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ADVANCES IN MAPPING ICE-FREE SURFACES WITHIN THE NORTHERN ANTARCTIC PENINSULA REGION USING POLARIMETRIC RADARSAT-2 DATA

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ABSTRACT

Ice-free areas within the Northern Antarctic Peninsula region are of interest for studying changes occurring to surface covers, including those related to glacial coverage, raised beach deposits and periglacial processes and permafrost. The objective of this work is to map the main surface covers within ice-free areas of King George Island, the largest island of the South Shetlands archipelago, using fully polarimetric RADARSAT-2 SAR data.

Surface covers such as rock outcrops and glacial till, stone fields, patterned ground, and sand and gravel deposits form the most representative classes and account for 84 km^2 of the ice-free areas on the island. A distribution of complex geomorphological features and landforms was obtained, being some of them considered indicators of periglacial processes and presence of permafrost.

Index Terms RADARSAT-2, polarimetry, geomorphology, South Shetland Islands, Antarctica

1. INTRODUCTION

The western and northern parts of the Antarctic Peninsula have experienced the greatest increase of warming in Antarctica over the last 60 years [1]. This has resulted in retreating glaciers, reduced snow fields and thawing permafrost, which affects the surface hydrology and influences the land surface morphology and often vulnerable and fragile ecosystems within ice-free areas. The, freeze-thaw cycling effects together with other surface processes contribute to a highly dynamic and complex distribution of geomorphological features [2].

Remote sensing techniques offer a great potential to identify relief and landscape features, as well as detect changes in areas where access is difficult and little or no data are available [3]. Synthetic Aperture Radar (SAR) sensors are useful for determining physical properties of terrestrial land covers such as structure and roughness [4]. Furthermore, in environments encountered in the Antarctic Peninsula region, using SAR data is of advantage because microwaves function in all-weather conditions.

The objective of this work is to map land surface covers, in many cases related to periglacial, glacial and marine landforms, within ice-free areas of King George Island in the South Shetland Islands using fully polarimetric RADARSAT-2 data. The work is based on field data obtained from a representative and accessible ice-free area and extrapolated to the remaining island surface using advanced SAR techniques.

2. STUDY AREA

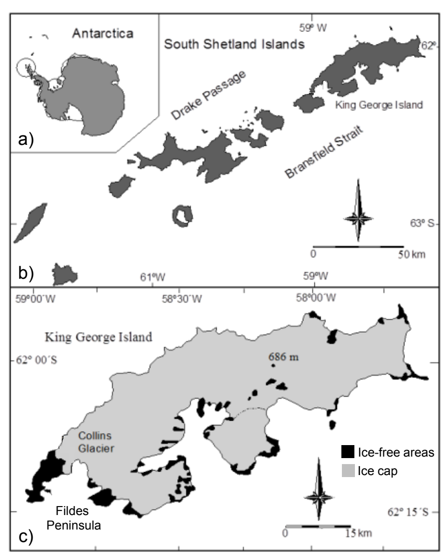

Figure 1. Study area in Antarctica (a) within the South Shetland Islands (b) and King George Island (c).

King George Island is the largest of the South Shetland Islands (Figure 1), lying 120 km off the coast of Antarctica in the Southern Ocean. At its widest it is 24 km wide and extends over 64 km along the line this arc of islands. King George Island is 1,150 km^2 and over 90% of the island's surface is permanently glaciated. A large ice cap lies over the central part of the island reaching a maximum height of 610 m above sea level.

3. DATA AND METHODS

The method outlines the field and image data used, as well as the processing steps to map the ice-free areas (Figure 2).

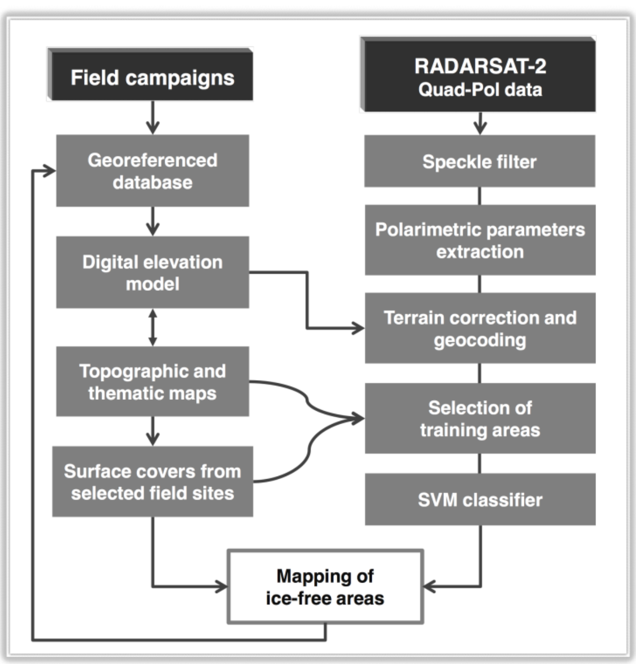

Figure 2. Method outline.

3.1. Data

Field data was obtained during several campaigns where the most recent one took place during the austral summer in early 2017. During these campaigns, *in situ* surface covers representing many of them different periglacial processes and landforms were characterized on Fildes Peninsula (Figure 1c). Fildes Peninsula with an area of 30.5 km^2 is considered representative as it is the largest ice-free area on King George Island. Collecting field data from Fildes Peninsula is relatively easy as there is access and different stations for logistical purposes. These data are compiled in a georeferenced database containing further maps and eventually the results obtained.

Two fully polarimetric C-band RADARSAT-2 images (Single Look Complex data, fine wide in ascending mode) were acquired through the Canadian Space Agency within the framework of the Science and Operational Applications Research Program (Project SOAR-5169) on the 21st and 28th of March 2015.

3.2. Pre-processing of the SAR data

The pre-processing of the RADARSAT-2 quad-pol data included extracting the fully polarimetric data files and generating the complex (3 x 3) coherency matrix (T3) with a 2 x 2 presuming factor using the Sentinel Application Platform (SNAP) application [5]. After applying a nonlocal bilateral speckle filter, derived from a newly proposed method to filter tomographic dataset [6], 65 polarimetric parameters were extracted (Table 1) using the decomposition methods available in the PolSARpro program [7]. These parameters were related to the different surface covers according to the backscattering characteristics received by the sensor (Table 1).

Table 1. Extraction of polarimetric parameters.

Alpha (α1, α2, α3)	Beta (β_1, β_2, β_3)	Gamma (γ_1, γ_2, γ_3)
Delta (δ1, δ2, δ3)	Entropy (H)	Anisotropy (A)
Combination Entropy/Anisotropy	Anisotropy12	Asymetry
Entropy Shannon Intensiy/Polarity	Gini Simpson Index	Index qualitative variation
Inverse Simpson Index	Pseudo probability (p_1, p_2, p_3)	Pedestal
Perplexity	Polarisation Fraction	Rényi_Entropy (2, 3, 4)
Radar Vegetation Index	SERD, DERD	Shannon/Simpson Index
Element of the coherency matrix T (9 parameters)	Praks_Colin	An Cui Yang

A terrain and geometric correction were carried out using a digital elevation model. The final spatial resolution of the RADARSAT-2 data is 25 by 25 m^2.

3.3. Supervised classification

A supervised classification was carried out using Support Vector Machine (SVM). This is a standard classifier that was considered the best option when the amount of training data is limited [8]. In this case, the SVM is based on the Gaussian Radial Basis Function (RBF) kernel from the e1071 package [9] implemented in the R language [10]. The input data set was made up of the 65 polarimetric decomposition parameters that were stacked and scaled to a range of 0–1. The characterizations of selected field sites from Fildes Peninsula were used as reference to choose the most representative surface covers to train the SVM classifier. For each class, between 9 and 16 training sites were selected for the supervised classification.

4. RESULTS AND DISCUSSION

A total of six classes were defined to map the surface covers within the ice-free areas of King George Island (Figure 3). This is based on field data obtained from Fildes Peninsula, a representative and accessible ice-free area and extrapolated to a wider region accounting for inaccessible smaller areas on the coastal fringe of the island using polarimetric SAR data and techniques.

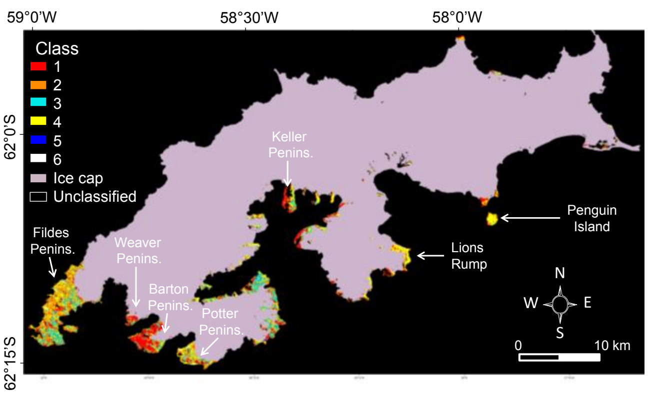

Figure 3. Surface cover distribution within ice-free areas of King George Island (legend described in Table 2).

Typically, most of the surface covers are found on the largest ice-free areas such as Fildes Peninsula, Barton Peninsula and Potter Peninsula. However, smaller ice-free areas are significant even if they are more isolated. The most representative surface covers are class 1, 2 and 4, respectively (Table 2).

Table 2. Surface areas within the ice-free areas occupied by each class.

Class	Surface cover type	Ice-free area (km^2)	(%)
1	Rock out crops, glacial till deposits	21.0	25
2	Stone field	21.6	25
3	Patterned ground	16.0	19
4	Sand, fine gravel	25.1	30
5	Lakes and flooded regions	0.5	1
6	Ice and snow cover	1.0	1
	Total	**85.2**	**100**

The surface cover classes 1-4 are related with principal geomorphological characteristics, topography and physical properties such as texture and structure. These individual surface covers have different physical structures influencing the backscattering of the electromagnetic radiation received by the SAR sensor. Variations in their size, surface structure (smooth or rough), a possible influence of a sparse to a moderate vegetation cover, and the environmental conditions at the time of the data acquisition are all factors that will influence the final backscattering signal. Therefore different levels of entropy and anisotropy, and scattering mechanisms (SM), such as surface, volume and multiple scattering, can be associated to the different surface covers.

The surfaces such as rock outcrops and glacial till (class 1), lakes and flooded regions, and ice and snow cover (classes 5 and 6) have well defined scattering mechanisms and make their identification in most cases straight forward.

The rock outcrops and glacial till deposits (class 1) have abrupt changes in the form of cliffs, big blocks separated with depressions and steep slopes (> 30%). Varying rock size and exposed rock surfaces with debris slopes at the foot slope and moraine sediment lead to medium and high entropy with volume and multiple (SM).

Stone fields (class 2) are found on slightly sloping to undulating terrain (2-8%). These are fractured rocks with a low entropy and anisotropy with surface SM.

Patterned ground (class 3) are on flat or undulating terrain with a maximum slope of <30%. The geometric (polygons or circles) figures with 1 to 3 m diameter, a sorted distribution and clasts up to about 30 cm show a high entropy and low anisotropy with random SM. These surface features indicate presence of permafrost and an active layer.

Sand and fine gravel deposits are related to present day and Holocene raised beaches as well as colluvium deposits on slopes and material accumulated in flat and in depression areas. The deposits consist of coarse sediments to rounded pebble sized stones. A low to medium entropy and high anisotropy is observed with surface and volume SM.

Lakes and flooded regions (class 5) are flat and smooth surfaces with a low entropy and surface SM. However, in windy conditions, this surface is unstable.

Ice and snow cover within the ice-free areas (class 6) is a flat or undulating surface on a maximum slope of <30%. They have a smooth surface, but are season dependent and contain low to medium entropy and surface SM.

Considering the sensor characteristics and spatial resolution, preliminary satisfactory results were obtained to map complex geomorphological features such as periglacial landforms. This was initially tested for the area of Fildes Peninsula where satisfactory results were obtained as shown in previous work [4]. However, for the wider area the ground information and other ancillary sources are considered limited, at this moment, to carry out a robust validation. In this case, characterizing and monitoring the distribution of these landforms is useful as they are often an indicator of the presence of permafrost and related to hydrological processes that are affected by ongoing processes associated to climate change.

5. CONCLUSIONS

Characterizing ice-free areas is considered important within a highly dynamic area such as the Antarctic Peninsula region where meteorological conditions are adverse and where, due to the dispersion of the ice-free surfaces, direct accessibility in the field is often limited. Therefore, using fully polarimetric RADARSAT-2 data and advanced SAR remote sensing techniques proved to be successful for mapping complex surface landforms. Extrapolation of the results to other ice-free areas on King George Island were satisfactorily carried out using the method in this work. However, site specific information is considered important when working with remotely sensed data taking into account environmental conditions. It is considered important to establish a method that facilitates comparing past and future results and monitoring areas affected by changing environmental factors and increasing direct and indirect human induced activities.

6. ACKNOWLEDGMENTS

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