SENTINEL-1 SYSTEM OVERVIEW AND PERFORMANCE

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ABSTRACT

The paper provides an overview of the Copernicus Sentinel-1 system characteristics including the SAR imaging modes and their key performance parameters, as well as the specifics of related attitude and orbit control modes (i.e. roll steering mode and zero-Doppler steering mode). In addition, the Sentinel-1 SAR interferometry (InSAR) capabilities are discussed.

1. INTRODUCTION

In the framework of the EU/ESA co-funded Copernicus/Global Monitoring for Environment and Security (GMES) program, 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 ERS and ENVISAT SAR types of mission. Each Sentinel-1 satellite is designed for an operations lifetime of 7 years with consumables for 12 years. The S-1 satellites will fly in a near polar, sun-synchronized (dawn-dusk) orbit at 693 km altitude.

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 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 the monitoring of surface deformations (e.g. subsidence due to permafrost melt) 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 Fig. 1. All modes, except the WV mode can be operated in dual polarization

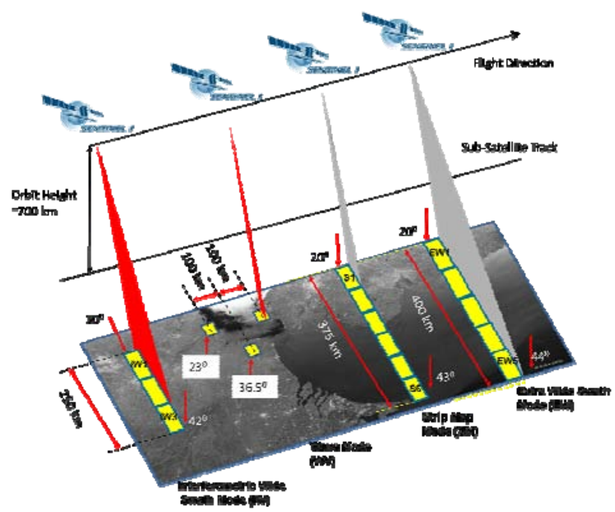

Figure 1. Sentinel-1 SAR imaging modes

Both the IW and EW mode operate in TOPS (Terrain Observation with Progressive Scans in azimuth) mode [2] providing 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. Specifically, in the TOPS SAR imaging mode,

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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 complete azimuth antenna pattern eliminating almost entirely the scalloping effect and achieving constant azimuth ambiguities and signal-to-noise ratio (SNR) along azimuth. However, the fast azimuth beam steering reduces the target dwell time, and as such, the spatial resolution in azimuth. Key parameters of the Sentinel-1 SAR imaging modes are summarized in Table 1.

Table 1. Characteristics of Sentinel-1 SAR Imaging Modes

Mode	**Incidence Angle [deg]**	**Chirp Bandwidth [Hz]**	**Single-Look Ground Resolution [m]**
SM (S1-S6)	20-43	87.6-42.2	5 x 5
IW (1-3)	30-42	56.5-42.8	5 x 20
EW (1-5)	20-44	22.2-10.4	20 x 40
WV (1&2)	23 & 36.5	74.5 & 48.2	5 x 5

The Noise Equivalent Sigma Zero (NESZ) for all four SAR imaging modes is required to be better than -22 dB. Fig. 2 shows the expected NESZ performance for each sub-swath of the IW mode. The requirement for the absolute radiometric accuracy is 1 dB (3σ) for all modes.

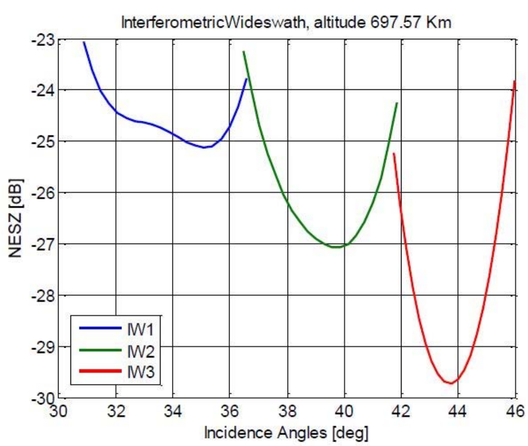

Figure 2. NESZ performance for the Sentinel-1 (IW) mode at 693 km altitude

Considering that the instrument is capable of providing imaging operations time of up to 25 minutes per orbit, the baseline observation scenario foresees the acquisition of dual polarimetric data in Interferometric Wide Swath (IW) mode over Europe, Canada and the maritime transport zones while over open oceans the Wave mode (WV) mode is continuously operated with up to 74 min per orbit. Therefore, a complete global SAR image coverage can be achieved within the satellite's 12-day orbit cycle. The average global revisit time is shown in see Fig. 3.

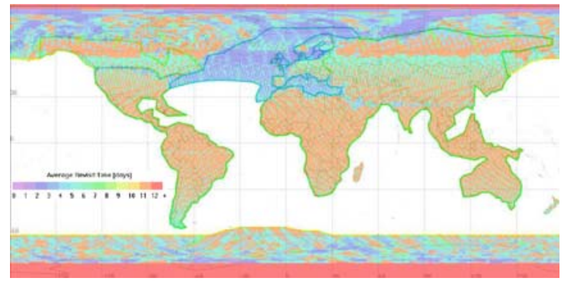

Figure 3. Sentinel-1average revisit time

3.2. Sentinel-1 Attitude Steering Mode

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 changes in the satellite's altitude around the orbit, hence maintaining a specific, quasi "constant", slant range for each SAR imaging mode. This enables the use of a single Pulse Repetition Frequency (PRF) per swath or sub-swath around the orbit, except for Stripmap mode SM-5 (i.e. different PRF for SM-5N and SM-5S). Another advantage is the use of fixed set of constant elevation antenna beam patterns. Fig. 4 illustrates that for the minimum orbital height (693 km) the mechanical 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°.

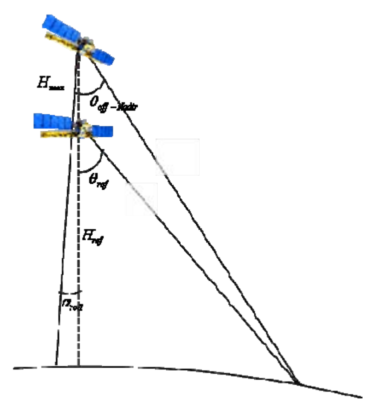

Figure 4. Illustration of the Sentinel-1 roll-steering mode

4. SENTINEL-1 SAR INTERFEROMETRY CAPABILITY

4.1. Orbit and Baseline Considerations

As both satellites, S-1A and S-1B, will fly in the in the same orbital plane with *180 deg.* phased in orbit, see

Fig. 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 Fig. 6 will enable the generation of geographically comprehensive maps of surface change such as for measuring ice velocity in the Polar regions, as well as monitoring geohazard related surface deformation caused by tectonic processes, volcanic activities, landslides, and subsidence e.g., due to Arctic Permafrost melt.

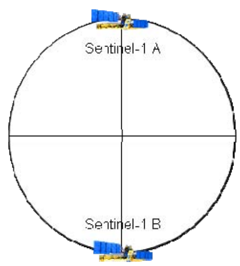

Figure 5. Orbital configurations for the Sentinel-1 constellation

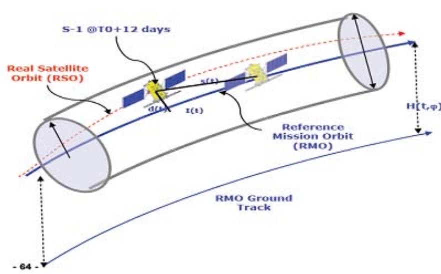

Figure 6. Orbital tube with respect to the Reference Mission Orbit

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 enable TOPS burst synchronization of repeat-pass datatakes. Specifically for the IW and EW modes, the TOPS burst duration is 0.82s and 0.54s (worst case), respectively, with a requirement to achieve a synchronization of less than 5ms between corresponding repeat-pass bursts. The goal is to minimize the otherwise resulting spectral misalignment in azimuth.

4.3. Co-Registration of TOPS InSAR Images

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:

$$\phi_{az_{err}} = 2\pi \ f_{DC} \ \Delta t \tag{1}$$

where f_{DC} is the Doppler centroid frequency and Δt 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 0.003 samples is required to achieve a phase error of less than 10 degrees.

5. REFERENCES

1. *GMES Sentinel-1 Mission Requirements Document*: Issue 1 revision 4. ESA-RS-ESA-SY-0007, 2007.
2. F. De Zan and Andrea Monti Guarnieri, "*TOPSAR: Terrain Observation by Progressive Scans*", IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, No. 9, September 2006, pp 2352-2360.
3. P. Prats et al., "*Processing of Sliding Spotlight and TOPS SAR Data Using Baseband Azimuth Scaling*", TGARS, Vol. 48, no. 2, pp. 770-780, February 2010.

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