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THE SENTINEL-1 CONSTELLATION FOR INSAR APPLICATIONS — EXPERIENCES FROM THE INSARAP PROJECT

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ABSTRACT

The two-satellite Copernicus Sentinel-1 (S1) constellation became operational in Sep 2016, with the successful in-orbit commissioning of the S1B unit. During, the commissioning phase and early operational phase it has been confirmed that the interferometric performance of the constellation is excellent, with no observed phase anomalies. In this work, we show an analysis of selected performance parameters for the S1 constellation, as well as selected results based on the available data from the first months of operations.

Index Terms— Copernicus, Sentinel-1, InSAR

1. INTRODUCTION

The Copernicus Sentinel-1 constellation brings a paradigm shift to the field of InSAR, with its operational characteristics: mission configuration, acquisition planning, and data distribution policy[1]. The objective of the ESA SEOM INSARAP project is to perform a qualitative and quantitative evaluation of the S1 constellation for interferometric analysis. The evaluation encompasses both algorithmic robustness and scientific applications [2].

In this work we first present an early evaluation of the interferometric compatibility of the S1A and S1B units. We conduct an analysis of basic InSAR performance metrics, and present some early scientific case studies. Finally, we discuss the initial findings and outline the analysis to be presented in the final manuscript.

2. SELECTED RESULTS

2.1. First interferogram

Already the day before the S1B unit reached the nominal orbit, a 6-day interferometric pair was available, see Figure 1 and [3]. The perpendicular baseline was still about 500 m, leading to volumetric decorrelation in vegetated areas. However, in the coherent areas, we can observe that no phase artifacts are present.

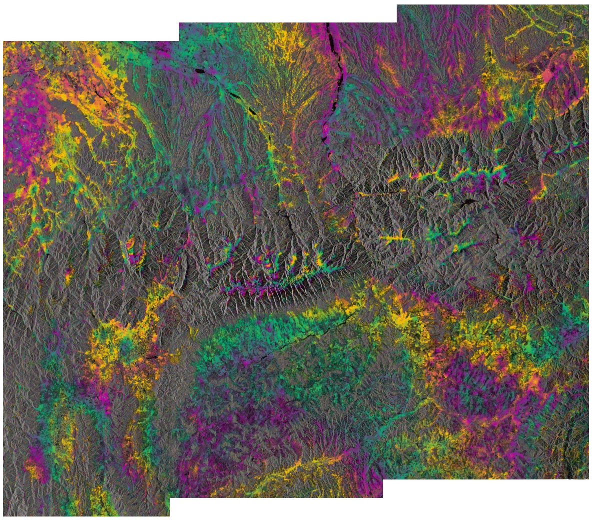

Fig. 1. First S1A/S1B cross-interferogram. The interferogram is based on IW data from 2016-06-09 (S1A) and 2016-06-15 (S1B), acquired in descending track 7 over Romania. The interferogram phase is mixed in with the corresponding backscatter data in the incoherent areas.

2.2. InSAR performance

Basic InSAR performance metrics, including

- doppler centroid

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- perpendicular baseline
- burst synchronization

where followed closely during the S1B commissioning phase. Initialle, the S1A and S1B units had slightly misaligned doppler bands due to mispointing, but this was corrected a few weeks before the first products where publicly released. Since early Sep 2016, the two satellites show no statistical difference in parameters relevant for InSAR. Further analysis of these parameters is outside the scope of this work.

In the following, we present two other metrics relevant for InSAR. First, we show a quantitative analysis of coherence as a function of temporal baseline. Then the potential effects of radar clock frequency errors are discussed, and results from estimation of the S1A/S1B clock frequencies presented.

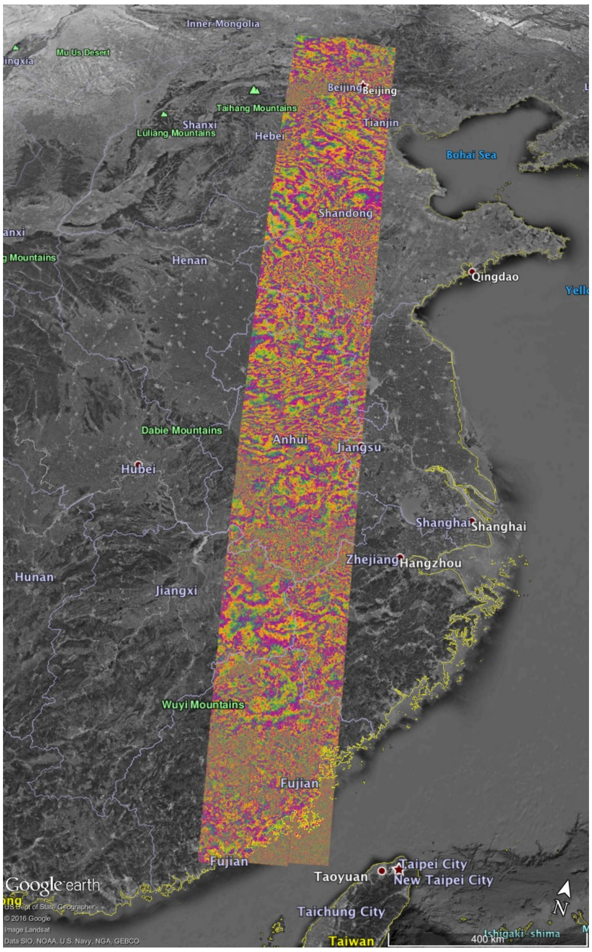

Fig. 2. Example 6-day interferogram from ascending track 142 over Eastern China.

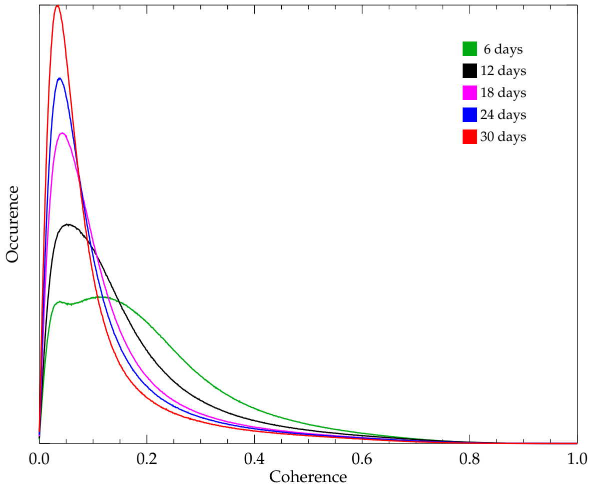

Fig. 3. Large-scale summer-time coherence statistics for 6-30 days temporal baselines, for a multilook factor of 64x16. Due to slight oversampling in the original data products, the effective factor smaller by a roughly 40%.

2.2.1. *Coherence*

To quantize the effect on coherence of the doubled temporal sampling from one image every 12 days (S1A) to one image every 6 days (S1A+S1B), a stack of thirteen 1900 km datatakes over Eastern China has been analysed. The data cover a large variety of land cover classes. One example 6-day interferogram is shown in Figure 2.

From the stack, all interferogram combinations up to 30 days are generated, using a multilook factor of 64 in range and 16 in azimuth. This corresponds to a 200-m ground resolution. Then histograms are formed over all coherence values for 6-, 12-, 18-, 24- and 30-day interferograms, respectively. The results are shown in Figure 3. The part of the histogram around its peak represents the incoherent targets. The peak is not at zero coherence due to the inherent bias in standard coherence estimators. Notic how the fraction of incoherent targets (as measured by the value of the histogram peak), decreases significantly from 18 to 12 days, and even more from 12 to 6 days. For the 6-day coherence histogram, notice that the histogram is now dominated by the coherent pixels, which means that there is at least some coherence almost everywhere.

This case study is large in spatial scale, but limited in time and to a single track. Nevertheless, it provides a good indication that 6- and 12-day temporal sampling are good choices for a C-band interferometric mission. Increasing the temporal sampling interval beyond 12 days has an impact on the ability to observe, e.g. discrete tectonic events in areas with dense vegetation.

2.2.2. *Effects of radar clock errors*

An important requirement of a multi-satellite interferometric SAR mission is the stability of the radar hardware clock frequencies, used to generate relevant radar parameters, including

- Carrier frequency
- Range sampling rate
- Pulse repetition frequency

Acceptable relative offset from nominal clock frequency is for a SAR instrument typically specified to be within 10^{-7}–10^{-9}, i.e. 1-100 parts per billion (ppb).

Constant absolute errors of this level for one or both satellites have no noticable effect on the InSAR performance. On the other hand, if there is an *unknown linear drift* over time for one or both satellites, this will result in a time dependent range direction phase ramp that will be misinterpreted as linear tilt of the entire swath. For the ENVISAT ASAR instrument, this effect was significant [4].

And if there is an constant *unknown difference* in the clock frequency between two satellites, there will be a constant range direction phase ramp in all interferograms, independent of temporal baseline. This effect is in principle possible to estimate and remove in the post processing.

To estimate the clock frequencies, we exploit the fact that in addition to the radar clock, all SAR missions necessarily include a maintained source of absolute time, used for time tagging of instrument data. By analyzing the relative difference between actual time tags with respect to the ones expected from the nominal radar timing parameters, it is possible to estimate the radar clock frequency with very high precision. Such an analysis is only using the time tags of each acquired line, not the actual data. Thus, it can be carried out based on L0 annotation products if available, or else from standard L0 products.

Table 2 shows preliminary estimated clock errors during the commissioning phase, based on more than 1000 L0 annotation products per instrument. Both clocks show spectacular performance, with errors less than 1 Hz. To further check for a possible long-term drift of one or both of the clocks, we analysed time tags for all datatakes in track 139 descending over Norway during the entire mission lifetime. Figure 4 shows the estimated clock error (squares), together with modelled linear trends (dotted lines). The estimated errors as of July 2016 are identical to the preliminary results, confirming the initial analysis. In addition, we now have estimated decay rates of -1.0 ppb/year for S1A, and -1.1 ppb/year for S1B, respectively. The fact that the decay rates are virtually identical, means that the relative error between S1A and S1B clocks will remain constant. The decay rate is slow enough that even after a decade of operation, the clock errors will remain close to the current values.

$$
\begin{aligned}
\Delta f_{\mathrm{S1A}} &\approx -f_{\mathrm{ref}} \cdot 10.1 \times 10^{-9} \approx -0.38\,\mathrm{Hz} \\
\Delta f_{\mathrm{S1B}} &\approx -f_{\mathrm{ref}} \cdot 16.8 \times 10^{-9} \approx -0.64\,\mathrm{Hz}
\end{aligned}
$$

Table 1. Preliminary estimated clock frequency offsets for the S1 mission, based on L0 annotation data from Jun-Aug 2016. Here, $f_{\mathrm{ref}} = 37534722.24\,\mathrm{Hz}$ is the nominal clock frequency.

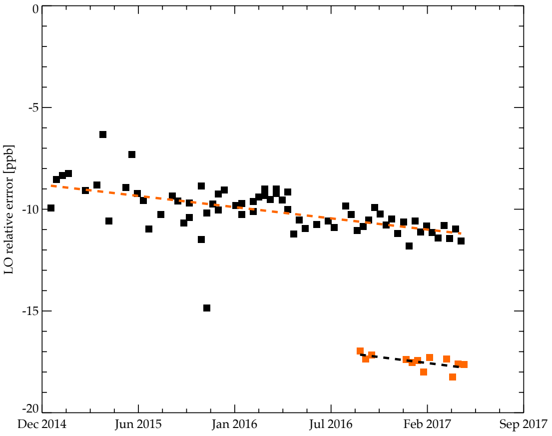

Fig. 4. Estimated clock error of S1A (black squares) and S1B (orange squares) based on long datatakes in track 139D. The dotted lines show the estimated linear trend.

$$
\begin{aligned}
\Delta f_{\mathrm{S1A}} &\approx -f_{\mathrm{ref}} \cdot (9.9 + 1.0t) \times 10^{-9} \\
\Delta f_{\mathrm{S1B}} &\approx -f_{\mathrm{ref}} \cdot (16.3 + 1.1t) \times 10^{-9}
\end{aligned}
$$

Table 2. Estimated clock frequency offset drift for the S1 mission, see Figure 4. Here, $f_{\mathrm{ref}} = 37534722.24\,\mathrm{Hz}$ is the nominal clock frequency. The time variable t is the number of years since 2016-01-01.

2.3. InSAR deformation analysis

In this Section, we present two case studies, one earthquake analysed with single S1A/S1B interferograms, and one two-year time series analysis based on S1A/S1B data.

2.3.1. Amatrice earthquake

A shallow M6.2 earthquake hit Central Italy, the area of city of Amatrice, on 24 August 2016. The quake epicentre was southeast of Norcia, Italy, in an area near the borders of the Umbria, Lazio, Abruzzo and Marche regions. The earthquake occured in the final part of the commissioning phase of S1B, and ESA released a number of S1B scenes to the scientific community as part of the relief effort. Figure 5 shows a 2D decomposition based on ascending and descending 6-day interferograms, both acquired on Aug 21 and 27, 2016, in tracks 117 and 22, respectively. Note that this analysis was made available only 4 days after the disaster, demonstrating the operational capability of the S1 constellation. The data set can be found in [5].

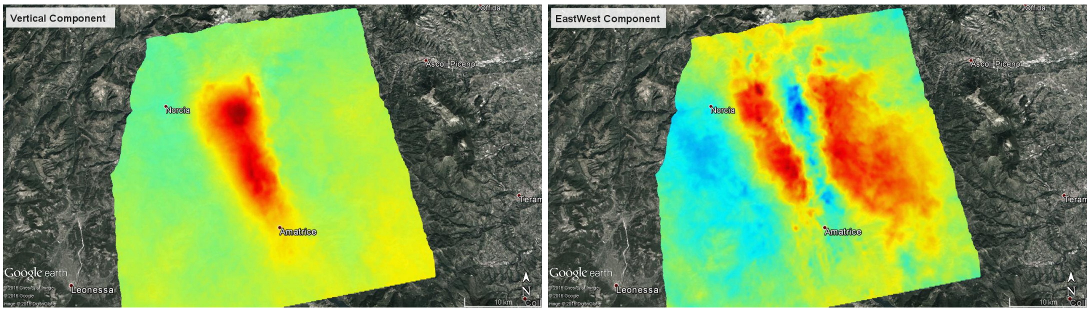

Fig. 5. Left panel: Vertical component, with color scale range [-250 mm, 250mm], red is down, green is zero. Right panel: East West component, with color scale range [-100mm, 100mm], red is East, blue is West.

Fig. 6. Sentinel-1 PSI analysis using data from S1A and S1B, descending track 139, Dec 2014 – Nov 2016.

2.3.2. *Subsidence of Oslo train station*

The area around the train station in Oslo is reclaimed land and has experienced subsidence for decades or more. We performed a PSI analysis, based on a 2-year long S1 stack with 43 images from descending track 139. The linear velocity component is shown in Figure 6 (see also [6]). The observed deformation rates agree well with existing results from other SAR missions.

3. DISCUSSION

To summarize, the S1 constellation already shows an excellent interferometric performance, with no unexpected technical problems. In particular, the coherence for 6-day interferograms has been shown to improve the signal quality significantly compared to only 12-day interferograms. We have also confirmed that both radar clocks are extremely stable, with no expected long-term impact on the InSAR performance.

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