Sentinel-1 Constellation Product Performance Status

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Sentinel-1 Mission Performance Center

The scope of the MPC is to maintain and improve the product performance along the mission lifetime.

S-1 MPC is composed by value adding company and laboratory spread over Europe providing expertise in SAR and S-1 in particular.

- **CLS brest (F)**: Prime, L2 algo
- **BAE Systems (UK)**: Radiometric Cal.
- **UZH (CH)**: Geometric Cal.
- **Aresys (IT)**: L1 algo & Instrument
- **Norut (N)**: L2 algo
- **Ifremer (F)**: L2 Validation

Dedicated support from:

- **DLR** for the provision of the precision transponders
- **ODL** for expertise on the Radial Velocity
SAR constellation at C-band. Two satellites located 180deg apart

S-1 can be operated in 4 exclusive acquisition modes:
High Bit Rate modes:
- Stripmap (SM)
- Interferometric Wide Swath (IW)
- Extra Wide Swath (EW)
- *IW and EW are operated under the TOPS acquisition mode*
- HBR are single or dual polarisation,

Low bit Rate mode
- Wave Mode (WV). in single polarisation only (VV)
Sentinel-1 Wave Mode

- S-1 WV mode is the default mode over open ocean where no other mode is requested by a Copernicus/national services.
- S-1 WV is the direct continuation of ERS and ASAR WV mission providing swell measurement with several major differences:

<table>
<thead>
<tr>
<th></th>
<th>ASAR</th>
<th>Sentinel-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swath</td>
<td>Single IS2 : 23° equivalent to IM/IS2</td>
<td>Alternating (leap-frog): WV1: 23° equivalent to SM/S2 WV2: 36.5° equivalent to SM/S4</td>
</tr>
<tr>
<td>Imagette size</td>
<td>10x20 Km</td>
<td>20x20 Km</td>
</tr>
<tr>
<td>Imagette sampling</td>
<td>100 Km</td>
<td>100 Km</td>
</tr>
<tr>
<td>Polarisation</td>
<td>Single (HH or VV)</td>
<td>Single (HH or VV)</td>
</tr>
<tr>
<td>Resolution</td>
<td>16MHz</td>
<td>WV1: 74.5MHz WV2: 48.2MHz</td>
</tr>
</tbody>
</table>

\[23°\] \[36.5°\]
S-1 is the first SAR mission providing a L2 OCEAN (OCN) product designed to deliver up to three main geophysical components:

- Ocean surface wind field (OWI)
- Ocean swell wave spectra (OSW) not available for TOPS
- Radial surface velocity (RVL)

<table>
<thead>
<tr>
<th></th>
<th>WV</th>
<th>IW/EW</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>OWI</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>OSW</td>
<td>✓</td>
<td>✕</td>
<td>✓</td>
</tr>
<tr>
<td>RVL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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L2 OCN production mask

The L2 OCN production mask has evolved in time with the product maturity and with the increase of the processing capacity.

For WV mode:
- S1A: global* since 2015.02
- S1B: global* since 2016.05
  - *Global stands for within latitude band of [-40, 40] deg and everywhere else there is no IW/EW/SM
  - North Atlantic largely missing due to IW/EW acquisitions

For IW/EW/SM: Validation and super sites since mid-2015:
- Since 2015.07: Agulhas, Alboran Sea, Gulfe of Maine, Iroise Sea, US West Coast
- Since 2017.03: All Mediterranean and Baltic Sea
- Since 2017.11: systematic processing over ocean. Made possible thanks to the porting of the OCN processor from IDL to python allowing to increase the number of processing nodes.
PLATFORM AND INSTRUMENT STATUS
S-1A/B instrument internal drift

- The internal calibration is a key indicator of the instrument health/degradation
- Very stable internal calibration over time
- S-1A jumps and drops of power are related to the failure/recovery of antenna elements
S-1 Burst Synchronisation (BS)

- BS is mandatory to ensure INSAR compatibility
- Burst sync is well below the requirement of 5ms
- Same orbital pattern likely related to external seasonal effects
- Burst Synch is not a problem (so far) for the S-1 mission
S-1A/B Pointing performance: Doppler stability

S-1A Fdc evolution as a function of the star tracker configuration
S-1A/B AOCS optimization campaign

- The platform pointing is well enough into the specification → stable enough Doppler Centroid Frequency (DCF) for INSAR

- The analysis of the DCF for RVL purposes has revealed several issues:
  - Attitude bias dependent on the STar Trackers (STT) configuration
  - Light aberration correction not performed
  - AOCS gain not optimised

- The troubleshooting of the RVL requires to address those issues:
  - STT re-aligned during CP for S1B and 03.2017 for S-1A
  - Light aberration correction and AOCS fine tuned 12.2017 → 02.2018

### S-1A STT re-alignement

- S-1A: 31 ± 20 Hz
- S-1B: 14 ± 16 Hz

### Histogram of DC values over still land

- S1A: 30.7 ± 7.5 Hz
- S1B: 14.7 ± 6.8 Hz
L1 CALIBRATION STATUS
LEVEL 1 RADIOMETRIC CALIBRATION

• Main calibration site located over Germany close to DLR.
• Two calibration campaigns outside the CP of few months:
  • S-1A: spring / summer 2015
  • S-1B: Winter 2016/2017
• During these campaigns other configuration of mode/polarisation was acquired
• Other (shorter) campaigns might be needed on the future based on need
S-1A/B Radiometric Calibration

IW/EW

S-1A radiometric accuracy improved by a factor wrt to S-1A IOC

IW/EW

S-1B radiometric accuracy

+0.01 ± 0.25dB

+1.33 ± 0.32dB
S-1A/B radiometric evolution for 2017

- S-1A/ B radiometric accuracy is based on the last calibration campaign
- Radiometric calibration is monitored using different sites in the nominal IW/VV-VH configuration
- Based on DLR transponder measurements during 2017 and early 2018, the mean radiometric error is for:
  - S1-A IW products -0.06+-0.27 dB
  - S1-B it was -0.12+-0.23 dB
- Slight difference of 0.06dB closely monitored to ensure system cross-calibration
S-1 WV calibration

- For WV mode, no measurement was made (ever) over any well characterized calibrations sites
- Calibration is performed comparing SAR NRCS with CMOD-IFR2
- WV1/VV slight bias has been corrected back in 10.2017
- The dedicated test two-months campaign with S-1B in HH (not the operation polarisation) revealed a different bias for WV2
Noise Equivalent Sigma Zero: Instrument sensitivity

S-1A

IW

EW

S-1B

S-1B NESZ : K= 1.40000dB

S-1A NESZ : K= 0 dB
Improved noise removal

• S-1 data (especially x-pol) is quickly impacted by the NESZ leading to large radiometric biases and obvious swath transitions

• Necessary to provide more accurate denoising information to foster the efficient usage of the x-pol (soil moisture, wind estimates,...)

• Dedicated noise calibration campaign in summer 2017 leading to processor update in 03.2018 (updated format and denoising TN)

• → full range/azimuth denoising with more accurate vectors
GEOMETRIC CALIBRATION

Dubendorf

Torny
S-1A/B Absolute Location Error

- S-1A/B geolocation accuracy is measured using proper geocoding approach, precise orbit and specific correction
- The geometric accuracy of the system obtained is very good
- The careful analysis has revealed unexpected swath dependent biases

Schubert A., Small D., Miranda N., Geudtner D., Meier E. (2015), Sentinel-1A Product Geolocation Accuracy: Commissioning Phase Results, Remote Sens. 2015, 7(7), 9431-9449; doi:10.3390/rs70709431

S-1A/B Absolute Location Error

• Most recent analysis have identified the root cause of swath dependency and lead to significant improvement in the geolocation accuracy. Finally reaching the goal

• The issue is related to the compensation of satellite motion during the pulse travelling time (stop-and-go approximation)

• The current status is to not correct the processor for it as it will break the interferometric phase continuity

• Documentation will be made in order to describe how to correct for these effects in the existing data ¹

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L2 VALIDATION STATUS
L2 Ocean Swell (OSW)

Day 1, 11:00: Sentinel-1 WV OSW Validation

Day 1, 11:30: History on Sentinel-1 L2 wind product performance (OWI): Calibration/Validation strategy, status and coming evolution

L2 Ocean Wind (OWI)

L2 Radial Velocity (RVL)

4) Day 1, 09:40: Sentinel-1 WV HR Image Cross Spectra—perspectives for surface current retrieval from Sentinel1 Doppler
L2 OCN: swell for WV

- The OCN.osw (swell) component provides global swell measurement over open ocean. It is a legacy mode from ERS/ASAR WV providing:
  - 2D swell spectra with partitioned swell systems
  - Integral parameters (Hs, WI, Tp) for each partition

- MTF was updated in May 2016 to improve Hs bias and to harmonise WV1 and WV2 performances
  - Still residual bias when comparing the Hs eff with WW3 of <0.2m. Improvements expected soon

- The quality of the OSW has consistently increased and major effort was made to enhance partitioning, improve and harmonise performance for the two set of incidence angles

Known issues:
- Missing a quality flag to tag low-frequency contamination (atmosphere footprint) or scene heterogeneity in general
- Wave direction inversion issue
L2 OCN: wind for HBR

- The OCN.owi (wind) component provides SAR derived wind fields at high spatial resolution grid of 1x1Km using CMOD-IFR2 as GMF derived from the co-pol.

- Generated systematically for all modes IW/EW (SM) since last fall over seas

- Wind estimation benefits from the improvement of the radiometric accuracy and processor normalisation and will further benefit of the improved noise annotation for low wind speeds

- An overall bias of ~ -0.3m is observed (vs ECMWF winds) with a slight under-estimation at high wind speed.
  - Update of the GMF and noise removal (for low wind) might help in further improving

**Known issues:**
- GMF outdated
- Removal of bright targets to be further enhanced
L2 OCN: Radial Velocities

RVL aims at providing the radial surface velocity: 

\[ U_r = \frac{F_{dc_{phys}} - F_{dc_{wind}}}{2k_{rad}} \]

The partitioning of the SAR Doppler is a challenging problem. The best known breakdown is:

\[ F_{dc_{phys}} = F_{dc_{SAR}} - F_{dc_{AOCS}} - F_{dc_{elec}} \]

The Doppler anomaly \((F_{dc_{phys}})\) accuracy target is better than 5Hz imposing stringent requirements on the knowledge of each component

where:
- \( F_{dc_{phys}} \) is the DCF induced by the current to be measured. Also called Doppler anomaly
- \( F_{dc_{AOCS}} \) is the DCF induced by the platform pointing
- \( F_{dc_{elec}} \) is the DCF induced by the antenna electronic mispointing coming from the non-idealities, drift, failure.
The RVL challenge relies on the estimation/prediction of each $F_{dc_{phys}}$ component:

- $F_{dc_{SAR}}$ is estimated by the SAR processor $\rightarrow$ robust estimators but impacted by scalloping for TOPS. A first attempt to reduce it was introduced but a better correction is under preparation.

- $F_{dc_{elec}}$ was hoped to be predicted by a specific Antenna Model implemented in the processor. The results are overall good but are limited by the accuracy of the antenna ground characterization.
  - This is a relatively slowly changing in time and the AM prediction could be replaced by a characterization from data (e.g. over the rain forest).

- $F_{dc_{AOCS}}$ this the issue. Scalloping or antenna contribution are second order effect. The prediction of platform is the main contributor to achieve an accurate Doppler anomaly.
L2 OCN: RVL status

- The AOCS optimization has improved the pointing accuracy to an unprecedented level. As a result the correlation between radial wind speed and Doppler significantly increased.

- However there is still a major issue with the pointing knowledge (black).

- The AOCS optimization although being a necessary milestone didn’t bring any sensible improvement on the pointing knowledge (hence on Fdc\textsubscript{AOCs}).

- However, it has been demonstrated that a better attitude can be achieved (red) but there are still residual biases that are not understood.
L2 OCN: RVL status

• The RVL component of the OCN product is not qualified for operational use.

• The main issue relies on the knowledge of the pointing.

• Major activities were performed in order to fine-tune the AOCS, leading to an unprecedented pointing stability. This was a necessary process on which we can build.
  • AOCS fine tuning will continue for chasing remaining STT alignment and or pointing biases.

• Ground attitude restitution outperforms the information provided by the AOCS. However, it is not perfect and requires further work (under investigation).

• Other approaches are being investigated thanks to the improved quality of the WV imagettes.

(1) Ocean doppler anomaly and ocean surface current from Sentinel 1 tops mode, Johnsen H. et al.
CONCLUSION

• S-1 is the largest provider of SAR data in the world. Both satellites are working nominally and are providing data serving an ever increasing number of users and applications

• The quality of the data is a major commitment for ESA and requires a permanent engagement

• The radiometric and geometric calibration of the L1 product has improved along the mission lifetime and a constant effort is maintained to further improve

• S-1 is the first ever SAR mission providing a comprehensive L2 OCEAN product tree building on the ERS/ASAR heritage and introducing several new challenges for the swell and radial velocities in particular

• The performance of the L2 product is constantly monitored, directly benefits from the improvement made on the L1 and will continue improving.

• The L2 components (except RVL) are reaching good level of quality and a lot remains to do for exploiting their full potential