SENTINEL-1 SYSTEM CAPABILITIES AND APPLICATIONS

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ABSTRACT

The paper provides an overview of the Copernicus Sentinel-1 system capabilities and applications. In particular, the characteristics of the Sentinel-1 SAR imaging modes and their key performance parameters are described. In addition, the Sentinel-1 SAR interferometry (InSAR) capabilities, especially for TOPS InSAR and the strategy for maintaining the orbital baseline as well as the requirements for TOPS image co-registration are discussed.

Index Terms—Sentinel-1, SAR, TOPS, InSAR

1. INTRODUCTION

In the framework of the EU/ESA co-funded Copernicus program (Global Monitoring for Environment and Security - GMES), ESA is undertaking the development of a series of five Sentinel missions with the objective to provide routinely Earth observation data for the implementation of operational Copernicus and national services. The Copernicus services comprise mapping and forecasting activities for Land, Marine, Atmosphere, Emergency, Security, and Climate Change monitoring.

2. SENTINEL-1 MISSION

As part of the Copernicus space component, the Sentinel-1 (S1) mission is implemented through a constellation of two satellites (A and B units) each carrying an imaging C-band SAR instrument (5.405 GHz) providing data continuity of the ERS and ENVISAT SAR missions. Each Sentinel-1 satellite is designed for an operations lifetime of 7 years with consumables for 12 years. The Sentinel-1 satellites will fly in a near polar, sun-synchronized (dawn-dusk) orbit at 697 km altitude.

Sentinel-1A was successfully launched on April 3rd, 2014. The launch of Sentinel-1B will follow about 18 months later.

The Sentinel-1 mission, including both S-1A and S-1B satellites, is specifically designed to acquire systematically and provide routinely data and information products to Copernicus Ocean, Land and Emergency services, as well as to national user services. These services focus on operational applications such as the observation of the marine environment, including oil spill detection and Arctic/Antarctic sea-ice monitoring, the surveillance of maritime transport zones (e.g. European and North Atlantic zones), as well as the mapping of land surfaces including vegetation cover (e.g. forest) and mapping in support of crisis situations, such as natural disasters (e.g. flooding and earthquakes) and humanitarian aid [1].

In addition, the 12-day repeat orbit cycle of each Sentinel-1 satellite along with small orbital baselines will enable SAR interferometry (InSAR) coherent change detection applications, such as monitoring of surface deformations (e.g., subsidence and tectonics) and cryosphere dynamics (e.g., glacier flow).

3. SENTINEL-1 SYSTEM

3.1 Sentinel-1 SAR Instrument

The Sentinel-1 SAR instrument with its active phased array antenna supports four exclusive imaging modes providing different resolution and coverage: Interferometric Wide Swath (IW), Extra Wide Swath (EW), StripMap (SM), and Wave (WV), see Figure 1. All modes, except the WV mode can be operated in dual polarization.

Both the IW and EW mode are implemented as TOPS (Terrain Observation with Progressive Scans in azimuth) modes [2] to provide large swath width of 250 km at ground resolution of 5m x 20m and 400 km at ground resolution of 20m x 40m, respectively with enhanced image performance as compared to the conventional ScanSAR mode.

The characteristic of the TOPS SAR imaging mode is that the antenna azimuth beam is steered from aft to the fore at a constant rate. As a result and in contrary to ScanSAR, all targets on ground are observed by the entire azimuth antenna pattern. This eliminates almost entirely the scalloping effect and also leads to constant azimuth ambiguities and signal-to-noise ratio (SNR) along azimuth. However, the trade-off is that the fast azimuth beam steering reduces the target dwell time, and as such, the spatial resolution in azimuth.
The instrument is capable of operating in each SAR imaging mode up to 25 minutes per orbit. As a result, the baseline observation scenario foresees the acquisition of dual polarimetric data (HH/HV or VV/VH) in the Interferometric Wide Swath (IW) mode over Europe, Canada and the maritime transport zones whilst over open oceans the Wave mode (WV) mode is continuously operated with up to 74 min per orbit. Hence, a complete global SAR image coverage can be achieved within the satellite’s 12-day orbit cycle. The average global coverage and revisit time is shown in Figure 3.

The main advantage of the systematic data acquisition using the Sentinel-1 IW mode is that it allows the build-up of long data time series at equidistant time intervals. This will especially support applications such as soil moisture monitoring and permanent scatterer SAR interferometry (PS-InSAR).

### 3.2 Sentinel-1 Attitude Steering Modes

Sentinel-1 will be operated in a so-called roll-steering mode. This mode introduces an additional roll angle as a function of latitude to compensate for changes in the satellite’s altitude around the orbit due to the shape of Geoid, hence maintaining a specific, quasi “constant”, slant range for each SAR imaging mode. This enables the use of a single PRF per swath or sub-swath around the orbit, except for SM-5 (i.e., different PRF for SM-5N and SM-5S), and a fixed set of constant elevation antenna beam patterns. Figure 4 illustrates that for the minimum orbital height (693 km) the SAR antenna off-nadir angle is more shallow (30.25°) than is for the maximum orbital height (726 km). In the latter case the mechanical SAR antenna off-nadir angle is 28.65°.
In addition, Sentinel-1 will be operated in the total zero-Doppler steering mode to account for Earth rotation effects by yaw and pitch adjustments around the orbit with the goal to achieve Doppler centroid frequencies close to zero Hz.

4. SENTINEL-1 SAR INTERFEROMETRY

4.1 Orbit and Baseline Considerations

As both satellites, S-1A and S-1B, will fly in the in the same orbital plane, but 180 deg. phased, see Figure 5, and each having a 12-day repeat orbit cycle, it will facilitate the formation of SAR interferometry (InSAR) image pairs (i.e., interferograms) having of 6-day time interval. This along with the fact that the orbital deviation of each Sentinel-1 satellite will be maintained within a tube of +/- 50 m radius (RMS), see Figure 6 will enable the generation of geographically comprehensive maps of surface change. Applications may include the measure of ice motion in the Polar regions and the monitoring of geohazard related surface deformation caused by tectonic processes, volcanic activities, landslides, and subsidence e.g., due to Arctic Permafrost melt and underground mining, respectively.

4.2 Burst Synchronisation

To support the implementation of TOPS SAR interferometry (InSAR), including the generation of TOPS SAR interferograms and coherence maps, the Sentinel-1 SAR system is designed to achieve TOPS burst synchronization of less than 5ms between corresponding repeat-pass bursts. The goal is to minimize the otherwise resulting spectral misalignment in azimuth and to increase the geometric overlap. The TOPS burst duration for the IW and EW mode is 0.82s and 0.54s, respectively.

4.3 Co-Registration of TOPS Image Pairs

The accurate co-registration of Sentinel-1 IW TOPS image pairs and stacks is of crucial importance for achieving best TOPS InSAR performance. It is known that in conventional Stripmap mode InSAR image pairs due to the antenna squint, linear phase ramps are induced in the focused SAR impulse response function. In this case, a small azimuth co-registration error would cause a constant phase offset in the interferogram. However, in the TOPS mode, a similar small co-registration error in azimuth would introduce a linear azimuth phase ramp in the interferogram due to the SAR antenna azimuth beam sweeping causing Doppler centroid frequency variations of about 5 kHz [3]. The resulting phase error can be calculated as follows:

$$\phi_{\text{err}} = 2\pi f_{\text{OC}} \Delta t$$

where $f_{\text{OC}}$ is the Doppler centroid frequency and $\Delta t$ is the co-registration error expressed in azimuth time. In the case of Sentinel-1 TOPS InSAR image pairs, an azimuth co-registration accuracy of about 0.003 azimuth samples is required to achieve a phase error of less than 10 deg.
REFERENCES


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