A Global Performance Assessment Approach for the TerraSAR-X Staring Spotlight and Wide ScanSAR Modes

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Abstract

For the TerraSAR-X mission two new modes have been implemented and are operational since autumn 2013. One is a high azimuth resolution Staring Spotlight mode and the other is a wide ScanSAR mode with doubled ground range coverage compared to the nominal TerraSAR-X ScanSAR. This paper gives an overview about SAR performance analyses conducted during the mode design and implementation phases and focuses on a global performance assessment approach. This approach is described in detail and results are shown.

1 Introduction

Since the launch of TerraSAR-X in 2007 four SAR imaging modes have been operationally available. They ranged from sliding spotlight modes called Spotlight (SL) and High-Resolution Spotlight (HS) with azimuth resolutions down to 1.1 m over Stripmap (SM) to a four beam ScanSAR (SC) mode with a range coverage of 100 km (cf. **Table 1**). In order to make new applications accessible, two new modes have been developed since 2012 and are operationally available since autumn 2013. These are a Staring Spotlight (ST) mode with an azimuth resolution of 24 cm for applications like airfield surveillance, and a ScanSAR variant with six elevation beams. The latter one is called wide ScanSAR (wSC) and has a range coverage of more than 200 km, e.g., for ship detection and sea ice monitoring. The improved azimuth resolution of ST comes at the cost of a reduced scene size and the larger swath width of wSC results in a coarser resolution.

The development of these new operational modes was based on detailed system and performance analyses for both modes [1], [2], and a pilot study for ST [3], [4]. Both modes are very demanding in their own respect. ST uses a very wide azimuth antenna steering. At the maximum steering angle of 2.2° the gain of the strongest grating lobe is equal to the used main lobe gain. This makes azimuth ambiguities a design driver and the Pulse Repetition Frequencies (PRF) selection critical [2]. For wSC new, wider elevation beams have been designed in order to cover the largest possible ground swaths. These large ground swaths require long echo windows on receive, complicating the timing calculation [1]. Besides this, the wide beams have to be carefully designed, otherwise range ambiguities get dominant even at relatively low PRFs, if the first ambiguity is already within the main lobe. The mentioned challenges are the reason, why these modes have not been available since the start of the TerraSAR-X mission. For the design not only a performance analysis at a medium orbit altitude and with an ellipsoidal earth model is required. It is also necessary to validate the derived commanding parameters on a global scale to estimate the impact of timing variations. The TerraSAR-X orbit altitude changes from 510 km to 537 km above the WGS84 ellipsoid and topographic variations further change the timing conditions. Therefore, in the framework of the operational mode implementation of ST and wSC, a statistical acquisition simulation approach was developed.

The outline of this paper is as follows. Section 2 describes the global SAR performance assessment approach. In section 3 results are presented for ST and wSC separately. Section 4 concludes the paper with a summary.

Mode	range swath width	azimuth resolution
Staring Spotlight (ST)	≈ 5 km	0.24 m
Sliding Spotlight (SL/HS)	10 km	1.7 m/1.1 m
Stripmap (SM)	30 km	3.3 m
ScanSAR (SC, 4 beams)	100 km	18.5 m
ScanSAR (SC, 6 beams)	≥ 200 km	40.0 m

Table 1: Operational TerraSAR-X imaging modes.

2 The Global Performance Assessment Approach

The operational mode implementation of ST and wSC was carried out in two steps. First the mode was designed and commanding parameters were derived. Afterwards a verification had to prove the applicability of the chosen settings on a global scale. The focus of this paper is on the second step.

2.1 Mode Design

The mode design consisted of performance simulations taking into account the satellite altitude, an ellipsoidal Earth model, and an Ulaby backscatter model [5]. This step delivered optimized commanding parameters like a PRF range for each elevation beam [2], the duty cycle, the azimuth antenna steering for ST and beam definitions and

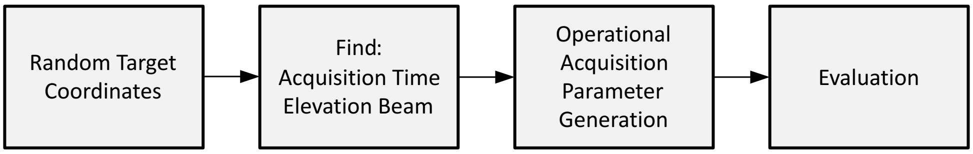


Figure 1: Workflow of the global verification and performance simulation used in the framework of the operational ST and wSC mode implementation.

the number of elevation beams to use for wSC [1]. These parameters are the input for the operational commanding system. Additionally, the TerraSAR-X commanding chain itself [6] had to be updated to be able to handle the new modes. Algorithms had to be adapted and new workflows have been defined.

2.2 Global Acquisition Simulations

The workflow of the verification step is depicted in **Figure 1**. First a target coordinate is randomly selected over the Earth's land masses. Then, for this coordinate all TerraSAR-X acquisition possibilities with different elevation beams over the full incidence angle range are calculated and one is randomly selected. Afterwards the operational algorithms for the TerraSAR-X instrument commanding are invoked for this special acquisition scenario. These consider the commanding parameters derived during the mode design step, but also take into account the reference orbit position of the satellite for the simulated acquisition and accurate DEM information of the target scene. The last step called "evaluation" consists of two stages. The first one is the evaluation of status messages generated by the command generation software, giving hints about timing problems and possible scene size degradations or even failed results. The second one is to estimate the performance of the simulated acquisition. The operationally calculated imaging PRF together with the performance predictions of the mode design step are used to predict the ambiguity to signal ratios (ASR) in range (RASR) and azimuth (AASR). This simulation workflow is repeated for thousands of randomly selected target coordinates. **Figure 2** shows the local distribution of more than 20000 scene center coordinates used during the ST operationalization. Almost the same amount of scenes has been simulated for wSC.

3 Evaluation Results

The results of the simulation have been used to further improve the commanding parameters during the mode design. For wSC even a few iterations have been necessary until the final beam definitions could be found. Furthermore, the results are directly fed into the basic product specification document for TerraSAR-X products [7].

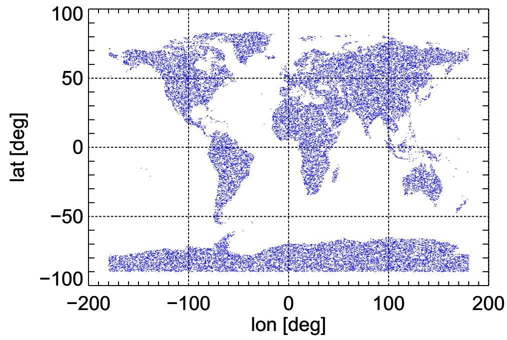


Figure 2: Global distribution of target coordinates used to simulate more than 20000 statistical acquisitions; each point represents a scene center coordinate.

3.1 Staring Spotlight

One of the first very promising results of the 20000 global ST simulations was that every acquisition was generated without any problems. The operational algorithms reported no failed result. The timing could be calculated even for very difficult terrain with steep slopes. To prove the validity, some of the data takes over rough terrain have been commanded on the satellite. The acquired image products showed no peculiarities.

The range scene extent of ST products as offered to the user is limited by instrument constraints, namely a data rate limit and an echo buffer limit. The data rate is a function of the PRF which is varying with the incidence angle in order to cope with timing and ambiguity constraints. The result is a variation of the range swath width with incidence angle. Additionally, the PRF is individually chosen to satisfy the underlying topography of each scene. Thus, the range extent at a specific incidence angle may vary for different topographic conditions and therefore is different for every acquisition scenario. Furthermore, the scene size is reduced by margins to cope with the finite accuracy of the orbit and the available DEM, and with inherent effects in the SAR processing, e.g., the range cell migration. **Figure 3** shows the two-dimensional histogram of the scene extent as delivered to the user for the 20000 simulated acquisitions. For the majority of the acquisitions, the range scene extent is larger than 4 km and up to 8.5 km for very steep incidence angles. The overall trend of decreasing range scene extent with increasing incidence angle is mainly driven by the slant to ground range projection.

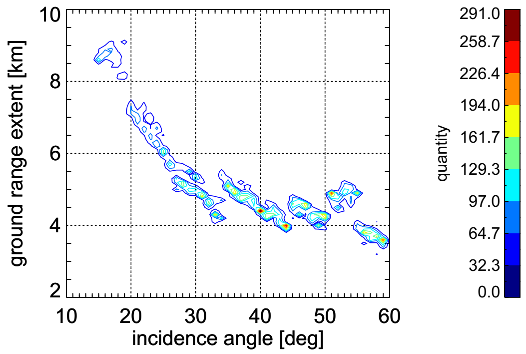


Figure 3: Contour lines of the two-dimensional histogram of the simulated, nominal ground range scene extent.

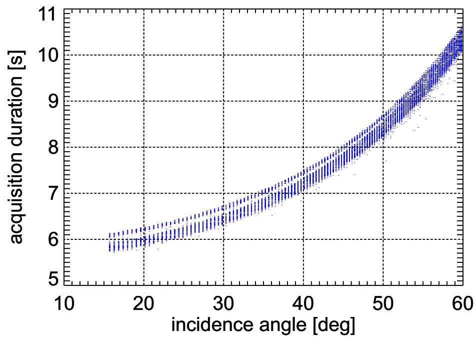


Figure 4: Net duration of the simulated ST acquisitions as a function of the incidence angle. Calibration and noise pulse recording before the start and after the end of the acquisition prolongate the total duration by about one second.

Another important parameter for the ST mode is the duration of an acquisition. All spotlight modes are non-continuous in azimuth by definition. The longer the acquisition duration is, the larger is the gap between two consecutive ST acquisitions. **Figure 4** depicts the duration of ST acquisitions as function of the incidence angle. The duration is determined by the commanding algorithms taking into account geometry and used azimuth steering span. The duration of a data take on-board the spacecraft is even longer since calibration and noise pulses are acquired before and after the actual SAR data. The variation of the duration for a fixed incidence angle is due to the orbit altitude variations. An acquisition at a higher altitude covers a longer orbit section using the same antenna steering angles. The longest durations occur over Antarctica where the satellite altitude is the largest.

3.2 Wide ScanSAR

From all about 20000 simulated wSC scenes none showed a high degradation or failed result. Only 2.9% of the acquisitions showed a small degradation due to timing problems during the radar parameter generation in one of the sub-swaths. These difficulties arise over mountainous terrain like depicted in **Figure 5**. A higher amount of data takes with a degradation (marked in orange) is visible over the Andes and Himalaya. Degradations arise due to two different reasons: a shortening of the necessary echo window due to the next transmit event or the appearance of a nadir echo in the focused echo window. The observed degradations are regarded acceptable because they are very small and for most of the acquisitions they occur in the near and far range margin area of the scenes.

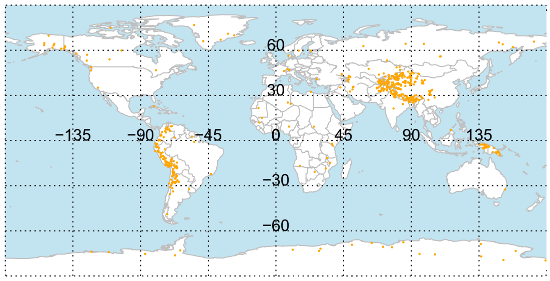
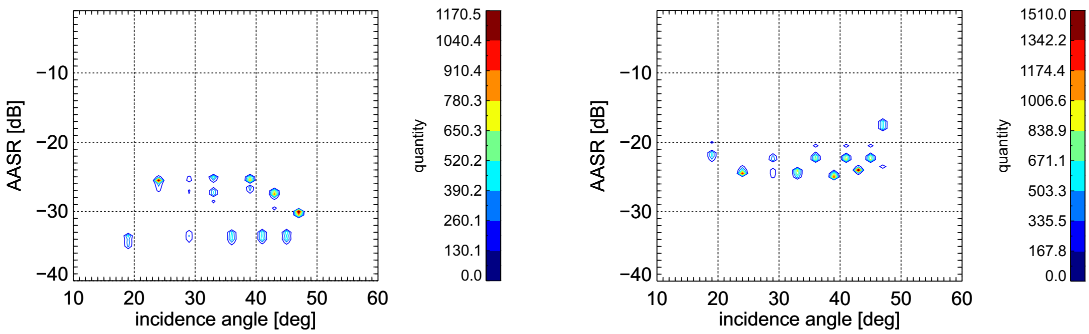


Figure 5: Location (orange points) of simulated wSC acquisitions for which a degradation was annotated during the acquisition parameter calculation.

Like for ST [2] the ambiguity performance of wSC was estimated based on the acquisition simulation results. Several point targets have been considered covering the whole ground range and a comparable portion of the azimuth scene extent. **Figure 6** shows the distributions of the best (left) and the worst AASR values (right) within all simulated wSC scenes. The simulation results are depicted as the contour lines of a two-dimensional histogram. The ten elevation beams used for wSC can be clearly distinguished. The best values within a scene are below -24 dB AASR and even the worst values in the scenes are better than -17 dB. In **Figure 7** the RASR for all elevation beams is shown with the best (left) and worst range target (right) within each simulated scene. A RASR value of better than -19 dB can be achieved for all possible simulation scenarios, even for the worst range target. The predicted performance of the simulated acquisitions reflects the actually selected PRF, driven by the acquisition geometry (orbit height and topography) and therefore should be very close to a real acquisition. Therefore a good ambiguity performance was expected for wSC which was later validated by data takes [1].

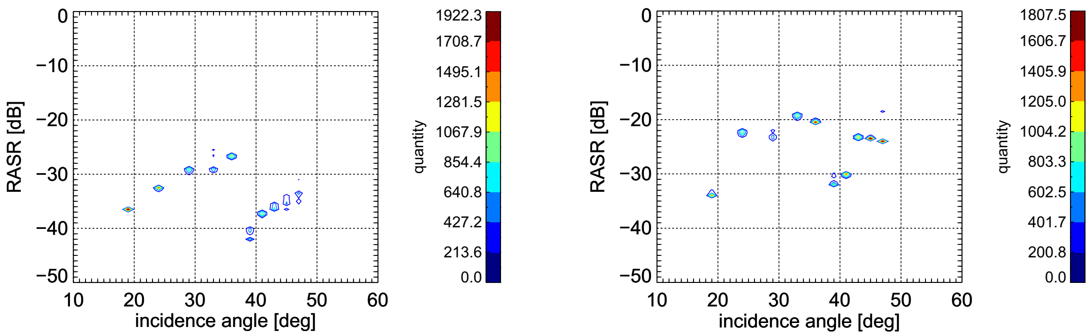
4 Summary

The paper describes a global SAR performance assessment approach for the implementation of an operational mode. Both new modes of TerraSAR-X, the Staring Spotlight (ST) and wide ScanSAR (wSC) are investigated with this approach. It consists of a mode design step based on detailed performance estimates and the simulation of thousands of acquisitions all over the Earth's land masses. The evaluation of the simulation results can be seen as a verification step for the command generation system but also delivers an estimate of the image products performance parameters on a global scale taking into



(a) (b)

Figure 6: Contour lines of the two-dimensional histogram of the AASR for the best target (a) and of the worst target of the scene (b) of each simulated acquisition, highlighting the dominant regions of predicted AASR.



(a) (b)

Figure 7: Contour lines of the two-dimensional histogram of the RASR for the best target (a) and of the worst target (b) of each simulated acquisition.

account orbit and DEM accuracies. The focus of the evaluation for the described modes was on the range scene size and acquisition duration for ST and RASR, AASR as well as the operational status messages for both modes. However, the list of globally analyzed parameters could be extended, depending on the specific challenges faced. Both new TerraSAR-X imaging modes are very demanding and require operating the radar at the edge of its capabilities. Only with a global simulation and verification approach it is possible to reduce margins to a minimum and operate a radar instrument at its limits on an operational basis. Since the new modes have been declared as operational, no problems or unexpected behavior has occurred or was reported by the users. Thus, the global performance assessment approach proved to be successful.

References

[1] U. Steinbrecher, T. Kraus, G. C. Castellanos, C. Grigorov, D. Schulze, B. Bräutigam: *TerraSAR-X: New operational Wide ScanSAR Mode*, Proc. of EUSAR 2014, Berlin, Germany, June 2014.

[2] T. Kraus, B. Bräutigam, C. Grigorov, J. Mittermayer, S. Wollstadt: *TerraSAR-X Staring Spotlight Mode Optimization*, Proc. of APSAR 2013, Tsukuba, Japan, Sept. 2013.

[3] J. Mittermayer, S. Wollstadt, P. Prats, R. Scheiber: *The TerraSAR-X Staring Spotlight Mode Concept*, IEEE Trans. on Geosci. Remote Sensing, Aug. 2013

[4] P. Prats, R. Scheiber, M. Rodríguez-Cassolà, S. Wollstadt, J. Mittermayer, B. Bräutigam, M. Schwerdt, A. Reigber, A. Moreira: *High Precision SAR Focusing of TerraSAR-X Experimental Staring Spotlight Data*, Proc. of IGARSS 2012, Munich, Germany, July 2012.

[5] F. T. Ulaby, M. C. Dobson: *Handbook of Radar Scattering Statistics for Terrain*, Norwood, MA: Artech House, 1989.

[6] U. Steinbrecher, D. Schulze, J. Böer, J. Mittermayer: *TerraSAR-X Instrument Operations Rooted in the System Engineering and Calibration Project*, IEEE Trans. on Geosci. Remote Sensing, vol. 48, no. 2, Feb. 2010.

[7] T. Fritz, M. Eineder: *TerraSAR-X Basic Product Specification Document*, public version 1.9, October 2013.

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