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Glacier mass change evaluation in Lambert-Amery Area from 2002 to 2012 using ASTER stereo images and ICESat GLAS laser altimetry

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Abstract. Currently, one of the major issues is to transform different remote sensing observations into a global reference for sustainable global-scale glacier change monitoring. In order to put glacier changes into a broader temporal context, it is desirable to extend the glacier observation time as far back as possible. In this paper, we present a case study of registering ASTER satellite stereo images to ICESat GLAS laser altimetry data, by matching terrain features identified from the ICESat measurements to those corresponding in the ASTER images. Features like ridges and nunatak can be extracted from ICESat data, and these features can also be measured in ASTER stereo images. A rigid body transformation (3 translations, 3 rotations) is applied for an optimal fit of these two sets of feature points. After transforming the ASTER photogrammetry measurements into the ICESat reference frame, we compute elevation change rates at each ICESat point by using a linear interpolation to obtain an estimate of surface elevation from ASTER. The surface firm/ice density model is used in converting the elevation changes to mass changes. Our study indicates that Lambert Glacier is close to being in mass balance between 2002 and 2012.

1. Introduction

Understanding the mass balance and surface dynamics of the Earth's major ice sheets in Antarctica is of fundamental importance for accurate predictions of future sea-level rise¹. Traditional photogrammetric techniques have been used successfully to determine velocities and elevations of glaciers in both the Arctic and Antarctic². Surface elevation data are collected by many sensors using various techniques, and differencing between the multi-temporal elevation products is becoming a common method for monitoring surface changes, particularly of glaciers³.

Schenk et al. showed the feasibility of using ICESat as ground control for Aerial photographs and complimentary aero photogrammetric DEMs by selecting visible nunatak areas and minimizing the vertical deviations of these areas through a 2-D regression⁴. And developed a novel method to detect surface elevation changes from satellite and airborne laser altimetry and repeat stereoscopic imagery⁵. This is important because the ICESat across-track up to 10 km in polar region. It demonstrate the proposed methodology to determine surface changes and mass balance where no satellite radar

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coverage. E DongChen et al. (2009) extracted high-accuracy topographical information based on fusion of ASTER stereo-data and ICESat/GLAS data in Antarctic ⁶.

NASA's Ice, Cloud and land Elevation Satellite (ICESat) was launched in January 2003, into a near-circular orbit at 94° inclination and approximately 600-km altitude. Since then it has collected laser altimeter data during several operational periods⁷. The mission's primary goal was to measure elevation changes of the polar ice sheets with sufficient accuracy to assess their impact on global sea level.

The major difficulty of this approach is that in Antarctic, there is almost no visible topographic features in remote sensing images, except a few bare rocks. In this paper we described how information from ICESat altimetry data and ASTER stereo images can be combined to measure surface changes over outlet glaciers.

2. Data and methods

2.1. Study area

This study focuses on the surface elevation changes in the Lambert - Amery system (LAS), east Antarctica. LAS is an important drainage system and one of the significant contributors to the mass budget of the Antarctica. The change of this area and its surroundings is important for understanding the response of east Antarctica to present and future changes in temperature of both the atmosphere and ocean [Williams et al., 2002]. The elevation of the Amery Ice Shelf increased over the period of 1992 - 2001⁸. In recent years, however, non-agreeable results in this region have been reported by a number of studies.

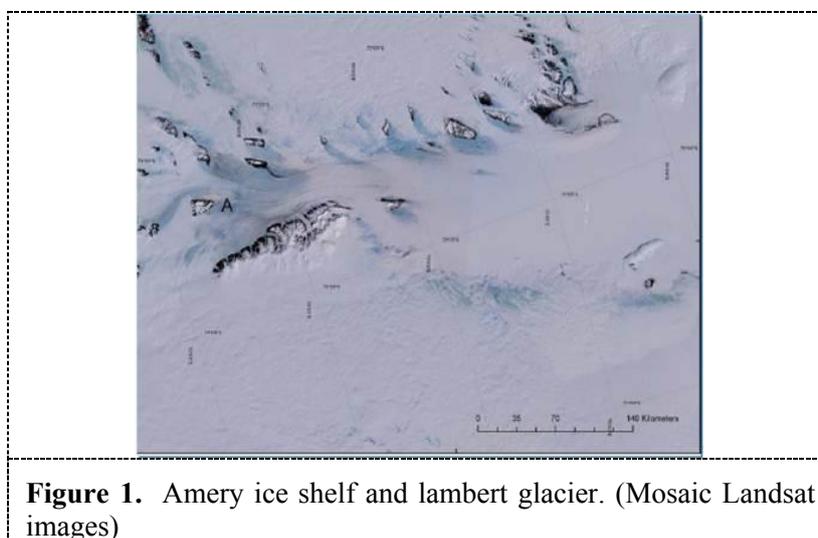


Figure 1. Amery ice shelf and lambert glacier. (Mosaic Landsat images)

2.2. Extract terrain feature line from ASTER stereo images

In the experiment, the ASTER 1A level data were acquired in 2002, 2005, 2006, 2007 and 2012 respectively. ASTER scene size is approximately 60km*60km. In order to get more accurate result, we use the ASTER senses which cloud coverage is within 10%. Before derive the 3D terrain feature line, we computes RPCs use the ephemeris (satellite position, velocity) and attitudes vectors (φ , ω , κ). Then compute the latitude, longitude and elevation based on the RPCs and selected common points along the bare rocks peaks, hollows and boundaries.

Table 1. Characteristics of the ASTER Sensor Systems. (ASTER User Handbook V2) .

Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution	Quantization Levels
NIR	1	0.52-0.60	15m	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30m	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
	TIR	10		
11		8.475-8.825		
12		8.925-9.275		
13		10.25-10.95		
14		10.95-11.65		

2.3. Extract terrain feature points from ICESat laser altimeter

For the registration we use Antarctic and Greenland Ice Sheet Data Product (GLA12 Release 531) acquired for the period 2003 ~ 2009. We apply data filter to reduce the range error⁹. Terrain feature characteristic points can be extracted from GLAS track elevation profiles, for example at abrupt changes of slopes.

2.4. Methodology

Terrain feature points extracted from ICESat transects should coincide with the 3D lines measured from the ASTER stereo images. For registered we used Iterative Closest Point method, it is based on minimizing the shortest distance between characteristic points and corresponding terrain features in a least-squares sense, Figure 3 shows after transformation ASTER DEM profile and ICESat track profile.

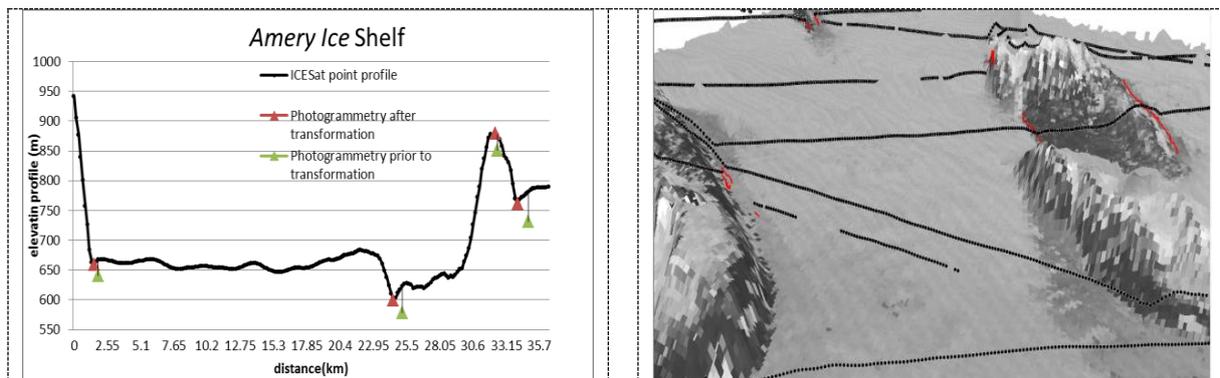


Figure 2. (left) ICESat surface elevation profile across Antarctic nunatak, black circles is ICESat elevations, and triangles are elevations from ASTER stereo images photogrammetry prior and after the transformation. (right) A small area of the ASTER 3D Scenes. Black dots indicate the image positions of laser points and the red lines are terrain features measured stereoscopically on the images.

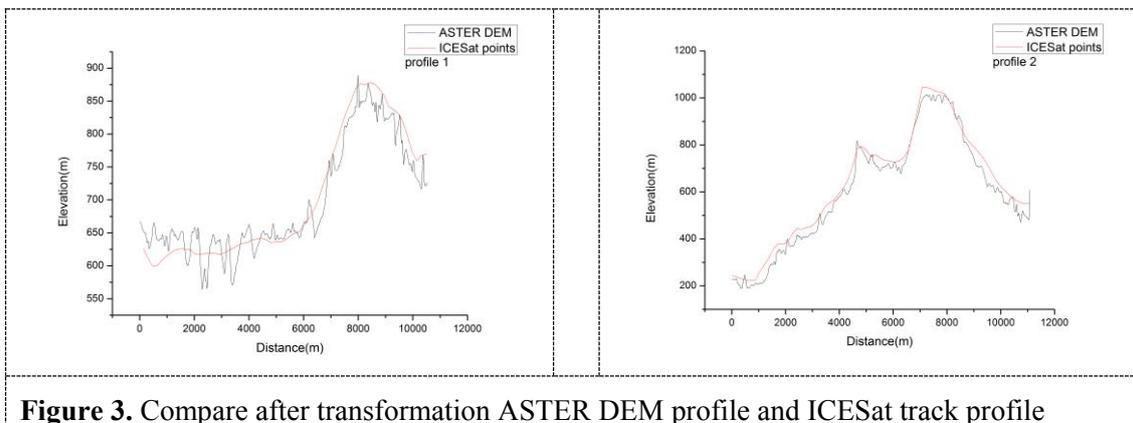


Figure 3. Compare after transformation ASTER DEM profile and ICESat track profile

3. Results and discussion

3.1. Ice Surface Elevation Changes

After register the photogrammetric ASTER DEM into ICESat, we estimates surface elevation changes over Amery ice shelf. For ICESat data, we use repeat tracks to obtain elevation-change rates, and differenced ASTER DEM's offer a supplemental where ICESat coverage is sparse. The accuracy of elevation changes is affected by the accuracy of ICESat and images 3D measurement points, and the registration error.

3.2. Mass balance of Lambert-Amery

Mass changes can be derived from observations of ice sheet surface elevation changes though a surface firm density model. The mass changes derived from the ICESat data are mainly contributed by firm dynamics. Specifically, such changes are caused by a combination of ice dynamic imbalance, temporal variations in accumulation and ablation rate, firm compaction, and underlying bedrock motion¹⁰.

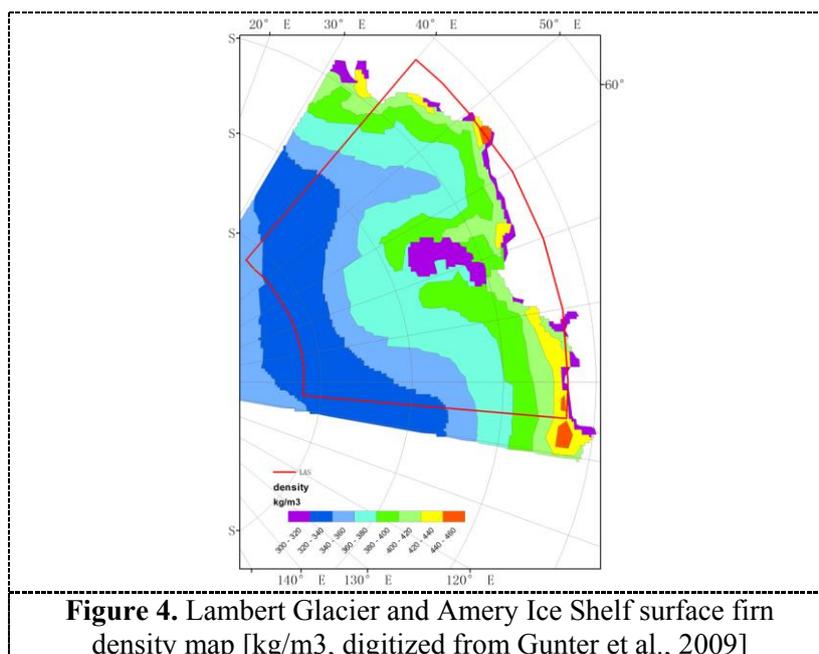


Figure 4. Lambert Glacier and Amery Ice Shelf surface firm density map [kg/m³, digitized from Gunter et al., 2009]

4. Conclusion

In this study we registered ASTER images to ICESat laser altimeter data, then derived the elevation change in all regions include where there is no satellite radar coverage. The surface firm density model was used in transformation of mass change from elevation change. Our study indicates that Lambert Glacier is close to being in mass balance between 2002 and 2012.

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