The DALO-ARCTIC campaign: Multi-spectral SAR Imaging of Ice Features in Greenland

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Abstract

In May 2015, the Danish Defence Acquisition and Logistics Organization (DALO) together with the German Aerospace Center (DLR) conducted the joint DALO-ARCTIC airborne SAR campaign with the F-SAR sensor over several test-sites in Greenland. Principal goal of this campaign was to demonstrate the capabilities of SAR for security applications in arctic environments, as well as to investigate various advanced methods for extracting ice and snow parameters from SAR data. During this campaign, the ability of F-SAR to simultaneously record fully-polarimetric SAR data in several frequency bands was used for the first time on a large scale. Due to the significantly varying penetration depth of the different bands into ice and snow, it is of particular interest to understand and analyse what can be seen in each band and what are the dominating scattering processes. This paper will discuss this based on examples of polarimetric multi-band imaging of ice and snow layers from data acquired during the DALO-ARCTIC campaign. In this way, the huge potential of multi-spectral SAR imaging for the analysis of ice bodies will be demonstrated.

1 Introduction

Most current SAR sensor are only capable of operating at one single frequency band at a time. For enhancing the observation space, only polarimetric or interferometric techniques are employed, while multi-spectral imaging, being a standard in optical remote sensing, has mostly been ignored in SAR. The F-SAR sensor of DLR is capable of operating in up to 4 frequency bands simultaneously in fully polarimetric mode. This opens a new dimension in SAR image interpretation, as additionally the variation of backscatter over the wavelength becomes directly observable.

One of the most interesting surfaces to be analysed with multi-spectral polarimetric SAR is ice and snow. It is a well-known fact that the penetration capabilities of microwaves into (dry) ice and snow are generally quite high and significantly depending on the wavelength. Already at X-band, penetration depths in the order of several metres have been observed over the Greenland inland ice in Tandem-X satellite data. Deeper ice features can be expected to become visible in the longer wavelength.

During the DALO-ARCTIC F-SAR campaign to Greenland in 2015, multi-spectral polarimetric SAR imaging was employed on most of the test-sites. In the following, based on these data, different wavelength-dependent scattering effects in ice and snow will be pointed out and discussed.

2 The DALO-ARCTIC campaign

The DALO-ARCTIC flight campaign 2015 took place from April 27 until May 24 at nine sites in Greenland: Kangerlussuaq, K-Transect, Godhavn, Nuuk, DYE-3, EGIG, Helheim, Lost Squadron and South Dome. The campaign was jointly organised by the Danish Defence Acquisition and Logistics Organization (DALO) together with the German Aerospace Center (DLR) and included, apart from the F-SAR flights, a significant amount of ground truth measurements on the test-sites. Fig. 1 shows the approximate location of the measured sites in Greenland.

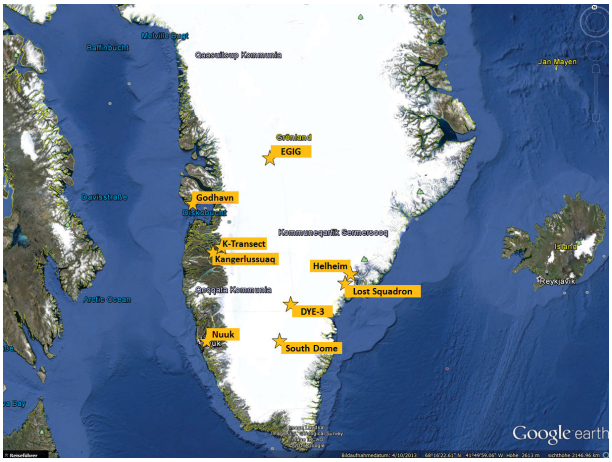

Figure 1: Test site locations of the DALO-ARTIC airborne SAR campaign to Greenland.

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The principal goals of the campaign have been twofold: On the one hand to analyse the potential of high-resolution polarimetric SAR for security and environmental protection applications in arctic environments, on the other hand to investigate various advanced methods for extracting ice and snow parameters from SAR data.

3 The F-SAR sensor

F-SAR's main design feature is the fully polarimetric operation in five frequency bands, X-, C-, S-, L- and P-band, with the ability to measure several different frequency bands and/or polarisations simultaneously its four recording channels [1]. It also features high radiometric accuracy and spatial resolution and across-track interferometers in X- and S-band. The main system parameters are summarised in Tab. 1.

	X	C	S	L	P
f [GHz]	9.6	5.3	3.25	1.325	0.435
PolSAR	quad	quad	quad	quad	quad
InSAR	√	-	√	-	-
BW [MHz]	760	380	300	150	50
power [W]	2500	1000	1250	750	750
rg res. [m]	0.25	0.5	0.6	1.0	4.0
az res. [m]	0.1	0.25	0.3	0.5	2.0
swath [km]	2 to 5, depending on altitude				

Table 1: F-SAR's principal imaging parameters. Repeat-pass InSAR modes are available at all bands.

F-SAR cannot operate C- and S-band subsystems simultaneously. At the time of the flights in Greenland, F-SAR also haven't had yet a joint airworthiness certificate for XCSL-band and P-band subsystem together on board. Consequently, only the XCL- and XSL-mode have been available. Nevertheless, XCSL quad-band imaging has been performed using consecutive passes. P-band acquisitions with few days separation after re-equipping the plane have been done, too.

4 Experimental results

Data processing of the campaign is currently on-going. Up to now, only imagery from few test-sites is available and not yet fully analysed. As an example, Fig. 2 shows the area around the airport in Kangerlussuaq in four different wavelength. The C-band image has been acquired in a consecutive pass 30 min after the XSL-band acquisition. While the airport and city region appear very similar in all the bands, the backscatter from quite homogeneous snow-covered flood plain on the left side of the image changes with wavelength. At X-band, several dog sledge tracks stand out, which become less and less visible in the longer wavelength being less sensitive to the snow surface itself and more to the underlying sand and rubble. In the middle of the image, south of the runway, even more variable backscattering can be observed, linked to the spatially varying grain sizes of the rubble along the river bed and varying surface structures of the wind blown snow cover in this area.

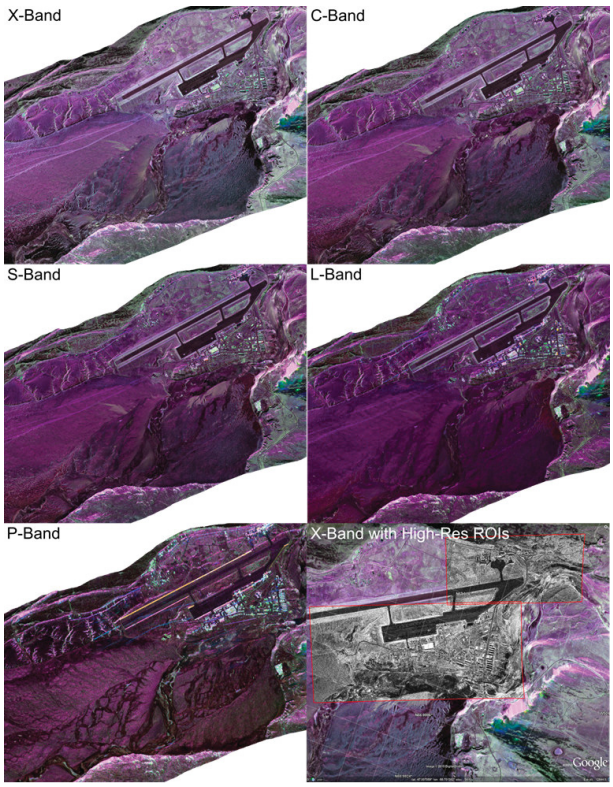

Figure 2: Kangerlussuaq test-site imaged by F-SAR in X-, C-, S-, L- and P-band (C-band from a consecutive pass to XCS-band, P-band has been acquired separately). Colours: HH=red, VV=blue, XX=green

Another example is presented in Fig. 3. It shows a zoom into a part of the Foxx-Gull test-site located on the transition between inland ice and coastal ablation zone north of Jakobshavn Isbrae. Dry ice conditions are dominating here, meaning that a significant penetration can be expected at the longer wavelength, but also to a certain amount at X-band. In the middle of the image, a crevasse area can be found, with high cross-polar backscatter in all three bands. To both sides of it, huge differences between the bands are emerging. To the right, some close-to-surface features can be observed at X- and to a lesser extend at C-band, including remainders of a small supraglacial lake. The visible features are presumably a result of last year's thawing period and at the time of data acquisition hidden under the last winter's snow and ice cover.

At L-band, a completely different backscattering is noticeable. Here, areas with very low backscatter in all polarisations alternate with areas of high cross-polar backscatter. The origin and vertical location of these features is not fully clear and further investigations are ongoing. However, presumably the dark spots are caused by percolating superficial thaw water causing water accumulations dozens of metres under the surface, freezing in the next winter season and leaving a locally modified ice structure. Similar multi-frequency studies have been

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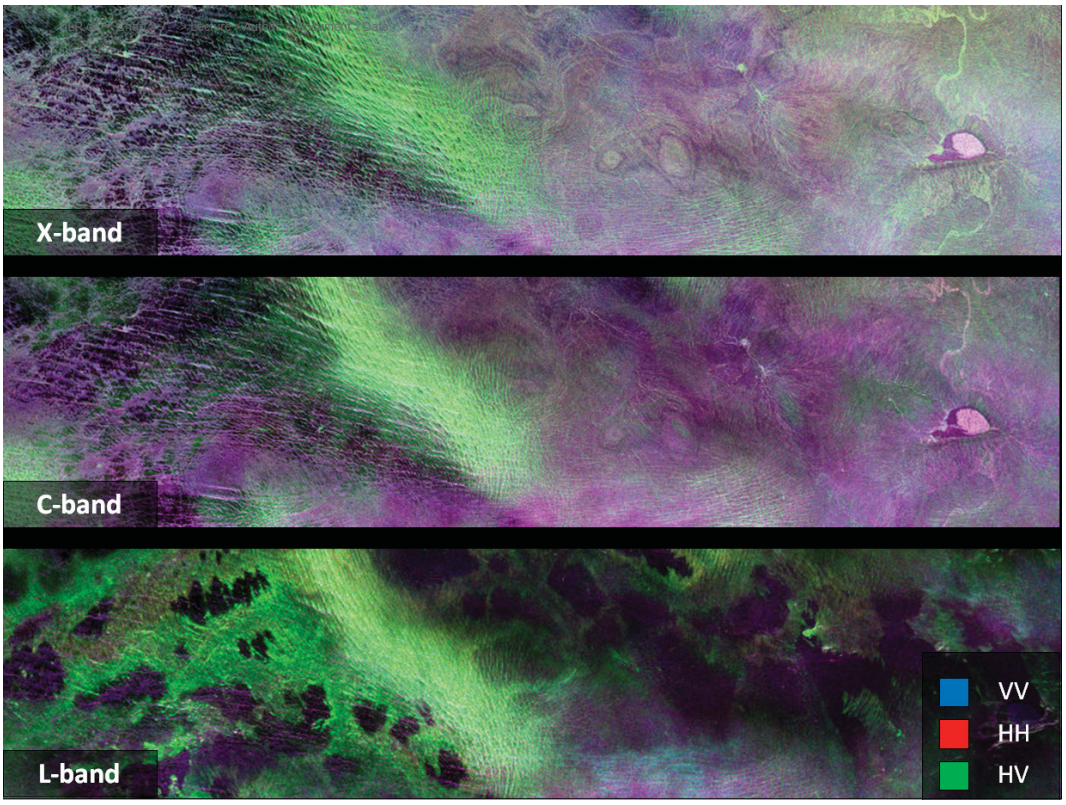

Figure 3: Subset of the Foxx-Gull test-site imaged by F-SAR in X-, C- and L-band. Colours: Colours: HH=red, VV=blue, XX=green.

performed on other test-sites with different ice structure. Also, long transects starting in the costal regions and ending deep in the inland ice shield have been acquired, covering various ice and snow types in a single acquisition.
Another focus of the DALO-ARCTIC campaign was to evaluate the potential of interferometric and polarimetric change detection approaches in arctic scenarios [2], using temporal baselines ranging from less than one hour to more than three weeks. The data analysed show that changes in environmental conditions can and regularly do have a significant impact on the fully polarimetric SAR imagery acquired in Arctic regions, irrespective of the frequency band used. Especially for longer temporal baselines, the detection output can be dominated by differences in environmental conditions, limiting the direct applicability of conventional automated change detection without further refinement.

5 Conclusions

This paper presents imaging results from the DALO-ARCTIC airborne SAR campaign to Greenland. During this campaign, the ability of F-SAR to simultaneously record fully-polarimetric SAR data in several frequency bands was applied to acquire unique SAR imagery of various ice and snow types, demonstrating the huge potential of multi-spectral SAR imaging for the analysis of ice bodies.

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