Technical Note for Capella Data Assessment

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AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
0.1	02/11/2021	Initial draft
1.0	07/03/2022	First issue of the TN, addressing comments received from ESA

ACRONYMS

CR	Corner Reflector
EAP	Elevation Antenna Pattern
GEC	Geocoded Ellipsoid Corrected
GEO	Geocoded Terrain Corrected
IRF	Impulse Response Function
NESZ	Noise Equivalent Sigma Nought
RF	Rain Forest
SLC	Single Look Complex
SM	Stripmap
SP	Spotlight
SS	Sliding Spotlight

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1. EXECUTIVE SUMMARY

1.1 Mission Quality Assessment

The Capella Space mission is made of a constellation of microsatellites each one carrying an X-band SAR instrument for Earth observation.

In the framework of the EDAP activity, we report here an assessment of the quality of the products, provided directly from the Capella team, following the EDAP assessment guidelines. For the time being, the assessment is only performed for SLC products.

The format of the products is not standard but a well detailed product format allowing to easily interpret them is available. The ancillary information provided with the data is quite exhaustive and allows an easy interpretation of the data. The information is provided in JSON files.

The independently performed analyses allow to conclude that the data show good quality in terms of IRF, geometric resolution, geolocation accuracy and relative radiometric calibration accuracy. The measured NESZ level is lower than the values reported in the products' annotations, suggesting a possible residual error in the absolute radiometric calibration.

In conclusion the assessment of Capella products performed in the framework of the EDAP activities is positive. Some calibration activities are still ongoing and could further improve the overall data quality. Furthermore, the availability of more documentation, in particular related to calibration and quality assessment activities, could be useful for Capella data users.

1.2 Mission Quality Assessment Matrix

Product Information	Product Generation	Ancillary Information	Uncertainty Characterisation	Validation
Product Details	Sensor Calibration & Characterisation Pre-Flight	Product Flags	Uncertainty Characterisation Method	Reference Data Representativeness
Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch	Ancillary Data	Uncertainty Sources Included	Reference Data Quality
Product Format	Additional Processing		Uncertainty Values Provided	Validation Method
User Documentation			Geolocation Uncertainty	Validation Results
Metrological Traceability Documentation				

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent
Information Not Public

Figure 1 – Mission Product Quality Evaluation Matrix.

2. MISSION ASSESSMENT OVERVIEW

2.1 Product Information

Product Details	
Product Name	*CAPELLA_C03_SP_SLC_PP_YYYYMMDDhhmmss_YYYYMMDDhhmmss*
Sensor Name	*Cnn (CAPELLA-nn)*
Sensor Type	*X-Band SAR*
Mission Type	*Constellation of micro satellites*
Mission Orbit	*~500 km 90-minutes polar orbit*
Product Version Number	*1.8*
Product ID	*A string of 8-4-4-4-12 digits and letters (individual for each product)* *e.g. : 6f4745d8-3182-4526-bd1f-b9c4051ce3ab*
Processing level of product	*SLC*
Measured Quantity Name	*Complex numbers:* *RADAR backscatter:* $\beta_0 = sc * \lvert pixel \rvert^2$ *, where sc is a Scale Factor annotated in the products*
Measured Quantity Units	m^2/m^2 *(power)*
Stated Measurement Quality	*Radiometric accuracy not declared in the product.*
Spatial Resolution	*Slant range 0.5-0.75 m, azimuth 1.0-1.2 m*
Spatial Coverage	*Range: 5 km, azimuth: 10-20 km*
Temporal Resolution	*Few hours depending on satellites available in the constellation*
Temporal Coverage	*2020 to now*
Point of Contact	*https://www.capellaspace.com/*
Product locator (DOI/URL)	*Online catalogue available at: https://console.capellaspace.com/* *Guidelines for Python SDK API available at: https://capella-console-client.readthedocs.io/*
Conditions for access and use	*https://www.capellaspace.com/wp-content/uploads/2021/08/Capella-CPQ-Order-Terms-and-Conditions-Ver.-1.1-August-2021.pdf*
Limitations on public access	*CAPELLA data have to be purchased by the users. A portion of Capella historical archived imagery is available through the Open Data Program: https://www.capellaspace.com/community/capella-open-data/*
Product Abstract	*Complex, single-look, range-compressed and focused data in slant range, processed and projected to zero Doppler SAR coordinates.*

Availability & Accessibility	
Compliant with FAIR principles	*No*
Data Management Plan	*Data can be ordered through the online catalogue or the API. Ready-to-download data can be retrieved according to geographical research and filters concerning sensing, acquisition and processing options. Tasking requests can also be placed for customized products.*
Availability Status	N/A

Product Format	
Product File Format	*Product is delivered in the form of a TIFF file plus a JSON file. The product format is fully described in [RD1]*
Metadata Conventions	*JSON*
Analysis Ready Data?	*No*

User Documentation		
Document	*Reference*	*QA4ECV Compliant*
Product User Guide	*[RD2] has been provided directly from CAPELLA space but is not available for the user yet. The "Product Doc" section is currently present in the support page but still under construction: https://support.capellaspace.com*	*No*
ATBD	Not available	N/A

Metrological Traceability Documentation	
Document Reference	*No*
Traceability Chain / Uncertainty Tree Diagram Available	*No*

2.2 Product Generation

Sensor Calibration & Characterisation – Pre-Flight	
Summary	*Performed calibration are mentioned in [RD5]. No details on the applied methods are available.*
References	*[RD5]*

Sensor Calibration & Characterisation – Post-Launch	
Summary	*Performed calibration are mentioned in [RD5]. No details on the applied methods are available.*
References	*[RD5]*

Additional Processing	
Projection on geographic coordinates	
Description	*The SAR data in RADAR coordinates (SLC) are projected into geographical coordinates on Ellipsoid (GEC) or on a Digital Elevation Model (GEO).*
Reference	*[RD1]*

2.3 Ancillary Information

Product Flags	
Product Flag Documentation	*Flags related to the antenna pattern correction, radiometry, calibration and telemetry are provided (see [RD1]))*
Comprehensiveness of Flags	*Intermediate*

Ancillary Data	
Ancillary Data Documentation	*Ancillary data are provided as JSON file associated to the RADAR measurements. The ancillary data include information about acquisition, orbit, attitude and processing.*
Comprehensiveness of Data	*Good*
Uncertainty Quantified	*No*

2.4 Uncertainty Characterisation

Uncertainty Characterisation Method	
Summary	*The methods for uncertainty characterization are not documented.*
Reference	

Uncertainty Sources Included	
Summary	*The information related to the main uncertainty sources is a NESZ peak value representing the thermal noise level foreseen in the data.*
Reference	*[RD1]*

Uncertainty Values Provided	
Summary	*A NESZ value with the thermal noise level foreseen in the data is available in the product metadata.*
Reference	*[RD1]*
Analysis Ready Data?	*No*

Geolocation Uncertainty	
Summary	*The geolocation uncertainty is not provided*
Reference	*None*

2.5 Validation

Impulse Response Function	
Independently Assessed?	*Yes*
Reference Data Representativeness	
Summary	*Impulse Response Function (resolution) of Capella products has been assessed for SM, SP and SS products. The analysed data, acquired over dedicated calibration sites, are representative of the available Capella products.*
Reference	*Section 3.2.1*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.2.2*
Validation Method	
Summary	*The Impulse Response Function of Capella product has been validated extracting the range and azimuth profiles from Corner Reflectors available in dedicated calibration sites.*
Reference	*Section 3.2.3*
Validation Results	
Summary	*The following parameters have been analysed:* • *Range resolution* • *Azimuth resolution* • *Side lobe levels* *The analysed parameters are in line with products specifications.*
Reference	*Section 3.2.3*

Geolocation accuracy	
Independently Assessed?	*Yes*
Reference Data Representativeness	
Summary	*Geolocation accuracy (range and azimuth localisation errors) of Capella products has been assessed for SM, SP and SS products. The analysed data, acquired over dedicated calibration sites, are representative of the available Capella products.*

Reference	*Section 3.2.1*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.2.2*
Validation Method	
Summary	*The geolocation accuracy of Capella products has been validated by comparing the measured position of reference targets in the image with their known position.*
Reference	*Section 3.2.4*
Validation Results	
Summary	*The following parameters have been analysed:* • *Range Absolute Localisation Error* • *Azimuth Absolute Localisation Error* *The geolocation accuracy estimated from the data is good.*
Reference	*Section 3.2.4*

NESZ Level Assessment	
Independently Assessed?	*Yes*
Reference Data Representativeness	
Summary	*NESZ level of Capella products has been assessed for SM and SS products. The analysed data, acquired over dedicated calibration sites, are representative of the available Capella products.*
Reference	*Section 3.3.1*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.3.2*
Validation Method	
Summary	*The data acquired over Mono Lake are masked to remove regions with high backscatter and the effect of incidence angle is compensated to obtain NESZ profiles.*
Reference	*Section 3.3.3*
Validation Results	
Summary	*The NESZ level of Capella products is well below the expected value, which is an issue for de-noising purpose and can also reveal some calibration issue.*
Reference	*Section 3.3.3*

EAP Correction Assessment	
Independently Assessed?	*Yes*
Reference Data Representativeness	
Summary	*Capella acquisitions over rain forest areas are analysed to assess the elevation antenna pattern correction*
Reference	*Section 3.4.1*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.4.2*
Validation Method	
Summary	*The data acquired over rain forest are masked to remove non homogeneous regions (e.g. rivers) and the effect of incidence angle is compensated to obtain γ^0 profiles.*
Reference	*Section 3.4.3*
Validation Results	
Summary	*The γ^0 profiles measured from Rain Forest acquisitions are not flat revealing an issue in the EAP correction.*
Reference	*Section 3.4.3*

3. DETAILED ASSESSMENT

3.1 Capella Overview

The Capella mission is a constellation of microsatellites each one operating at an altitude of about 500 km. At the moment of the production of this TN (March 2022), the constellation is mad of 6 satellites:

- 2 satellites operating in a 45° inclination orbit
- 2 satellites operating in a 53° inclination orbit
- 2 satellites operating in a polar SSO with 97° inclination

The constellation provides an average imaging revisit times of less than one hour (see [RD1], [RD2]).

All the satellites carry on board an X-band SAR instrument with up to 500 MHz bandwidth. The antenna is single-polarization, allowing steering in both elevation and azimuth and capable of operating in Stripmap, Spotlight and Sliding Spotlight imaging modes, as pictorially described in **Figure 2**. Few more details are provided in **Table 1**, concerning the main system characteristics.

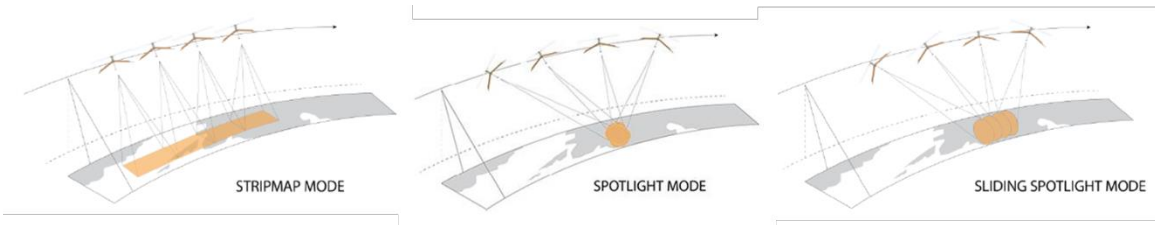

Figure 2 – Capella acquisition modes

Frequency Band	X-band (9.4 – 9.9 GHz)
Imaging Bandwidth	Up to 500 MHz
Imaging Modes	Spotlight (SP) | Sliding Spotlight (SS)|) | Stripmap (SM)
Imaging Polarizations	Single-Pol (HH and VV)
Imaging Orbit Directions	Ascending & Descending
Imaging Look Directions	Left & Right

Table 1 – Capella SAR system characteristics

Capella's SAR data product portfolio currently includes three product types:

- **Single Look Complex (SLC – L1A)**: complex, single-look, range-compressed and focused data in slant range, processed and projected to zero Doppler SAR coordinates.
- **Geocoded Ellipsoid Corrected (GEC – L1C)**: Multi-looked data projected to ground range and geocoded onto the ellipsoid, radiometrically calibrated. No terrain correction applied.
- **Ground Terrain Corrected (GEO – L1D**) Geocoded and terrain-corrected using Digital Elevation Model (DEM)
- **Sensor Independent Complex Data (SICD):** U.S. national geospatial-intelligence (GEOINT) standard designed for the storage and dissemination of SAR SLC image data

in a sensor-independent manner. The SICD standard is designed specifically for SAR SLC image data and relevant metadata stored in the well-established National Imagery Transmission Format (NITF) file format. Capella's SICD format complex image products are compliant with version 1.2.1 of the SICD standard published on 13 December 2018 [RD3]

Table 2 and Table 3 provides the available specifications for the standard SLC and GEO image products, respectively. Besides the standard products, which are defined with predefined sets of imaging acquisition parameters in order to provide the optimal full performance range of the Capella radar system, Capella company allows to retrieve also customized SAR imagery products by giving to the user the possibility to submit acquisition tasking requests with specific SAR imaging parameters and characteristics.

Regarding the number of looks reported in Table 3, please note that they are obtained processing extra Doppler bandwidth to generate N independent SLC products that are then incoherently summed. The extra Doppler bandwidth is achieved by antenna steering to increase the targets dwell time. For this reason, the geometric resolution of the GEO products is aligned with the SLC values.

Imaging Mode	Nominal Scene Size	Azimuth Resolution	Slant Range Resolution	Look Angle Range
Spotlight	5 km x 5 km	0.5 m	0.3 m	25° to 40°
Sliding Spotlight	5 km x 10 km	1.0 m	0.5 m	25° to 40°
Stripmap	5 km x 20 km	1.2 m	0.75 m	25° to 40°

Table 2 – Specifications of the standard SLC image product type.

Imaging Mode	**Nominal** Scene Size	# Of Looks	**Azimuth** Resolution	**Ground Range** Resolution	Pixel Spacing	Look Angle Range
Spotlight	5 km x 5 km	9	0.5 m	0.5 m to 0.7 m	0.35 m	25° to 40°
Sliding Spotlight	5 km x 10 km	5	1.0 m	0.8 m to 1.2 m	0.6 m	25° to 40°
Stripmap	5 km x 20 km	1	1.2 m	1.1 m to 1.6 m	0.8 m	25° to 40°

Table 3 – Specifications of the standard GEO image product type.

3.2 Point Target Data Assessment

3.2.1 Point Target Calibration Site

The following figures provide an overview of the Rosamond calibration site and of the corner reflectors (CR) used for the Capella point target acquisitions analyses ([RD4]). A total of 38 CRs are available, with the following properties:

- 23 CRs with a 2.4 m leg, among which 10 with an azimuth heading of 350° and 13 with an azimuth heading of 170°
- 5 CRs with a 4.8 m leg, all with an azimuth heading of 350°
- 10 CRs with a 0.7 m leg, among which 5 with an azimuth heading of 350° and 5 with a heading of 90°

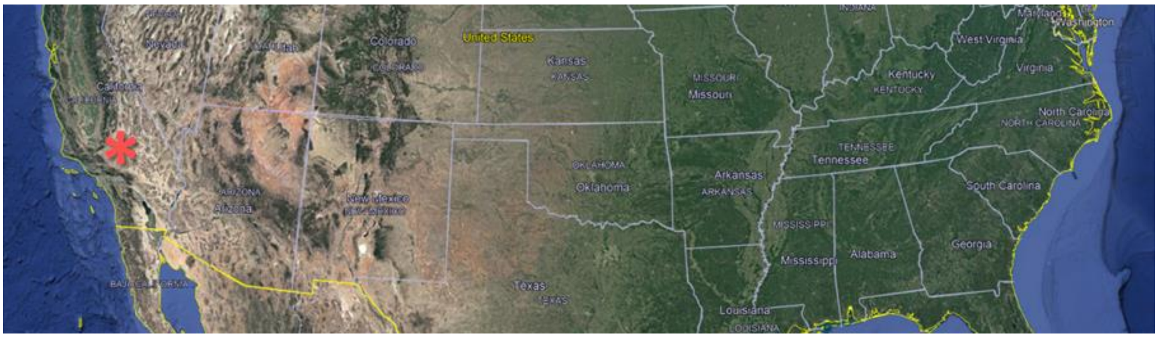

Figure 3 – Location of Rosamond calibration site, California.

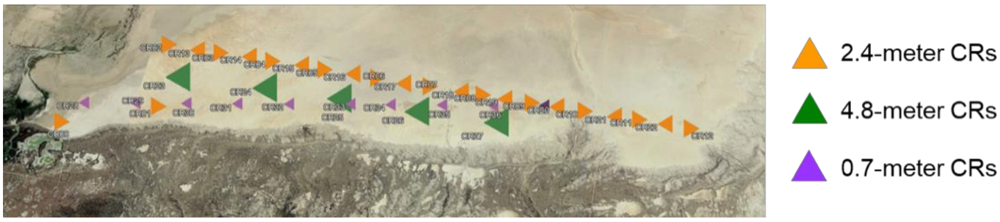

Figure 4 – Corner reflectors exploited for point target acquisitions analyses.

3.2.2 Analysed Dataset

The following table provide the list of Capella acquisitions exploited for Point Target analyses. The table provides information on date, duration, acquisition mode, polarization, pass (A for ascending and D for descending) and looking side. In particular the analyses were performed over the following 29 L1A SLC products:

- 12 Stripmap (8 H/H and 4 V/V)
- 10 Spotlight (all H/H)
- 7 Sliding Spotlight (5 H/H and 2 V/V)

ID	Start Time	Duration [s]	Mode	Pol	Pass	Side
CAPELLA_C03_SM_SLC_HH_ 20210402052547_20210402052551	02-APR-2021 05:25:48	2.9626	SM	H/H	A	RIGHT
CAPELLA_C03_SM_SLC_HH_ 20210422180352_20210422180356	22-APR-2021 18:03:53	2.9075	SM	H/H	D	LEFT
CAPELLA_C03_SM_SLC_HH_ 20210515051733_20210515051737	15-MAY-2021 05:17:34	2.8995	SM	H/H	A	RIGHT
CAPELLA_C03_SM_SLC_HH_ 20210517180534_20210517180538	17-MAY-2021 18:05:34	2.9032	SM	H/H	D	LEFT
CAPELLA_C03_SM_SLC_HH_ 20210526044658_20210526044702	26-MAY-2021 04:46:59	2.8982	SM	H/H	A	LEFT
CAPELLA_C03_SM_SLC_HH_ 20210528173443_20210528173447	28-MAY-2021 17:34:44	2.8603	SM	H/H	D	RIGHT

CAPELLA_C03_SM_SLC_HH_ 20210605173725_20210605173729	05-JUN-2021 17:37:26	2.8951	SM	H/H	D	RIGHT
CAPELLA_C03_SM_SLC_HH_ 20210625051856_20210625051900	25-JUN-2021 05:18:56	2.8739	SM	H/H	A	RIGHT
CAPELLA_C03_SM_SLC_VV_ 20210417172514_20210417172519	17-APR-2021 17:25:15	2.9324	SM	V/V	D	RIGHT
CAPELLA_C03_SM_SLC_VV_ 20210606172556_20210606172601	06-JUN-2021 17:25:57	2.9137	SM	V/V	D	RIGHT
CAPELLA_C03_SM_SLC_VV_ 20210619045413_20210619045417	19-JUN-2021 04:54:14	2.9016	SM	V/V	A	LEFT
CAPELLA_C03_SM_SLC_VV_ 20210627045543_20210627045547	27-JUN-2021 04:55:44	2.9183	SM	V/V	A	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210313173209_20210313173212	13-MAR-2021 17:32:10	0.71218	SP	H/H	D	RIGHT
CAPELLA_C03_SP_SLC_HH_ 20210409054258_20210409054302	09-APR-2021 05:43:00	0.71171	SP	H/H	A	RIGHT
CAPELLA_C03_SP_SLC_HH_ 20210415043642_20210415043645	15-APR-2021 04:36:43	0.71232	SP	H/H	A	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210517045457_20210517045500	17-MAY-2021 04:54:58	0.71391	SP	H/H	A	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210603180020_20210603180022	03-JUN-2021 18:00:21	0.71111	SP	H/H	D	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210721180745_20210721180748	21-JUL-2021 18:07:46	0.7135	SP	H/H	D	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210812051852_20210812051854	12-AUG-2021 05:18:53	0.71287	SP	H/H	A	RIGHT
CAPELLA_C03_SP_SLC_HH_ 20210814180517_20210814180520	14-AUG-2021 18:05:18	0.71289	SP	H/H	D	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210822180339_20210822180342	22-AUG-2021 18:03:40	0.71224	SP	H/H	D	LEFT
CAPELLA_C03_SP_SLC_HH_ 20210909173431_20210909173433	09-SEP-2021 17:34:32	0.7109	SP	H/H	D	RIGHT
CAPELLA_C03_SS_SLC_HH_ 20210405180328_20210405180343	05-APR-2021 18:03:35	1.517	SS	H/H	D	LEFT
CAPELLA_C03_SS_SLC_HH_ 20210411052045_20210411052059	11-APR-2021 05:20:51	1.5142	SS	H/H	A	RIGHT
CAPELLA_C03_SS_SLC_HH_ 20210419052625_20210419052640	19-APR-2021 05:26:31	1.5614	SS	H/H	A	RIGHT
CAPELLA_C03_SS_SLC_HH_ 20210520173128_20210520173143	20-MAY-2021 17:31:35	1.5409	SS	H/H	D	RIGHT
CAPELLA_C03_SS_SLC_HH_ 20210531052400_20210531052415	31-MAY-2021 05:24:07	1.5372	SS	H/H	A	RIGHT
CAPELLA_C03_SS_SLC_VV_ 20210405045242_20210405045257	05-APR-2021 04:52:49	1.4978	SS	V/V	A	LEFT
CAPELLA_C03_SS_SLC_VV_ 20210416173615_20210416173630	16-APR-2021 17:36:22	1.5035	SS	V/V	D	RIGHT

Table 4 – List of acquisitions exploited for point target analyses

3.2.3 Impulse Response Function Validation

The Capella IRF was characterised in terms of:

- Slant range resolution
- Azimuth resolution
- Side lobe levels

Figure 5 provides an example of the IRF analysis performed over CR01 (2.4 m leg, 170° azimuth heading) for a SP HH acquisition. The point target response is first automatically detected within the data (the detection starting point is the expected target position according to the orbit information) and the 2D IRF is then oversampled to allow a better estimation of the IRF parameters. The parameters are estimated independently in the azimuth and range directions.

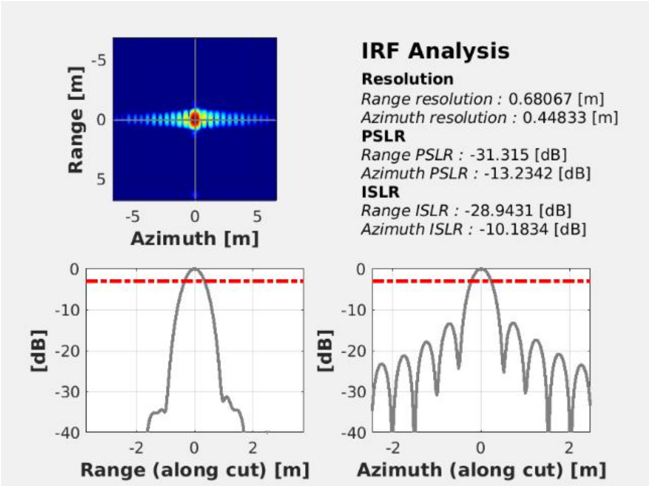

Figure 5 – Example of IRF analysis performed over Rosamond corner reflector CR01 for acquisition CAPELLA_C03_SP_SLC_HH_20210409054258_20210409054302

Figure 6 shows the measured resolution as functions of the incidence angle in the slant range direction (left plot) and in the azimuth direction (right plot). The horizontal dashed lines represent the theoretical resolution values, while the vertical dashed lines represent the nominal access range of the mission. Custom acquisitions can be commanded outside this nominal access area.

The range resolution is higher than the values declared in [RD2] due to the application on the range spectrum of an exponential window [RD6] introducing a broadening factor of 1.27 on the theoretical main lobe width. Furthermore, for the SP range resolution, the expected value is variable depending on the customizable processed bandwidth.

The azimuth resolution is in line with products specification.

Table 5 provides a resume of the resolution analysis showing the average and the standard deviation of the slant range and azimuth resolution together with the expected values, for each mode separately.

In general, there is a good agreement between the measured and the theoretical values, in particular, the azimuth resolution is almost always better than the declared values.

The level of the side lobes of the IRF was also assessed in the framework of this activity. They depend on the window applied to the range and Doppler spectra during the processing:

- Range window is an exponential window [RD6] with parameter α = 1.25 resulting in a PSLR of about -30 dB
- Azimuth window is a rectangular window for SP and SS products resulting in a PSLR of about -13 dB. Please note that the azimuth antenna pattern is not compensated in the CAPELLA products.

Side lobe levels consistent with the theoretical performance (see Figure 5 for an example) were measured in the analysed products. Please note that the measure of range side lobes, due to their very low level, is made difficult by the presence of clutter and noise.

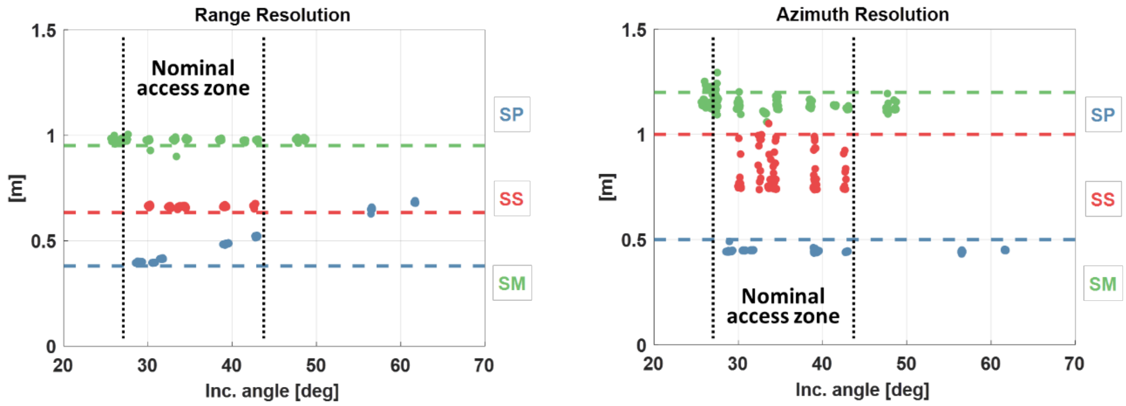

Figure 6 – Slant range resolution (left) and azimuth resolution (right) measured from acquisitions over CRs as a function of the incidence angle. Horizontal dashed lines represent the theoretical resolution, vertical dashed lines the nominal access of Capella products.

Swath	Slant Range Res. [m]			Azimuth Res. [m]		
	Expected	Mean	Std.	Expected	Mean	Std.
SP	variable	0.492	0.10	0.50	0.446	0.01
SS	0.63	0.661	0.01	1.00	0.667	0.21
SM	0.95	0.978	0.01	1.20	1.137	0.03

Table 5 - Resume of IRF resolution analysis results

3.2.4 Geolocation Data Assessment

The geolocation accuracy assessment is performed by comparing the measured point target position against the expected one. The point target position in SAR coordinates is measured from the data by estimating the position of the maximum of the target IRF. The expected point target position in SAR coordinates is obtained performing an inverse geocoding over the sensor orbit annotated in the product, starting from the known target position in ECEF reference system. The Absolute Localisation Error (ALE) in azimuth and range direction is then computed as the difference between the measured and the expected position:

$$ALE_{az/rg} = \mathrm{P}_{meas,az/rg} - \mathrm{P}_{exp,az/rg} \quad (1)$$

The results of the geolocation accuracy assessment are reported in Figure 7 where the measured geolocation errors have been plotted separately per acquisition mode. The colour of the triangles represents the corner reflector size while the direction of the triangle represents the sensor side looking (east/west). Results are also summarized in Table 6 where the mean and the standard deviation of the measured range and azimuth ALEs are reported.

Both the range and azimuth ALEs vary mostly in the range from -4 to 4 m and anyway ALE is never higher than 6.3 m in range and 7.6 m in azimuth. It can be assessed that the overall geolocation performance is good.

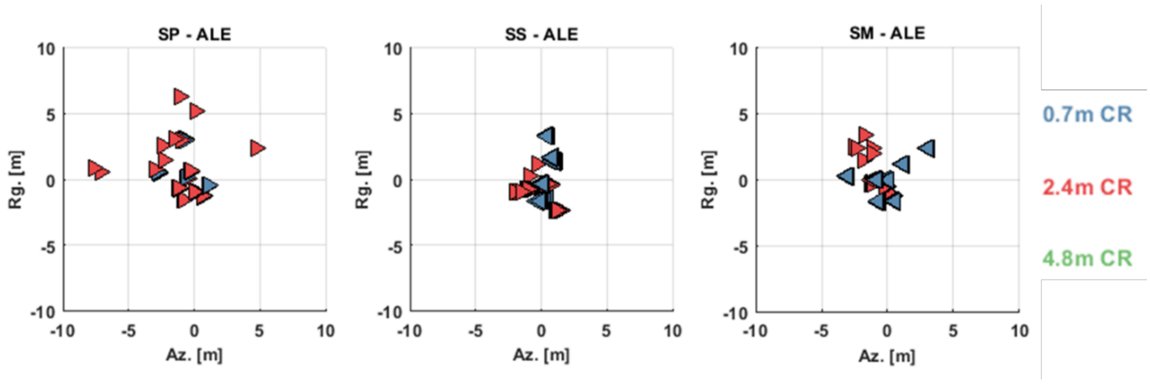

Figure 7 –Measured Absolute Localisation Error

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
SM	-0.03	1.26	-0.22	1.58
SP	0.38	1.57	-0.73	1.52
SS	0.06	1.66	0.21	0.79

Table 6 - Resume of geolocation accuracy assessment results

3.3 Noise Equivalent Sigma Nought

3.3.1 Calibration Site

The estimation of the noise level in Capella data has been performed exploiting dedicated acquisitions over the Mono Lake area. In such a calm water basin the backscatter is so low that the Noise Equivalent Sigma-Nought (NESZ) can be directly measured from the SLC data.

Figure 8 – Mono Lake area exploited for NESZ level assessment

3.3.2 Analysed Dataset

The following table provides the list of Capella acquisitions exploited for the NESZ level assessment. The table provides information on date, duration, acquisition mode, polarization, pass

(A for ascending and D for descending) and looking side. In particular the analyses were performed over the following 6 L1A SLC products:

- 3 Stripmap H/H products
- 3 Sliding Spotlight V/V products

ID	Start Time	Duration [s]	Mode	Pol	Pass	Side
CAPELLA_C03_SM_SLC_HH 20210618181524_20210618181528	18-JUN-2021 18:15:25	2.9509	SM	H/H	D	LEFT
CAPELLA_C03_SM_SLC_HH 20210827052821_20210827052825	27-AUG-2021 05:28:22	2.9283	SM	H/H	A	RIGHT
CAPELLA_C03_SM_SLC_HH 20210904052554_20210904052558	04-SEP-2021 05:25:54	2.9678	SM	H/H	A	RIGHT
CAPELLA_C05_SS_SLC_HH 20210814221359_20210814221410	14-AUG-2021 22:14:04	1.2638	SS	H/H	D	RIGHT
CAPELLA_C05_SS_SLC_HH 20210817100524_20210817100538	17-AUG-2021 10:05:30	1.293	SS	H/H	A	RIGHT
CAPELLA_C05_SS_SLC_HH 20210819225141_20210819225154	19-AUG-2021 22:51:47	1.262	SS	H/H	D	LEFT

Table 7 – List of acquisitions over Mono Lake

3.3.3 NESZ Level Validation

The performed analysis, based on the NESZ level estimation from the SLC data, is quite simple and is pictorially illustrated in Figure 9.

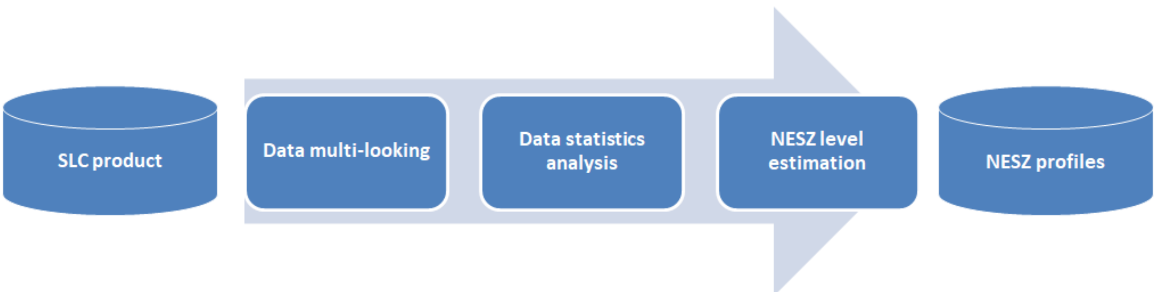

Figure 9 – Flow chart for NESZ level estimation

The data are divided into blocks of 2000 azimuth lines (out of about 20000 lines for SM and 25000 lines for SS) to cope with the natural variability of the observed scene. First of all, a multi-looking operation is performed to enhance the radiometric resolution of the noise level estimation process. The operation is performed through a 7 x 7 window in time domain. The selection of the window size is a trade-off between the need of a large window to enhance radiometric resolution and the need of a small window to avoid including backscatter variations in the analysis. The second step is the statistical analysis of the filtered block of data to identify for each range line the most likely NESZ level. The range-by-range processing is necessary due to the fact that the radiometric corrections applied by the processor make the noise level variable in range. The processing consists in the identification of a given percentile to be associated to the NESZ level in the data. The percentile selection is dependent on the considered multi looking window (the larger the window the lower the percentile). Ideally, for a very large window, the NESZ level would be associated to the minimum backscatter value measured in the range line. Considering the azimuth block size (2000 lines) and the multi look window size the percentile 1 was selected for the present analysis. Please note that the selected value is quite robust against outliers which could result in the estimation of very low NESZ values. On the other hand, in case that only few pixels are close to the noise floor the estimated NESZ level will be slightly higher than the actual value (overestimation). In the end a NESZ profile for each analysed data block is obtained.

As an example, Figure 10 shows a detail of the quick look of an acquisition over the Mono lake area, in which it can be observed how the backscatter is particularly low in the region over the lake. In Figure 11 the NESZ profiles obtained from the analysis of the same acquisition are reported. The image represents the 2D distribution of the profiles.

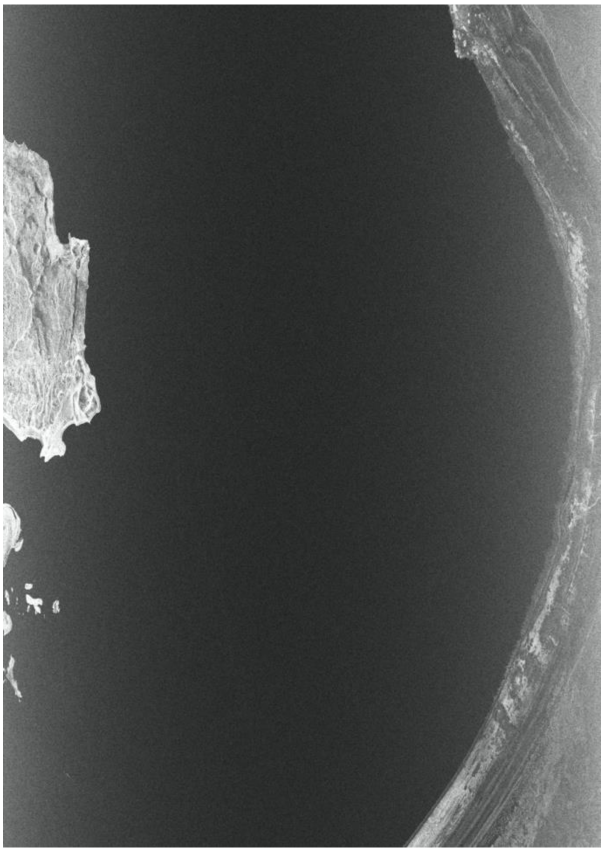

Figure 10 – Detail of a quick look of acquisition CAPELLA_C03_SM_SLC_HH_20210904052554_20210904052558 over Mono Lake

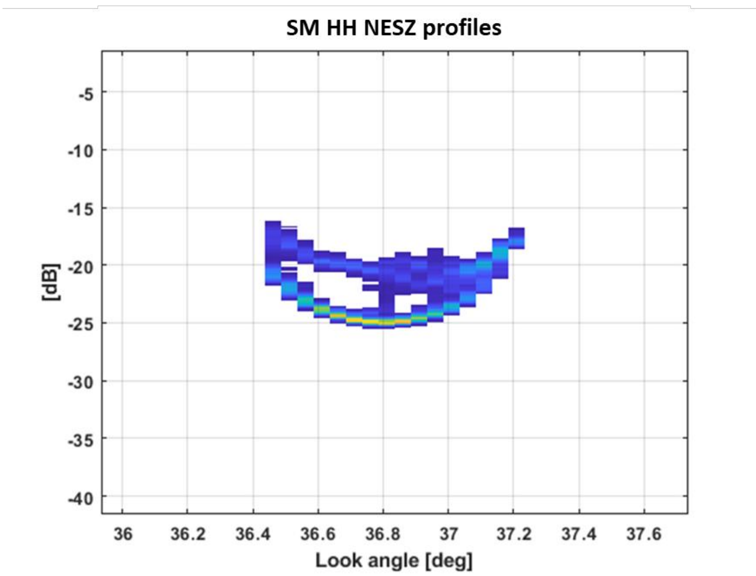

Figure 11 – NESZ profiles obtained from the analysis of acquisition CAPELLA_C03_SM_SLC_HH_20210904052554_20210904052558 over Mono Lake

Figure 12 and Figure 13 summarize the final NESZ profiles estimated from all the analysed products, Sliding Spotlight and Stripmap, respectively. The profiles are plotted as a function of the look angle. The profiles measured from the data, in blue, are compared with the theoretical NESZ values as annotated in the metadata, in red.

From the plots it can be observed that the NESZ level is very low w.r.t. the annotated one. The discrepancy between the measured level and the theoretical one likely suggests an issue in the radiometric calibration of the data.

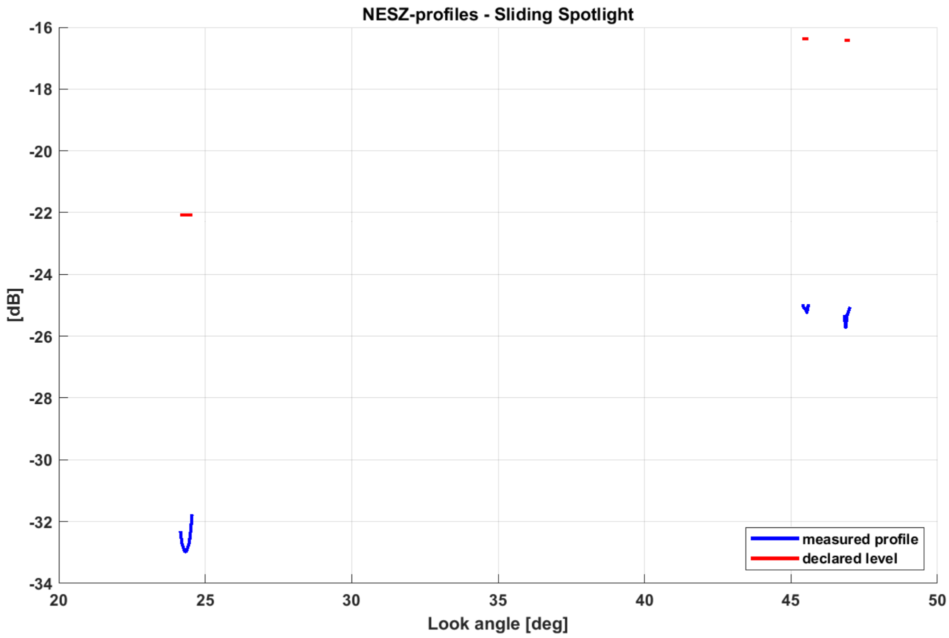

Figure 12 – NESZ profiles measured from Sliding Spotlight acquisitions

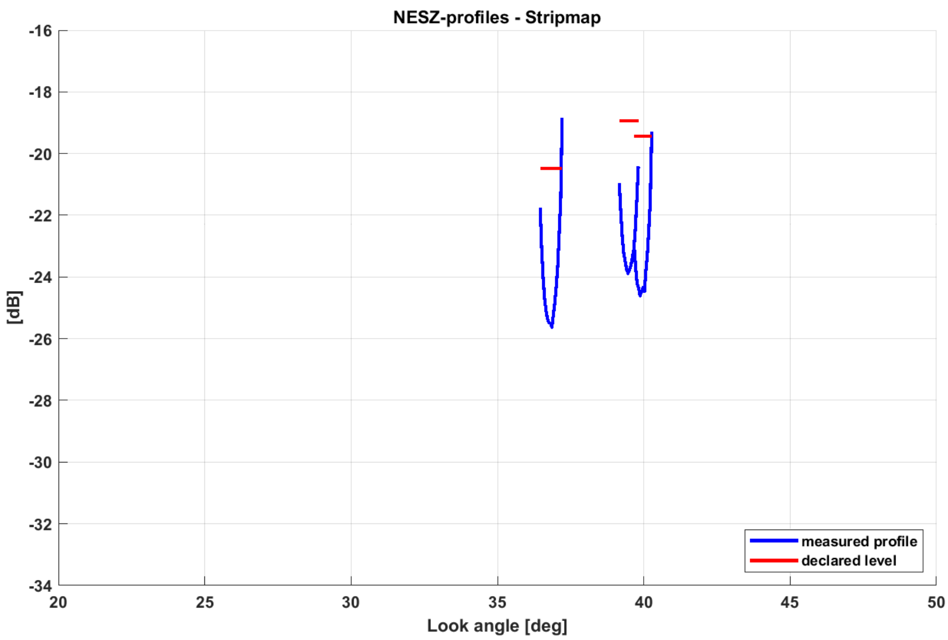

Figure 13 – NESZ profiles measured from Stripmap acquisitions

Finally, the variation of NESZ level as a function of the azimuth position within the Starting Spotlight products was assessed. The results of the assessment are reported in **Figure 14** for the product acquired on the 18th August 2021. The plot shows a difference of about 1 dB in the NESZ level between the centre of the image (red line) and the edges (blue and green lines). A similar behaviour can be observed in the other analysed products.

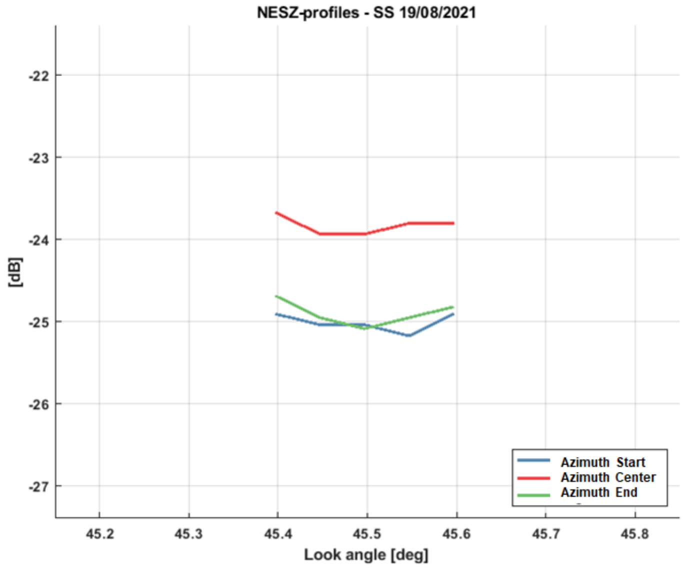

Figure 14 – NESZ profiles measured from a Staring Spotlight product for different azimuth positions

3.4 Rain Forest Data Assessment

3.4.1 Rain Forest Calibration Site

Rain Forest (RF) is a natural calibration site for SAR missions due to the homogeneity of the scene. Two different RF areas have been selected for the Capella Elevation Antenna Pattern (EAP) validation:

- Amazon area (CEOS area)
- Congo area

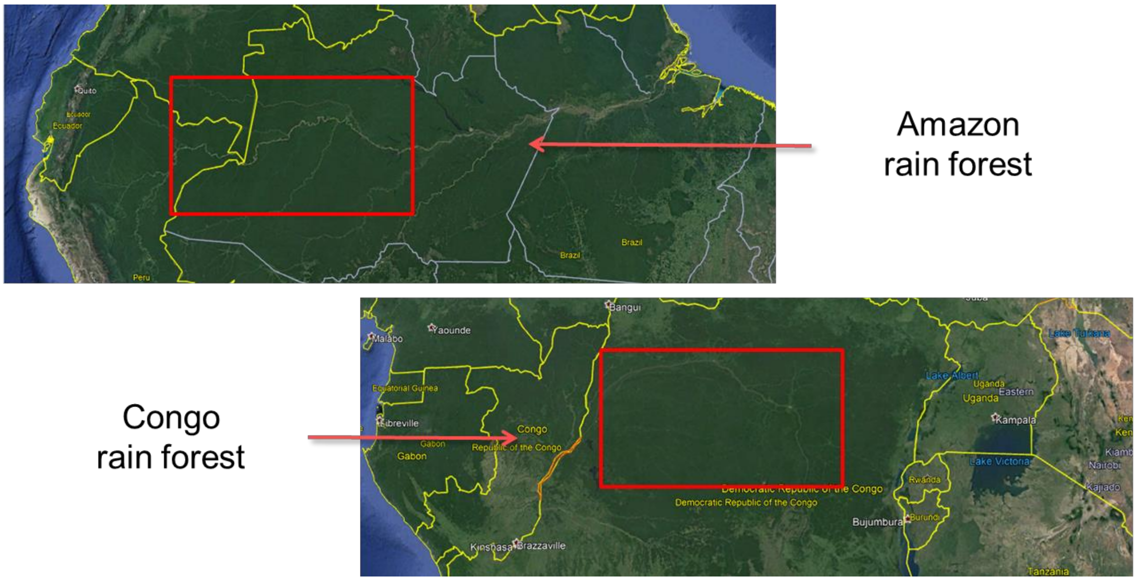

Figure 15 – Rain Forest areas

3.4.2 Analysed Dataset

The following table provide the list of the Capella acquisitions exploited for the EAP analysis. The table provides information on date, duration, site, acquisition mode, polarization, pass (A for ascending and D for descending) and looking side. In particular the analyses were performed over the following 12 L1A SLC products:

- 6 Stripmap H/H products
- 6 Stripmap V/V products

ID	Start Time	Duration [s]	Site	Mode	Pol	Pass	Side
420046ff-70aa-4f6b-b021-e6a1e5c01dec	23-JUL-2021 08:22:23	2.9064	CON	SM	H/H	D	LEFT
46515ae2-6574-46a2-a415-250f8826e725	07-AUG-2021 20:26:39	2.8974	CON	SM	V/V	A	RIGHT
5531801d-3e1a-4b35-bf73-af931720e4cb	03-AUG-2021 02:11:10	2.9146	AMA	SM	H/H	A	LEFT
6f4745d8-3182-4526-bd1f-b9c4051ce3ab	15-JUL-2021 20:15:41	2.8756	CON	SM	H/H	A	RIGHT
84afccaf-525d-4040-b269-7eb78f3e4c8a	15-JUL-2021 08:21:53	2.8928	CON	SM	V/V	D	LEFT
897841b8-2f30-48d8-9c77-74b612aa8e11	18-JUL-2021 02:11:37	2.8783	AMA	SM	H/H	A	RIGHT
95218814-9dbc-4aa2-85ff-da9f38efd043	22-JUL-2021 20:28:03	2.8871	CON	SM	V/V	A	RIGHT
9ee5fe45-4606-45fa-8fba-8beb8f20fc5f	26-JUL-2021 14:07:27	2.8962	AMA	SM	V/V	D	LEFT
9feeae8a-3106-4dba-afd9-6846b8e4527c	19-JUL-2021 02:00:49	2.8786	AMA	SM	V/V	A	RIGHT
cb0e7a4f-6734-4924-a6de-0b14ace50ff2	30-JUL-2021 20:27:35	2.8954	CON	SM	V/V	A	RIGHT
ddac14e8-7139-4cec-bb9a-f4d2b3f3275a	10-AUG-2021 02:21:58	2.8704	AMA	SM	H/H	A	LEFT
e9d21a50-14a8-44a0-9a9f-9d0b67c4f6e2	25-JUL-2021 02:23:16	2.9194	AMA	SM	H/H	A	RIGHT

Table 8 – List of acquisitions over RF sites

3.4.3 Elevation Antenna Pattern Validation

The RF data are exploited to perform an assessment of the Capella EAPEAP. In particular, under the assumption that the γ^0 is independent from the incidence angle, it is possible to verify the agreement between the patterns exploited for data compensation and the actual patterns by assessing the flatness of the γ^0 profiles.

The SLC products of RF acquisitions are processed according to the steps illustrated in the Figure 16. The following steps are performed:

1. **Noise removal**: thermal level is removed from the RF products. This step is not deemed mandatory since Capella NESZ level is well below average RF σ^0 (also considering that only co-pol data are available);
2. **Data masking**: SLC data intensity is analysed from a statistical point of view to discard any outlier related to non-homogeneity of the imaged scene (e.g. rivers or bright areas);
3. **Geometric calibration**: the $\beta\beta^0$ values are converted into γ^0 values;
4. **Profiles filtering**: the obtained γ^0 values are averaged in the azimuth direction to get an elevation profile of the analysed product. The obtained profiles are further filtered to remove remaining outliers.

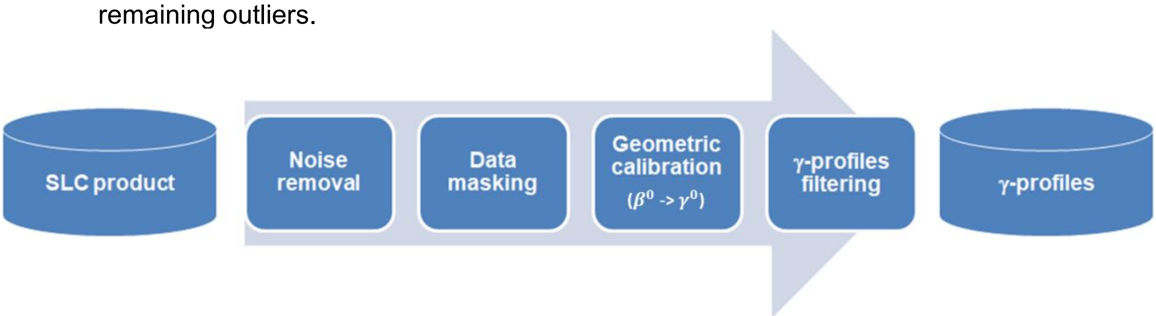

Figure 16 – Processing of Rain Forest data for γ^0 profiles derivation

The γ^0 profiles obtained according to the described processing refer to the corrections performed by the Capella processor. Residual corrections can be applied to the obtained profiles to compensate for effects not accounted by the processor. These effects include:

- Errors in the annotated attitude: the annotated roll angle is different from the roll angle estimated with EN analysis.
- Topography effects: the correction applied by the processor refer to the Ellipsoid.

After such corrections the γ^0 profiles can be exploited to assess Capella EAP. Figure 17 shows a detail of a quick-look of a SMSM HH acquisition over Amazon Rain Forest. Figure 18 shows the results of the γ^0 profiles estimation from the same product. The colour represents the number of points falling in a certain bin (off-boresight angle vs radiometric level) and the dashed black line is the estimated average γ^0 profile. In this example the obtained profile is flat but shows some slight slope which suggests some small residual pointing error in the compensation of the EAP.

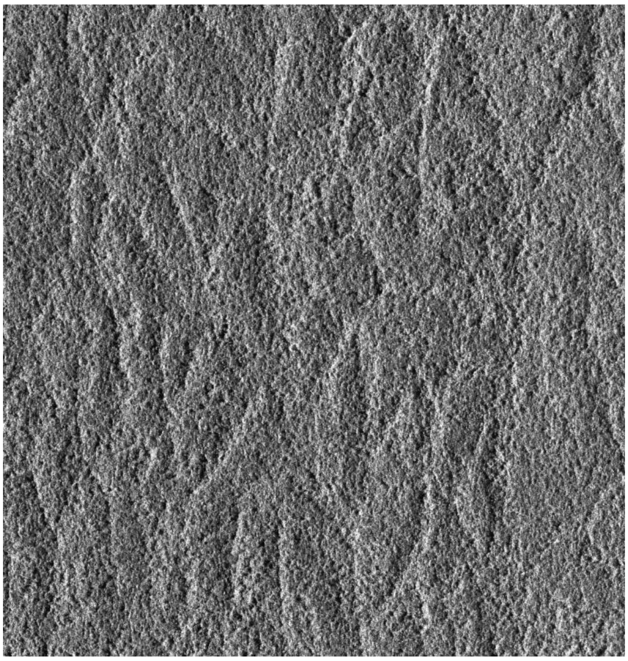

Figure 17 – Detail of a quick-look of SM acquisition of 15/07/2021-20:15:41 over Amazon rain forest

Figure 18 – Results of γ^0 profiles extraction from SM acquisition 15/07/2021-20:15:41 over Amazon rain forest. The colour represents the number of points falling in a certain bin. The dashed black line is the estimated average γ^0 profile.

Figure 19 shows the γ^0 profiles estimated from all the analysed products. The profiles are plotted as a function of the off-boresight angle w.r.t. the nadir direction (look angle). Top plots refer to HH products while bottom plots refer to VV products. The γ^0 profiles are quite flat apart from some slight residual slopes, suggesting that the EAP is correctly compensated with some residual mis-pointing errors. Moreover, it can also be assessed that the radiometric level is quite homogeneous among the analysed set of products. The usual γ^0 level observed in L and C band is around -6.5 dB suggesting a potential residual calibration error of about -1.5 dB that partly confirms the outcome of the NESZ assessment, i.e., CAPELLA products absolute calibration still requires some tuning. The CAPELLA team responsible of products calibration is currently working on this.

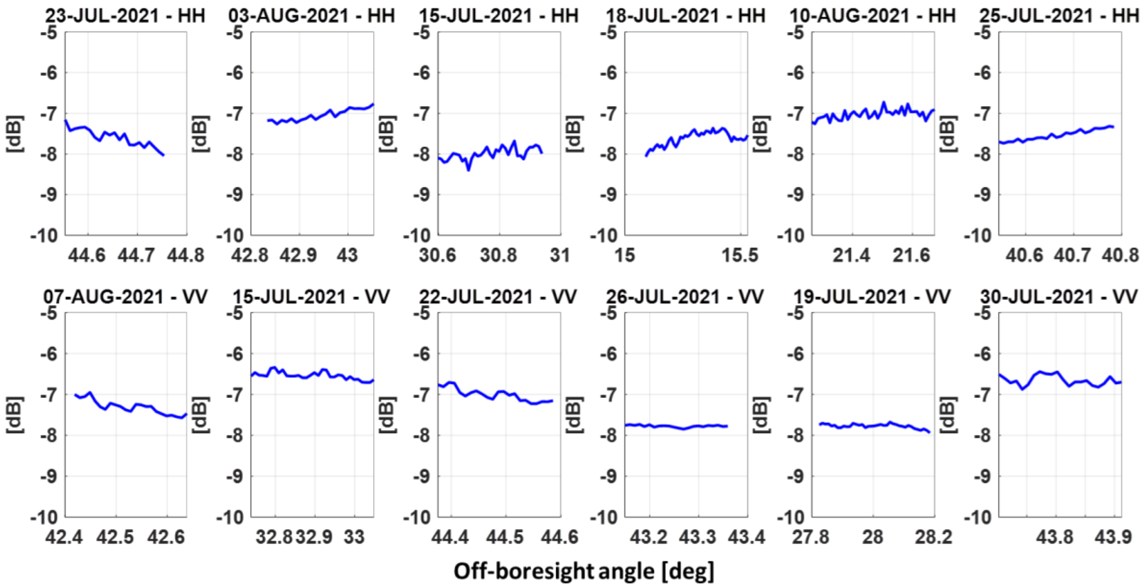

Figure 19 – γ-profiles measured from Rain Forest acquisitions

3.5 Summary of the assessment

The results of the independent assessment of Capella data quality have been reported in the previous sections. The main outcomes of the assessment are resumed here below:

- The assessment of the IRF quality has shown that geometric resolution is in line with the products specification.
- The assessment of the geolocation accuracy has shown that the measured geolocation accuracy is good and does not reveal any bias.
- The assessment of the NESZ level has shown that the measured NESZ level is lower than the theoretical values annotated in the products, suggesting a possible issue in the radiometric calibration.
- The assessment of the rain forest products has underlined that the radiometric level is in general homogeneous and that the elevation antenna pattern is well compensated apart from a slight residual mis-pointing bias.

It must be underlined that activities for the refinement of calibration of the Capella products are still ongoing and that the highlighted issues are known to the Capella team. A further iteration of the quality assessment in the next months could show a further improvement of the Capella products quality.

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[RD4] ROSAMOND CALIBRATION ARRAY https://uavsar.jpl.nasa.gov/cgi-bin/calibration.pl

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[RD6] Avci, Kemal & Nacaroglu, Arif. (2013). Exponential Window Family. Signal & Image Processing : An International Journal. 4. 1-12. 10.5121/sipij.2013.4401.