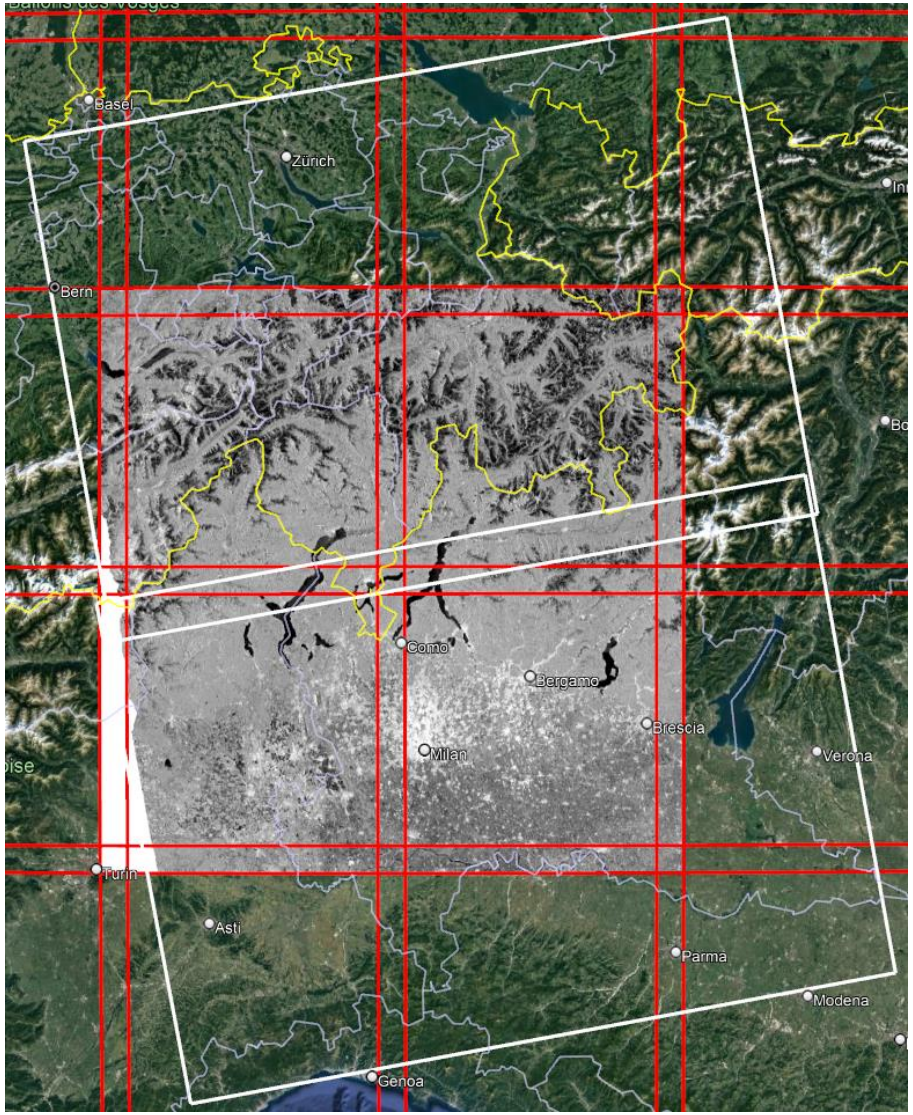
CEOS Analysis Ready Data

Under Development / Assessment

Product	CEOS-ARD Type	PFS Version	Agency	Mission(s)	Access (DOI)	Info	Self Assessment	Peer Review	Sample Products
...									
Landsat L2 Provisional Aquatic Reflectance	Aquatic Reflectance	v1.0	USGS	Landsat 8, 9	TBA	Link	TBA	TBA	Link
NovaSAR-1 RTC	Normalised Radar Backscatter	v5.5	CSIRO	NovaSAR-1	TBA	Link	Ongoing	TBA	TBA
Resourcesat-2/2A	Surface Reflectance	v5.0	ISRO	Resourcesat-2, 2A	TBA	Link	Ongoing	TBA	TBA
RISAT-1A (EOS-04) NRB	Normalised Radar Backscatter	v5.5	ISRO	RISAT-1A (EOS-04)	TBA	TBA	TBA	TBA	TBA
Sentinel-1 NRB	Normalised Radar Backscatter	v5.5	ESA	Sentinel-1 (A, B)	TBA	Link	TBA	TBA	TBA
Sentinel-1 ORB	Ocean Radar Backscatter	v1.0	ESA	Sentinel-1 (A, B)	TBA	TBA	TBA	TBA	TBA

ESA-DLR NRB Product Characteristics

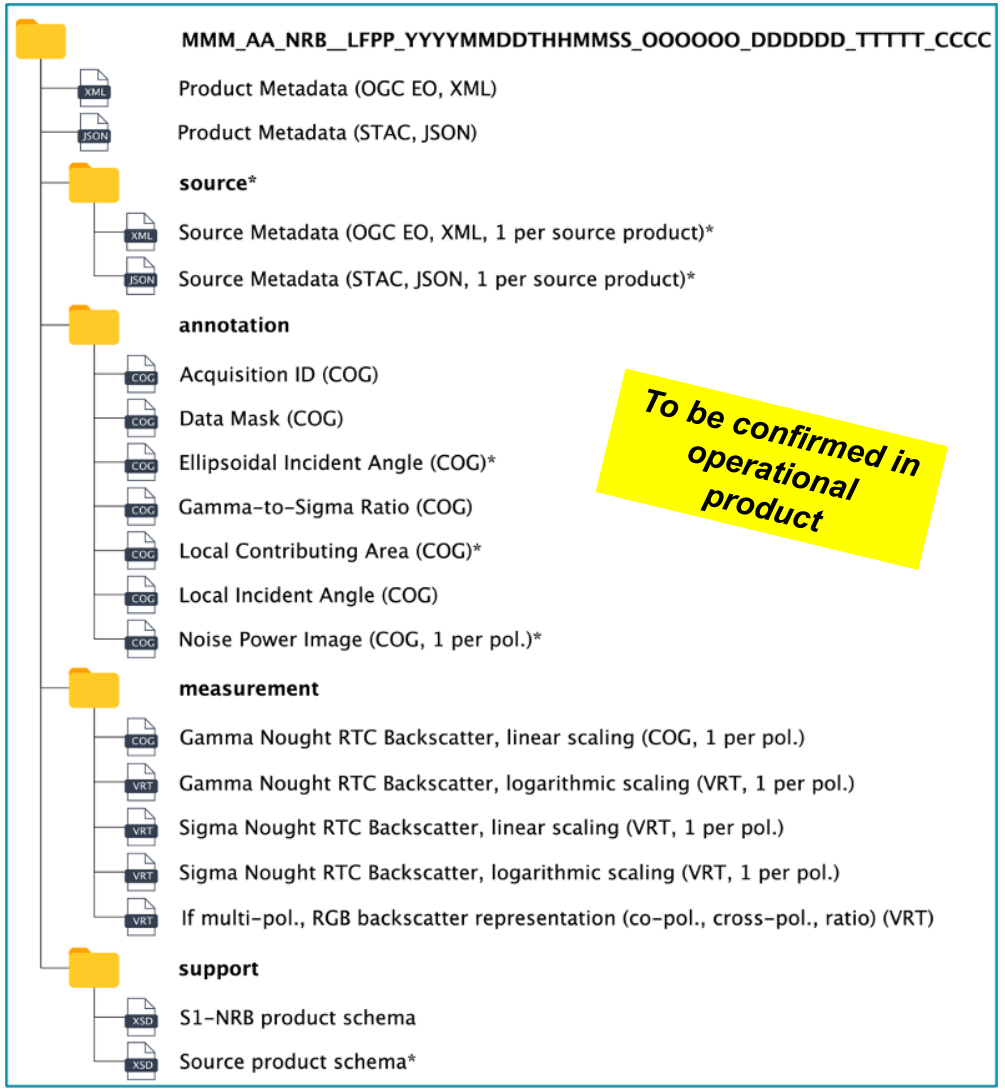
- Seamless mosaics of multiple source scenes
- Exact extent of Sentinel-2 grid cells
  (based on Military Grid Reference System MGRS)
- UTM projection (UPS over poles)
- 10 m spacing
- 100 km tile plus overlap:
  - 10980 * 10980 pixels
  - 109.8 * 109.8 km
- Cloud Optimized GeoTIFF (COG)
  - 512 * 512 tiling
  - Overview levels: 2, 4, 9, 18, 36
- “LERC_ZSTD” Raster Compression



https://sentinel.esa.int/web/sentinel/sentinel-1-ard-normalised-radar-backscatter-nrb-product

Product content

- Measurement: radiometrically terrain corrected (RTC) gamma nought (γ_T^0) backscatter per polarisation
- Ancillary Data:
  - Acquisition ID mask: source scene ID per pixel
  - Data mask: ocean, layover and shadow
  - Ellipsoidal incidence angle
  - Gamma-sigma ratio: convert measurement to RTC sigma nought
  - Local contributing area: area exposed to the sensor
  - Local incidence angle: angle of illumination
  - Noise power: noise subtracted from measurement
- Metadata: OGC EO XML, SpatioTemporal Asset Catalog (STAC) JSON

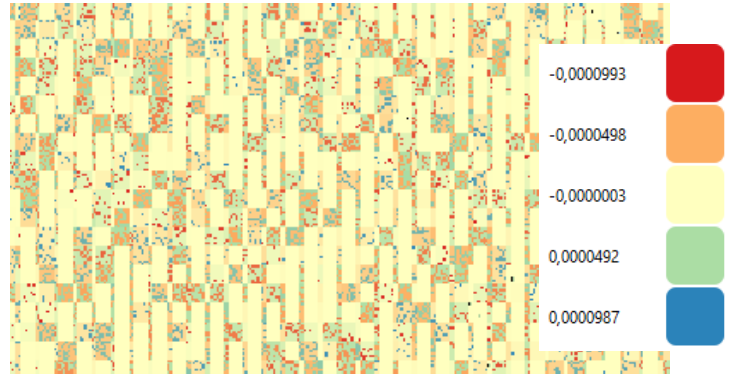


Product Size

- Example product over the Alps (tile 32TNS)
- “worst case scenario” with full data coverage and strong terrain variation
- Higher ratios in flat terrain (due to higher auto-correlation)
- Near-linear decrease of product size with reduced data coverage
- Overall volume: 3-4 x GRD

Image	Max. error	Plain [MB]	Plain, overviews [MB]	Compressed, overviews [MB]	Ratio
Acquisition ID	0	115	153	3.9	39.5
Data Mask	0			0.1	1620.4
Noise power VH	2e-5	460	611	149.3	4.1
Noise power VV	2e-5			150.1	4.1
Gamma/Sigma Ratio	1e-4			209.8	2.9
VH gamma0	2e-5			171.9	3.6
VV gamma0	2e-5			218.3	2.8
Ellipsoidal Incident angle	1e-3			26.2	23.3
Local incident angle	1e-2			211.3	2.9
Local contributing area	0.1			66.2	9.2
TOTAL		**3909**	**5194**	**1207**	**4.3**

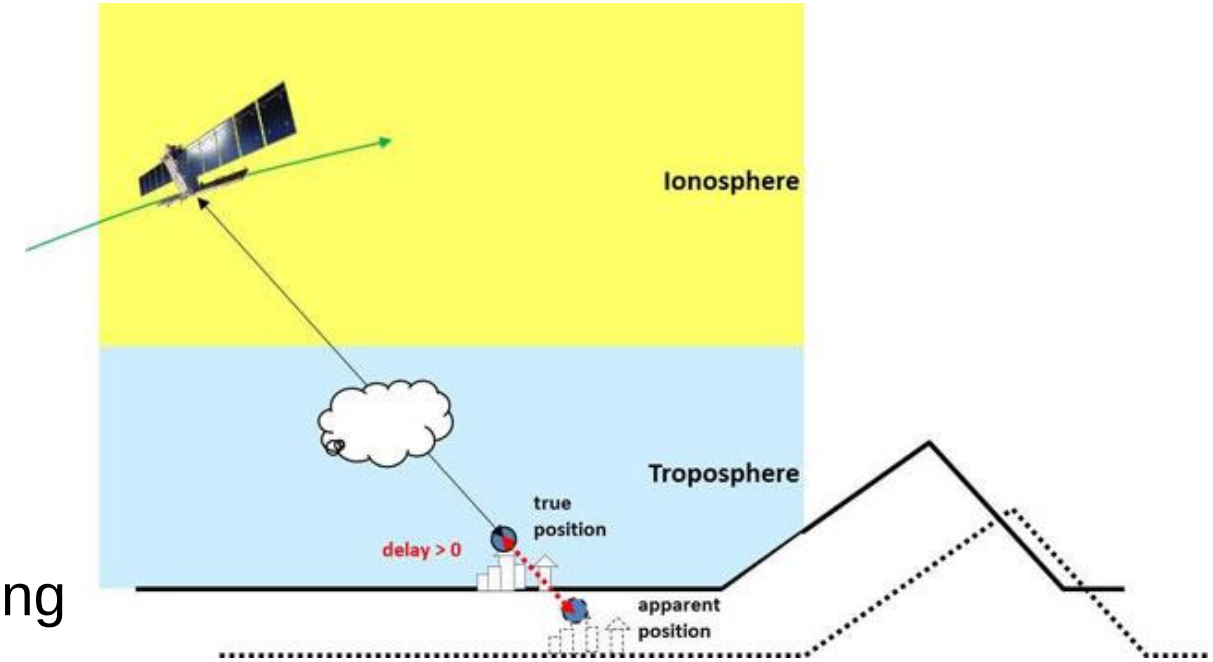
Tile location



LERC compression artifacts (tile overlap difference) with 1e-4 error

Extended Timing Annotation Dataset (ETAD)

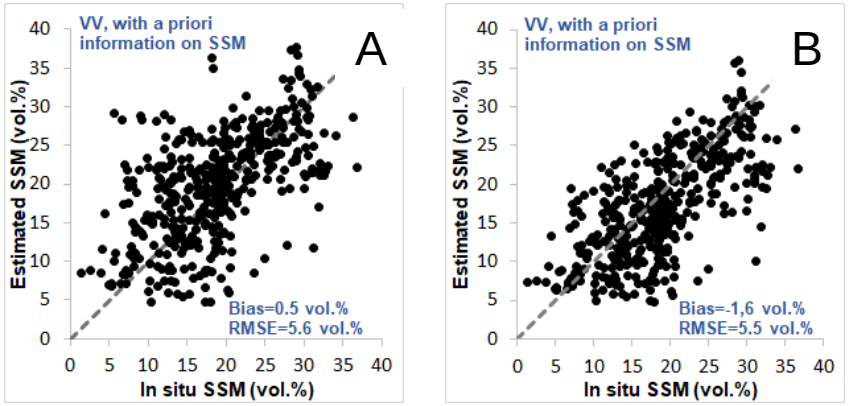
- Geolocation accuracy of Sentinel-1 is approx. 3 m (non-geocoded)
- Main factors for inaccuracies:
  - Atmospheric delay
  - Solid earth tides
  - Instrument movement
- Accuracy can be improved to 0.1 m by utilising the ETAD product
- A new Sentinel-1 product can be created from an existing one and the corresponding ETAD product
- ETAD products will be openly available in the second half of 2023
- Additional inaccuracies in NRB product due to interpolation and DEM



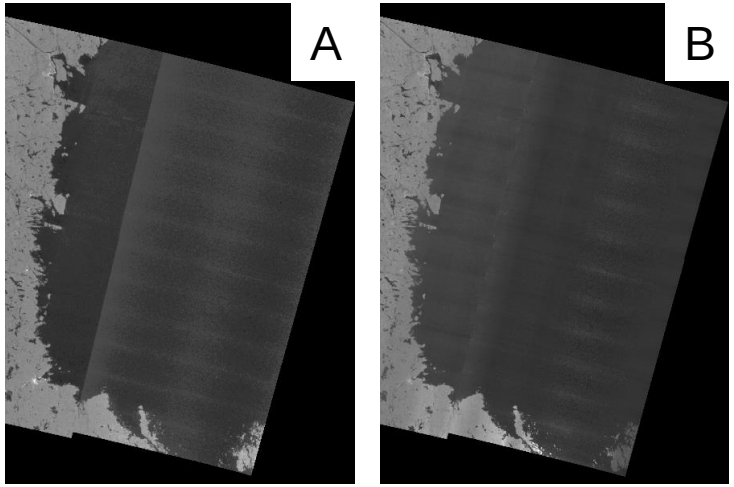
https://sentinel.esa.int/web/sentinel/missions/sentinel-1/data-products/etad-dataset

Use Cases

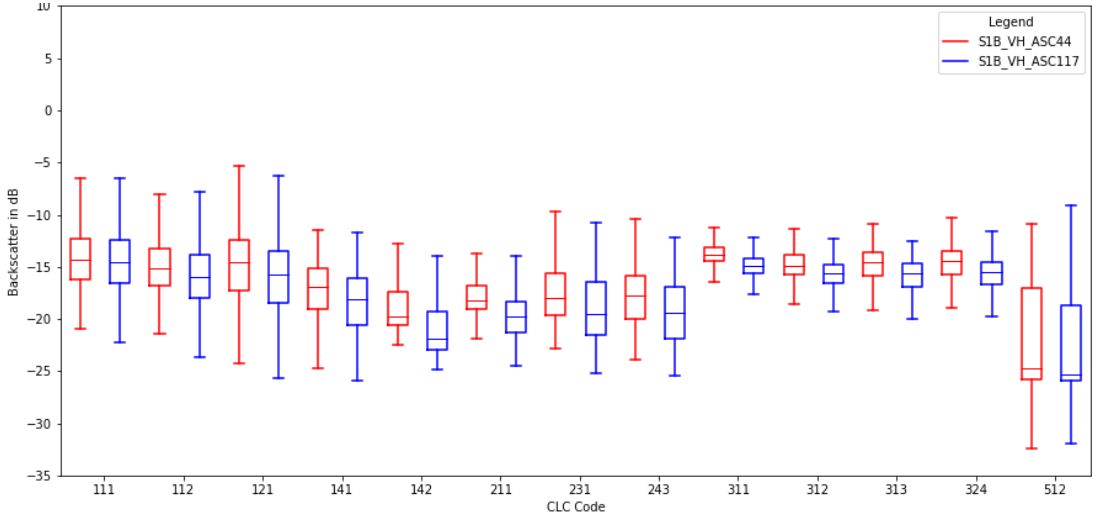
- Soil Moisture (INRAE, France)
  - Investigation of gamma nought RTC suitability for soil moisture retrieval
- Sea Ice (FMI, Finland)
  - Comparison of methods for removal of thermal noise and scalloping effects
- Land Use / Land Cover (Uni Jena, Germany)
  - Testing of S1-NRB data cube capabilities
  - Analysis of backscatter time series variability across different LULC classes and observation scenarios



Surface soil moisture retrieved from σ_E^0 (A) and γ_T^0 (B).

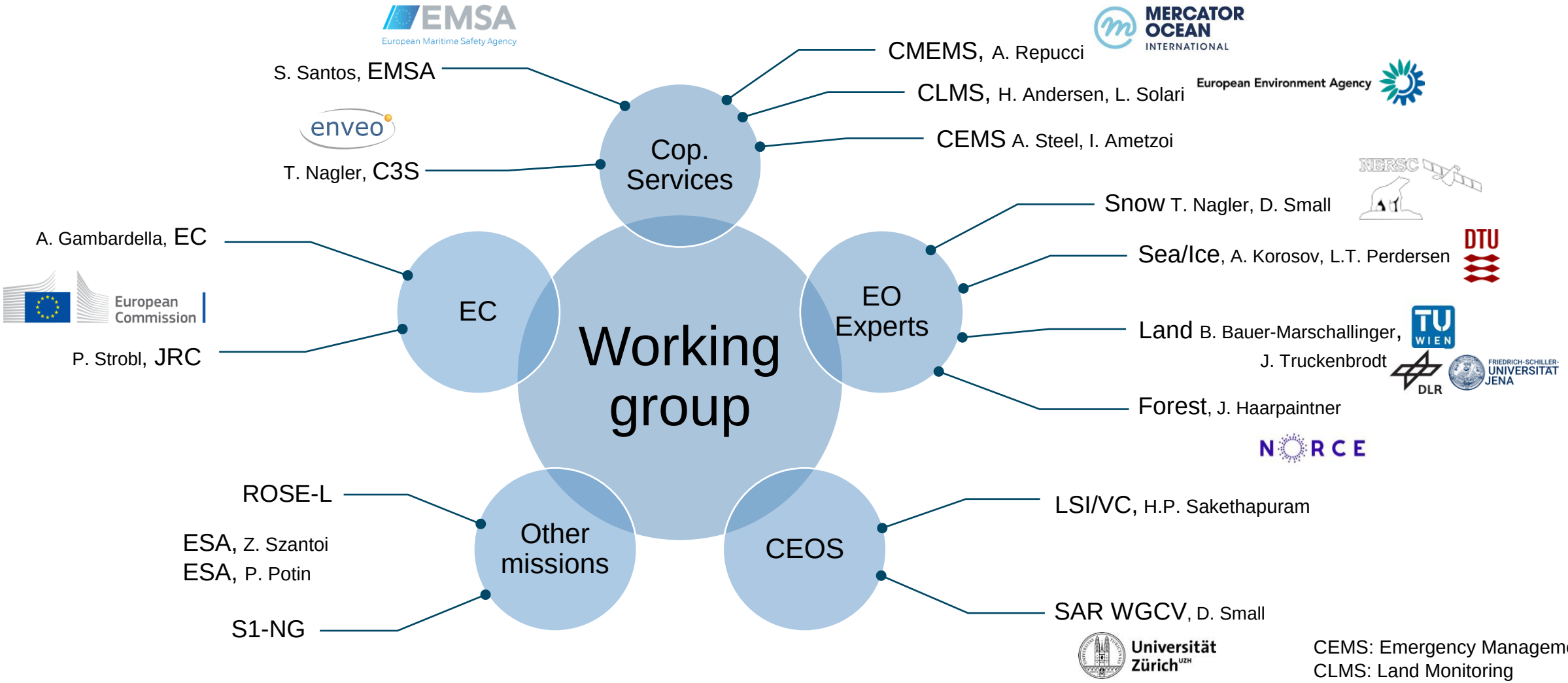


S1 EW VH image after noise removal using the NERSC (A) and FMI (B) methods.



Comparison of backscatter from near range (ASC44) and far range (ASC117) for different CORINE classes.

NRB Working Group



CEMS: Emergency Management
CLMS: Land Monitoring
CMEMS: Maritime Env. Monitoring
CMS: Maritime Surveillance
C3S: Climate Change
EGMS: Ground Motion

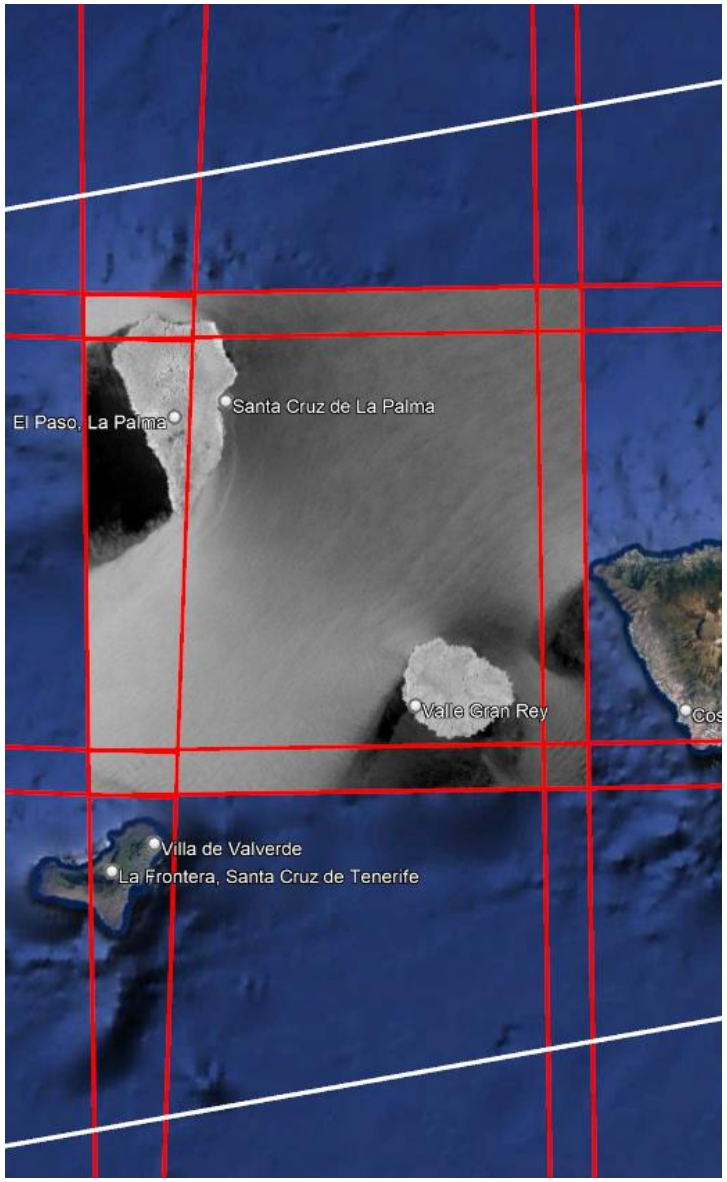
Instrument Processing Facility

- The IPF processes raw Level-0 data to Level-1 (GRD, SLC) for user uptake
- The Sentinel-1 IPF has undergone several changes since the start of the mission
- Consistent quality of NRB products cannot be assured
- Reprocessing of Sentinel-1 Level-1 products is currently being considered at DLR

version	delivery	start usage	end usage	notes
003.61	2023-03-17 12:00:00	2023-03-30 10:19:46		
003.52	2022-05-12 00:00:00	2022-05-12 10:48:19	2023-03-30 09:29:57	
003.51	2022-03-04 00:00:00	2022-03-23 16:25:31	2022-05-12 09:31:31	
003.40	2021-10-08 00:00:00	2021-11-04 07:56:32	2022-03-23 12:25:17	
003.31	2020-06-19 12:00:00	2020-06-30 12:00:00	2021-11-03 11:08:26	
003.30	2020-03-09 12:00:00	2020-06-23 08:00:00	2020-06-30 12:00:00	
003.20	2019-12-16 12:00:00	2020-01-29 10:00:00	2020-06-23 08:00:00	
003.10	2019-06-04 15:00:00	2019-06-26 10:00:00	2020-01-29 10:00:00	
002.91	2018-05-29 00:00:00	2018-06-26 08:30:00	2019-06-26 10:00:00	
002.90	2018-01-16 00:00:00	2018-03-13 12:00:00	2018-06-26 08:30:00	
002.84	2017-07-12 00:00:00	2017-08-22 10:00:00	2018-03-13 12:00:00	
002.82	2017-02-27 00:00:00	2017-03-28 06:00:00	2017-08-22 10:00:00	
002.72	2016-07-29 00:00:00	2016-08-23 12:00:00	2017-03-28 12:00:00	
002.71	2016-04-21 00:00:00	2016-05-11 12:00:00	2016-08-23 12:00:00	
002.70	2016-03-31 00:00:00	2016-04-13 12:00:00	2016-05-11 12:00:00	
002.60	2015-10-09 00:00:00	2015-11-20 12:00:00	2016-04-13 12:00:00	
002.50	2015-06-30 00:00:00	2015-07-02 12:00:00	2015-11-24 12:00:00	
002.40	2015-03-09 00:00:00	2015-03-19 00:00:00	2015-07-02 12:00:00	

Extension to Ocean Radar Backscatter

- Development so far focused on NRB for land applications
- The CEOS ARD ORB specification was published in 09/22
- A follow-up activity was started in 04/23 to extend the ESA-DLR product specification to ORB
- Formation of a new working group
- Major points being addressed:
  - Pixel spacing(s)
  - Correction of thermal noise
  - Interfacing with NRB in coastal areas
  - Data quality and overall usability
  - Replaceability of GRD product



Data Cube capabilities

Sentinel-1 NRB STAC Catalog / Sentinel-1 NRB STAC Collection
/ S1A_IW_NRB__1SDV_20210607T171530_20210607T171555_038237_04832F_32TMS_ABCD

S1A_IW_NRB__1SDV_20210607T171530_20210607T171

https://raw.githubusercontent.com/maawoo/copa-nrb-stac/main/32TMS/S1A_IW_NRB__1SDV_20210607T171530_20210607T171555_038237_

Preview | Assets | Links

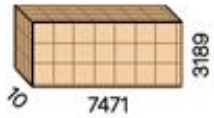
Name	Roles	Content-Type
CARD4L XML Metadata File	metadata, card4l	application/xml
Data Mask Image	data-mask, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Ellipsoid Incidence Angle	ellipsoid-incidence-angle, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Gamma0 RTC to sigma0 RTC ratio	gamma-sigma-ratio, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Local Contributing Area	contributing-area, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Local Incidence Angle	local-incidence-angle, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Noise Power VH	noise-power, metadata	image/tiff; application=geotiff; profile=cloud-optimized
Noise Power VV	noise-power, metadata	image/tiff; application=geotiff; profile=cloud-optimized
VH backscatter data	backscatter, data	image/tiff; application=geotiff; profile=cloud-optimized
VV backscatter data	backscatter, data	image/tiff; application=geotiff; profile=cloud-optimized

METADATA	
Keywords	sar, backscatter, esa, copernicus, s
Collection	Sentinel-1 NRB STAC Collection
First Acquisition	7.6.2021, 17:15:30 UTC
Last Acquisition	7.6.2021, 17:15:55 UTC
Created	21.8.2021, 03:11:23 UTC
Instruments	c-sar
Constellation	sentinel-1
Platform	sentinel-1a
GSD	10 m
Acquired	7.6.2021, 17:15:30 UTC
CARD4L	
Specification	Normalised Radar Backscatter
Specification Version	CARD4L-NRB v5.0
Measurement Type	gamma-0

```
[4]: nr = ds.where((ds['sat:relative_orbit'] == 44), drop=True).chunk((-1, 1, 1024, 1024))
     fr = ds.where((ds['sat:relative_orbit'] == 117), drop=True).chunk((-1, 1, 1024, 1024))
     fr
```

```
[4]: xarray.DataArray 'stackstac-31de2c1eacc17eb3540f38b874c70d96'
(time: 60, band: 10, y: 3189, x: 7471)
```

	Array	Chunk
Bytes	106.51 GiB	480.00 MiB
Shape	(60, 10, 3189, 7471)	(60, 1, 1024, 1024)
Count	39181 Tasks	320 Chunks
Type	float64	numpy.ndarray



▸ Coordinates: (55)

▾ Attributes:

spec : RasterSpec(epsg=32632, bounds=(614990.0, 5618680.0, 689700.0, 5650570.0), resolutions_xy=(10.0, 10.0))
crs : epsg:32632
transform : | 10.00, 0.00, 614990.00|
| 0.00,-10.00, 5650570.00|
| 0.00, 0.00, 1.00|
resolution : 10.0

```
[6]: eia_min_nr = nr.sel(band='ellipsoid-incidence-angle', time=nr.time[0]).min().values
     eia_max_fr = fr.sel(band='ellipsoid-incidence-angle', time=fr.time[0]).max().values

     print(f'The Ellipsoid Incidence Angle range is between {eia_min_nr.round(2)}°',
           f'and {eia_max_fr.round(2)}°')
```

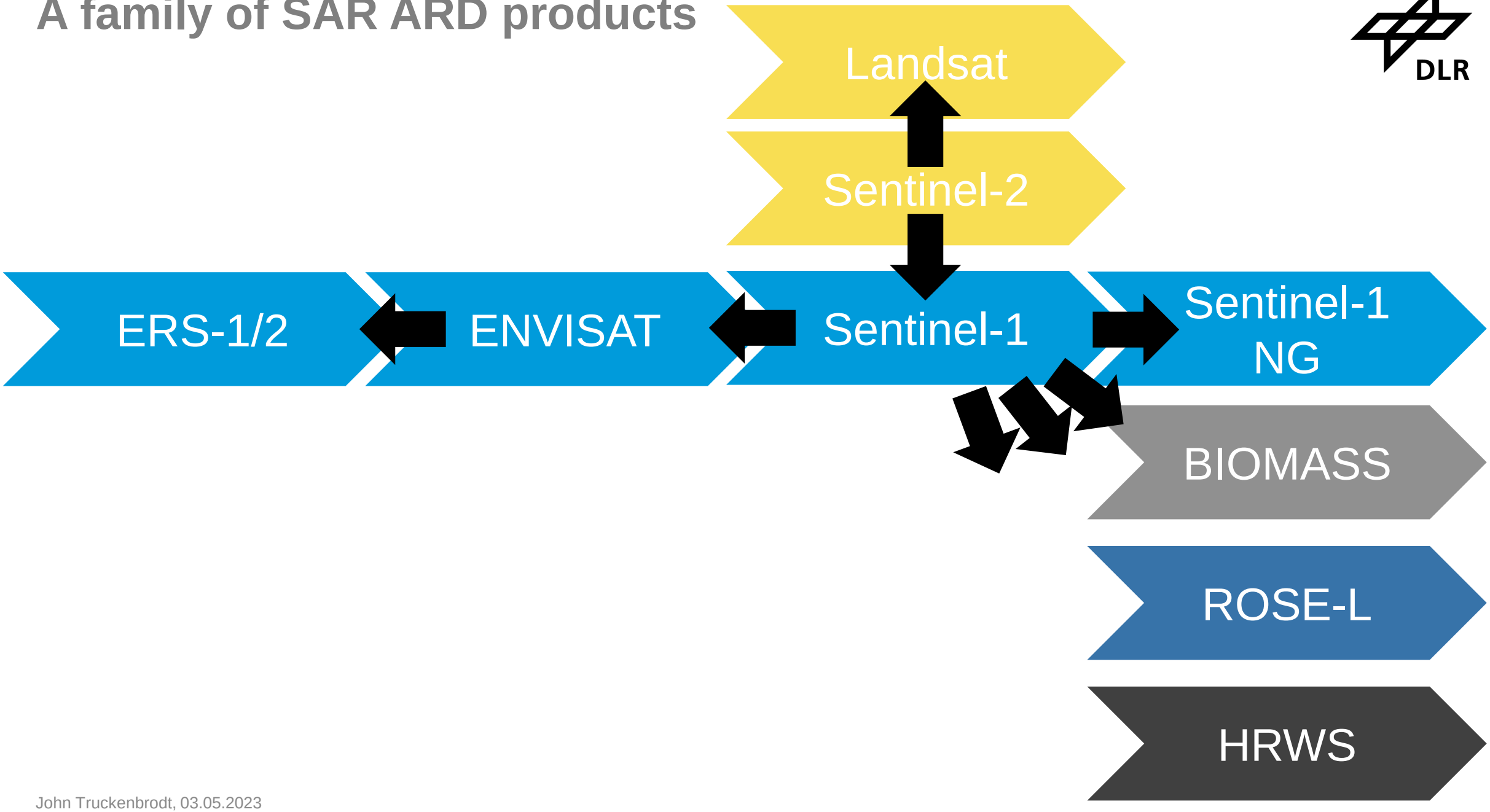
```
The Ellipsoid Incidence Angle range is between 31.41° and 44.9°
```

STAC xarray DASK

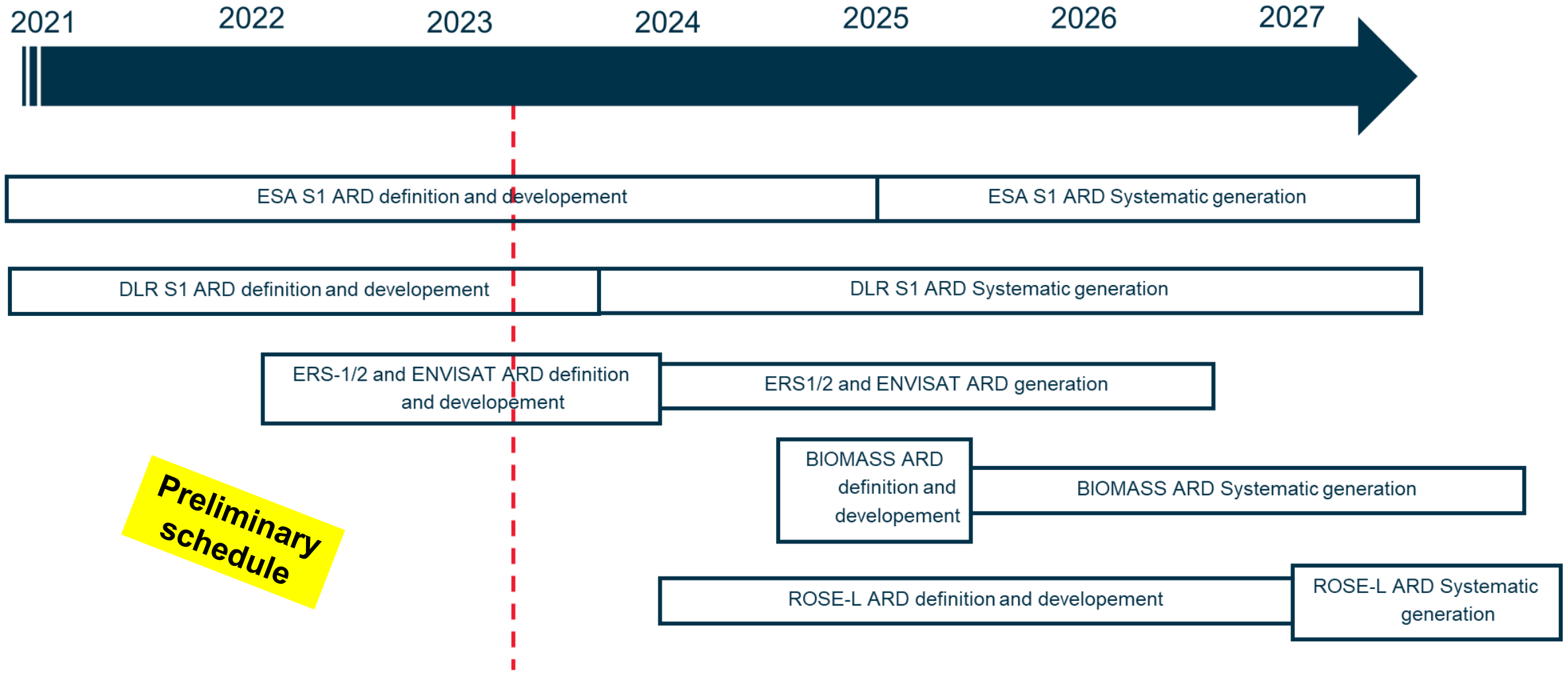
ESA-DLR coordination around 5 axes

1. Joint Sentinel-1 ARD NRB product:
    - *Objective to have ESA and DLR product definitions aligned.*
2. Joint ESA and DLR Sentinel-1 ARD NRB processor:
    - *Exchanges of modules and code developed.*
    - *Share the new modules developed (e.g. file packaging).*
3. Coordination on use cases:
    - *Complementary use cases in terms of spatial and temporal coverage, and instruments.*
4. Coordination on validation:
    - *Complementary validations in term of radiometry, geometry, processing modules, etc.*
5. Exchange of information related to internal ESA and DLR activities:
    - *Monthly coordination meetings.*

A family of SAR ARD products



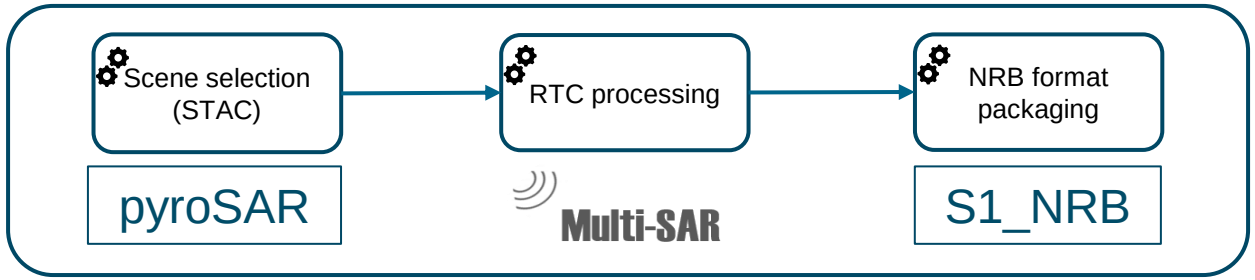
Time schedule and access for users to ARD NRB



NRB Processor

- Open-Source prototype based on Python and ESA SNAP
- Python tools are further developed to increase robustness
- SNAP component is being replaced with DLR in-house Multi-SAR
- Tools have been made compliant with STAC catalogue and HPC Slurm processing environment
- Workflow orchestration is currently being set up

Multi-SAR



S1_NRB

A prototype processor for the Sentinel-1 Normalised Radar Backscatter product

Please refer to the Documentation for more details about installation and usage instructions, general processor information and the API reference.

Further information about the S1-NRB product can also be found here.

pyroSAR

A Python Framework for Large-Scale SAR Satellite Data Processing

build passing | build passing | coverage 50% | docs passing | pypi package 0.19.0 | conda-forge v0.19.0

The pyroSAR package aims at providing a complete solution for the scalable organization and processing of SAR satellite data:

- Reading of data from various past and present satellite missions
- Handling of acquisition metadata
- User-friendly access to processing utilities in SNAP and GAMMA Remote Sensing software
- Formatting of the preprocessed data for further analysis
- Export to Data Cube solutions

Head on over to readthedocs for installation instructions, examples and API reference.

https://github.com/johntruckenbrodt/pyroSAR
https://github.com/SAR-ARD/S1_NRB

DLR: terrabyte platform

External data sources

esa

NASA

USGS science for a changing world

DLR EO long-term

100 PB archive storage

terrabyte @ LRZ

terrabyte

Processing to ARD

≈40 PB net storage
320 Nodes (273 CPU + 47 GPU)
by end of 2023

Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities

International activities for EO platforms

- **CEOS:**
  - WGISS
  - LSI-VC ARD
- **ESA**
  - WG Data Access & Preservation
  - WG Common Architecture
- **OGC**
  - EO Exploitation Platform DWG
  - GeoDataCube SWG
  - Analysis Ready Data SWG
- Space agency collaborations
  - **USGS-DLR:** Clouds, Data Access
  - **CNES-DLR:** FaaS, Zeebe, STAC
- **CCSDS:** Cloud Standardization Group


Thank You!