ATI and GMTI Performance Analysis of Post-Sentinel-1 SAR Systems based on Simulations using OASIS

Thomas Börner(1), Gerard Marull Paretas(1), Stefan Baumgartner(1), Paco López Dekker(1), Stefan Sauer(1), Gerhard Krieger(1), Salvatore D'Addio(2)
(1) German Aerospace Center – DLR (Microwaves and Radar Institute), thomas.boerner@dlr.de, Germany
(2) European Space Agency – ESA, Netherlands

Abstract

With the Sentinel-1 expected to be launched at the end of 2013, ESA is already funding activities to study the next generation of C-band SAR instruments. One of the drivers for these developments is the strong user requirement for high resolution and wide swath (HRWS) operations, which can be realized by using Multiple Azimuth Phase centers (MAPS). The current reference system for a post-Sentinel-1 instrument features a 12.8 m long antenna divided along-track in 8 panels which, on receive, are sampled independently. To investigate the final performance in terms of surface current velocity estimation errors, a full multi-channel SAR simulator for open-oceans (OASIS: Ocean ATI-SAR SImulator) has been implemented. This simulator generates multi-channel raw data corresponding to a time-varying simulated ocean surface that includes all main environmental effects, and uses prototypes of the proposed processing algorithms. A detailed performance analysis in terms of final ATI performance is presented in this paper. The GMTI simulations for ocean data were not finished at the time of paper deadline, and thus will be presented at the conference.

1 Introduction

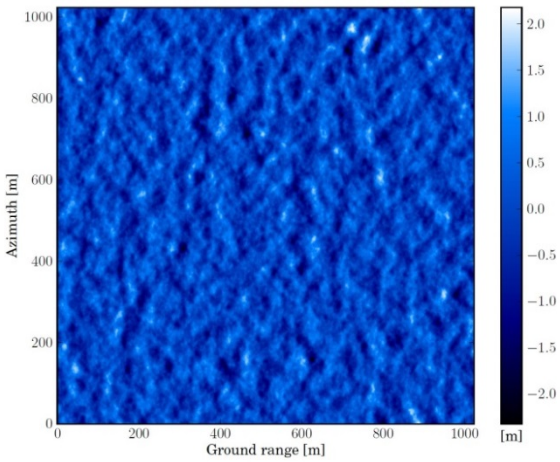
Future HRWS systems will break the classic direct trade-off between azimuth strip-map resolution and achievable swath. The key to achieve this is the use of Multiple Azimuth Phase centers (MAPS), which allows decreasing the PRF (thus allowing a wider unambiguous swath) while maintaining the number of azimuth samples. In addition, multiple channels in elevation will allow the use of Digital Beamforming (DBF) techniques such as Scan-on-Receive (SCORE), in this case to relax the trade-off between antenna gain and swath width.

The availability of multiple receive channels and the use of DBF will give future systems new degrees of freedom with regard to how they are operated. In this context, the German Aerospace Center (DLR) is leading an ESA funded activity to assess the Ground Moving Target Indication (GMTI) and Along-Track Interferometry (ATI) potential of the current reference post-Sentinel-1 architecture. One particular area of interest is the use of ATI for ocean current estimations. This paper reports on some key findings of this activity and, in particular, on the performance of such future SAR systems.

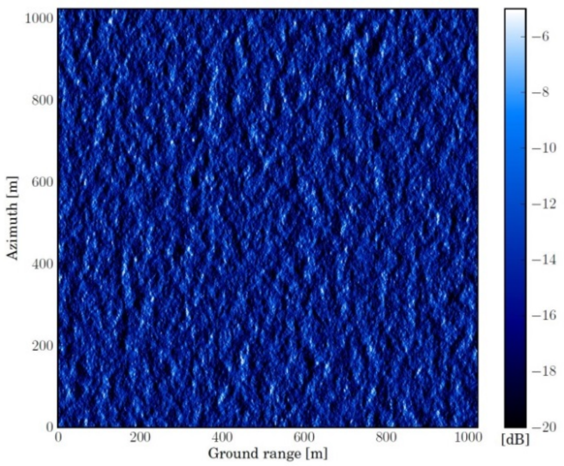
The reference system, on which the performance analysis is based, features a 12.8 m long antenna divided along-track in 8 panels which, on receive, are sampled independently. In transmit, the full antenna is always used in order to harvest all the available RF power. For high resolution operation modes, the azimuth transmit pattern needs to be broadened so that the beam width approximately matches that of a single receive element. This is achieved using phase spoiling techniques. The same system can be run in a lower resolution mode simply by narrowing the transmit beam (for example by using a linear phase tapering in azimuth). In this case, the multiple receive-channels can be added directly on-board, thereby significantly lowering the data rate.

A more interesting alternative use of the available channels is to view the system as an ATI or GMTI system. In these techniques the system must be able to generate multiple independent SAR images. For example, if we consider an ATI configuration in which we want to interfere a SAR image obtained with the four fore receive panels with the one obtained with the four aft panels, the SAR performance needs to be derived considering only this half-length receive antenna. The shorter receive antenna leads to a wider receive azimuth-pattern that translates to a larger Doppler bandwidth which, in turn, leads to a higher PRF requirement.

To investigate the final performance in terms of surface current velocity estimation errors, a full multi-channel SAR simulator for open-oceans (OASIS: Ocean ATI-SAR SImulator [1]) has been implemented. This simulator generates multi-channel raw data corresponding to a time-varying simulated ocean surface that includes all main environmental effects, and uses prototypes of the proposed processing algorithms. The approach taken by OASIS is to first generate an ocean surface by using empirical or semi-empirical spectral models based on linear wave theory and, subsequently, backscattering is calculated from this surface by using a variety of different models, e.g. the Romeiser composite model [2]. This approach allows simulating backscattering of time-evolving surfaces, although it is computationally slow. In fig. 1 an example is shown of how an ocean surface (a) is translated into radar backscatter (b).



(a)



(b)

Figure 1: (a) Ocean surface generates using an Elfouhaily spectrum (wind speed = 10 m/s); (b) NRCS in *HH* polarisation.

2 Performance Analysis

Using the OASIS tool, an extensive set of ocean data has been simulated, where parameters like wind speed, wind direction, ocean current magnitude, ocean current direction, incidence angle, etc. have been varied. For ocean ATI, only 2-channel data with a PRF of 2500 Hz is required. However, for the GMTI performance evaluation, also multi-channel data had to be generated, and, in order to meet the DPCA (Displaced Phase Center Antenna) condition [3], the PRF needs to be set to higher values, as shown in section 2.2 (see also table 1). The size of the data sets has to be chosen such that computing time and a decent statistical variability was in maintainable balance, i.e. usually an ocean patch of 500 m in range and 2000 m in azimuth.

2.1 Ocean ATI Performance

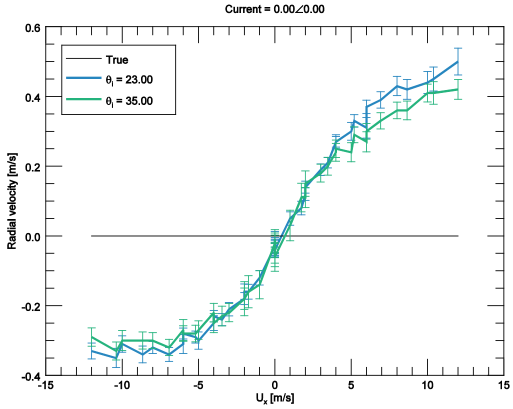
ATI acquisitions of the ocean surface have been simulated varying the reference wind-speed (U_{10}) between 2 and 12 m/s, and the wind direction between 0 degree (down-wind) and 180 degree (up-wind). The results shown correspond to the simplest case, in which no surface current was simulated. Figure 2 (a) shows the ATI estimated Doppler radial (line-of-sight) velocity as a function of the cross-track component of the surface wind-vector. The error bars show the standard deviation of the estimates for a product resolution of 250 x 250 m^2. This standard deviation is in the order of 5 cm/s, which meets typical scientific requirements. However, the most salient feature is the strong wind-dependence of the mean value. This dependence is generally consistent with experimental observations of, for example, the Doppler centroid anomaly, but has, nevertheless, often been ignored in the ATI literature.

Figure 2 (b) shows again the estimated Doppler radial velocity and corresponding error bars, but this time showing the dependence with respect the wind direction. The dashed lines indicate, for each wind speed, the standard deviation of the radial velocities of the simulated surface.

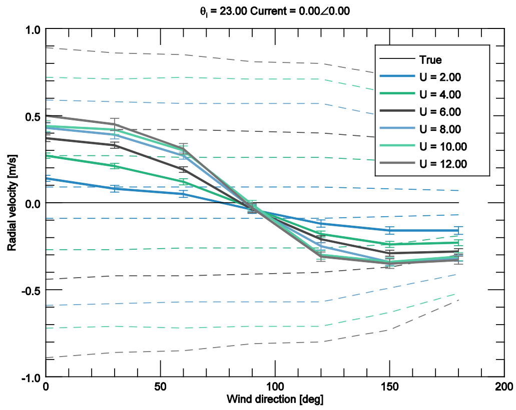
Without entering to discuss the separation of the different contributors to the measured Doppler velocities, the results illustrate the potential of future HRWS systems to retrieve high quality estimates of the effective Doppler velocity with product resolution orders of magnitude better than what can be currently achieved through Doppler centroid estimates.

2.2 OCEAN GMTI Implementation

OASIS is providing ocean SAR raw data reflecting the above-mentioned instrument design and thus data for up to 8 along-track channels can be generated and used for ingestion into the GMTI algorithms. Once the multi-channel range-compressed SAR raw data for each channel is available, next step is the azimuth SAR focusing and the posterior multi-channel processing of the focused data, as shown in fig. 3. The implemented multi-channel processing techniques consist of a) simple 2-channel ATI, b) multi-channel DPCA [4], c) EDPCA (E = enhanced) [5], and d) ISTAP (Imaging Space-Time Adaptive Processing) [5].



(a)

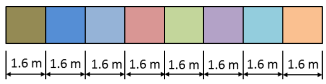
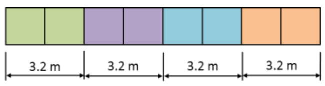
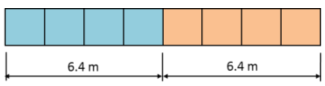


(b)

Figure 2: a) ATI estimated radial Doppler velocity as a function of the cross-track wind component. b) Estimated velocity as a function of wind direction for a range of wind velocities. In both panels, the error bars indicate the standard deviation of the velocity estimates for a 250 x 250 m^2 product, while the dashed lines in the bottom panel indicate the standard deviation of the radial velocities of the simulated surfaces.

As mentioned before, to enable unambiguous velocity estimation, the PRF has to be chosen such that it is guaranteed that the DPCA condition is fulfilled. The DPCA condition and the PRF for meeting this condition are connected to the smallest available along-track baseline. Assuming that the full antenna (12.8 m) is used for transmit, it can be computed as $PRF_{DPCA} = 2v_p/d_a$, where v_p is the platform velocity and d_a is the smallest along-track baseline. In the worst case, i.e. 8 channels, this PRF has to be 9375 Hz. Table 1 summarizes possible RX cannel combinations and the corresponding PRFs for meeting the DPCA condition. However, the PRF can be decreased by digitally combining adjacent receive channels after acquisition. Note that fulfilling the DPCA condition for adjacent RX channels is no absolute requirement in case of ISTAP, which does not require receive channel coregistration.

Table 1: Possible receive channel combinations and corresponding PRFs for meeting the DPCA condition.

Receive Channel Combination	d_a [m]	PRF_{DPCA} [Hz]
	1.6	**9375**
	3.2	**4687**
	6.4	**2344**

For application of GMTI techniques a moving target is required and thus has to be properly ingested into the ocean raw data. The target azimuth signal, taking into account motion parameters and antenna patterns, is generated for each receive channel and inserted in the range center of the array, as depicted in the flowchart shown in fig. 4.

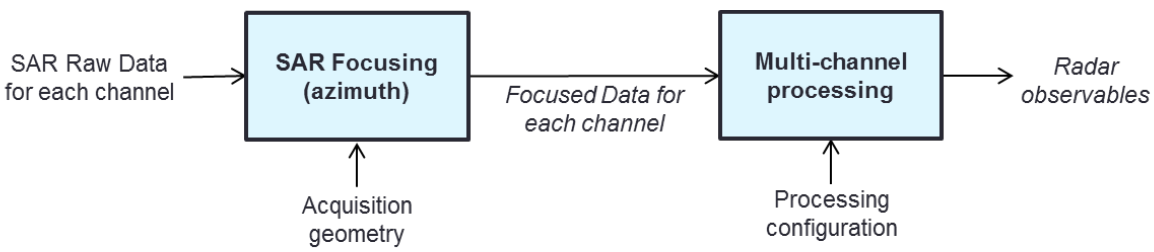


Figure 3: Block diagram of the multi-channel SAR processing.

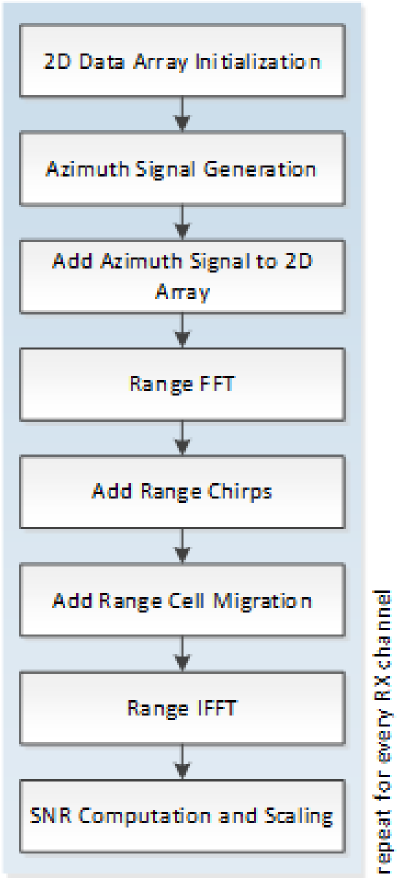


Figure 4: Flowchart for multi-channel moving target signal generation.

The array is then transformed to range-frequency/azimuth domain using a range FFT, followed by adding range chirps and range cell migration. The data is transformed back to time domain via range IFFT, and finally the single-channel single-pulse SNR is computed using the system parameters and the specified target radar cross section σ_t.

The aforementioned GMTI processing techniques can now be applied to this data. In general all these techniques are coregistering the channels (except ISTAP), apply a range cell migration correction and an azimuth compression. All following steps for clutter suppression and extraction of target position and movement parameters are individually different, and the detailed description is out of the scope of this paper. However, all methods will measure the same set of observables, i.e. the target velocity vector components in range and azimuth, the direction of the movement w.r.t. line of sight, the azimuth and range displacements (used for repositioning the target onto its actual position) and the signal to clutter noise ratio (SCNR). Since in a simulation the target position and the velocity vector are well-defined input parameters, the estimated values can finally be compared to the "truth", and with this the performance of the processing techniques in a variety of different scenarios can be evaluated. The considered scenarios include calm and rough ocean states with low or high underlying currents, slow or fast targets with different RCS values and the use of 2 up to 8 channels. For ensuring statistically valid answers, Monte-Carlo simulations will be carried out, i.e. many different realisations of ocean raw data with equal simulation parameters have to be used as background clutter.

3 Conclusions

The ATI simulations illustrate the potential of the HRWS system to retrieve high resolution and high quality estimates of the effective radial Doppler velocity. The simulations are consistent with the experimental observation that this Doppler velocity is highly correlated with the cross-track component of the surface wind vector.

The general implementation of GMTI processing techniques and the envisaged strategy for the performance analysis has been described. However, the intended analysis results were not available at paper due. Performance results will be ready and presented at the conference.

References

[1] Gerard Marull-Paretas: *Development of a multi-channel SAR simulator for open-oceans: OASIS*. Master Thesis, October 2013.

[2] R. Romeiser, W. Alpers, and V. Wismann: *An improved composite surface model for the radar backscattering cross section of the ocean surface: 1. Theory of the model and optimization/validation by scatterometer data.* J. Geophys. Res., 102(C11):2156–2202, 1997.

[3] S. Chiu, M. V. Dragosevic: *Moving Target Indication via RADARSAT-2 Multichannel Synthetic Aperture Radar.* EURASIP Journal on Advances in Signal Processing, vol. 2010, 2010.

[4] F. R. Dickey, M. M. Sante, *Final Report on Anti-Clutter Techniques*. General Electric Co., Heavy Military Electron. Dept., Syracuse, NY, Rep. No. R65EMH37, 1953.

[5] D. Cerutti-Maori, I. Sikaneta, C.H. Gierull, *Optimum SAR/GMTI Processing and Its Application to the Radar Satellite RADARSAT-2 for Traffic Monitoring*. Trans. Geosci. Remote Sensing, vol. 50, is. 10, pp. 3868 - 3881, Oct. 2012.