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GNSS-R 2D Imaging with Swarms of Nano-Satellites

Yiqing Wan[1,2*], Estel Cardellach[1,2], William Hill[3], Nicolo Bernardini[3], Martin Unwin[3], Camille Pirat[4]

[1] Institute of Space Sciences (ICE-CSIC), Barcelona, Spain
[2] Institute of Space Studies of Catalonia (IEEC), Barcelona, Spain
[3] Surrey Satellite Technology Ltd. (SSTL), Guildford, UK
[4] European Space Agency, ESTEC, Noordwijk, The Netherlands

Yiqing Wan
(*Corresponding author: ywan@ice.csic.es)

Introduction

The HydroSwarm mission concept first proposed, and the Horizon Europe GLITTER project now, are both aimed at studying instrumental concepts based on distributed GNSS-R payloads across the swarm. In our simulations, 6 nanosatellites equipped with GNSS-R receivers are used for 2D imaging, saving much budget and offering more manoeuvrability. The satellites are in a concentric circular scheme, which is one of the most performing yet easy-to-maintain orbit configurations.

Two types of simulations are presented in this poster: Impulse response simulations, in which the signal is reflected only at one point, while the instrument attempts a 2D image of the surface; and shape response simulations, in which the signal comes from a limited area on the surface, filling a given shape.

Single Point Response

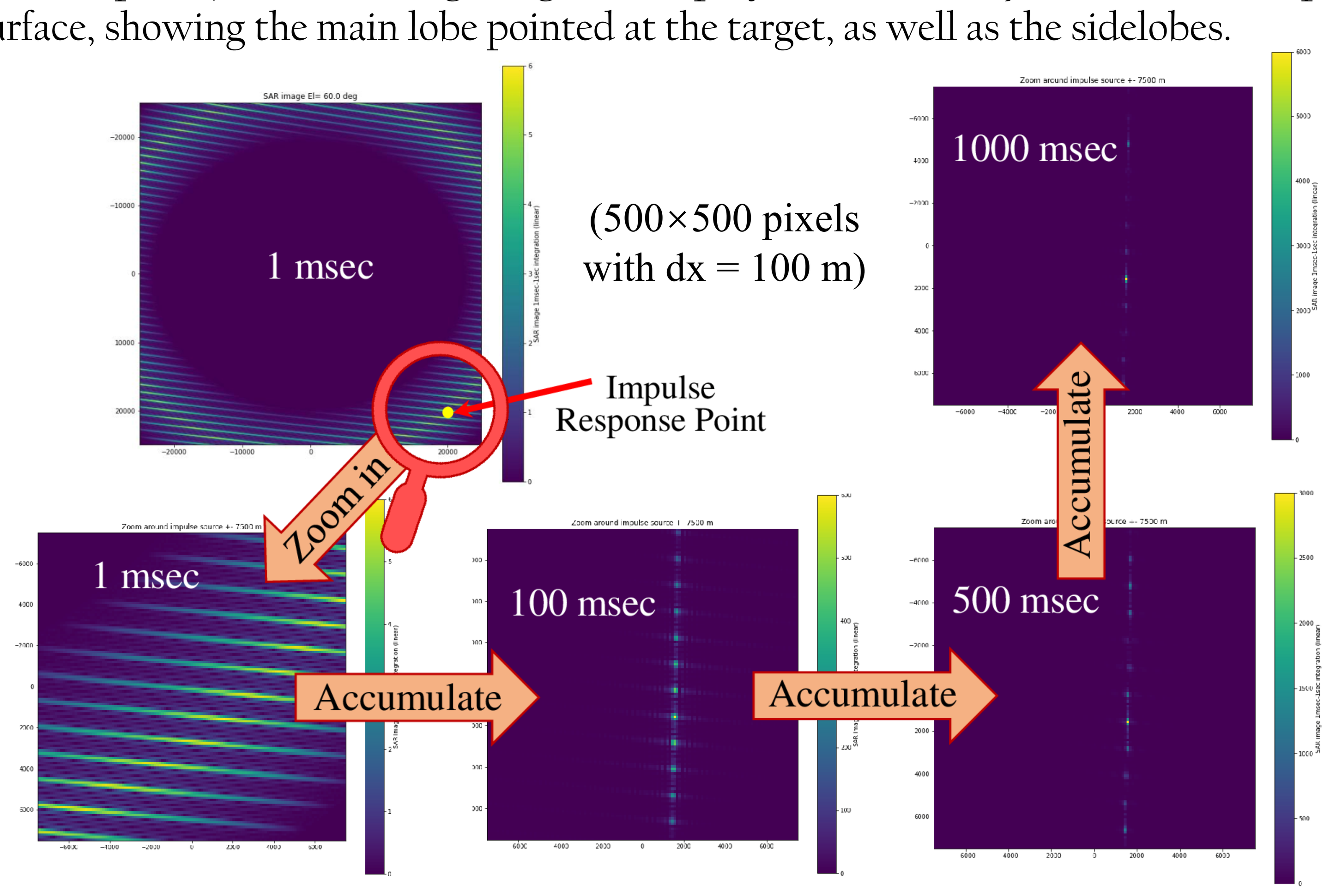
Single point response informs us about the residual ambiguities, the achievable pixel-size resolution, the areas on the surface with better / worse performance and the swarm formation that optimizes the results.

Different Accumulation Time

In the single point response mode, each receiver in the swarm compensates for the delay and Doppler effect of the desired pixel. The results obtained from all receivers are then coherently integrated. The equation for a short initial integration time (e.g., 1 msec) is:

$$Focus(x_c, y_c) = \sum_{i}^{N} A_i(\rho_i(x_c, y_c), f_{Doop_i}(x_c, y_c)) \qquad (1)$$

Through these calculations, a 2D image can be drawn. If only one point is providing the signal (impulse response), the resulting image is the projection of the synthetic antenna pattern onto the surface, showing the main lobe pointed at the target, as well as the sidelobes.



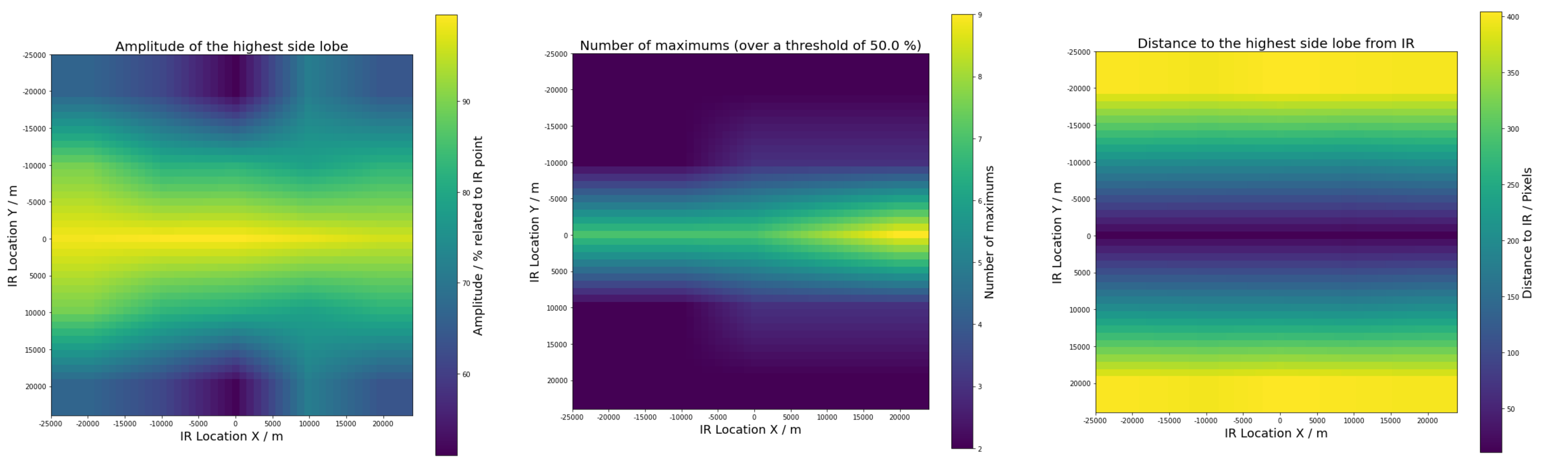
To mitigate the Doppler and sidelobe ambiguity, the focused signal should be accumulated through a period with the movement of the nanosatellites. The above figures display the result for an accumulation from 1 to 1000 msec. With an integration time T, equation (1) becomes [Yueh et al., 2021]:

$$Pixel(x_c, y_c) = \sum_{T}\sum_{i}^{N} A_i(T, \rho_i(T, x_c, y_c), f_{Doop_i}(T, x_c, y_c)) = \sum_{T} Focus(T, x_c, y_c) \qquad (2)$$

As the accumulation time increases, the pattern is firstly narrowed significantly in X-direction (along the moving direction of the satellites). As more time passes by, the impulse response point becomes more recognizable also in Y-direction.

Behaviors at Different IR Locations

The performance of impulse response (IR) varies with the locations of their locations. Map charts of behaviors are made from an interpolation of 25 sets of IR locations. The result shows that there tend to be fewer and lower sidelobes when IR is located further from the X-axis, instead of being at the center. There is no obvious difference in FWHM with different IR locations.



Amplitude of the Highest Sidelobe | Number of Local Maxima | Distance of the Highest Sidelobe from IR

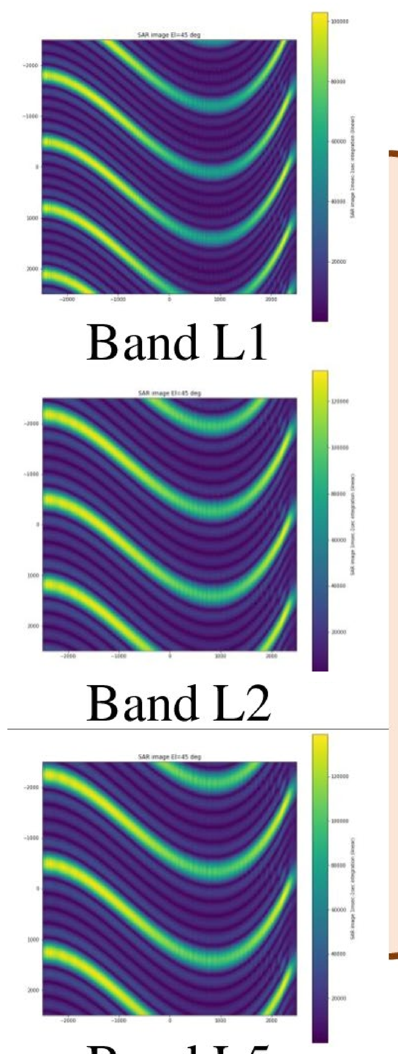
At Different IR Locations

2D Shape Response

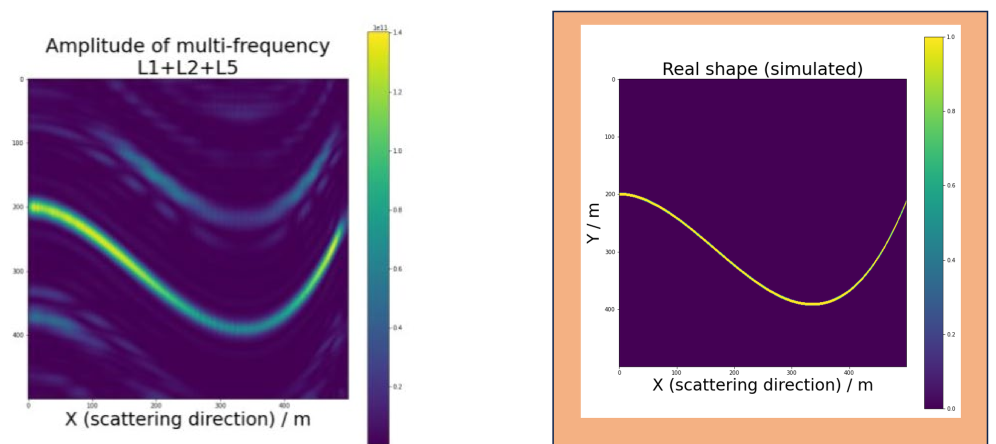
2D shape simulations inform about the capacity to retrieve the shape in the final image, blurring-edges and cross-contamination effects.

Multi-Frequency Measurement

The swarm is available for multiple frequency bands from the GNSS satellites. When the object is extended to multiple points and complex shapes, the importance of multi-frequency becomes more apparent. The figure shows the GNSS-R 2D imaging of a river-shaped object. It is obvious that there are many side noises when only one frequency is used, but they are significantly suppressed when different bands are combined coherently.



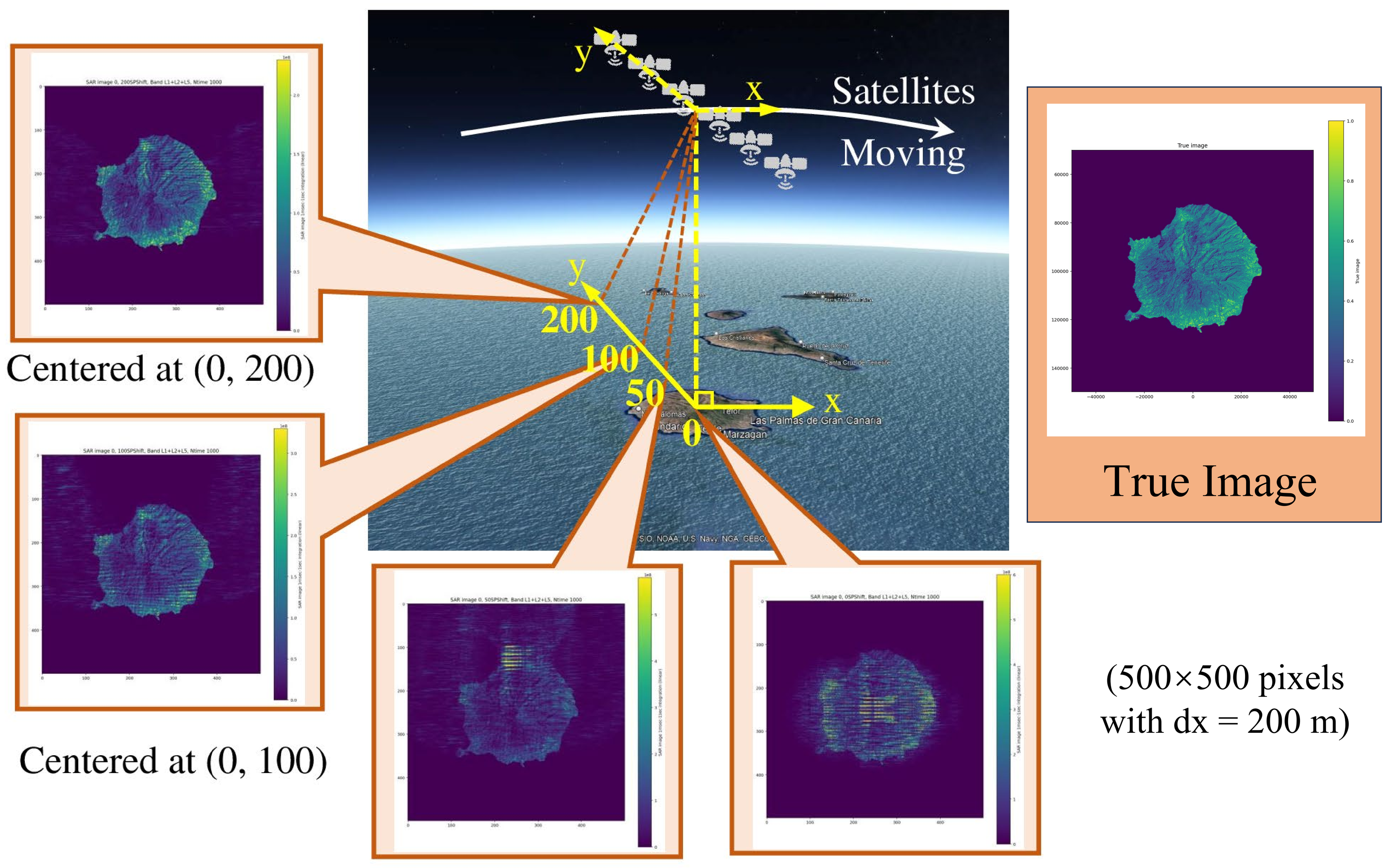
Band L1
Band L2
Band L5



L1 + L2 + L5 Multi-frequency

True Image

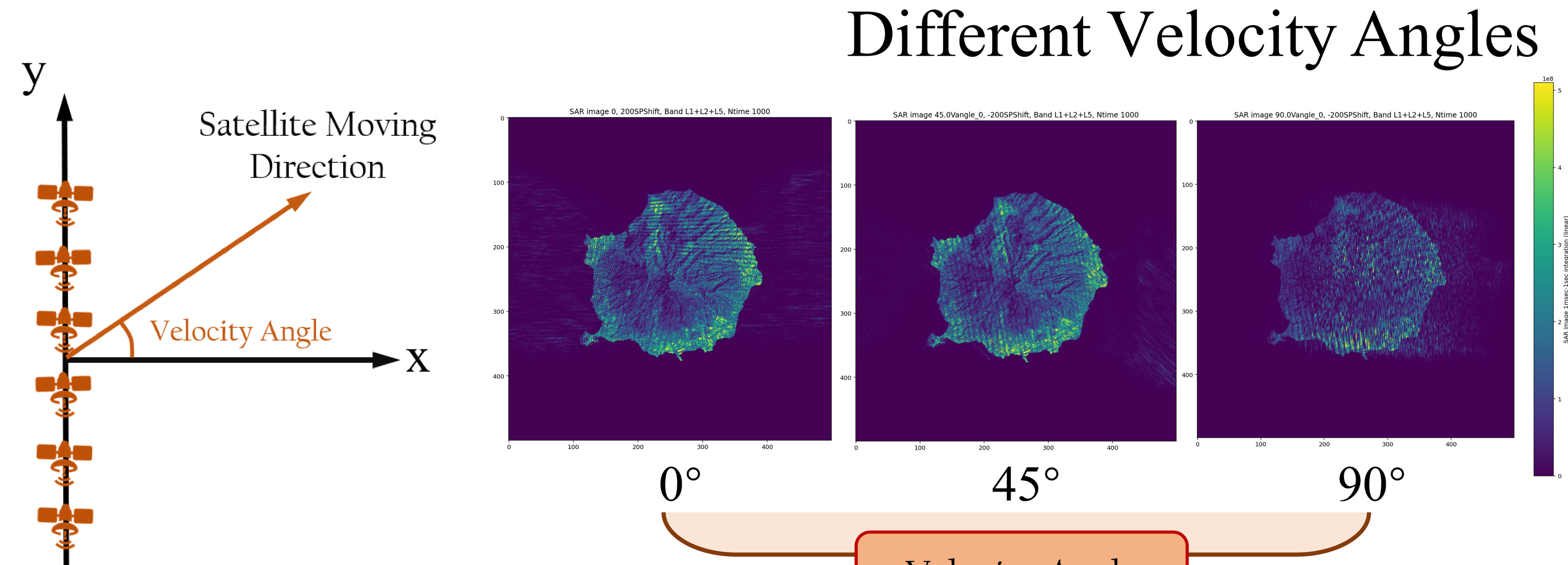
Different Locations Related with Center



Centered at (0, 200) | Centered at (0, 100) | Centered at (0, 50) | Centered at (0, 0) | True Image

An example of our 2D object is the Gran Canaria island. For the input, all pixels outside the island are set to 0, while the values of the pixels within the island are set as their reflectivity, according to their brightness from the satellite map. According to our results of the single point scenario, in order to obtain less noise, the object should be located not at the central specular point (SP), but some pixels away. In this section, the island is tested for 0 – 200 pixels away from the center, along the Y-axis. It is found that there are many noise strips when located along the SP track, while the details within the island become clear when located more than 100 pixels away.

Different Velocity Angles



The velocity angle also influences the SAR performance. For the island object centered at (0, 200), there is no much difference when the velocity angle is less than 60°. The details of the island are still clear, except for some noise strips being more obvious. However, if the velocity angle increases to 90°, the SAR image is much worse, and no details within the island can be recognized. This is due to bad geometry because the velocity of the swarm is parallel to its linear distribution.

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