KARIN – THE KA-BAND RADAR INTERFEROMETER ON SWOT: MEASUREMENT PRINCIPLE, PROCESSING AND DATA SPECIFICITIES

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1. INTRODUCTION

The principal instrument of the SWOT (Surface Water and Ocean Topography) altimetry mission is KaRIn, a Ka-band interferometric SAR system operating on two near nadir swaths on opposite sides of the satellite track [1-3]. This article briefly describes the measurement principle, the processing steps and the specificities of the interferometric SAR data as compared to conventional spaceborne SAR systems.

A series of SAR systems for earth observations have been launched over the last three decades, with frequency bands ranging from X- to L-band, and incidence angles typically between 20 and 40° (10-50° in extreme cases). These missions generally aimed at a relatively wide range of applications, and the main drivers for their evolution have been increased resolution, better spatiotemporal coverage, and improved polarimetric and interferometric acquisition capacities. More specialized SAR systems are now studied by several space agencies. Among them, the SWOT mission, which is part of the Decadal Survey Program of NASA, with phase 0 and A studies currently being carried out jointly by JPL and CNES, carries an innovative SAR system that bridges the gap between conventional radar altimetry and SAR interferometry. The principal instrument KaRIn (Ka-band Radar Interferometer) is a bistatic SAR system operating in Ka-band, covering two near nadir swaths (incidence angles 1-4°) on both sides of the satellite track. The observation geometry is illustrated in Figure 1 (left).

The main mission goals are to improve the spatiotemporal coverage with respect to today's oceanographic radar altimeters (while keeping a height precision of the order of a cm on a km scale grid), and extend the altimetric measurements to continental water surfaces, including lakes, reservoirs, wetlands, and rivers down to a width of 50-100 m (represented on a triangular irregular network with an average spacing of 50 m).

2. MEASUREMENT PRINCIPLE

The illustration in Figure 1 (right) resumes the principle of absolute height estimation based on the interferometric measurements realized by KaRIn. For simplicity, a single target is considered here and the effect of roll and tropospheric delay is not taken into account.

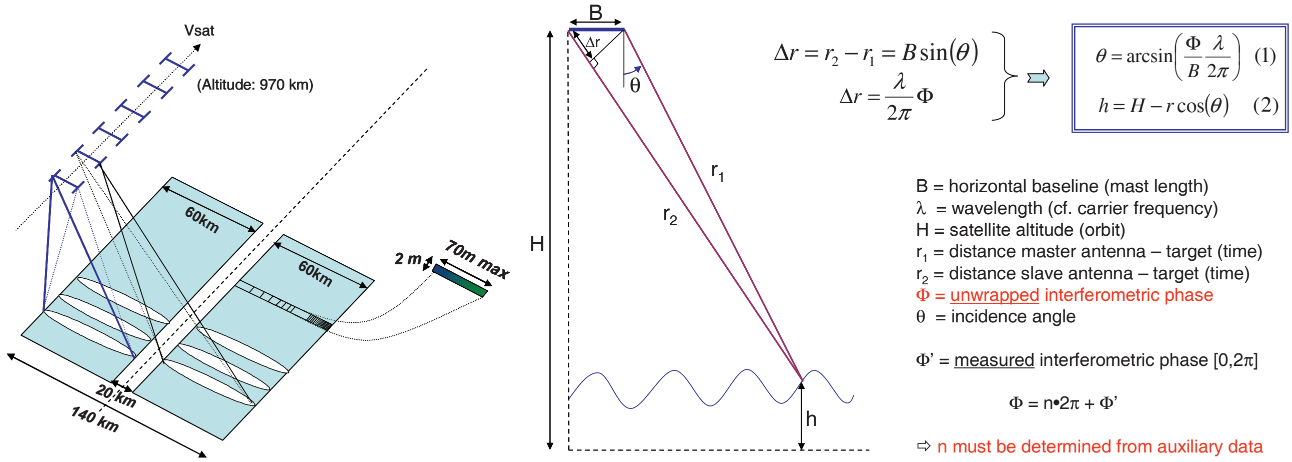


Figure 1: Illustration of the acquisition geometry of KaRIn on SWOT (left) and measurement principle (right).

The phase difference Φ enables us to estimate very precisely the view angle θ (1). This interferometric phase is however measured modulo 2π by the instrument (phase difference between the electromagnetic waves received by the two antennas. In terms of relative heights, a difference of 2π corresponds to the altitude of ambiguity E_a. As a consequence, it is necessary to have auxiliary data to remove this ambiguity, i.e. an absolute height reference whose precision is within $\pm E_a/2$ (typically a numerical terrain model in hydrology mode, and mean sea level and tidal models or nadir altimeter measurement in oceanography mode). After this phase unwrapping stage, the incidence angle θ can be computed (1).

The absolute height h of the target can then be derived from the distance r (range) between the antenna and the target (time between transmission and reception) and precise knowledge of the satellite altitude H (2). It should be noted that r and H must be estimated with very high accuracy.

The above equations allow us to estimate absolute height on a pixel-by-pixel basis, but this strategy implies a need for tropospheric correction throughout the swath, which seems difficult to realize over land, where there may be fast spatial variations in tropospheric conditions. To overcome this problem for continental surfaces, the phase unwrapping and height restitution could alternatively be done spatially ("horizontally") from a reference point, similar to the computation of relative heights in conventional SAR interferometry, but taking the particular evolution of the altitude of ambiguity in range into account (see sec. 4.2).

3. DATA PROCESSING

In terms of processing and data products, KaRIn features a low resolution (LR) mode dedicated to oceanography (km scale grid) and a high resolution (HR) mode dedicated mainly to continental hydrology (triangular irregular network with 50 m average spacing). The processing steps can be divided into the following main categories:

1. SAR processing (range and azimuth compression)

2. Interferometric processing (co-registration, computation of interferometric phase and coherence)
3. Restitution of acquisition geometry (geolocation, precise orbit determination, correction of roll, baseline variations, tropospheric delay, …)
4. Extraction of geophysical parameters (HR water surface detection, computation of absolute heights, etc)
5. Multitemporal analysis (medium and long term variations, flooding, floodplains, …)

In the LR mode (oceanography), a considerable part of the data processing is done onboard, including unfocussed SAR processing and computation of raw interferograms, as well as incoherent averaging (multilooking) that reduces noise and further degrades the spatial resolution to about 1 km^2 pixels. These operations reduce the data rate considerably, from more than 1 Gbps to 0.2 Mbps. Unfocussed SAR processing implies a very limited loss of performance with respect to full SAR processing in this configuration (after multilooking to 1 km^2 pixels).

The HR mode (hydrology) has very limited onboard processing: only presummation by a factor 2 in azimuth (and BAQ coding). It is crucial to preserve high spatial resolution (4 m x 10-70 m) in order to detect, localize and characterize relatively small water surfaces. The price to pay is a very high output data rate (around 300 Mbps).

It should be noted that several strategies are possible concerning the order in which the processing steps are carried out and that there generally are several candidate algorithms for each processing step (e.g. many different algorithms for water surface detection), so that comprehensive prototyping and testing is needed to establish the operational processing chain. (More details will be given in the full paper.)

4. SPECIFICITIES OF KARIN DATA

4.1. Ka-band SAR imaging and interferometry

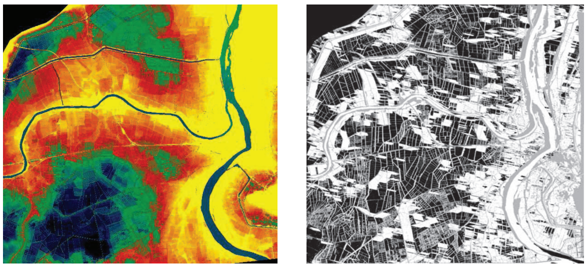
The smaller wavelength of Ka-band SAR (about 8 mm) compared to X- and C-band implies that:

- less surfaces appear smooth, implying less specular reflection
- weaker penetration into vegetation, soil, snow,…
- higher sensitivity to tropospheric conditions; rain will generally make acquisitions unexploitable
- a smaller baseline can be used for bistatic interferometry: as an illustration, a 10 m mast yields sufficient antenna separation for KaRIn, whereas a 60 m mast was needed for the SRTM mission (C- and X-band).

There are few reports on backscattering from natural surfaces in Ka-band, and they are generally limited with respect to the variety of surface types taken into account, and the number and range of associated parameters (local incidence angle, soil humidity and roughness, water salinity, wave height, etc.). The empirical results can be completed through carefully selected electromagnetic models. We have so far considered three surface types (and associated EM scattering and dielectric models): bare soil (Hybrid IEM-GO [9] and Hallikainen-Dobson [4]), water surfaces (Hybrid IEM-GO [9] and Meissner and Wentz [5]) and vegetation/trees (Radiative Transfer (Order 1) [10] and Ulaby and El-Rayes [6]). Simulation results based on these models is shown in Figure 2.

4.2. Near nadir SAR imaging and interferometry

One of the key features of the KaRIn configuration is its near-nadir incidence. In this case distortions caused by layover, which occurs when the terrain slope exceeds the local sensor look angle, are expected to be very important. Any terrain feature presenting a slope greater than 1º in near range and 4º in far range will produce layover, disturbing the final image analysis. Figure 2 shows the DEM of a region of moderate topography (a few tenths of m), and the simulated layover map for KaRIn. The zones polluted by layover are shown in white, the zones causing layover in light grey, and shadow in dark grey. Only the black zones are not affected by distortion.



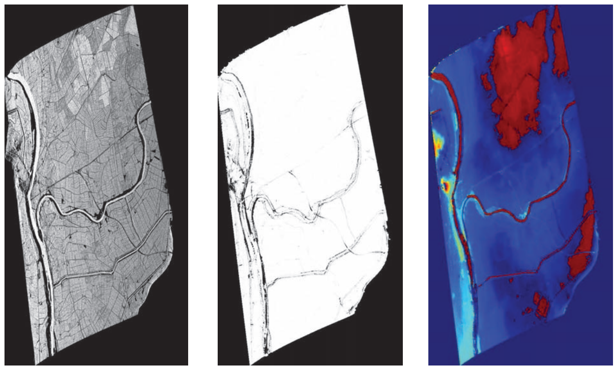


Figure 2: DEM of area with moderate topography and associated layover mask for KaRIn (left). Simulated KaRIn SAR master image, coherence image and interferometric phase after elimination of orbital fringes (right).

The impact of layover on the height restitution over continental water surfaces, depends strongly on the radiometric contrast between water and land surfaces. Indeed, as we are close to nadir, the backscattering coefficient of water is generally assumed to be much higher than that of land surfaces [7], in which case the layover could have limited impact. However, far less favorable conditions in terms of contrast can occur.

KaRIn operates in a narrow range of viewing angles (1-4°), but the relative variation in incidence is very important (1:4) compared to other SAR satellites. Several key parameters therefore vary considerably over the swath. There is a certain evolution in the water/land contrast, but there is a much stronger variation in the pixel size (70-10 m) and altitude of ambiguity (10-60 m), and the unwrapped phase (orbital fringes) turns very quickly in the case of KaRIn [8]. Particular care must therefore be taken in the unwrapping and multilooking steps.

5. REFERENCES

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