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PERFORMANCE OF 2-D DEFORMATION MEASUREMENTS BY THE MULTI-STATIC HARMONY (STEREOID) MISSION

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ABSTRACT

This paper debates the performance of the HARMONY (STEREOID) ESA EE-10 candidate mission in measuring the two-dimensional (2D) terrain deformation. Thanks to its Stereo configuration, where the two passive spacecrafts span a large along-track baseline centered on the Sentinel-1 satellite, a large observation angle diversity in azimuth can be achieved. This theoretically leads to promising deformation performance in the north-south direction component, which will play an extremely important role for the surface displacement analysis in the future

Index Terms**—**Bistatic/Multi-static SAR system, deformation measurement, atmospheric disturbance

1. INTRODUCTION

HARMONY (Stereo Thermo-Optically Enhanced Radar for Earth, Ocean, Ice, and land Dynamics (STEREOID)) is one of the three ESA Earth Explorer 10 candidate missions [1]. The novel multi-static synthetic aperture radar (SAR) constellation is formed by two passive spacecrafts (HARMONY -1 A and B), running in the same orbit with Sentinel-1 satellite and receiving its echoes. Under its Stereo configuration, two passive sensors will fly ahead and behind the Sentinel-1 satellite with approximately the same distance. Three independent line-of-sight (Los) measurements can be achieved simultaneously. With the help of the large observation angle diversity in azimuth, HARMONY is deemed to greatly improve the deformation retrieval accuracy in the north-south direction [2]. Therefore, the mission is of great value for an improved understanding of the global climate change and small-scale geophysical motion processes.

Prior to the novel HARMONY mission, the single-satellite spectral diversity/multiple aperture interferometry was utilized to realize 2-D deformation measurements [2]. However, it can only obtain low-accuracy azimuth deformations. Later, multi-static SAR configurations, such as the SESAME mission [3] and the multi-squint SAR system [4], were conceived to break through the limitation of system's observation angle and improve the performance for 2-D deformation measurements.

In this paper, we focus on the analysis of the 2-D deformation measurement performance by HARMONY. In Section 2, the measurement geometry of the HARMONY system are demonstrated. Although three Los directions are measured, only 2-D high accurate deformation can be achieved as they almost belong to the same plane. Numerical performance analysis simulation is carried out in Section 3, where the impacts of atmospheric disturbances, the bistatic angle on the radar cross section (RCS) and the distance between the Sentinel-1 and the passive HARMONY satellites are discussed. Finally, Section 4 concludes this paper and gives research perspectives.

2. 2-D DEFORMATION MEASUREMENTS BY HARMONY

The Stereo configuration of HARMONY is shown in Fig. 1, which has three Los measurements. 2-D deformation (Sentinel-1's Los and azimuth) can be calculated based on at least two of the three measurements by using the least square method [4].

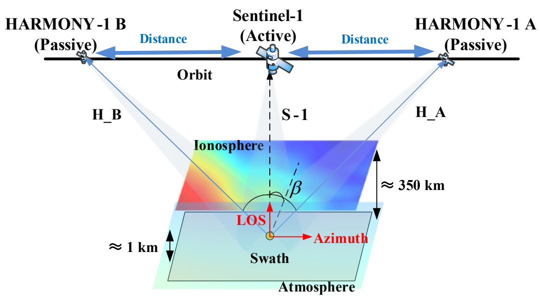


Figure 1 Sketch map of the 2-D deformation measurement by the HARMONY's Stereo configuration

Table 1 Performance simulation parameters

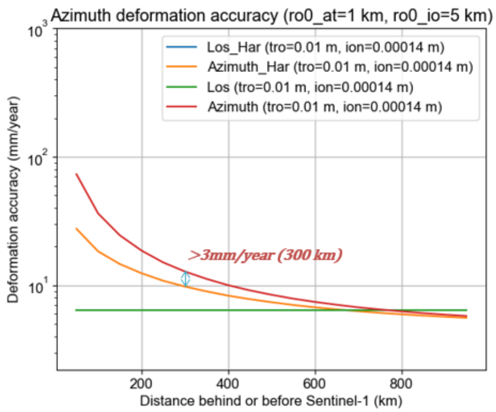
parameter	value	parameter	Value
Carrier central frequency(GHz)	5.4	Orbit height (km)	693
Incidence angle (deg)	[28.5, 30.5]	Repeat time (day)	12
ABL height (km)	1	Ionosphere height (km)	350
Observation period (day)	360	Number of looks	64

Three significant aspects are considered in the 2-D deformation retrieval accuracy analysis by HARMONY system. Foremost, the separation between the HARMONY satellites and Sentinel-1 satellite has a strong influence on azimuth deformation accuracy as it determines the observation angle diversity of the HARMONY satellites. Moreover, as pointed in [4], the azimuth deformation measurement in the multi-static SAR system has a benefit of canceling the partial correlated atmospheric phases. Because the troposphere is near the ground, the tropospheric impacts on the two HARMONY satellites are not independent, and will be eliminated partially during the differential processing. However, the ionospheric impact is different as the ionosphere is much higher concentrating at the height of 350 km. Although the ionospheric random disturbance turns small as the increase of the radar working frequency, the azimuth gradients brought by the smooth ionospheric phases should be compensated by the algorithm in [5]. At last, since HARMONY satellites work in the bistatic mode, it should be considered that the bistatic RCS might differ from the monostatic one [6], [7]. Therefore, in some scenarios, the HARMONY coherence could register a drop with respect to that of the Sentinel-1 image due to the loss of SNR under the bistatic geometry.

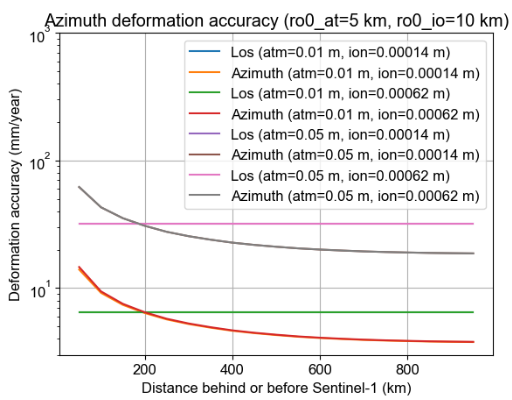
3. PERFORMANCE ANALYSIS SIMULATION

The utilized performance simulation parameters are shown in Table 1. In the simulations, exponential autocorrelation functions (ACFs) of atmospheric disturbance phases are utilized. In addition, we consider an infinitely far away reference point for deformation accuracy evaluation. Sentinel-1's data and two HARMONY satellites' data are exploited to retrieve the deformations in Sentinel-1's Los and azimuth respectively and the Hybrid Cramer-Rao bound analysis is taken into account for estimating the 2-D deformation measurement accuracy [4].

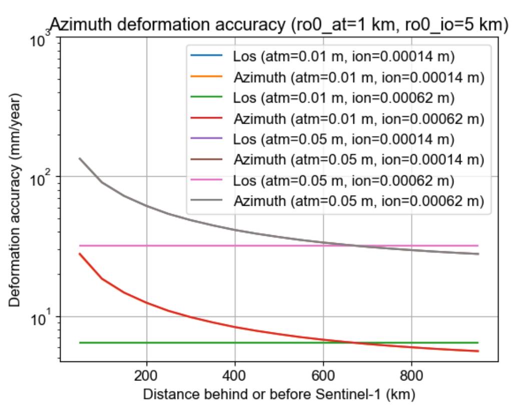
In Fig. 2, the accuracy of the 2-D deformation measurements under different atmospheric conditions is reported as a function of the HARMONY's distance behind or before Sentinel-1. Foremost, as the distance increases, the azimuthal observation angle difference turns larger and the azimuth deformation accuracy is improved. In contrast, the deformation estimation performance in range is independent of the distance. With respect to the dispersive ionospheric media, we study the impact of the ionosphere phase screen from weak to strong according to the carrier-equevalent navigation satellites' *in situ* measurements. As the ionospheric random phase impact in C band is weaker than that in L band, HARMONY is more sensitive to troposphetic disturbances. Fortunately, parts of the tropospheric disturbance can be canceled due to the correlated troposphere (see Fig. 2 (a)), which can bring a more than 3mm/year improvement of the azimuth deformation measurement accuracy under a 300 km along-track baseline case. Nevertheless, the tropospheric phase turns uncorrelated as the separation between the the active and the passive satellites increase, resulting to a less than 1 mm/year improvement when the along-track baseline is larger than 500 km. Comparing Fig. 2 (b) and (c), a longer tropospheric correlation length can decrease the residual tropospheric phase, which can finally help achieve a better azimuth deformation measurement performance.



(a)



(b)



(c)

Figure 2 (a): Improvement of the performance by canceling the partial correlated tropospheric phases; (b) and (c): 2-D deformation measurement accuracy under different atmospheric and ionospheric conditions

In Fig. 3, a RCS in-plane simulate case is obtained by the method of moment (MoM) as a function of scattering (bistatic) angle and of the incidence angle [7]. For simplicity, here we assume it is contributed by the averaged RCS of the objects composed of typical orthogonal dihedral corners with the sizes from 0.1 times to 10 times of the carrier wavelength (structures in the urban area), as they are the dominant scattering structures under the monostatic geometry [6], [7]. It can be noticed that a large bistatic angle makes the scatterer's RCS weak. Based on the simulated data, Fig. 4 shows the 2-D deformation measurement accuracy when the impact of the bistatic RCS on target's coherence is considered. The result implies that the azimuth deformation measurement accuracy deteriorates a bit (< 2mm/year @ 300 km along-track baseline) due to the loss of the targets' SNR in HARMONY's bistatic images compared with the SNR in Sentinel-1's monostatic images.

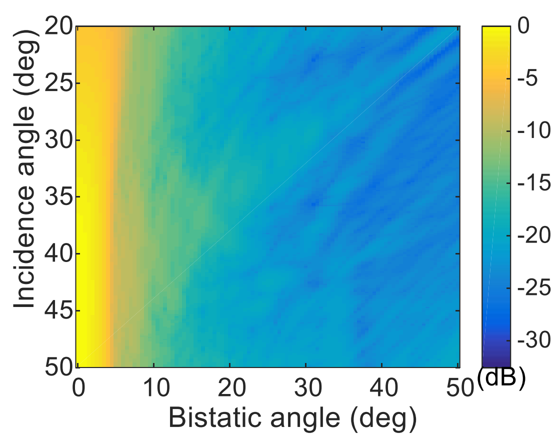


Figure 3 Bistatic RCS as a function of the bistatic angle and of the incidence angle

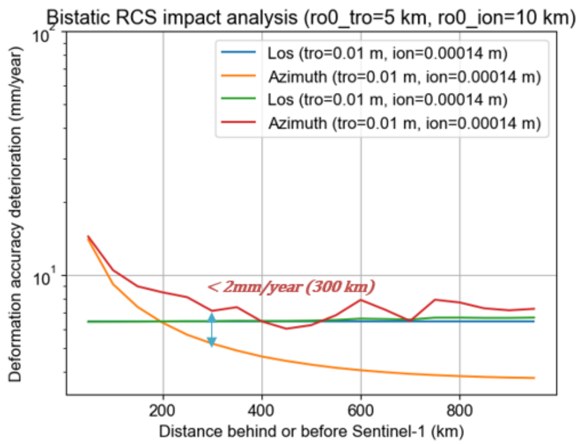


Figure 4 2-D deformation measurement accuracy if bistatic RCS impact is considered

Overall, on the basis of Fig. 2 and Fig. 4, the distance from 200 km to 400 km between HARMONY satellites and Sentinel-1 is a better choice as it is a good tradeoff between the complicity of the system and the 2-D deformation measurement accuracy (<15 mm/year in azimuth direction and <7 mm/year in Los direction).

4. CONCLUSION

In this paper, we have discussed the 2-D deformation measurement performance by the ESA HARMONY mission. Some important issues about the atmospheric impacts, the bistatic RCS impact and the selection of the distance between the passive and active satellites are studied. Our research verifies the good performance of HARMONY system for 2-D deformation monitoring, which suggests that an accuracy of several to a dozen of mm/year can be obtained under the general error cases if more than 300 km along-track baseline is selected, while the deeper investigation is still undergoing.

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