SPATIAL AND TEMPORAL VARIABILITY IN MASS BALANCE OF GLACIERS IN SVALBARD AND GREENLAND USING PALSAR

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1. INTRODUCTION

The majority of eustatic sea level rise over the next century will be due to changes in small glaciers and ice caps. It is therefore important to understand the changes taking place in glaciated regions in such a way that the rate of sea level rise can be predicted. Glaciers respond to long-term and more recent climate change not just in their surface mass balance and rate of melt, but also in their dynamics. A key component in understanding and predicting changes in the cryosphere is therefore the flow rate of glaciers.

Glacier flow rates may be measured in situ, but it is very difficult to achieve an appropriate rate of spatial or temporal sampling. In recent years, techniques of feature, speckle and coherence tracking have allowed a remote sensing approach to measuring the changes in flow rate. Synthetic Aperture Radar is particularly suited to such techniques because of the available spatial resolution, its independence to cloud cover, the consistency of the illumination, and the ability to image all-year-round, where polar night normally prevents optical data from being available at polar latitudes.

In the project we assess the use of ALOS PALSAR data in various imaging modes in measuring glacier flow rates in the Arctic. Svalbard is chosen as a suitable study area for its accessibility and for the wealth of other data available for key glaciers. We present results for a number of glaciers and consider the performance of PALSAR data against ERS SAR data.

2. STUDY AREA, SVALBARD

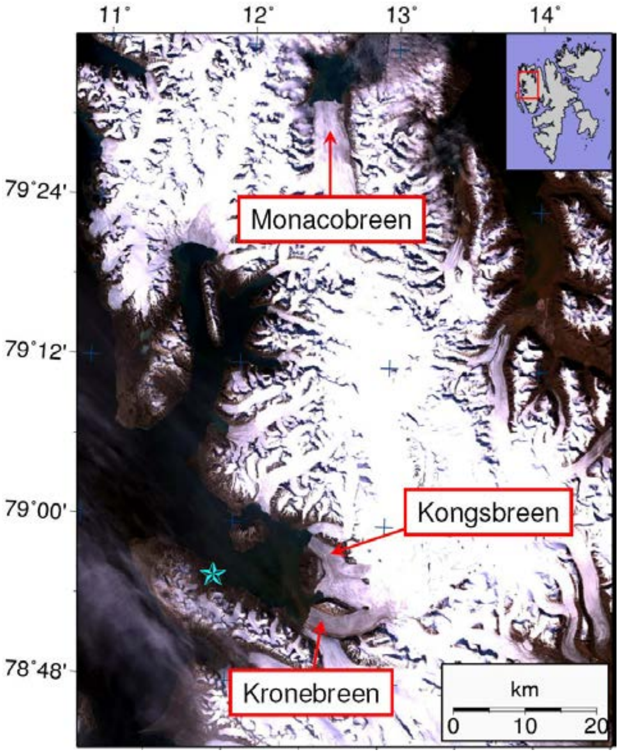
The Svalbard Archipelago is situated between 76-81° N and 10-35° E. Glaciers and ice caps cover 36,600 km^2 of the archipelago. The remaining 40% of land is in permafrost [Engeset, 2002, Dowdeswell, 2004]. The largest of the 4 main islands is called Spitsbergen and there are around 150 smaller islands. Austfonna on Nordaustlandet in eastern Svalbard is the largest ice cap in the Eurasian Arctic at 8120 km^2 and 1900 km^3 [Dowdeswell, 2004].

Most Svalbard glaciers are polythermal, commonly with subzero temperatures in the surface layer of the ablation area, and temperatures at the pressure melting point (PMP) in the accumulation zone [Engeset, 2002]. An important component of mass balance from Svalbard is through iceberg calving [Dowdeswell, 2004]. There are over 1000 km of sea-ice cliffs around Svalbard with an average thickness of 100 m, all of which have grounded margins.

This study focuses on three tidewater-terminating glaciers in northwest Svalbard; namely Monacobreen, Kongsbreen and Kronebreen. The locations of the glaciers investigated in this study are shown in Fig. 1.

2.1. Monacobreen

Monacobreen, (79° 24'N, 12° 34'E) is a surge-type glacier approximately 40 km long and flows north from Isachsenfonna icecap into Liefdefjorden. Monacobreen surged in the early 1990's (Luckman, 2002). Peak flow during the active surge phase is thought to have occurred in January 1994, shown by the two-fold increase of velocities from 1992 (Strozzi and others, 2002; Luckman and others, 2002).



1. Location of the three tidewater-terminating glaciers under investigation. The insert shows the location within Svalbard. The blue star shows Ny-Ålesund research centre. The underlying image is a Landsat 7 scene from July 1999.

2.2. Kongsbreen

Kongsbreen (78° 58'N, 12° 31' E) flows northwest into Kongsfjorden and is reported to be the most active calving glacier in Svalbard (Lefauconnier, 1994).

2.3. Kronebreen

Kronebreen (78° 49'N, 13° 19'E) has an area of ~530 km^2 draining the icefields icefields Dovrebreen, Holtedahlfonna and parts of Isachsenfonna (Sund, 2011). As a consequence of the large accumulation area draining through a narrow channel, Kronebreen has one of the continuously highest velocities measured in Svalbard (Liestøl, 1988). Velocities from Kronebreen have been measured over many time-scales using many methods. However few measurements have been made of velocity variations near the ice-cliff terminus.

3. DATA

3.1 ALOS PALSAR

All of the available 46-day pairs of Fine Beam Single Polarisation (FBS) and Fine Beam Dual Polarisation (FBD) ALOS PALSAR images which covered the three glaciers in this study were downloaded and unpacked using Gamma software. Fig. 2 shows the track, frame, orientation and location of the scenes used.

Table 1. provides details of all the ALOS PALSAR scenes ordered. After unpacking and calibration, sub-sets of the data were selected to cover Monacobreen, abd a subset including both Kronebreen and Kongsbreen glaciers.

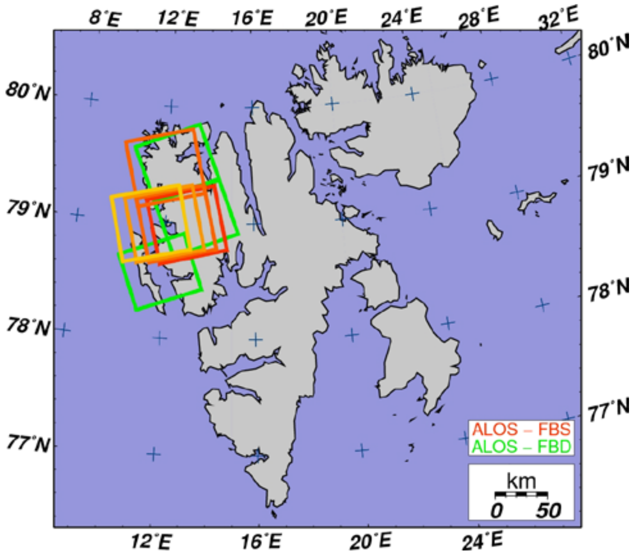


Fig. 2 46-day pairs used in this study from JAXA ALOS PALSAR. The red / orange shows the FBS tracks and frames, the green shows the track and frames of the FBD mode.

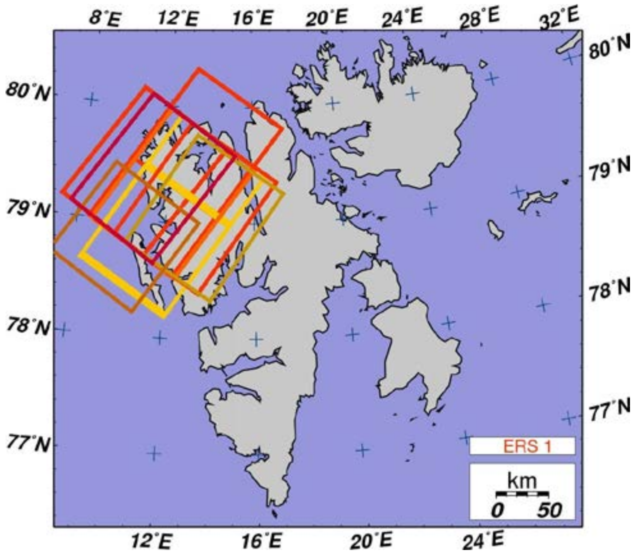


Fig. 3 35-day ERS-2 pairs used in this study.

Mode	Date	Track number	Frame number	Location
FBS	22/06/2006	616	1580	Kronebreen & Kongsbreen
FBS	07/08/2006	616	1580	Kronebreen & Kongsbreen
FBS	24/05/2006	617	1580	Kronebreen & Kongsbreen
FBS	09/07/2006	617	1580	Kronebreen & Kongsbreen
FBS	10/06/2006	618	1580	Kronebreen & Kongsbreen
FBS	26/07/2006	618	1580	Kronebreen & Kongsbreen
FBS	27/06/2006	619	1580	Kronebreen & Kongsbreen
FBS	12/08/2006	619	1580	Kronebreen & Kongsbreen
FBD	02/06/2008	601	1590	Kronebreen & Kongsbreen
FBD	18/07/2008	601	1590	Kronebreen & Kongsbreen
FBD	12/05/2009	605	1580	Kronebreen
FBD	27/06/2009	605	1580	Kronebreen
FBD	02/06/2008	601	1600	Monacobreen
FBD	18/07/2008	601	1600	Monacobreen

Table 1, the ALOS PALSAR scenes used in this study.

3.1 ERS 2

The ERS archive offers greater temporal coverage with a more complete archive of paired scenes from 35-day separation for ERS-2. Due to the greater temporal coverage a greater number of ERS scenes were used in this study. The track numbers, orientation, location and sensor are shown in Fig. 2.

4. METHOD

Glacier surface velocities were measured from ALOS PALSAR FBS and FBD image-pairs from 2006-2010 archived by Japanese Aerospace Exploration Agency (JAXA), and ERS-2 image-pairs from 2005-2010 archived by the European Space Agency (ESA). Glacier surface velocity was measured in both the slant-range and azimuth dimensions between repeat-pass satellite image pairs, by cross-correlating image patches in a process commonly referred to as feature tracking (Scambos and others, 1992; Strozzi and others, 2002). This technique has been widely used on tidewater outlet glaciers (e.g. Lucchitta and C. E. Rosanova, 1995; Luckman and Murray, 2005; Luckman and others, 2003, 2006), due to their heavily crevassed surface which provides unique features that can be tracked between repeat images.

The cross-correlation technique was developed for ERS and Envisat images, and has been modified to account for the different pixel spacing of ALOS PALSAR scenes. Low confidence correlations were discarded based on the strength of their signal-to-noise ratio, and also where the flow direction deviated significantly from the glacier flow line (Luckman and others, 2006). The resulting glacier surface velocity maps allow comparisons across multiple data types.

Errors from feature tracking arise from changes in the crevasse pattern through time and space, geometric transformations of the data, and errors in zero displacement reference points (Luckman and others, 2006). The errors are estimated to be below ±1 md^{-1} and were calculated by measuring the displacements of features which are assumed to be stationary such as rock-outcrops and nunataks. For a given zero velocity reference point the recorded displacement is therefore the error for that given image pair and surface velocity measurement. Multiple stationary features were selected, the apparent displacements of which were averaged for each image-pair to calculate the error.

5. RESULTS

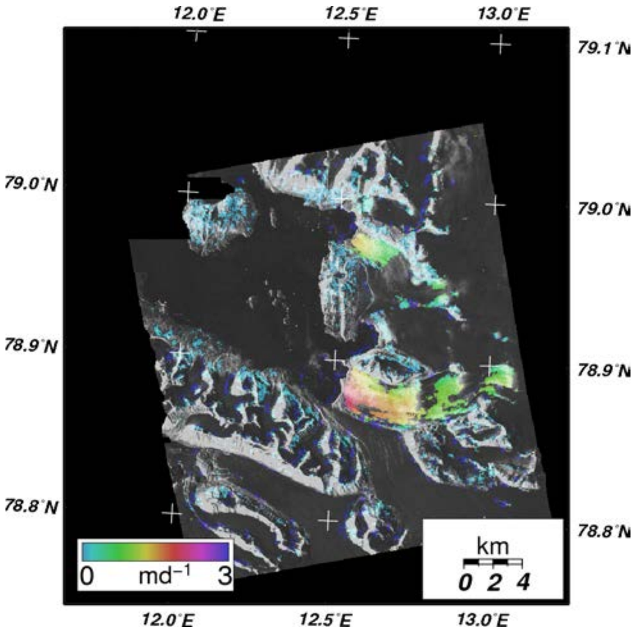


Figure 4. Ice surface velocity derived fro ALOS PALSAR FBS image-pairs track 619 frame 1580.

5.1. Glacier surface velocities from ALOS FBS and ERS -2 image-pairs

The quality of data from the single-pol (FBS) mode is high and the feature tracking techniques were successfully implemented on this data. The ALOS PALSAR data seems to be well suited to picking up surface features in fast flowing sections, and these can be tracked readily between 46-day repeat-pass pairs (Fig. 4 for Kronebreen and Konsgbreen). The improved across-track spatial resolution in comparison to ERS and Envisat SAR data is apparent in these data. Phase coherence is however very low for these data over the ice surfaces so SAR interferometry was not possible.

5.2. Glacier surface velocities from ALOS FBD scenes

Correlation feature tracking on the ALOS PALSAR FBD scenes with HH dual-polarization produced good coverage of surface velocity estimates. This can be directly compared to the result from the FBS scenes as the polarization, repeat cycle and wavelength are all consistent. The only difference being the time of acquisition and the resolution. The resolution of the FBD mode is not as good as the FBS mode. This is reflected in the spatial coverage of the velocity field produced which is not as complete as the FBS scenes. This coverage difference can is demonstrated by comparing Fig. 4 velocity map derived from FBS image-pairs with Fig. 5 velocity map derived from FBD image-pairs.

An example velocity map produced from ALOS ALSAR FBS scenes is shown in Fig. 5 for Kongsbreen and Kronebreen, and Fig. 6 for Monacobreen

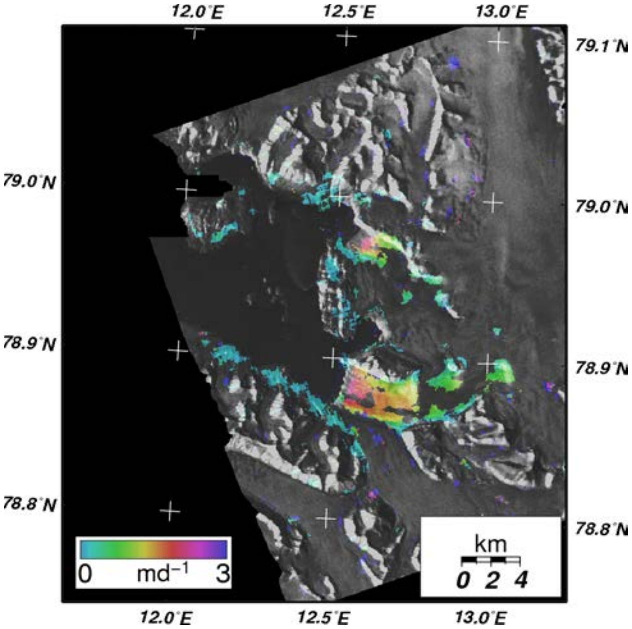


Figure 5. Ice surface velocity derived fro ALOS PALSAR FBD image-pairs track 601 frame 1590.

Feature tracking between the HV polarisation modes of FBD scenes did not produce worthwhile velocity estimates. This is most likely due to the reduced signal-to-noise ratio for this polarisation. Volume scattering dominates for this type of radar return and so surface features may not easily be identifiable in the image.

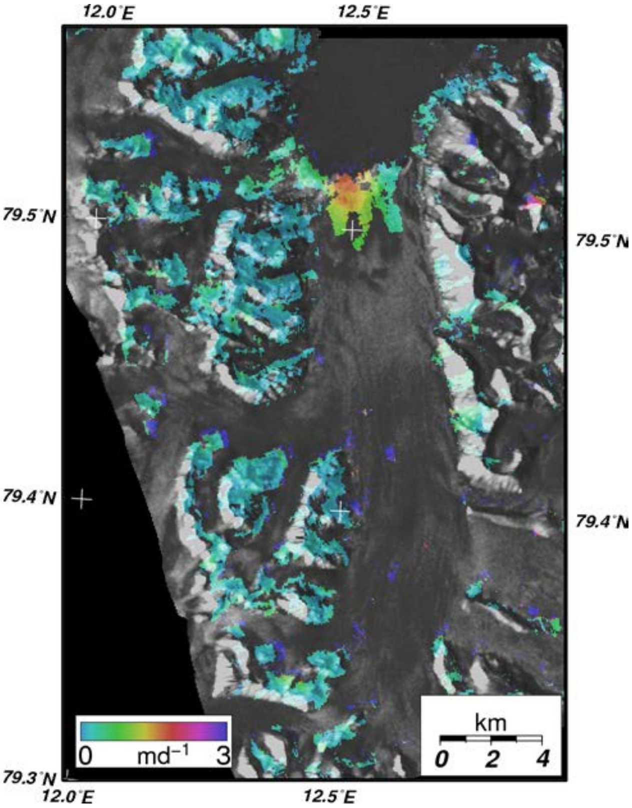
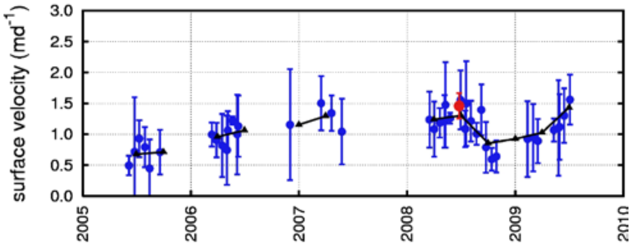
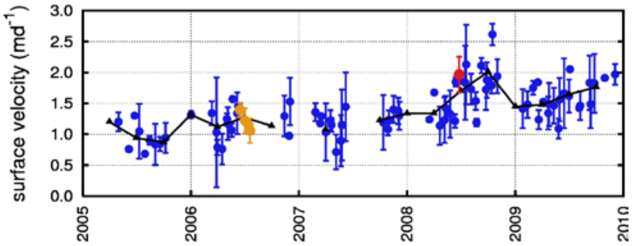


Figure 6. Ice surface velocity derived fro ALOS PALSAR FBD image-pairs track 601 frame 1600.

5.3. Velocity variations

The velocity time-series of the surface speeds extracted from the velocity maps of all the ERS, ALOS FBS and FBD image-pairs is shown in Fig. 7. The results show that velocities derived from ALOS PALSAR image-pairs closely match those derived from ERS image-pairs. The higher resolution of the ALOS scenes provides better spatial coverage of velocity maps making these scenes the most desirable for future investigations. However the lack of consistent image-pairs available makes investigations of ALOS PALSAR data very limited.


(a) Monacobreen


(b) Kongsbreen

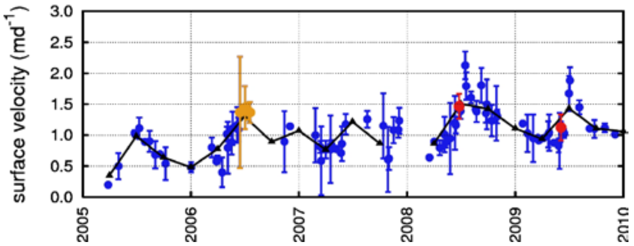

(c) Kronebreen

Figure 7. Surface velocity time-series for Monacobren (a), Kongsbreen (b) and Kronebreen (c). The blue circles indicate velocities from ERS-2 image-pairs, the orange circles are velocities from ALOS FBS image-pairs and the red circles are derived from ALOS FBD image-pairs. The red line is drawn through a seasonal average of the velocity values where there is sufficient temporal coverage.

6. CONCLUSIONS

In this study we have compared feature tracking between ALOS PALSAR images in FBS and FBD modes with a similar analysis of ERS data. It is clear that the quality of data is very high, both in terms of the radiometric parameters and the geometric processing of the images. Even with the longer repeat-period of PALSAR, the coverage of features tracking using PALSAR FBS is superior to ERS, probably because of the spatial resolution and the ability of the longer wavelength to achieve good contrast on the glacier surface features.

The main limitation of the PALSAR instrument is the availability of data. Monitoring of glacier velocities requires consistent repeat imaging or at least several repeat-pass image pairs per year. This has not been achieved by PALSAR, in contrast to the excellent archive of data acquired by ESA from sensors such as ERS SAR and Envisat ASAR, so the few velocity snapshots available from PALSAR are not enough to assess changes in velocity, at least where we have looked in Greenland and Svalbard.

In conclusion, although the acquisition strategy for PALSAR could be improved for glacier velocity monitoring, the quality of data has been shown to be very high and well suited to measuring glacier velocities using the feature tracking approach.

7. REFERENCES

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