

Estimation the Dongkemadi Glacier Thickness Change by ALOS/PALSAR

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Abstract. This paper presents a novel method to monitor the thickness changes of mountain glacier based on the deformation extracted by differential interferometric synthetic aperture radar (DInSAR) interferograms measurements of the glacier's surface. To estimate changes in surface elevation through time, we make use of differential phase and get the deformation of the glacier surface in the line of sight (LOS). The method exploits the one component of displacement along the LOS of radar beam for deriving the glacier thickness changes and uses these components to calculate thickness changes within glacier polygons. Using this method, we can monitor the thickness changes in cm-level accuracy. In order to demonstrate this method a practical example, the monitoring thickness changes of the Dongkemadi Glacier in Tibet Plateau of China, is given. The performance of this method is validated by GPS survey data. The result obtained with one DInSAR pair covering the Dongkemadi Glacier in the cold season.

1. Introduction

It is important to monitor thickness changes of mountain glaciers for their contributions to calculate ice volume loss and mass balance [1], [2]. Because many mountain glaciers are located in the inaccessible areas and environmental hazards, the traditional ground measurement techniques exist for measuring glacier thickness changes directly are considered to be labor-intensive, expensive and provide very limited spatial and temporal coverage. So the remote sensing data are an attractive source of information to complement *in situ* measurements [3], [4]. Differencing multi temporal digital elevation models (DEMs) generated from space-borne or air-borne observations becomes one of the effective methods to monitor the spatial patterns of glacier thickness and volume changes [5]. These methods include generation of DEMs from radar interferometry, for example, the Shuttle Radar Topography Mission (SRTM) DEM acquired in Feb, 2000 [6], or from spaceborne or airborne photogrammetry [7], or from laser altimetry [8]. However, the accuracy of the results derived from these methods depends mainly on the DEMs' accuracy. Because of the low precision of these DEMs, the estimation of glacier thickness change is difficult to satisfy the evaluation of ice loss with precision. Over the past decades, the spaceborne synthetic radar aperture interferometry (InSAR) technique has proved to be an effective remote sensing tool to map ground deformations [9], [10], [11]. Using the

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method known as DInSAR, pairs of SAR images can be processed to obtain high spatial resolution (a few meters) maps of surface deformation with large spatial coverage (thousands of km²) and typical accuracy on the order of centimeters [12]. Because the existing SAR satellite systems have relatively short revisit period, DInSAR has the capacity to resolve time-dependent deformation. During the last years, studies based on DInSAR have so far mostly concentrated on obtaining the glacier velocity, and little has been done on deriving the glacier thickness changes using the vertical component of surface deformation along the line of sight (LOS). The goal of this study is therefore to use the DInSAR algorithm to obtain the mountain glacier thickness change. The advantage of the presented DInSAR methodology is that the glacier motion measurement can achieve cm-level accuracy between the revisiting periods.

2. Study Site and Datasets

2.1 Study Area

Our test site, Dongkemadi Glacier (92 °05' E, 33 °04' N), is located in the head region of the Buqu River, on the northern slope of Tanggula Mountain, in the central part of the Qinghai-Tibetan Plateau (Figure 1). A sanatake (nunatak) separates the glacier into two branches, DDG and XDG. The DDG branch is 5.4 km long, with an area of 14.63 km². The summit and terminus of the glacier are at 5,926 and 5,275 m, respectively. The XDG is 2.8 km long, and is a small valley glacier with an area of 1.76 km². The summit and terminus of the glacier are at 5,926 and 5,380 m, respectively. The Dongkemadi Glacier is characterized by a small relative height, gentle glacial surface, no avalanche in the accumulation area, and no surface moraine in the ablation area of the glacier. There are no definite delimiting four seasons in the Dongkemadi glacier; instead, there is only the difference between cold and warm seasons. The cold season is long, at eight months (from Oct. to next year May), and the warm season is only four months long (from Jun. to Sep.) [11], [13]. The Dongkemadi Glacier is an extremely continental (polar) glacier. The annual precipitation in the glaciated area is in the range of 200-500 mm, and the annual and summer mean air temperatures at ELA are estimated at -10°C. In such extremely cold and dry conditions, most of the energy is expended as the evaporation process on the glacier surface, so ablation is very weak. Besides, the basal layers of glaciers are usually frozen to the bedrock and ice flows slowly [14].

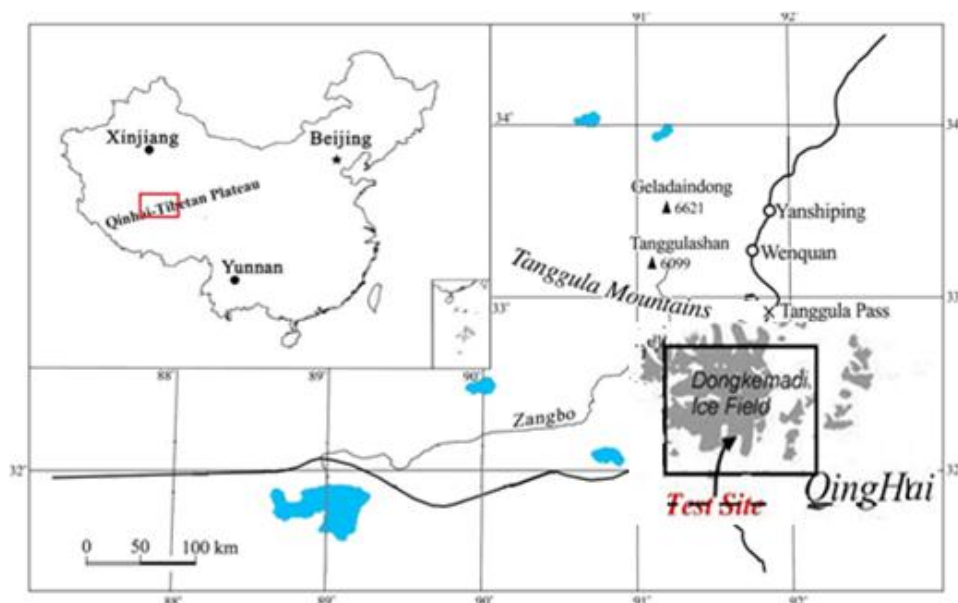


Figure 1. Map of the Dongkemadi Glacier.

2.2 SAR Datasets

The Tanggula Mountain at low latitudes is sparsely covered by archived data. We inspected the JAXA archives of SAR data to find one pair of SAR images suitable for InSAR processing. In order to minimize temporal decorrelation from surface melt, the data used were acquired in the winter season.

The ALOS satellite was launched by the Japan Aerospace Exploration Agency in January 2006 with three sensors: PRISM, AVNIR-2 and PALSAR. The Phased Array type L-band Synthetic Aperture Radar (PALSAR) frequency is 1.270 GHz, corresponding to a wavelength of 23.6 cm. PALSAR provides a higher performance than JERS-1's SAR. This sensor has a beam steerable in elevation and a ScanSAR mode, which allows a wider swath to be obtained than for conventional SAR. The L-band ALOS PALSAR instrument, due to its longer wavelength (23.6 cm), has the advantage of a deeper penetration of vegetated areas that contributes to reduce the temporal decorrelation. Moreover, its higher spatial resolution leads to an increase of the critical spatial baseline. For example, for a fine beam single-polarization (FBS) data pair, with a spatial resolution of about 9 m/pixel and an average sight angle of 38° , the critical spatial baseline exceeds 13 000 m. This allows increasing the number of suitable interferometric pairs for DInSAR applications. The capabilities of ALOS PALSAR have already been proved applying DInSAR in a very impervious region such as mountain areas [10].

For this study, two winter ALOS/PALSAR orbits (Table 1) acquired on Dec. 12, 2008 and Jan. 27, 2009 with HH polarization covering the Dongkemadi Glacier was exploited. All images have been acquired from ascending orbits, with the perpendicular spatial baselines of 229 m.

Table 1. ALOS/PALSAR data used for this study.

Acquisition Date	Orbit type	Season
2008-12-12	Ascending	Winter
2009-01-27	Ascending	Winter

3. Methods

3.1 DInSAR Method

In this paper, we utilize direct mountain glacier thickness measurements from L-band SAR data (ALOS/PALSAR) to estimate the glacier thickness changes of the Dongkemadi Glacier. The methodology is based on the usage of the DInSAR, which that estimates the velocity and DEMs from the interferometric phases. The phase differences in the two complex SAR images acquired during repeat passes, known as an interferogram, can be calculated by subtracting the phase in one image from the phase in the other. And the deformation of the glacier surface caused by glacier flow motion and thickness change in the time interval can be detected by the differential phases. For derivation of surface deformation or displacement, another interferogram has to be synthesized. The synthesized interferogram is generated from an external DEM. It is then subtracted from the original interferogram, thereby removing all phases that relate to ground elevation, leaving only phases that represent glacier surface deformation or displacement [12]. To estimate the changes in surface thickness, we make use of differential phase and get the deformation of the glacier surface in the line of sight (LOS). Then we separate the components that represent the glacier thickness changes from the deformation of the glacier surface in LOS and use these components to calculate glacier thickness changes.

3.2 Deriving the Glacier Thickness Change

In order to obtain estimates of the glacier thickness change vector of the mountain glacier, we made the following assumptions: glacier flow parallels surface topography, the DEM we use approximately provides the glacier surface topography [15], [16], [17] and the glacier moves slowly. Because the measurements in SAR coordinate provide only the projections of the true three-dimension displacement in the azimuth/range directions, all glacier surface deformation result is expressed in the two-dimension SAR geometry. Based on the above-mentioned assumptions, we can convert the SAR measurements patterns to the true glacier thickness change patterns.

4. Result and Analysis

The DInSAR method summarized and proposed algorithm in the previous section were applied to two ALOS SAR data frames from 2008 to 2009 that are relevant to an area located in the Dongkemadi Glacier and generated one interferogram. To measure the actual glacier thickness change, the resulting interferometric phases were used to calculate the deformation along the radar beam's LOS. The resulting glacier thickness change values are scaled to units of centimeters per 46 days and Figure 2 presents the glacier thickness change maps, which have been geocoded and superimposed on SRTM DEM of the area. This kind of representation is visually effective and allows us to easily get information about the detected glacier thickness changes.

In order to demonstrate the capability of the proposed approach to provide accurate glacier thickness change values, we designed a test to check the consistency of the result. The test of the glacier thickness change magnitude is calculated by the difference between the result computed from the ALOS dataset and those measured via on site precise GPS-RTK techniques.

For the test we mainly used the limited GPS survey data to validate our result from the InSAR pair of the years 2008 to 2009. Mountain glaciers are notoriously difficult objects for field observations. However, we installed five corner reflectors on the XDG surface during our fieldwork in October 2007. We measured the thickness changes of the five corner-reflectors (CR) by GPS-RTK technology on 17 October 2008 and 30 August 2009, respectively. The thickness changes of the CR derived from the two kinds of results are given in Table 2. By comparing the result derived by the method in this paper with the GPS-surveyed result, the precisions of the two results are of the same order (centimeters).

In Figure 2 the extracted glacier thickness changes and contour lines are overlapped together. The result show that the glacier thickness changes distribution of DDG displays spatial variations between the acquisition time intervals of the SAR data acquired. The result show that thinning at the glacier tongue, including DDG and XDG, in the cold season. However, from 5500 m to 5700 m, the result shows an interesting result: along the DDG central axis, the glacier thickness changes are divided into two different regions (thickening occurred at the left side and thinning occurred at the right side). Among the possible reasons of this phenomenon are probable the influence of the prevailing winds in this area during the cold season. The accumulation zone of Dongkemadi glacier shows a continuous glacier thickness changes. Net loss occurred mainly at the north-eastern glacier. A relatively large area in the accumulation zone shows thickness increase.

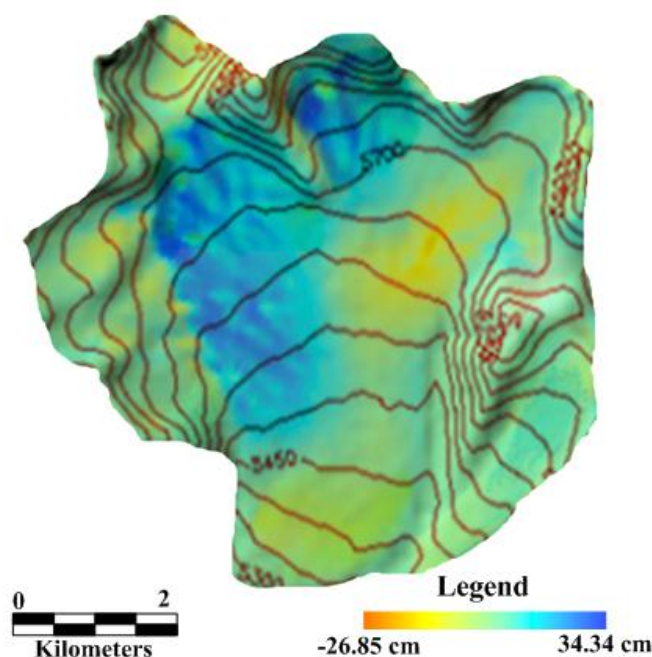


Figure 2. The thickness change of Dongkemadi Glacier and superimposed on SRTM DEM of the area.

Table 2. Glacier thickness changes at the corner reflector.

Results	CR1	CR2	CR3	CR4	CR5
Thickness changes from GPS (cm 46*day ⁻¹)	-20.47	-24.86	-15.26	-11.14	-8.93
Thickness changes from ALOS (cm 46*day ⁻¹)	-7.22	-7.51	5.44	8.58	13.47

5. Conclusions

In the present study, we presented the result of the first experiment carried out to investigate the feasibility of the new method based on the DInSAR technique to derive the mountain glacier thickness changes by using L-band SAR data. The presented result demonstrates the capability of the proposed approach to provide the glacier thickness changes information with an accuracy of centimeters. The glacier thickness change maps derived from the PALSAR interferogram can show more information than the simple point measurement or GPS-RTK measurement. This method is easy to implement compared to field measurement; moreover, the method is not subject to the weather conditions.

For what concerns the approach limitations and constraints, it is important to remark that this approach may not work so well in area smaller mountain glaciers because the coherence of these glaciers is always very small and do not meet the requirements of DInSAR. Meanwhile, if the mountain glaciers are rapidly melting, the approach may not be as effective because the temporal decorrelation becomes very serious in this period.

6. Acknowledgements

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7. References

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