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Monitoring snow parameters on the Antarctic Peninsula using satellite data - a new methodological approach -

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THE SITUATION

- The properties of glaciers on the Antarctic Peninsula are closely linked to local and regional climatic and meteorological settings.
- Their variations are well suited indicators of climatic change.
- Recent investigations on regional patterns and trends of glacial properties are based on few glaciers, only, and, as a consequence, the results are not statistically significant.

THE NEED

- The analysis of glacier properties needs a statistical approach.

THE SOLUTION

- The centerline approach is based on a great number of remote sensing data which are processed semi-automatically.

THE CENTRELINE APPROACH

A statistically representative number of glaciers on the Antarctic Peninsula is to be investigated. To optimise the processing of a huge number of remote sensing data, it is proposed to restrict the image analysis to areas covering only the glacier centrelines. The use of **centreline images** is evident to **minimize the difficulties** generated by shadowed illumination and saturated pixels occurring in areas with stepped terrain. Furthermore, the central part of the glacier is less affected by radar geometric distortions (e.g., shadowing, layover, foreshortening).

Glacier centrelines are lines following the main flow line of the glaciers (Figure 1). Masks of 600 m width centred along glacier centrelines are systematically created to be analysed.

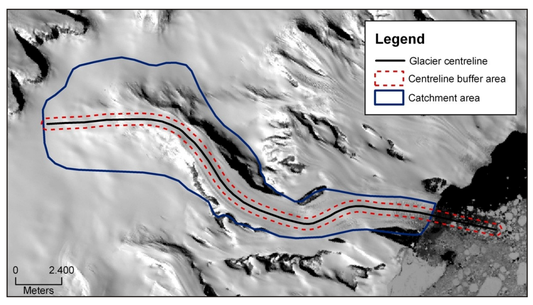

Figure 1 - Example of glacier centreline as were digitised on glaciers on the Antarctic Peninsula. The dashed line in red represents the area (600 m width) used in the image analysis.

RELATIONAL GLACIER DATABASE

To manage metadata and results of image analyses a relational glacier **database** was implemented. The designed table structure is **compatible** with the database of **the international project Global Land Ice Measurements from Space** (GLIMS). The prototype database has been implemented on the open source MySQL and the development of a geodatabase version is being tested.

GLACIER ZONES

Satellite imagery can be used to identify distinct zones on a glacier. However, these **zones develop and change location in time** and are therefore not always identical with glacier zones as described by Paterson (1994). Figure 2 shows the relation between the glacier zones described by Paterson (1994), and both classification schemes used in this study: (1) radar glacier zones as proposed by Rau et al. (2000) and (2) superficial zones interpreted from optical data.

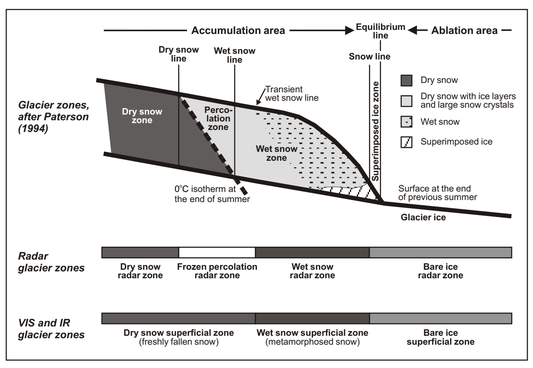

Figure 2 - Glacier snow zones as described by Paterson, and both classification schemes used in this study: (1) radar glacier zones as proposed by Rau et al., 2000 and (2) superficial zones interpreted from optical data. Modified after Rau el al. (2000).

SEMI-AUTOMATIC EXTRACTION OF GLACIER ZONES FROM OPTICAL DATA

The characteristics of snow and ice reflectance and the knowledge of glaciers on the Antarctic Peninsula were used in order to build the best knowledge base to be used as an operational routine to derive glacier parameters on that area.

The semi-automatic procedure is composed by two steps:
(1) raster analysis of the images, or classification (Figure 3);
(2) extraction of the data (e.g., glacier front, snow line and dry snow line) and integration into the database.

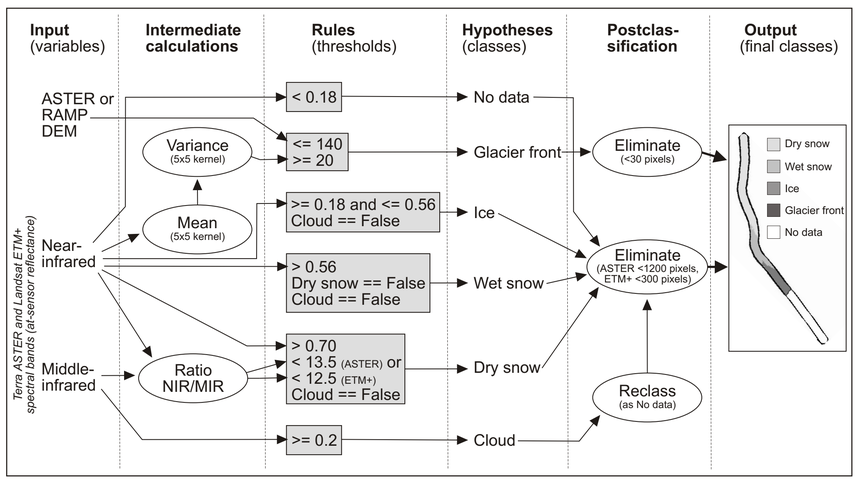

Figure 3 - Design of the knowledge base developed to classify the centreline images. The first column shows the data necessary to calculate the intermediate products in the second column or to apply the rules in the third to develop final classes in the last column.

Step 1 - Classification

The **centreline images are classified** in five classes: no data, glacier front, bare ice, wet snow and dry snow. A cloud mask is applied as well and clouds reclassified as no data.

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To identify the distinct classes automatically, **texture analysis** based on first-order statistics in the spatial domain is used, as well as **image ratio** and **threshold techniques**.

Step 2 - Extraction of the data to the database

Along the glacier centreline, which has a spatial resolution of 15 m, the **positions of class boundaries** are **extracted to vector files**. Points in each vector file are numerated by sequential identifier numbers (IDs) starting from the sea to the upper part of the glacier. In order to avoid iceberg borders or sea ice boundaries to be classified as glacier front, the greatest ID holding this class is selected as the glacier front position. Following, the algorithm selects the first point with the classes wet snow and dry snow to classify as snow line and superficial dry snow line respectively. The selected points are automatically exported as point features **and ingested to the database.**

VALIDATION

Snow line

To evaluate the determination of the snow/firn line with a threshold in the NIR reflectance of optical data, two **ASTER** scenes acquired on the same day as an **ERS-2 SAR** image (18 January 2002) were used.

The threshold values of backscatter coefficients (s° between -16 and -14 db) found by Braun and Rau (2000) and Rau et al. (2000) were used on the SAR image (Figure 4a and 4c) in order to determinate the **snow/firn line**. These lines are **in good agreement** with the snow lines derived from ASTER data by means of a threshold value (Figure 4b and 4d).

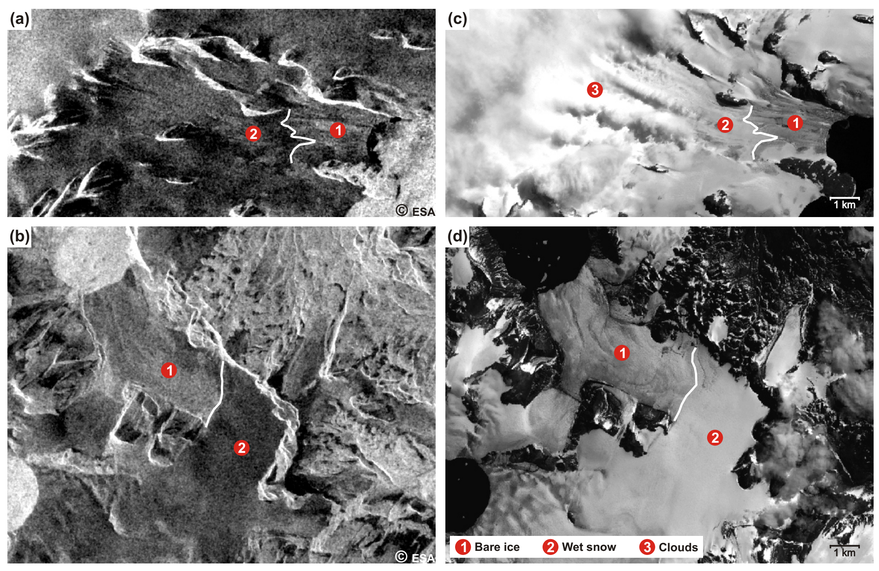

Figure 4 - Comparison of the position of the snow line derived from RADAR and optical data.
(a, b) Subsets of an ERS-2 SAR image showing the snow/firn line (in white) on Russell East Glacier (upper image) and the glacier JRI_125 (lower image) as determined using the thresholds proposed by Braun and Rau (2000) and Rau et al. (2000).
(C, d) Subsets of two ASTER images (NIR band) showing the snow/firn line as determined by this work. All images were acquired on 18 January 2002.

Dry snow line

In order to evaluate the procedures used to **differentiate dry snow from wet snow**, products of the NIR/MIR ratio from **ASTER** and **ETM+** images were compared with **MODIS** images acquired in the same day. The sensor MODIS onboard the satellite Terra has a spectral band between 1.23 and 1.25 µm. As in these wavelengths occurs the largest sensitivity of snow reflectance to grain size, it allows the unambiguous detection of snow zones in different stages of metamorphism. Figure 5 shows the identification of snow zones on James Ross Island and Caley Glacier, Danco Coast, and the corresponding zones identified in the MODIS images (Figure 5c and 5f). Both techniques lead to **corresponding results.**

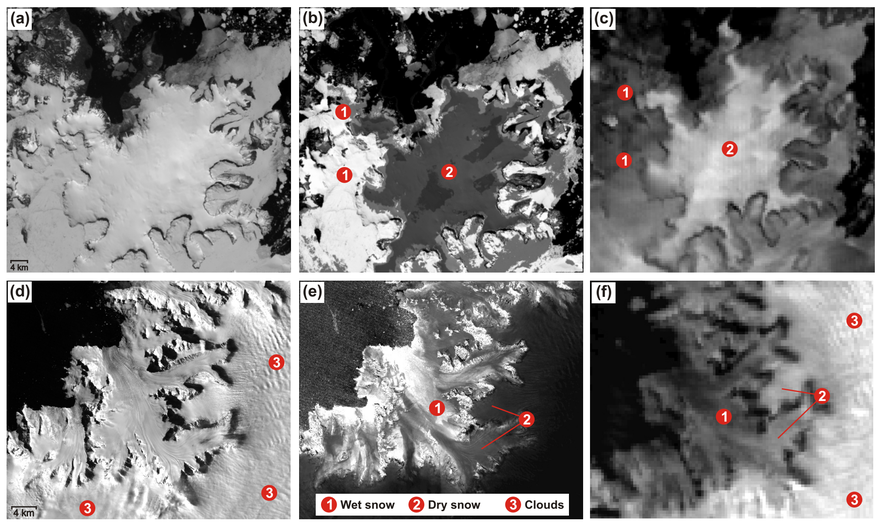

Figure 5 - Comparison of three types of images used for the identification of snow zones.
(a) NIR band of ASTER image on James Ross Island.
(b) NIR/MIR ratio image from ASTER.
(c) Spectral band of MODIS between 1.23 and 1.25 µm.
(d) NIR band of ETM+ on Caley Glacier, Danco Coast.
(e) NIR/MIR ratio image from ETM+.
(F) Spectral band of MODIS between 1.23 and 1.25 µm.

PRELIMINARY RESULTS

- 66 glaciers have been analysed using 3 Landsat ETM+ and 10 Terra ASTER images acquired on six different dates between February 2000 and December 2002.
- 213 analyses on centreline images were done.

Table 1 - Descritive statistics of the glacier parameters ingested in the database.

Number of analyses per glacier	Glaciers analysed	Glacier parameters extracted		
		Glacier front	Snow line	Dry snow line
2	20	40	40	28
3	19	57	56	53
4	19	76	74	51
5	8	40	40	26
Total	66	213	210	158

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