AN ASSESSMENT OF SPACEBORNE NEAR-NADIR INTERFEROMETRIC SAR PERFORMANCE OVER INLAND WATERS WITH REAL DATA

H. Tan [1]*, S. Y. Li [1], Z. W. Liu [1]

[1] Key Laboratory of Space Utilization, Technology and Engineering Center for space Utilization, Chinese Academy of Sciences, Beijing, China - tanhong@csu.ac.cn

KEY WORDS: Interferometry, Synthetic Aperture Radar, Altimetry, Calibration, Water surface extraction, Water elevation

ABSTRACT:

Elevation measurements of the continental water surface have been poorly collected with in situ measurements or occasionally with conventional altimeters with low accuracy. Techniques using InSAR at near-nadir angles to measure the inland water elevation with large swath and with high accuracy have been proposed, for instance, the WSOA on Jason 2 and the KaRIn on SWOT. However, the WSOA was abandoned unfortunately and the SWOT is planned to be launched in 2021. In this paper, we show real acquisitions of the first spaceborne InSAR of such kind, the Interferometric Imaging Radar Altimeter (InIRA), which has been working on Tiangong II spacecraft since 2016. We used the 90-m SRTM DEM as a reference to estimate the phase offset, and then an empirical calibration model was used to correct the baseline errors.

1. INTRODUCTION

For several decades, ocean topography measurements of radar altimeters have been collected, but very poor data over global inland waters are known. To understand the continental water balance and the dynamics and the storages of the inland waters, key measurements of water stage and water slope are currently made by in situ methods. However, dramatically changed spatial distribution of both the water stage and the water slope makes such measurements far from the satisfaction of the practical demands.

Recently, spaceborne near-nadir interferometric SAR (InSAR) at Ku or Ka band has been an important evolution for conventional radar altimeters, which extends the elevation measurements from over mere oceans to including inland water bodies (Biancamaria et al. 2016), such as lakes, reservoirs, rivers, and wet lands, etc. Those near-nadir InSARs can give measurements of ocean surface topography and inland water surface elevation with two-dimensional extended area rather than one-dimensional profile of conventional radar altimeters. Water slopes can then be derived from the elevations, which is important in hydrology.

Several real systems of such kind were proposed to develop. One is the Wide Swath Ocean Altimeter (WSOA) on Jason 2 (Pollard et al. 2002, Fu et al. 2004). Unfortunately it was abandoned for the budget shrink. Another example is the Ka-band Radar Interferometer (KaRIn) (Fjørtoft et al. 2014) on the altimetry mission Surface Water and Ocean Topography (SWOT) that is jointly designed by the National Aeronautics and Space Administration (NASA) and the Centre National d’Etudes Spatiales (CNES) and is planned to be launched in 2021 (Foust 2016).

In this article, we show first real measurements over inland waters of another spaceborne system, the Interferometric Imaging Radar Altimeter (InIRA) (Yunhua et al. 2007) designed by China, which has been launched with the Tiangong II space laboratory on September 15, 2016. Assessment of acquisitions over oceans can be found in (Kong et al. 2017).

2. INIRA CHARACTERISTICS

The InIRA was designed as a technical validation aboard the Tiangong II spacecraft. It works at Ku band and on an orbit height of 400 km with an interferometric baseline length of 2.3 m and an inclination angle of 5 degree. The looking angle is in the range of 2.5 degree to 7.5 degree. Parameters are summarised in Table 1 as a comparison between the InIRA and the planned KaRIn instrument.

INSTRUMENT	InIRA	KaRIn
Altitude (km)	400	873
Radio frequency (GHz)	13.58 (Ku)	35.75 (Ka)
Interferometric baseline roll angle (deg)	5	0
Interferometric baseline length (m)	2.3	10
Look angles (deg)	2.5-7.5	0.6-3.9
Looking direction	Right only	Right and Left simultaneously
SEA SURFACE HEIGHT PRODUCT		
Spatial resolution (km)	10 × 10	1 × 1
Precision (cm)	20	1-2
Swath width [distance from nadir] (km)	35 [17 - 52]	100 [10 - 60]
LAND SURFACE HEIGHT PRODUCT		
Spatial resolution (m)	200 × 200	250 × 250
Precision (cm)	Not defined	10 cm
Swath width [distance from nadir] (km)	Same as above	Same as above

Table 1. Characteristics of InIRA and KaRIn

---

* Corresponding author

https://doi.org/10.5194/isprs-archives-XLII-3-1635-2018

3. SYSTEM ERRORS

Measurement errors come from the random thermal noises, the wet tropospheric path delay, and the interferometric system uncertainties, such as the incorrect knowledge of the phase offset, the baseline roll angle, and the baseline length. The random noises can only be reduced by spatial averaging. The wet tropospheric path delay can be measured with a three-frequency microwave radiometer similar to that equipped on conventional altimeters on oceans (Fu et al. 2001), and it can be corrected with a tropospheric correction model on land (Fu et al. 2012). Here, we focus on the system errors.

3.1 Phase offset

Phase offset of the two antennas varies as the electronic system delay may change under the slowly changed temperature in space.

3.2 Baseline roll angle

Unknown errors occur on the baseline roll angle as the results of the nonperfect measurements of the attitude of the platform, or the deformation of the antenna mast.

3.3 Baseline length

Errors may be caused by mechanical perturbations and thermal effects.
To meet the requirements of centimetric accuracy, it is critical to know these three interferometric parameters precisely at all times.

4. CALIBRATION

The interferometric calibration was done in two steps after common interferometric processings were performed, such as the coregistration, the interferometric phase calculation, the phase unwrapping, and the phase-to-topography conversion. Firstly the phase offset was estimated and then the effective baseline errors were estimated and corrected.

4.1 Water surface extraction

The errors estimation and correction, and the later elevation results assessment were all conducted over water surfaces merely.
Figure 1 shows the Guanting Reservoir, which locates at the northwest of the city of Beijing with a distance of about 100 km. The Guanting Reservoir has a main body with a size of about 4 km width and 6 km long, where daily water level report is released by a hydrological station.
Figure 2 and Figure 3 show the interferometric coherence coefficients and the backscatter coefficients, i.e., σ^0, respectively.
As very high interferometric coherence and high returned echo power on water are observed for those near-nadir InSARs, the water area detection was performed by setting thresholds at the interferometric correlation coefficients and at the backscatter coefficients. The retrieved water area is shown in Figure 4.

Figure 1. Guanting Reservoir near Beijing

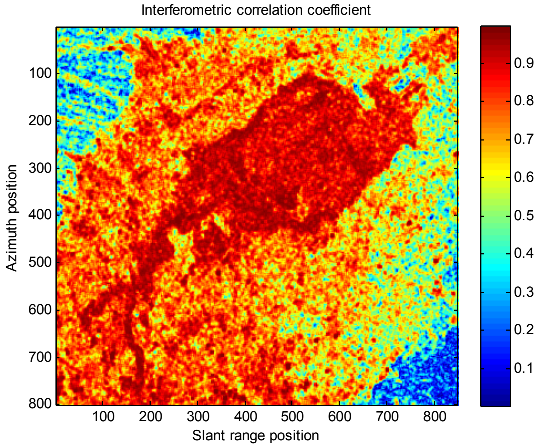

Figure 2. Interferometric correlation coefficients

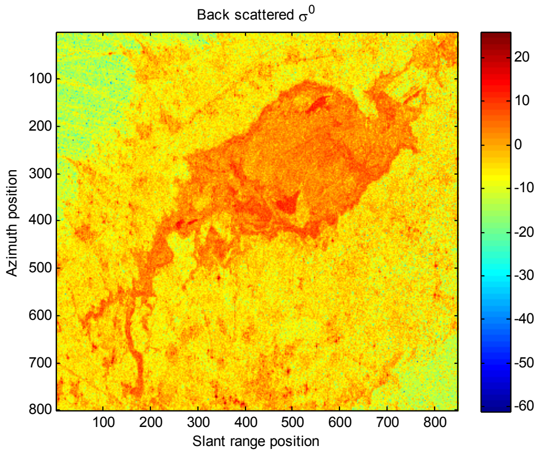

Figure 3. Backscatter coefficients

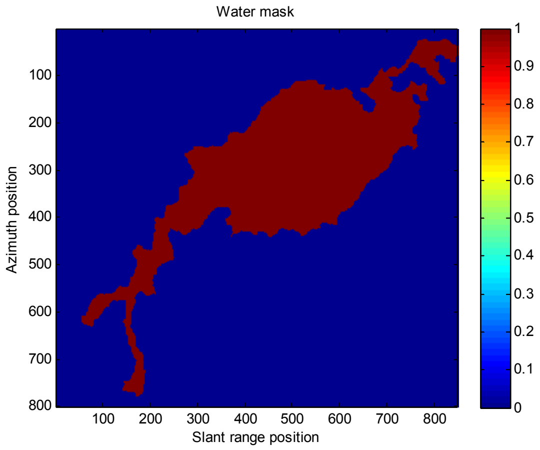

Figure 4. Retrieved water

4.2 Phase offset

The error in the constant interferometric phase offset of the instrument was estimated with a large number of ground control points (GCP) retrieved by taking the SRTM DEM as a reference. A mean value is used for the water elevation retrieve as shown in Figure 5.

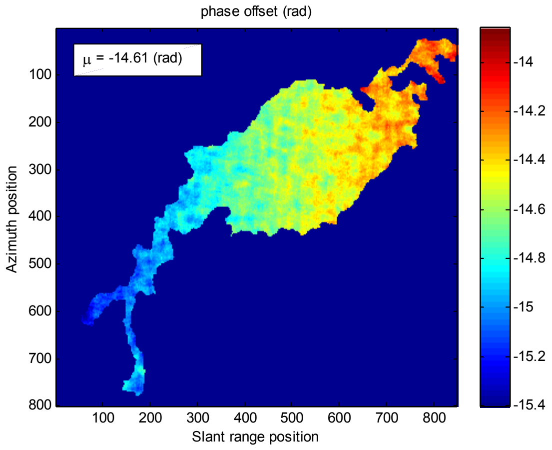

Figure 5. Phase offset estimation

4.3 Baseline errors

Residual topography errors of inland waters were estimated and corrected. The residual errors can be quantified by two metrics derived from an empirical model (Enjolras et al. 2009) (Dibarboure et al. 2012). One is the residual baseline length error, and the other is a residual effective roll error that contains errors from both the baseline roll angle and the interferometric phase. In the empirical model, the baseline length error would produce quadratic height errors along the range direction, and the effective roll angle error would produce linear height errors along the range direction. Therefore, the relative height variations over a flat inland water surface would reflect the residual baseline errors.

$$\delta h = \delta\alpha \cdot x; \delta h = \frac{\delta B \cdot x^{2}}{B \cdot H} \qquad (1)$$

where δh = height error
$\delta\alpha$ = effective baseline roll angle error
x = distance from nadir
δB = baseline length error
B = baseline length
H = platform height

To reduce the random instrument noise and the reference DEM random errors, an average over a 1-km distance along track was conducted. Then a second-degree polynomial fit to the difference between the measurements and the SRTM DEM reference was performed in the across-track direction to retrieve the two residual errors. The fit result is shown in Figure 6.

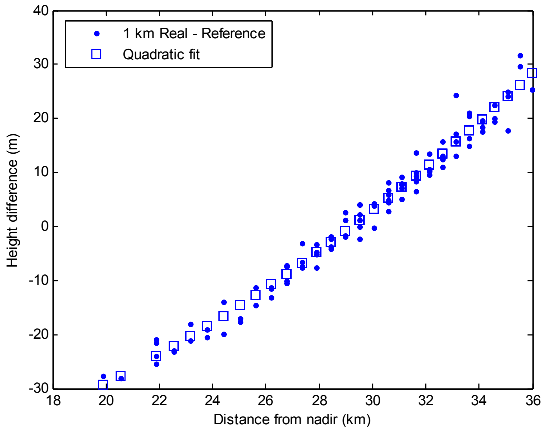

Figure 6. Residual baseline errors estimation

5. ASSESSMENT OF REAL ACQUISITION

When estimated residual errors were corrected, the elevation results of the Guanting Reservoir were retrieved as plotted in Figure 7 and Figure 8. The results were smoothed by sliding windows of different sizes, and those averaged with inadequate samples were removed.

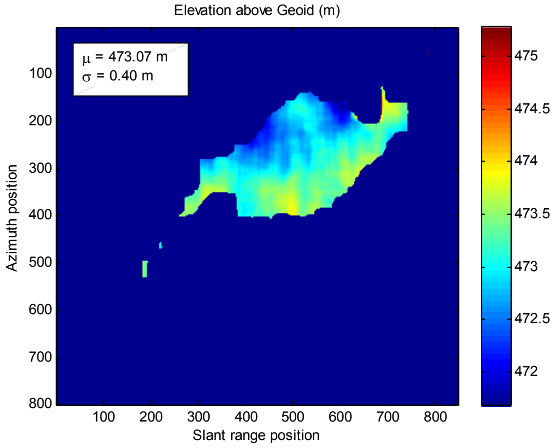

Figure 7. Water elevation above Geoid after smoothed by a sliding window of about 1 km (in azimuth) × 1 km (in range) size.

https://doi.org/10.5194/isprs-archives-XLII-3-1635-2018 | © Authors 2018. CC BY 4.0 License.

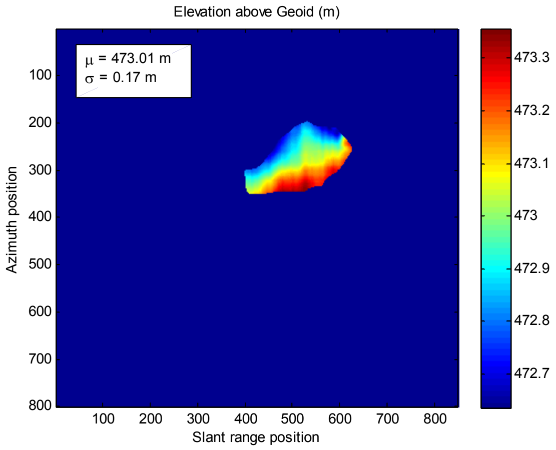

Figure 8. Water elevation above Geoid after smoothed by a sliding window of about 3 km (in azimuth) × 3 km (in range) size.

The standard deviation of the heights over the inland lake surface was assessed as in Table 2, which reflects the relative accuracy of the measurements. The standard deviation could be reduced when using a larger spatial average window size at a cost of spatial resolution. It seems that a resolution of at least 3 km is necessary for the InIRA to derive elevations of inland lakes.

Resolution	STD Error (m)
1 km	0.40
3 km	0.17

Table 2. Relative elevation errors of InIRA

However, the range distance errors induced by the tropospheric delay at Ku band, whose correction were not conducted as a result of the lack of data from a water vapor radiometer. It should be noted that there is no such a radiometer accompanied with the InIRA. The errors would impose varying vertical biases across track on the derived topography results, thus better results can be achieved when a water vapor radiometer is available.

6. CONCLUSIONS

From the results and the assessment aforementioned, it is well expected that the spaceborne near-nadir InSARs will give fine elevation measurements over inland waters and show great values in land hydrology.

ACKNOWLEDGEMENTS

Thanks to China Manned Space Engineering for providing space science and application data products.
The authors would like to thank X. Dong, W. S. Zhai, X. J. Shi, and Y. H. Zhang in the Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences, for their discussions on instrument design and help in generating complex images.

REFERENCES

Biancamaria, S., D. P. Lettenmaier and T. M. Pavelsky, 2016. The SWOT Mission and Its Capabilities for Land Hydrology. *Surveys in Geophysics,* **37**(2), pp. 307-337.

Dibarboure, G., S. Labroue, M. Ablain, R. Fjortoft, A. Mallet, J. Lambin and J. C. Souyris, 2012. Empirical Cross-Calibration of Coherent SWOT Errors Using External References and the Altimetry Constellation. *IEEE Trans. Geosci. Remote Sens.,* **50**(6), pp. 2325-2344.

Enjolras, V. M. and E. Rodriguez, 2009. An Assessment of a Ka-Band Radar Interferometer Mission Accuracy Over Eurasian Rivers. *IEEE Transactions on Geoscience and Remote Sensing,* **47**(6), pp. 1752-1765.

Fjørtoft, R., J. M. Gaudin, N. Pourthié, J. C. Lalaurie, A. Mallet, J. F. Nouvel, J. Martinot-Lagarde, H. Oriot, P. Borderies, C. Ruiz and S. Daniel, 2014. KaRIn on SWOT: Characteristics of Near-Nadir Ka-Band Interferometric SAR Imagery. *IEEE Trans. Geosci. Remote Sens.,* **52**(4), pp. 2172-2185.

Foust, J., 2016. "SpaceX wins contract to launch NASA Earth science mission." 2016, from http://spacenews.com/spacex-wins-contract-to-launch-nasa-earth-science-mission/.

Fu, L.-L. and A. Cazenave, 2001. Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications. San Diego, CA, Academic.

Fu, L.-L. and E. Rodriguez, 2004. High-Resolution Measurement of Ocean Surface Topography by Radar Interferometry for Oceanographic and Geophysical Applications. The State of the Planet: Frontiers and Challenges in Geophysics. R. S. J. Sparks and C. J. Hawkesworth. Washington, D. C., American Geophysical Union.

Fu, L., D. Alsdorf, R. Morrow, E. Rodríguez and N. Mognard, 2012. SWOT: The Surface Water and Ocean Topography mission: Wide-swath altimetric measurement of water elevation on Earth. Pasadena, CA, USA, Jet Propulsion Lab. **12**.

Kong, W., J. Chong and H. Tan, 2017. Performance Analysis of Ocean Surface Topography Altimetry by Ku-Band Near-Nadir Interferometric SAR. *Remote Sensing,* **9**(9), pp. 933.

Pollard, B. D., E. Rodriguez, L. Veilleux, T. Akins, P. Brown, A. Kitiyakara, M. Zawadski, S. Datthanasombat and A. Prata, 2002. The wide swath ocean altimeter: radar interferometry for global ocean mapping with centimetric accuracy. Proceedings, IEEE Aerospace Conference.

Yunhua, Z., Z. Xiangkun, M. Xin, L. Wei, Z. Zhixin and J. Jingshan, 2007. An interferometric imaging altimeter applied for both ocean and land observation. 2007 IEEE International Geoscience and Remote Sensing Symposium.