Specificities of Near Nadir Ka-band Interferometric SAR Imagery

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Abstract

The principal instrument of the SWOT mission is KaRIn, a Ka-band interferometric SAR system operating on two near nadir swaths on opposite sides of the satellite track. This article describes the specificities of images from such a SAR system as compared to images acquired by conventional spaceborne SAR systems. Both radiometric and geometric aspects are covered.

1 Introduction

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° (and not exceeding 10-50°). These missions generally aimed at a relatively wide range of applications, and the main drivers for their evolution have been increased resolution, better spatio-temporal coverage, and improved polarimetric and interferometric acquisition capacities. More specialized SAR systems are now studied by several space agencies. One example is the SWOT (Surface Water and Ocean Topography) 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. SWOT features 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. KaRIn can also be operated in a monostatic mode, in order to improve the interferometric sensitivity. The observation geometry is illustrated in Figure 1.

The main mission goals are to improve the spatio-temporal coverage of today's oceanographic radar altimeters (with 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 and rivers down to a width of 50-100 m (with a height precision of about 10 cm, represented on a triangular irregular network with an average spacing of 50 m).

In this article we focus on the specificities of SAR images and interferograms from such a system. This is done along two axes: First we describe the impact of the short wavelength (8 mm) of Ka-band radar. Then we deal with the implications of the particular near nadir observation geometry. Some preliminary simulation results obtained by CapGemini and Altamira Information in the framework of a 2009 R&D study for CNES are shown. A brief summary is given in the end.

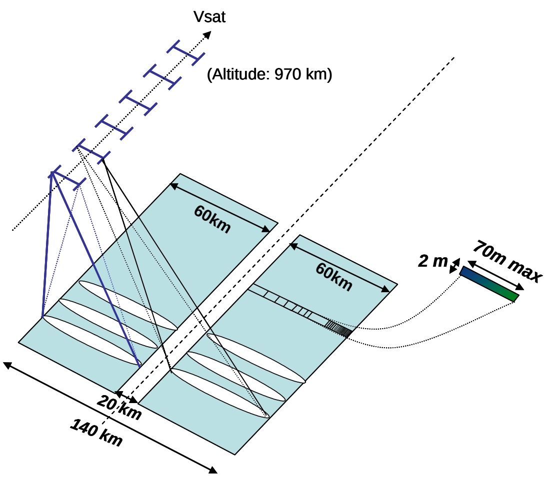

Figure 1 Illustration of the acquisition geometry of KaRIn on SWOT.

2 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 extinction on one hand, and less specular reflection on the other
- weaker penetration into vegetation, soil, snow,…
- higher sensitivity to tropospheric conditions; rain will generally make acquisitions useless
- a smaller baseline can be used for bistatic (or monostatic) 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 models):

- Bare soil (Hallikainen-Dobson [1])
- Water surfaces (Meissner and Wentz [2])
- Vegetation/trees (Ulaby and El-Rayes [3])

Simulation result based on these models are shown in section 4.

3 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 1° in near range and 4° in far range will produce layover, disturbing the final image analysis. Figure 2 illustrates the extent of layover in the case of ENVISAT ASAR and SWOT.

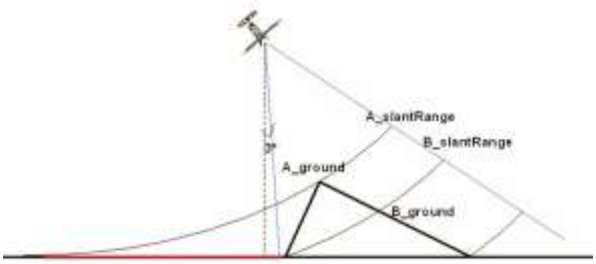

Figure 2 Illustration of the extent of layover in the case of ENVISAT ASAR (top) and SWOT (bottom).

Figure 3 shows the DEM of a region of moderate topography, 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 these geometric phenomena.

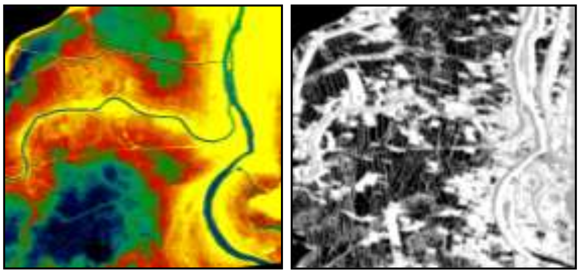

Figure 3 DEM of area with moderate topography (left) and associated layover mask for KaRIn (right).

The impact of layover on the height restitution over continental water surfaces, which is one of the main goals of SWOT, 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, in which case the layover could have very limited impact. Figure 4 shows the evolution in near range of the backscattering coefficient for water and land in Ka-band (graph inspired by Ulaby measurements [4]). However, this graph is only representative of a particular combination of surface characteristics. Less favourable conditions can occur (see section 4).

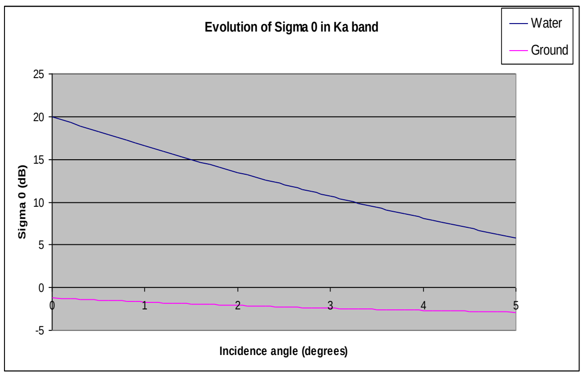

Figure 4 Example of evolution of σ_0 in near range for Ka-band imaging of water and land.

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 (Figure 4), but there is a much stronger variation in the pixel size (Figure 5). We see that he pixel size varies from about 70 m in near range to about 10 m in far range in the case of KaRIn, whereas it e.g. only varies ±10% for ERS-1. The histogram shows that a large majority of the KaRIn pixels have a range size below 30 m.

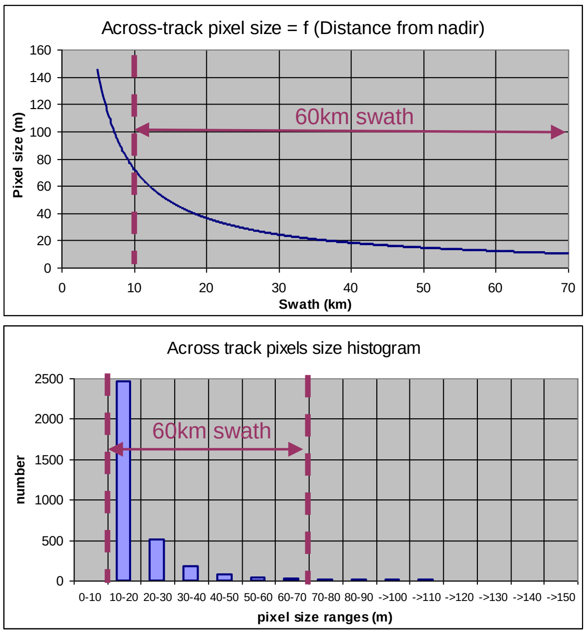

Figure 5 Evolution of the range pixel size in the swath (top) and the associated histogram (bottom).

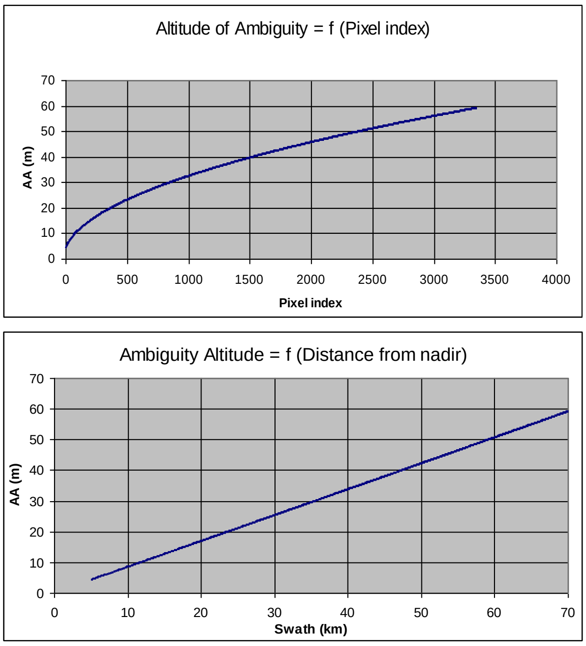

Figure 6 Evolution of the altitude of ambiguity in range for KaRin (in bistatic mode).

Likewise, the altitude of ambiguity of KaRIn varies from below 10m in near range to about 60 m in far range. Even after removing orbital fringes, the phase differences over the swath are not directly interpretable as relative heights; the evolution of the altitude of ambiguity must be taken into account.
Figures 7 and 8, respectively shows the wrapped and unwrapped phase variations throughout the swath due to flat earth geometry for KaRIn (top) and RadarSat (bottom) parameters, assuming a 10 m baseline in both cases. We see that the phase corresponding to orbital fringes turns extremely quickly in the case of KaRIn. Particular care must therefore be taken in the unwrapping and multilooking steps.

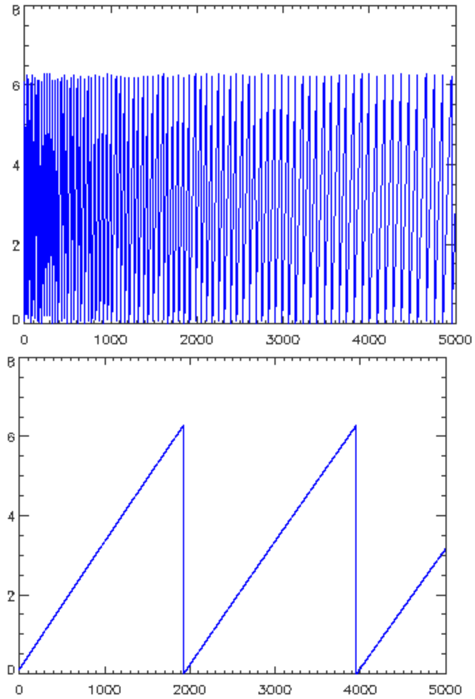

Figure 7 Wrapped phase [rad] as a function of the pixel index for KaRIn (top) and RadarSat (bottom).

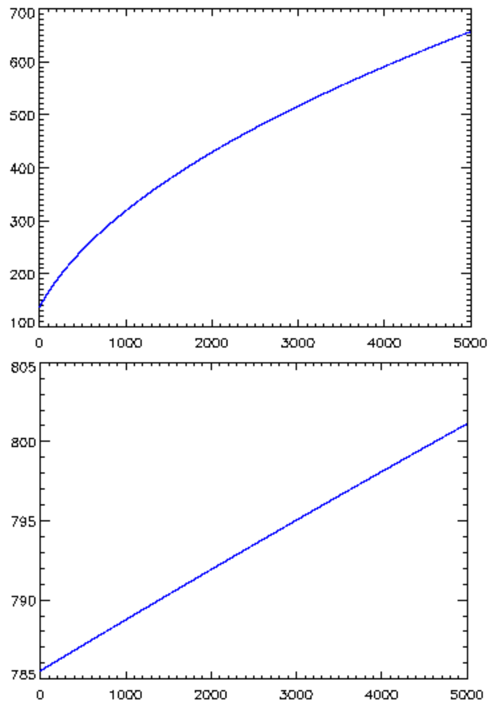

Figure 8 Unwrapped phase [rad] as a function of the pixel index for KaRIn (top) and RadarSat (bottom).

4 Preliminary simulation results

Simulation tools are very useful to study innovative SAR systems, especially when representative airborne data or other physical measurements are not available.

Simulators that cover both radiometric and geometric aspects have been developed in the framework of the CNES phase 0 study of SWOT. In terms of radiometry, sensitivity studies based on the models cited in section 2 have shown that the driving parameters for σ_0 are local incidence, humidity and roughness for bare soil, micro-roughness (due to wind) for inland water surfaces, and penetration depth for trees. Different scenarios in terms of combinations of parameters can then be studied for a given scene defined by a detailed DEM and a land cover map. Figure 9 shows two examples of histograms, corresponding to two different parameter sets for the three classes.

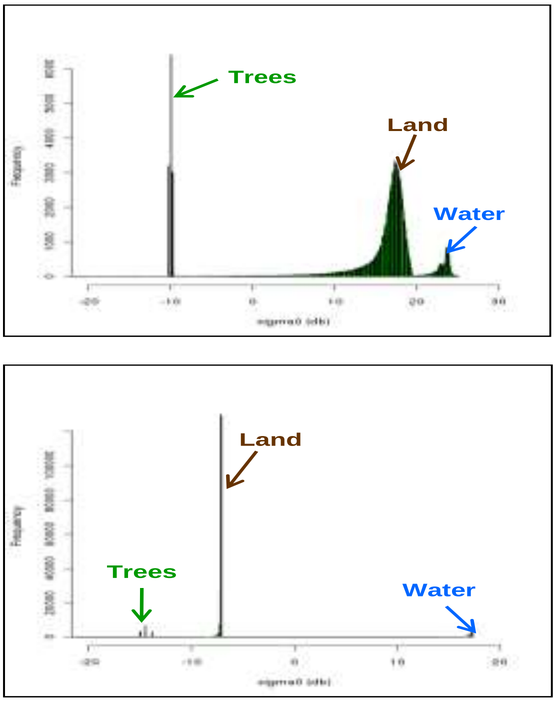

Figure 9 Histograms of σ_0 for two different scenarios in terms of surface parameters, based on the DTM shown in Fig. 3 and a land cover map.

Depending on the hypotheses taken, we see that the water/land contrast can vary considerably, which has direct impact on the capacity to detect water surfaces and exploit zones affected by layover. However, the contrast between water and vegetation (trees) generally remains high (around 35 dB in these examples).

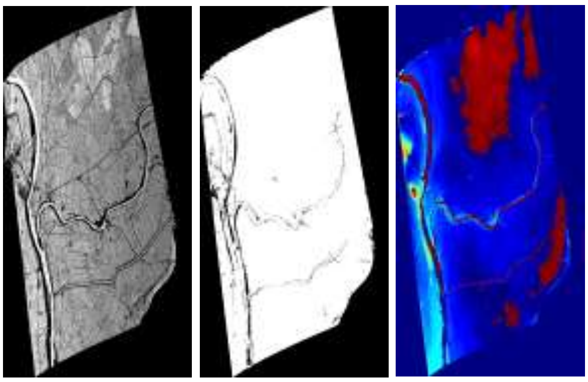

Figure 10 Simulated KaRIn SAR master image (left), coherence image (middle) and interferometric phase after elimination of orbital fringes.

Figure 10 shows KaRIn images obtained by a simulator that generates interferometric pairs of SLC (single look complex) SAR images, and computes interferometric phase and coherence. This simulator integrates the results of the radiometric simulator, adds speckle and takes geometric effects such as layover and shadows into account. The results can be used to study the attainable performances in terms of water surface detection and height estimation. A raw data simulator has been developed in order to study phenomena that vary during the integration time, in particular the impact of moving water on focusing and interferometric coherency.

5 Summary and outlook

Near nadir Ka-band SAR interferometry has a wide range of specificities compared to existing spaceborne SAR systems.

While the impact of shorter wavelength is quite predictable from a qualitative point of view (sensitivity to micro-roughness and tropospheric conditions, penetration depth, etc.), there are few detailed reports on backscattering from natural surfaces in Ka band. Backscattering coefficients for a larger set of surface types under a wider ranger of conditions can be obtained through careful modelling and simulation. Validation through ground measurements and airborne campaigns is nevertheless indispensable.

The near nadir acquisition geometry also implies a number of particularities. In particular, layover becomes a predominant problem, even in zones of moderate topography. We have also shown that several key parameters, that vary little or slowly in conventional SAR interferometry, have a much stronger or faster range variation in near nadir imaging, including pixel size, altitude of ambiguity and orbital fringes.

More information on the SWOT mission can be found at the SWOT homepage [5].

References

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