SAR-INTERFEROMETRIC FLOW VELOCITIES OF TWO TIDEWATER GLACIERS IN NW SPITSBERGEN: METHODS AND RESULTS

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ABSTRACT

This paper presents the results of flow velocity studies of two large tidewater glaciers in Svalbard, Aavatsmarkbreen and Comfortlessbreen. This study is part of the international GECALVEX project and interferometric analysis have been performed thanks to ESA project CP1-1076. During the field campaigns of July 2000 and April 2001 the GPS data of flow velocities and elevation have been registered, using static and kinematic methods. Also the flow velocity for the glaciers have been calculated from SAR interferometric satellite measurements using both ascending and descending satellite passes. To calculate flow velocity field from ascending and descending observations, a precise topographic information was required. As input data, the glacier slope and flow direction (this only in a case of calculations with single pass) must be known to a high level of accuracy. To prepare such data and to reduce the effect of topography on the interferogram the 20-m DEM provided by Cartographic Branch of the Norwegian Polar Institute (NP) have been applied. Additional problem have been identified in as much as the DEM presents very detailed and accurate height information for the ground but its accuracy for the glacier surfaces leaves much to be desired. Elevation data for glaciers was collected mostly in 1936 from photogrammetric surveys. Additionally, owning the interpolation errors of up to 50 m in respect of the sparse data elevation points, the quality of DEM on glaciers has been degraded.

To try to avoid this problem, the NP DEM have been updated for Aavatsmarkbreen and Comfortlessbreen areas using field GPS elevation data acquired in 2001. The front position was also updated using optical satellite ASTER image acquired in 2001.

1 INTRODUCTION

Svalbard glaciers are receding rapidly. Mass balance studies and survey of extent and thickness of glaciers are usually based on small, land-based types and little is known about such properties in the case of the larger, tidewater forms. Neither the mass loss due to calving of tidewater glaciers is fully understood. An overview of contemporary deglaciation of Spitsbergen will be incomplete until the processes which drive the geometry changes of its tidewater glaciers are much better studied.

Mass balance studies and surveys of the extent and thickness of glaciers are usually based on small, land-based types and little is known about such properties in the case of larger, tidewater forms. Neither is the mass loss due to calving in tidewater glaciers fully understood.

For calculation of ice discharge due to calving necessary are data on:
- front position changes - easy available from aerial photos and satellite images
- area of the glacier cross section near the front - estimated from cliff elevation and sea depth near terminus
- glacier flow velocity - needs special studies

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2 GLACIER FLOW VELOCITY ESTIMATION

Glacier flow velocity data are typically retrieved from field measurements using static GPS surveying. The common disadvantage of this method is that flow velocities are obtained only for few points on glacier but SAR interferometry allows to calculate flow velocity pattern over whole glacier in grid domain. With ERS SAR C-band data flow velocity measurements are strictly limited by temporal decorrelation (mostly water content in snow and wind action) which excludes data acquired in standard repeating-pass mode of 35-days. Practically only data acquired during tandem or ice missions are suitable for InSAR processing. Thus SAR interferometric flow velocity measurements are available only for archival data acquired in 1991, 1994 and 1995-6. Within the project the short interval InSAR data have been compared with ground GPS survey from the same season: late winter – April following assumption that flow velocity is similar for the same seasons from different years and the variations are occurring only over the year due to seasonal changes.

Glacier surface is less intense changed in the winter part of year. Therefore majority of properly analyzed interferograms are presenting data on period of lower glacier flow velocities than during the summer calving time. InSAR velocity measurements in Svalbard are still rare, focused on observations of surging glaciers: e.g. [1] and were related to autumn glacier flow e.g. [2].

3 ERS SAR DATA

For the project purposes the data from descending and ascending passes sets of ERS SAR data were selected (Fig.1.):

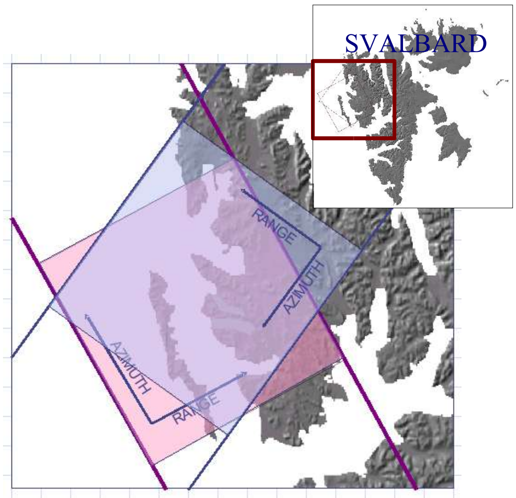

Fig.1. Location of study area and ERS SAR data coverage: blue – descending data, pink – ascending dataset

1. Ascending data acquired during II-nd ice phase (Tab. 1)

No.	Satellite	date	B_|_		
			1	2	3
1	E1	17.03.94	-	42m	11m
2	E1	20.03.94		-	31m
3	E1	29.03.94			-

2. Descending data acquired during tandem mission (Tab. 2)

No.	Satellite	date	B_|_	
			1	2
1	E1	11/04/96	-	60 m
2	E2	12/04/96		-

Due to gaps in temporal and spatial ERS SAR coverage over Svalbard and bad weather conditions during acquisitions the selection of datasets from the same year was unavailable.

Additionally, optical satellite data from TERRA ASTER acquired: 17.08.2000, 29.05.2001, 26.06.2001 were used. These data were applied for retrieving actual topographic informations like: glacier front positions and directions of crevasses and other linear features which may help to indicate flow directions.

4 INTERFEROMETRIC VELOCITY MEASUREMENTS

SAR interferometry provides a very accurate measurement of the displacement which occurs at time between two repeated acquisitions. However, InSAR allows to detect only one displacement vector along line-of-site (LOS) direction. In a case of glacier movement this measurement is not sufficient to reconstruct flow velocity field of a glacier (Fig. 2) without data from other sources.

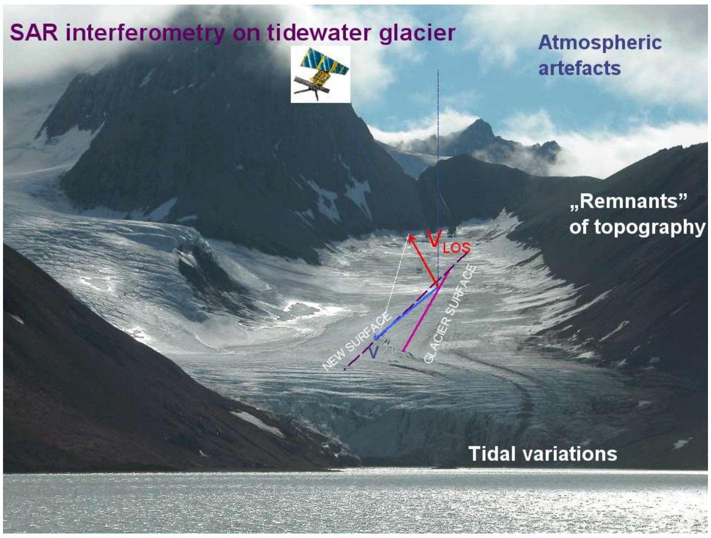

Fig. 2. The geometry of InSAR observation of glacier surface displacement due to ice flow

The calculation of glacier flow velocity field from InSAR data is possible through two different approaches assuming that flow is parallel to the ice surface and normal to topographic contours.

1. Application of single-pass interferometry and external data.
With this assumption surface slope and azimuth of flow direction must be known. Such data are very difficult to retrieve over whole glacier from field survey or photogrammetry. Single pass approach is used for velocity calculations in a points or profiles [3] or for comparison with surveyed velocities where external data exists [4]. An alternate approach [5] is to use line-of-site displacement with photogrammetric data for the estimation of the mass-balance distribution.

2. Application of data from Ascending and descending passes
This assumption have been developed by Joughin et al. [6]. It allows to estimate tree-component velocity vector. The data about flow direction are not required, however a precise Digital Elevation Model (DEM) is important to estimate surface slope.

Result of SAR interferometric processing an interferogram presents a very complex fringe pattern which includes together with surface displacement also the remnants of topography, atmospheric artifacts and in some cases tidal variation in ice elevation (calving glaciers). The key element of velocity estimation is actual and accurate DEM. For many areas external DEM is unavailable (SRTM mission data are not covering the polar regions), the topographic informations could be retrieved from additional InSAR couple. However, in a case of continuous glacier movement it is impossible to calculate topography-only interferogram with repeat-pass systems.

5 EXTERNAL DEM

Within presented project digital elevation model for study area have been supplied by Norwegian Polar Institute. This DEM with pixel size = 20x20 m have been interpolated from contourlines digitized from Svalbard Topographic Map scale 1: 100 000. This map have been constructed based on photogrammetric study performed in 1936 thus elevation data over glaciers presents 65 years time difference with its the recent positions. Moreover, during data analysis the significant errors from interpolation of sparse contours over glaciers have been identified. For the project purposes the DEM have been updated using GPS surveyed elevations (GEOCALVEX data collected in April 2001) and ASTER images. This work have been completed with semi-manual method (Fig. 3).

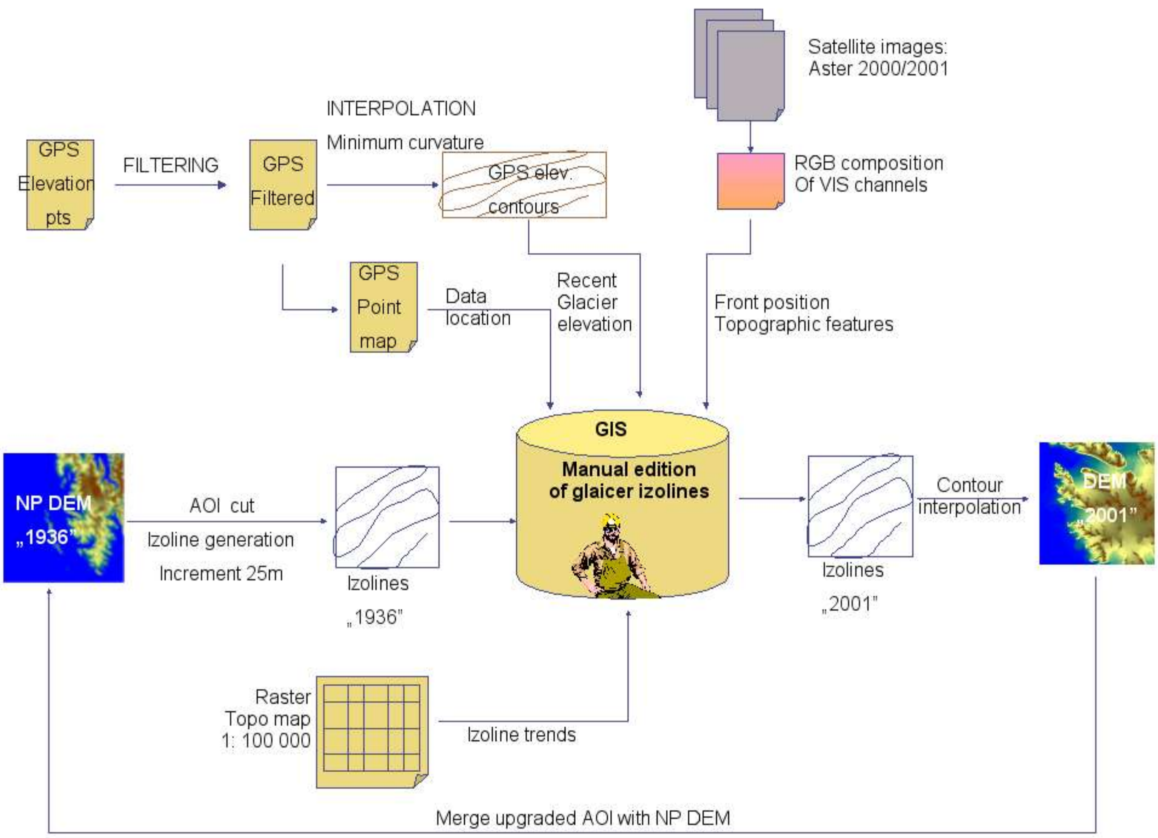

Fig.3. The scheme of semi-manual method for DEM upgrading with GPS and ASTER images

6 ERS SAR DATA PROCESSING

The interferometric processing was performed using the freely available Doris software package developed by the Delft Institute for Earth-Oriented Space Research (DEOS), Delft University of Technology.

ERS SAR data from descending pass have been processed using 2-pass approach and so called topographic fringes have been removed applying updated DEM. With 60m perpendicular baseline the data are very sensitive to topographic ambiguities. Comparison of the same interferogram processed with updated and not updated DEM shows significant difference (Fig. 4)

a) b)

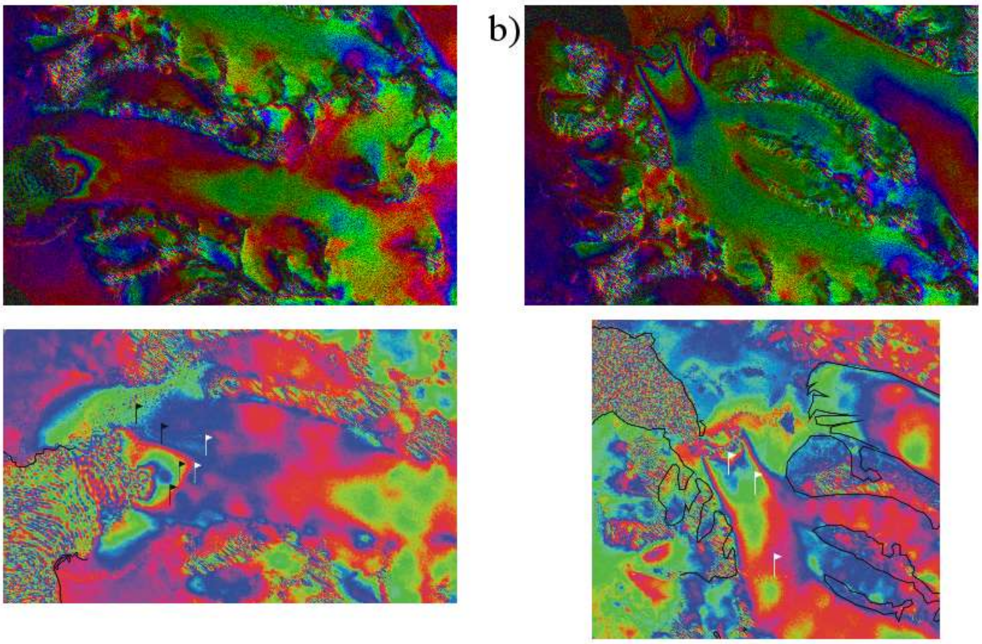

Fig.4. ERS SAR interferograms from tandem descending dataset (Tab.2) corrected with not updated DEM (top) and with updated DEM (bottom). a) Avatsmarkbreen, b) Comfortlessbreen

ERS SAR data from ascending pass have been processed using 3-pass approach which allows remove topography. This calculation was performed assuming that flow velocity was constant during a period of acquisitions. Longer temporal baselines (3 and 6 days) enlarges the displacement signal but also decrease the coherence. To improve the inteferogram the Goldstein filter was applied before phase unwrapping It is an adaptive filter based on the concept of multiplication of the Fourier spectrum of the small interferogram patch by its smoothed absolute value [7].
For phase unwrapping of the interferograms from ascending and descending passes the statistical-cost, network flow algorithm SNAPHU have been used [8].

7 FUTURE WORK

Applying modified Goldstein filter formula which making the filter parameter alpha dependent on coherence [9]. In that way the incoherent areas are filtered more strongly.
Compare updated NP-DEM with InSAR elevation data extracted from 3-pass data
Calculate DEM from ASTER optical data with photogrammetrical method.
Applying of both: ascending and descending passes to velocity field calculation.

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