# 4D VISUALISATION OF GEORGE VI ICE SHELF USING RADAR BACKSCATTERING COEFFICIENT $\sigma_0$

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## Abstract

The interpretation of any kind of data is a fundamental task, which has to be facilitated by a representative visualisation. Numbers and/or text are used in general to represent large n-dimensional datasets of raw data. This results in the difficulty that desired information and existing relations between data couples are not accessible in an intuitive manner. Therefore every visualisation aims to integrate higher dimensional data into a representation and to provide given coherences.

Remote sensing, which is a powerful tool for monitoring usually uses sensors working in passive mode. This means that data obtained from such observations can be interpreted very easily due to their close relation to natural phenomena such as thermal or reflected visible radiation. However, active sensors, which also play an important role in remote sensing, do not allow such a straightforward interpretation. In the present case which makes use of data gathered by a space borne Radar sensor, this task is much more complex due to the special characteristics of the observation method itself.

The retreat of ice shelves on the Antarctic Peninsula has been observed over the past decades. Especially George VI ice shelf has been reported to be close to its thermal limit of stability. So if this prediction is correct the ice shelf is in its pre-collapse phase that has to be monitored, visualised and analysed to understand its present behaviour.

Such variations can be identified by the use of the normalized backscattering coefficient $\sigma_0$. Backscattering itself depends on specific surface and subsurface properties, such as roughness and dielectricity, of the target area. Therefore areas that are covered by a wide variety of types of snow hence possess different dielectric constant. C-band observations can be used to analyse these circumstances and permit to differentiate for example wet and dry snow. So a study of the mass balance can be realized with the aim to identify and determine accumulation and ablation processes.

This paper describes a simple, but quite clear and accessible, 4D visualisation approach on the basis of ASAR WSM time series, which allows the analysis of snow, and ice variations of the northern ice front of George VI Ice Shelf.

The observations are firstly radiometrically corrected, despeckled, geocoded and a subset of the entire dataset is created. Finally, concerning the image processing steps, the subset is exported with the aim to get readable by the visualisation software.

Within the visualisation process, latitude and longitude information of the target area is assigned to the x and y plane, while the z value expresses $\sigma_0$. The fourth dimension t is obtained from the acquisition time of the observations. In this way each individual visualisation in 3D in the xyz space of an observation acquired at a specific moment t is primary used for classification purposes, while the combination of all observations made in the period between $t_0$ and $t_n$ allows to detect changes in the ice and snow distribution. Therefore, the final step consists in the generation of a 4D representation showing the behaviour of the area of interest, augmented by additional information to facilitate its analysis and interpretation.

Finally it is noteworthy that all software applied, for processing and visualisation issues, within this study and as well the images used are available free of cost without any exception. So an economic solution has been realised. It fulfils most of the needs for an accurate and comprehensible visualisation of complex, higher dimensional and large datasets.

## I Introduction

Embedded in George VI Sound and flanked by glaciers of Alexander Island to the west and Palmer Land to the east, George VI Ice Shelf is the largest Ice Shelf on the west coast of the Antarctic Peninsula (AP). The northern front (70°S 69°W) is limited by Marguerite Bay, while the southern (73°S 71°W) faces Ronne Entrance (see Figure 1). The Ice Shelf fills most of the Sound that has a length of approximately 500km and widens from 20km in the north to 70km in the south (Wager 1972).

George VI Ice Shelf has been reported by Vaughan & Doake (1996) to be close to its thermal limit of stability. Although until now no significant changes has been reported it is critical to take the opportunity to monitor this phase. Thorough studies have to been initiated to understand the ongoing changes of the Ice Shelf and the causes inducing them.

Its geographic location and the fact that it looses most of its mass due to melting rather than Iceberg calving (British Antarctic Survey 2008) makes it that interesting for investigation. It is suggested that George VI Ice Shelf may be most sensitive to ocean condition changes and therefore less sensitive than other Ice Shelves surrounding the AP to atmospheric changes.

Various studies of glacial Holocene history of George VI Sound and Marguerite Bay have been realized recently (Bentley et al. (2005), Smith et al. (2007), Roberts et al. (2008)). They all come to the result that Ice Shelf retreat has happened before and that absence of George VI Ice Shelf has occurred twice in Holocene period. Smith et al. (2007) conclude that two fundamental facts can be derived from their research:

1) The retreat of the Ice Shelf was a progress from north to south over several thousand years.

2) Early Holocene Ice Shelf retreat coincides with atmospheric and oceanic warming.

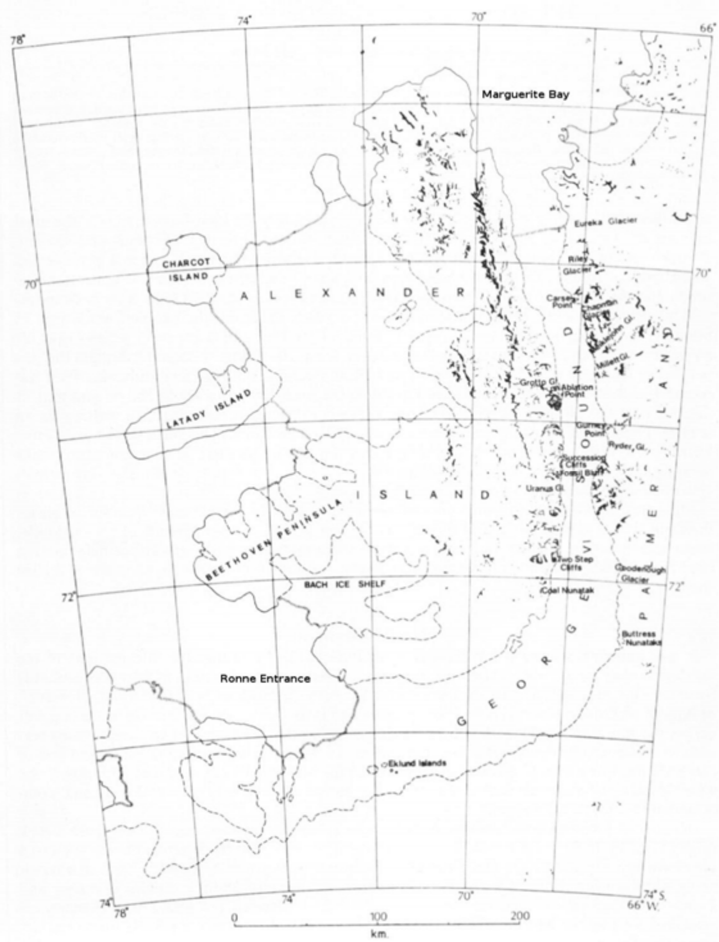



**Figure 1: Map of George VI Sound and Alexander Island**

SAR (Synthetic Aperture Radar) images represent the energy that was reflected back from an object to the sensor. The so-called backscattering coefficient $\sigma_0$ is expressed in dB and represents the strength of the reflected Radar signal. It varies with the incidence angle, wavelength, polarisation and the properties of the scattering surface itself. In Radar images brighter areas represent high backscatter, while darker ones represent low backscatter. Bright means that a large portion of energy has been reflected back to the emitting sensor, thus dark means that only little energy was reflected back. Flat surfaces like oceans and lakes always will appear dark in Radar images because they tend to a specular reflection of the Radar signals. Therefore rough surfaces will appear in general much brighter due to diffuse reflection of the signals.

## II 3D Visualisation approach

This paper describes an approach that aims to make use of these Radar specific properties and in consequence allows analysing George VI northern Ice Shelf front behaviours by a descriptive visualisation.

First of all an adequate representation of the ASAR Wide Swath Medium Resolution

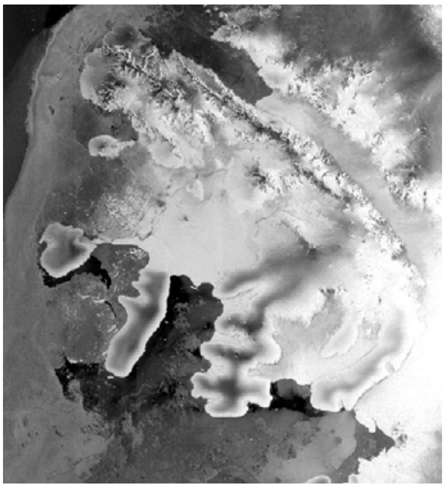


**Figure 2: ASAR image (corrected and de-speckled) of Alexander Island and George VI Sound taken on 22.11.2008**

Images (standard product for data that is collected while the ASAR instrument is in Wide Swath Mode) has to be found. This means that the $\sigma_0$ data has to be visualised in space and over time. One common solution is to define a Look-Up-Table and to assign specific gray value entries to each data value. This leads to a typical, almost visual, 2D data representation. Figure 2 shows a result of such visualisation using the Next ESA SAR Toolbox (NEST). Clearly visible are Alexander, Charcot and Latady Island as well as George VI Sound. Furthermore a first visual interpretation can be carried out to identify areas covered by water and ice. Because of backscatter characteristics, visualised here using grey-levels, dark areas represent water, while brighter areas represent ice (Sea ice, Pack ice, Ice Shelf). Specific pixel information like $\sigma_0$ which has been calculated during correction of the Level 1 data or spatial location found in the Metadata of the observation, can be queried by Mouseover events.

However in order to enhance understanding of scientific data a visual representation has to be achieved that allows interactivity and in case of geospatial data is visualised in 3D. Therefore ParaView, an Open Source Scientific Visualization Application, is used within this study. This software offers a large variety of visualisation and rendering capabilities.

To realise the proposed visualisation approach, this study makes use of the following assignments to a right-handed Cartesian coordinate system for a three-dimensional space:

- x-axis: Longitude $\phi$
- y-axis: Latitude $\lambda$
- z-axis: Backscatter coefficient $\sigma_0$

So every pixel is represented by a data triple ($\phi$, $\lambda$, $\sigma_0$) forming at first a spatial point cloud. This allows the generation of a digital terrain model whereas the z-value corresponds to the backscatter coefficient expressed in dB. $\sigma_0$ of areas covered by ice and snow is larger than for areas covered by water and therefore appear elevated in space. Such visualisation is adequate to analyse and describe ice, snow and water distribution in the research area.

The major advantages of such an approach are that spatial correlations of geospatial data are maintained (xy plane formed by geographic coordinates) and that interpretation of $\sigma_0$ and therefore analysis of the current situation are facilitated.

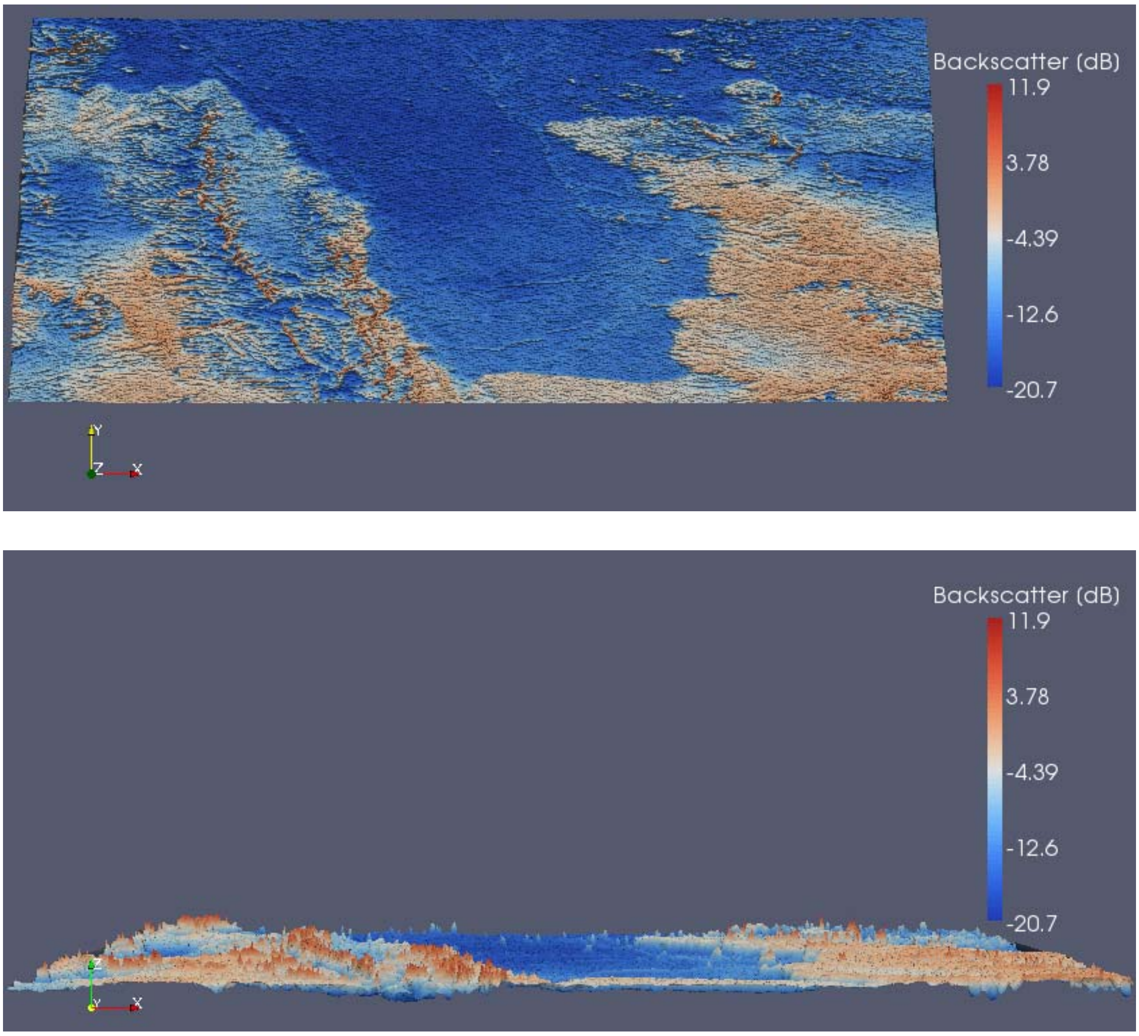



**Figure 3: ASAR image (corrected, de-speckled and georeferenced) of Alexander Island and George VI Sound taken on 22.11.2008 visualised in ParaView. View in z-direction (upper) and y-direction (lower)**

Figure 3 shows an example of an ASAR image subset (George VI northern Ice Shelf front) that has been corrected, de-speckled and finally georeferenced using NEST software. The scene has been rendered and visualised in ParaView. As in figure 2 ice and water can be distinguished from each other and the coastlines of Alexander Island and Palmer Land are clearly visible. The backscatter coefficient is now colour-coded; a solution that enhances not only significantly the visual impression of the scene but also permits its easy interpretation. Furthermore the 3D representation allows to navigate within the scene and to perceive a first impression of the topography, even though it is not a true height representation of the area. In consequence it is now possible to estimate ice distribution and characteristics in the investigation area. Wet snow, as well as water, has a significantly lower backscatter as dry snow and ice covered areas.

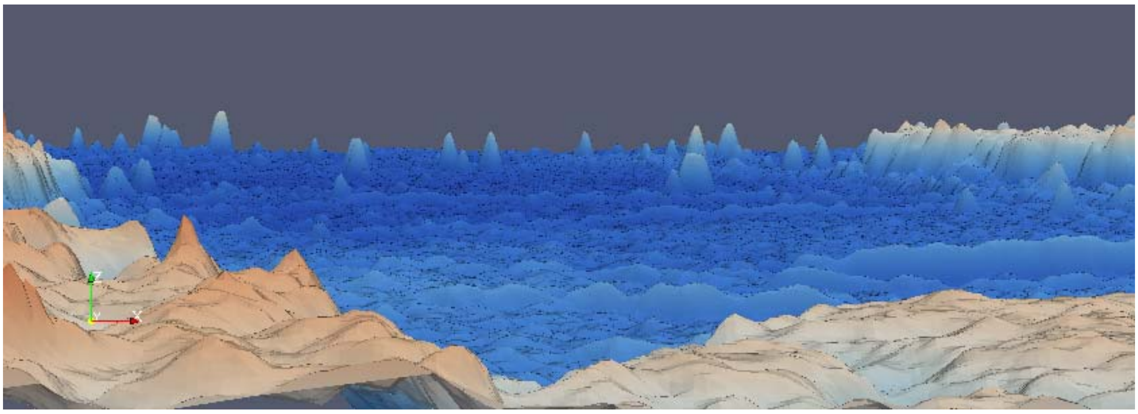


**Figure 4: 3D View of George VI Sound seen from George VI Ice Shelf**

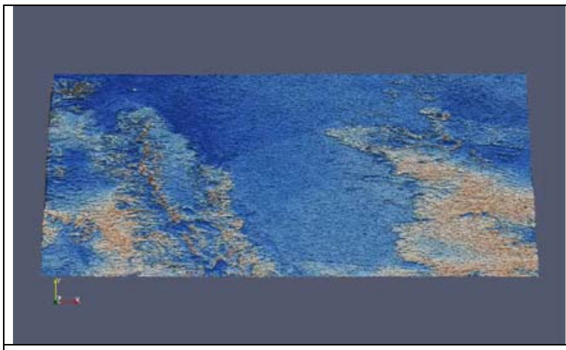
Coastal zone of Alexander Island is covered mainly be wet snow and only some areas by ice. On the contrary Palmer Land is almost completely ice covered. Furthermore the northern most zone of George VI Ice Shelf consists of pack ice and a clearly noticeable division (figure 4) from the main Ice Shelf.

## III 4D Experimental Results

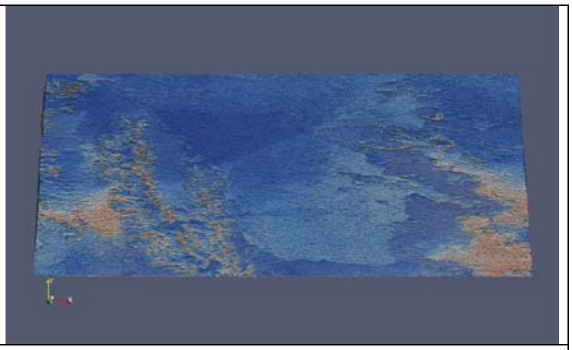
The fourth dimension, which is necessary to describe changes in ice and water distribution in the area of interest over a specific period of time, is represented by the respective acquisition moment of each $\sigma_0$. In general it has to be considered that Envisat orbits the earth with a repeat cycle of 35 days. However NEST allows applying ASAR calibration to provide true backscatter of the reflecting surface. The results permit comparison of observations acquired at different times. In consequence a better temporal interpolation for change detection can be achieved using observations acquired at a much shorter time interval.
A first approach makes use of a simple overlay of data whereas visibility is controlled by transparency. The advantage is that by visual interpretation changes in snow and ice distribution are easily determinable. Visualisation by transparency is useful to realise a kind of interpolation between the observations. That way comparison of two images and therefore their analysis facilitate.

Figure 5 shows an example using transparency. The sequence is made from observations acquired on December 18, 2008, January 22, 2009 and February 26, 2009. These three observations have been chosen according to the repeat cycle of Envisat. Images shown in Figure 5 (b) and (d) have been generated using 50% of transparency for each of the two source images, while images in Figure 5 (a), (c) and (e) are visualisations of the respective images at the mentioned observation time.

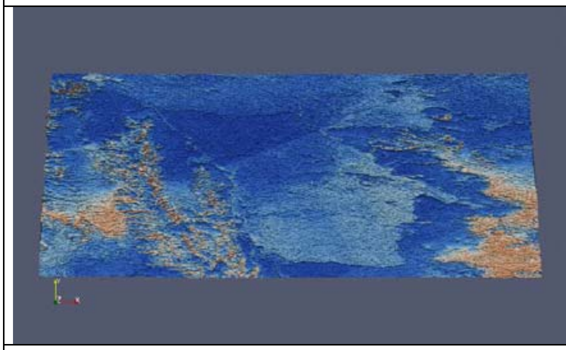
As a result, changes in snow and ice distribution in Marguerite Bay and George VI Sound can be detected. On December 18, 2008 the Bay is completely covered by ice and snow. Subsequent images show that this has changed and large areas covered by



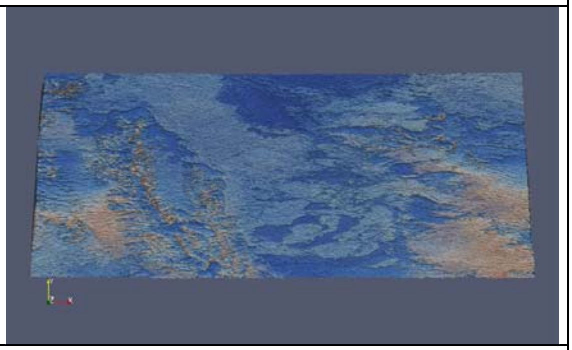
**(a) December 18, 2008**



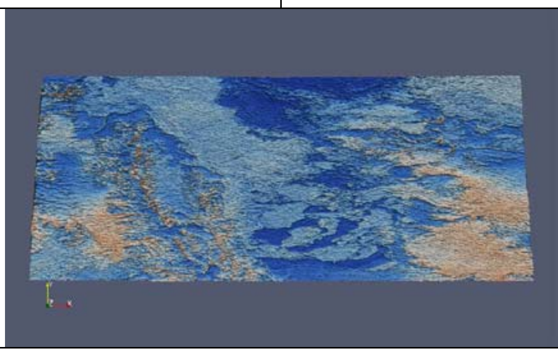
**(b) December 18, 2008 and January 22, 2009**



**(c) January 22, 2009**



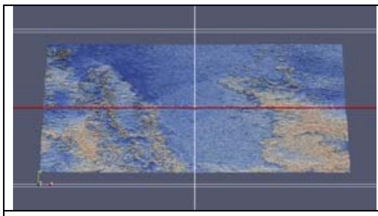
**(d) January 22, 2009 and February 26, 2009**



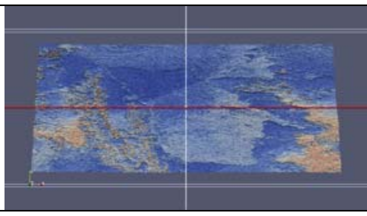
**(e) February 26, 2009**

water are getting visible. This process started at the coasts of Alexander Island and Palmer Land and led to the creation of water accumulation at the northernmost extent of George VI Sound. Snow and ice distribution at coastal zone of Alexander Island is almost unchanged. Only small variations are detectable. However Palmer Land undergoes some significant changes between December 18, 2008 and February 26, 2009. The ongoing reduction of snow-covered area is observable and only some of them are recovered until February 26, 2009.

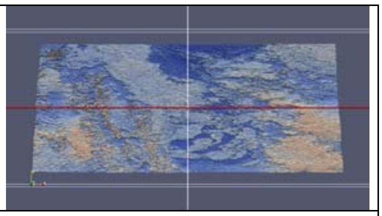
**Figure 5: Image sequence of ASAR WSM observations (December 18, 2008 – February 26,2009)**



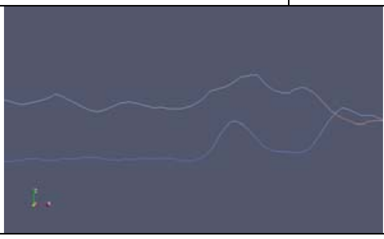
**(a) December 18, 2008**



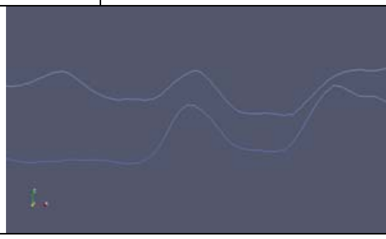
**(b) January 22, 2009**



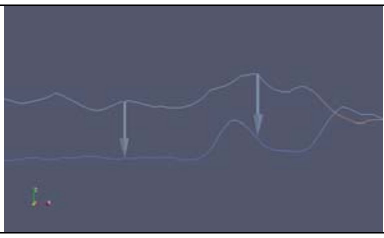
**(c) February 26, 2009**



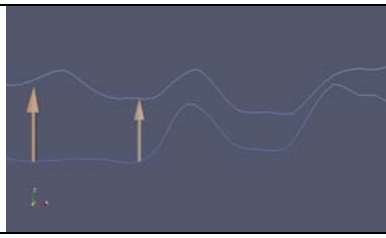
**(d) December 18, 2008 and January 22, 2009**



**(e) January 22, 2009 and February 26, 2009**



**(f) December 18, 2008 and January 22, 2009**



**(g) January 22, 2009 and February 26, 2009**

**Figure 6: Slices of ASAR WSM observations between December 18, 2008 and February 26, 2009**

The generation of slices is another possible solution that helps to detect and analyse changes in more detail. Figure 6 shows an example. As in figure 5 observations have been chosen according to Envisat's repeat cycle. For each image one slice has been generated in y direction (Latitude component), figures 6 (a), (b) and (c). Slices of consecutive observations have been overlaid for coastal zone of Alexander Island, detailed view in figures 6 (d) and (e), to visualise changes. For analyses purposes glyphs have been added showing the magnitude of temporal variations, figures 6 (f) and (g). As already mentioned, the coastal zone of Alexander Island undergoes only slight changes as it now can be proven by slice and glyph comparison.

## IV Discussion

Transparency, slices and glyphs are powerful 4D visualisation tools for change detection. With their help visual interpretation and quantification of variations can be started. Snow, ice and water distribution in George VI Sound and its surrounding area are detectable using backscatter coefficient $\sigma_0$ as height representation. Although medium spatial resolution observations from ASAR WSM are used for this task spatial distribution and temporal variations can be clearly detected. Observations acquired in ASAR WSM have great potential in both 3D and 4D visualisation and the study of Ice Shelf behaviour.

In this first approach the necessity for a descriptive 4D visualisation has been identified primarily due to Envisat's repeat cycle of 35 days. This interval for repetitive observations does not allow for example to determine a specific date which indicates both, end of snow retreat and start of its recovering.

## V Future work

- A permanent Ice Shelf monitoring is required to detect and to understand ongoing variations.
- Visualisation of the whole George VI Ice Shelf has to be realised to determine its behaviour throughout its spatial extent.
- Further studies have to clarify the causes of snow and ice variations in the study area. Therefore, as a next step Sea Surface Temperature observations will be used to investigate the correlation between temperature changes and George VI Ice Shelf front variations.

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