Ice thickness measurements and volume estimates for Znosko glacier (Antarctica) using Glabtop model

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Abstract

Around the world there is a consensus of the importance of knowladge the ice thickness distribution and total ice volume for estimating future glacier change for both glaciological and hydrological application, especially the Polar Regions for being important regulators of the global climate system and response rapidly to climate change. This work aimed to estimate the ice thickness distribution and total ice volume of Znosko glacier (King George Island, Antarctic Peninsula) using Glacier Bed Topography (Glabtop) model and ground data. Ground penetrating radar (GPR) measurements were collected in two field campaigns. GPR measurements were used to validate, calibrate (shape factor) and improve the accuracy of the ice thickness distribution model. The ice thickness (GPR) distribution is not uniform over the glacier, which varies from 0 to 155 m. The total stored ice volumen of Znosko glacier in 2020 is estimated to be 0.11 km3. Additionally, the model bounded areas in the bedrock topography below sea level, as a sign of future lake formation. Sensitivity analysis reveal that Glabtop model with a shape factor (f) = 0.5 gave best results when compared with ground penetrating radar (GPR) data measured on Znosko glacier and has an uncertainty range of ± 20.5%.

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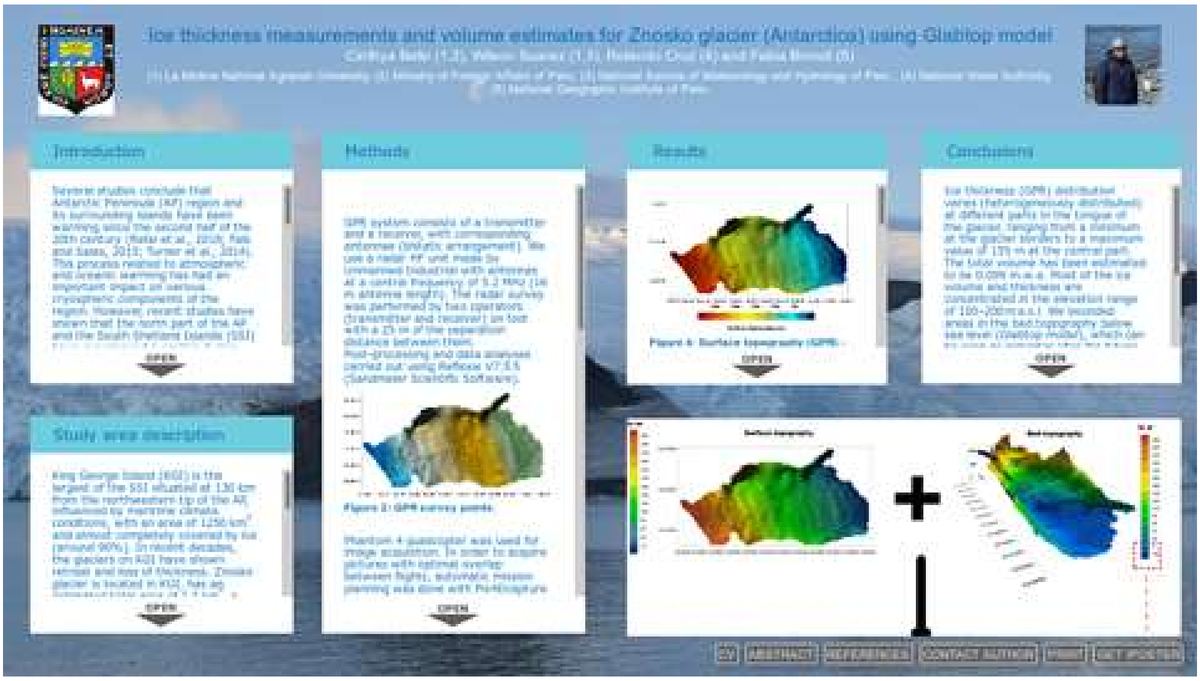

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PRESENTED AT:

INTRODUCTION

Several studies conclude that Antarctic Peninsula (AP) region and its surrounding islands have been warming since the second half of the 20th century (Rafal et al., 2018; Falk and Salas, 2015; Turner et al., 2014). This process related to atmospheric and oceanic warming has had an important impact on various cryospheric components of the region. However, recent studies have shown that the north part of the AP and the South Shetland Islands (SSI) have experienced a cooling during the last two decades (Turner et al., 2016; Oliva et al., 2016). Glacier change is an important measure of the climate, especially in Polar Regions, due to their high sensitivity to changes in meteorological conditions (Goosse et al., 2018). In situ measurements of glacier ice thickness in the AP region and its surrounding islands are very scarce because this area is inaccessible due to rough terrain and inhospitable atmospheric conditions. Although there are several studies at local, regional and global scale that use different methods to estimate glacier ice thickness in different regions of Antarctica, there is still a lack of information because ice thickness measurements are scarce (or absent) in some regions, which makes difficult to reliably extrapolate it (Morlighem et al., 2019; Farionotti et al., 2014). This work aimed to estimate the ice thickness distribution and total ice volume of Znosko glacier (King George Island) using Glacier Bed Topography (Glabtop) model and ground base data, as part of an effort to characterize the ice volume stored in Antarctica for future applications in glacier dynamics models.

STUDY AREA DESCRIPTION

King George Island (KGI) is the largest of the South Shetland Islands situated at 130 km from the northwestern tip of the Antarctic Peninsula, influenced by maritime climate conditions, with an area of 1250 km^2 and almost completely covered by ice (around 90%). In recent decades, the glaciers on KGI have shown retreat and loss of thickness. Znosko glacier is located (Figure 1) in KGI has an estimated total area of 1.7 km^2, a length around of 1.9 km, a maximum elevation of 300 meters above sea level (m.a.s.l.) and an average slope of 15%.

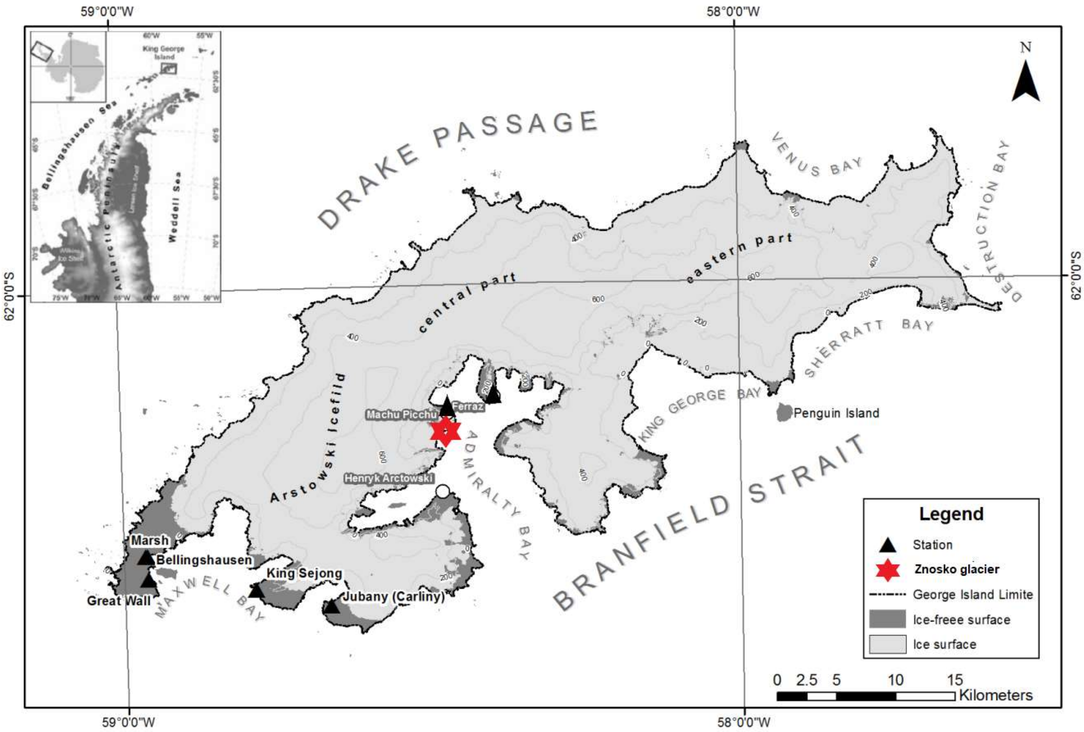


Figure 1: Location map of Znosko glacier.

METHODS

Ground penetrating radar (GPR) measurements were colllected in two field campaigns (2019-XXVI and 2020-XXVII Peruvian Antarctic Operation). GPR measurements were used to validate, calibrate (shape factor) and improve the accuracy of the ice thickness distribution model (Figure 2).

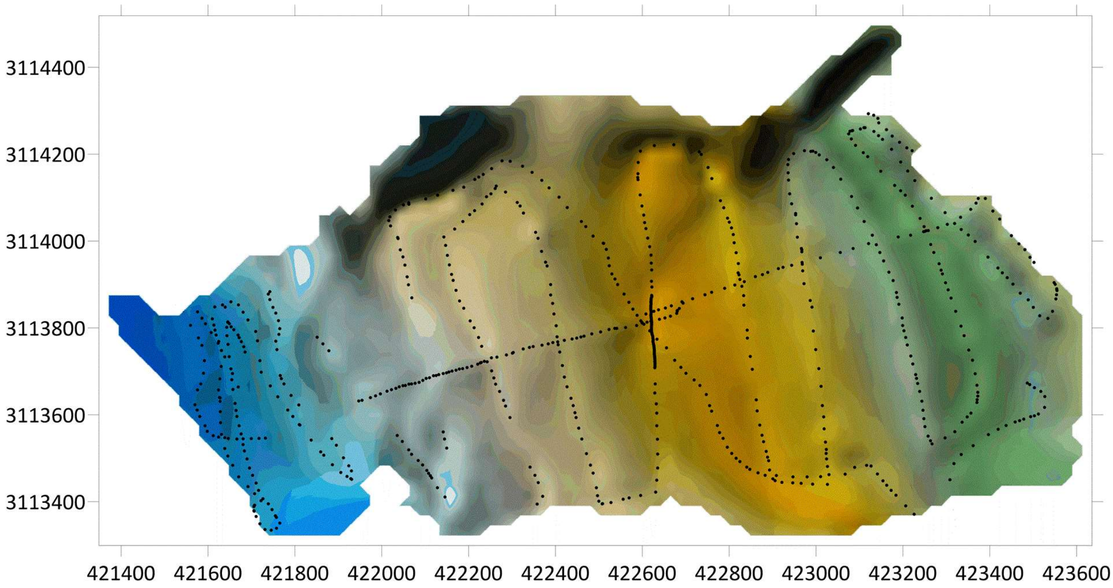


Figure 2: GPR spatial distribution.

GPR system consists of a transmitter and a receiver, with corresponding antennae (bistatic arrangement). We use a radar HF unit made by Unmanned Industrial with antennas at a central frequency of 5.2 MHz (16 m antenna length). The radar survey was performed by two operators (transmitter and receiver) on foot with a 25 m of the separation distance between them. Post-processing and data analyses carried out using Reflexw V7.5.5 (Sandmeier Scientific Software).

Phantom 4 quadcopter was used for image acquisition (5×5m gridded DEM). In order to acquire pictures with optimal overlap between flights, automatic mission planning was done with Pix4Dcapture application. Survey height was between 200 and 500 m. Ground sampling distance was 36 cm/pix. The speed of UAV was set to 10 m/s. For georeferencing purposes, a total of 8 ground-control points (GCP) were spread across the glacier.

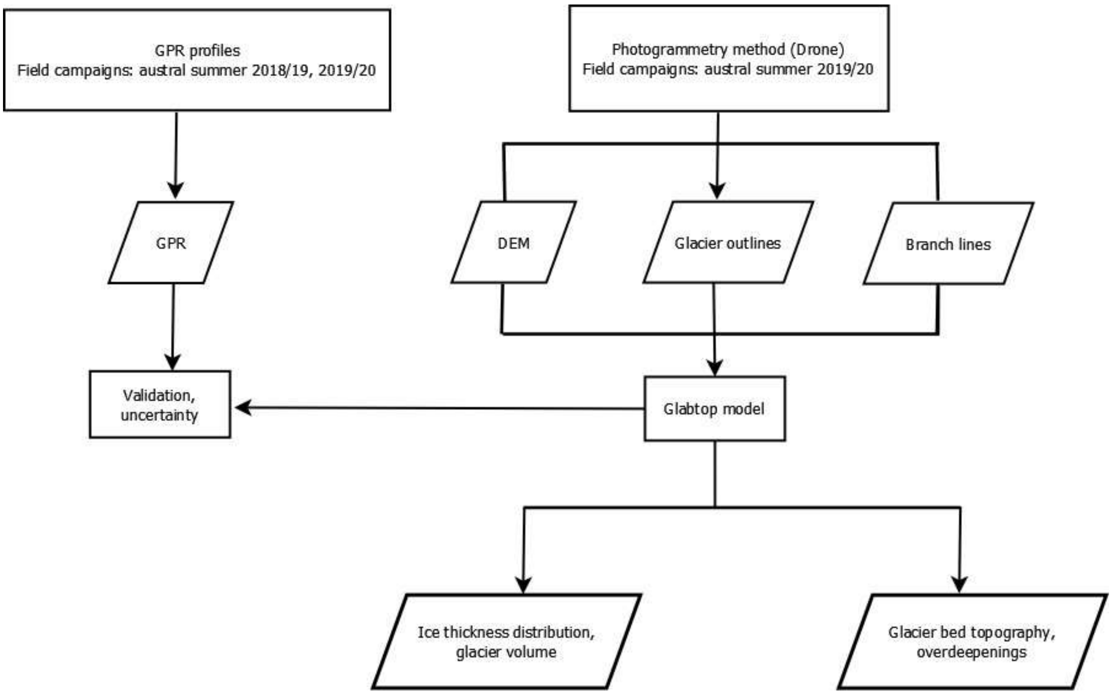


Figure 3: Schematic overview of the basic processing steps using Glabtop model.

Ice thickness (h) can be calculated by Glabtop model in the following way:

$$h = Tb/f.\,g.\,sin\alpha.\,\rho$$

Where f is the shape factor, α the zonal surface slope, ρ the ice density (900 kg m^{-3}) and g the acceleration due to gravity (9.8 m s^{-2}). The value of basal shear stress Tb (in kPa) is estimated from an empirical relation between Tb and glacier elevation range ΔH.

$$Tb = 0.005 + 1.598\Delta H - 0.435\Delta H^2,$$

$$Tb = 150 kPa for \Delta H > 1600m$$

The shape factor (f) was the only parameter that was calibrated in Glabtop model (between 0.5 and 0.9 with and interval of 0.01 ranging). We estimate RMSE (observed vs. measured ice thickness of 4 cross sectional profiles) to find an optimum f value.

RESULTS

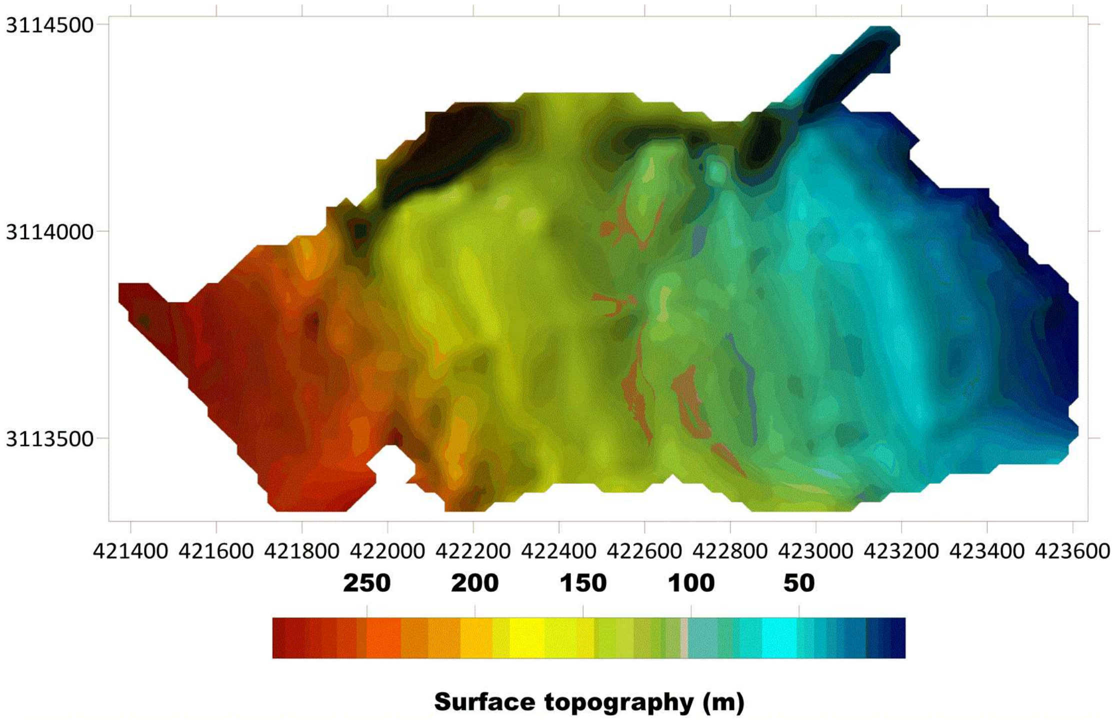


Figure 4: Surface topography map of Znosko glacier.

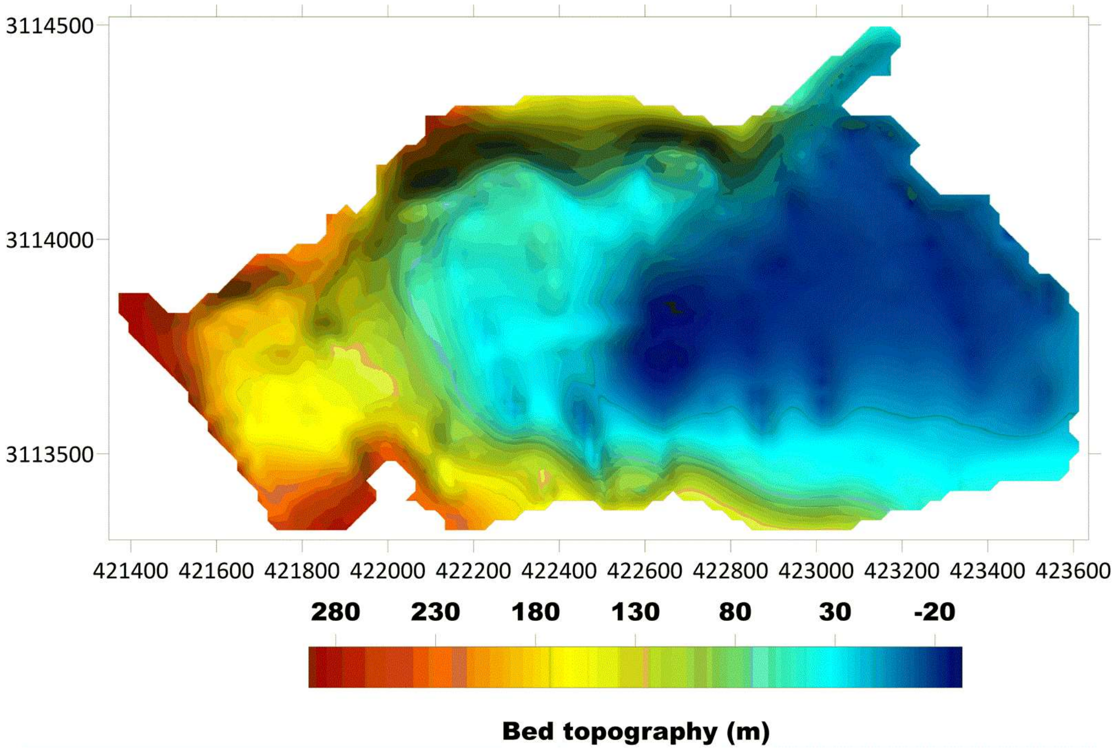


Figure 5: Bed topography map of Znosko glacier.

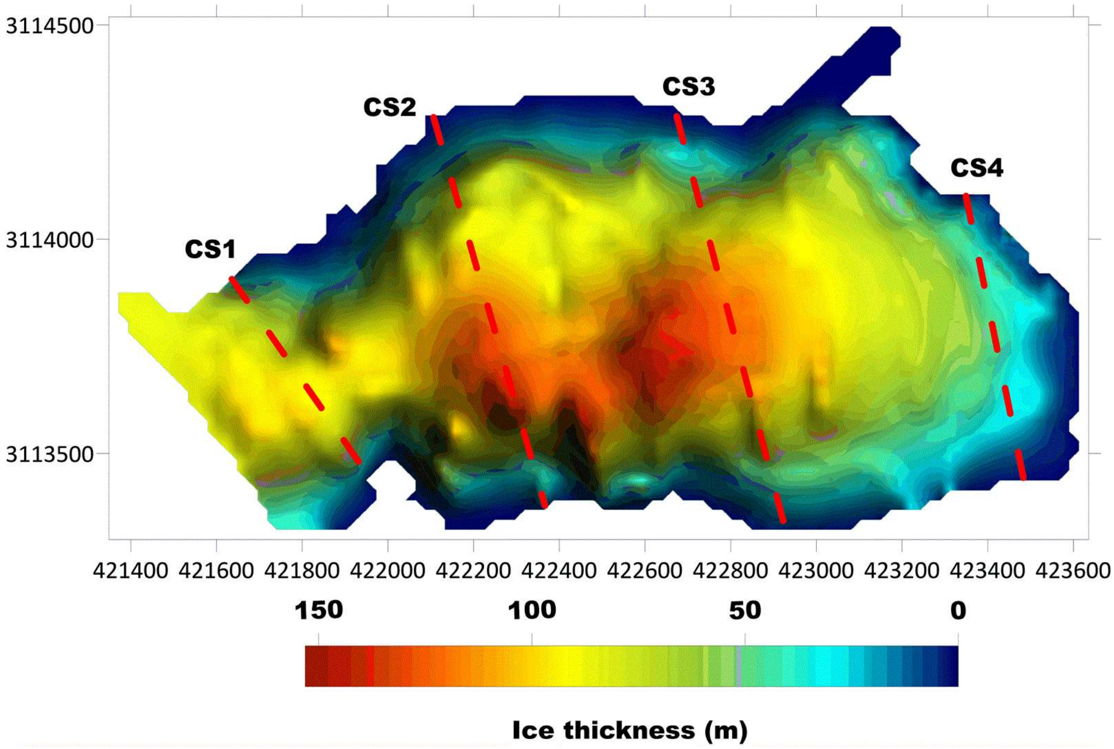
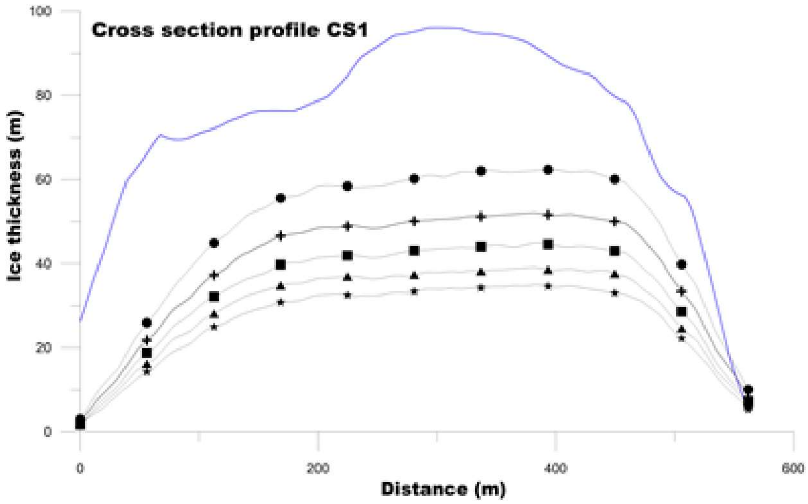
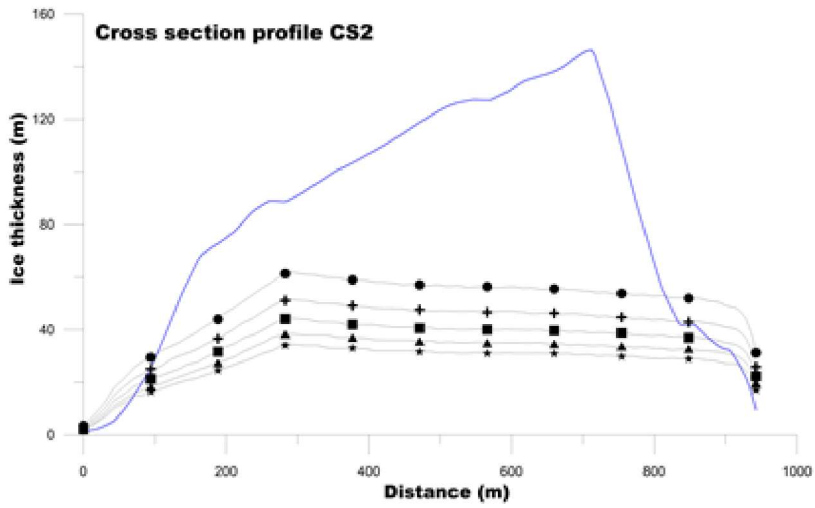
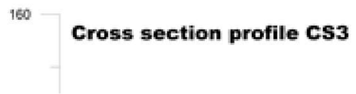


Figure 6: Spatially distributed ice-thickness (GPR) map of Znosko glacier and 4 cross sectional profiles (CS).







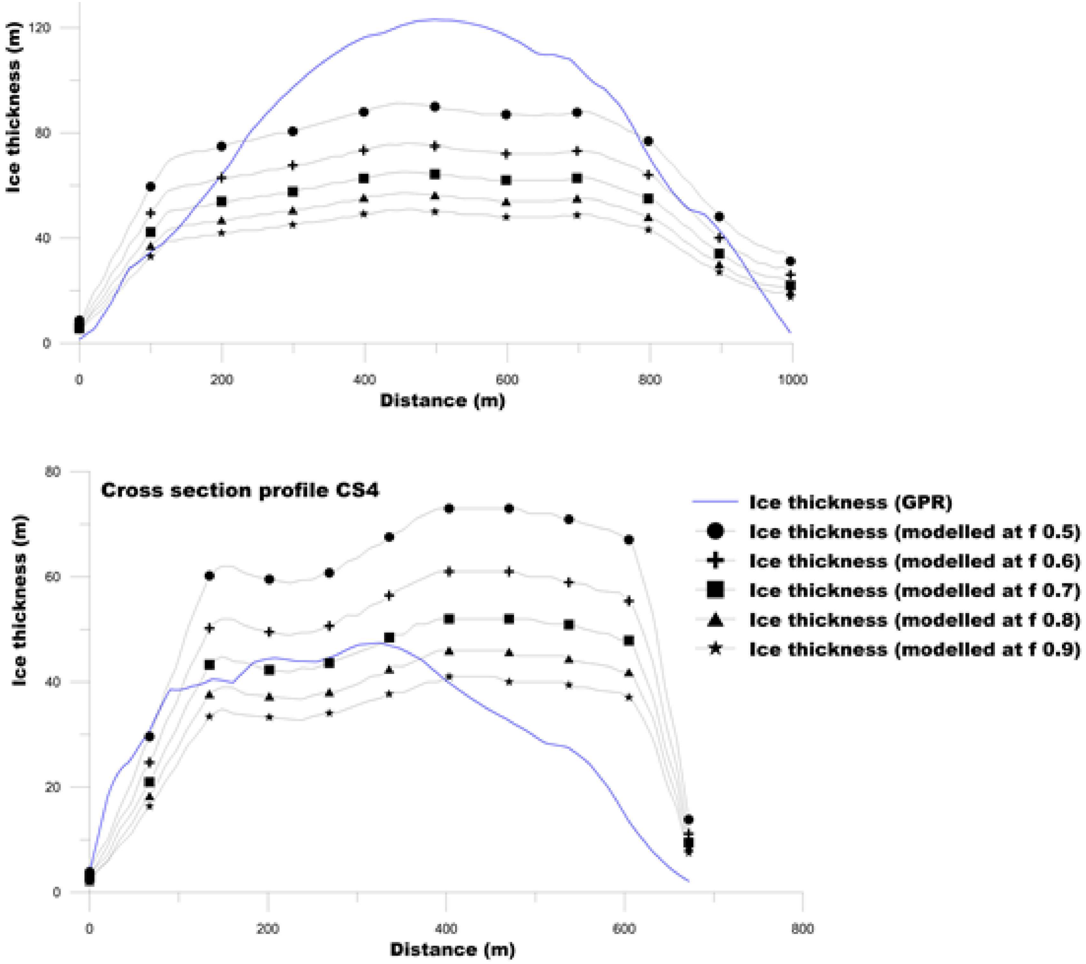
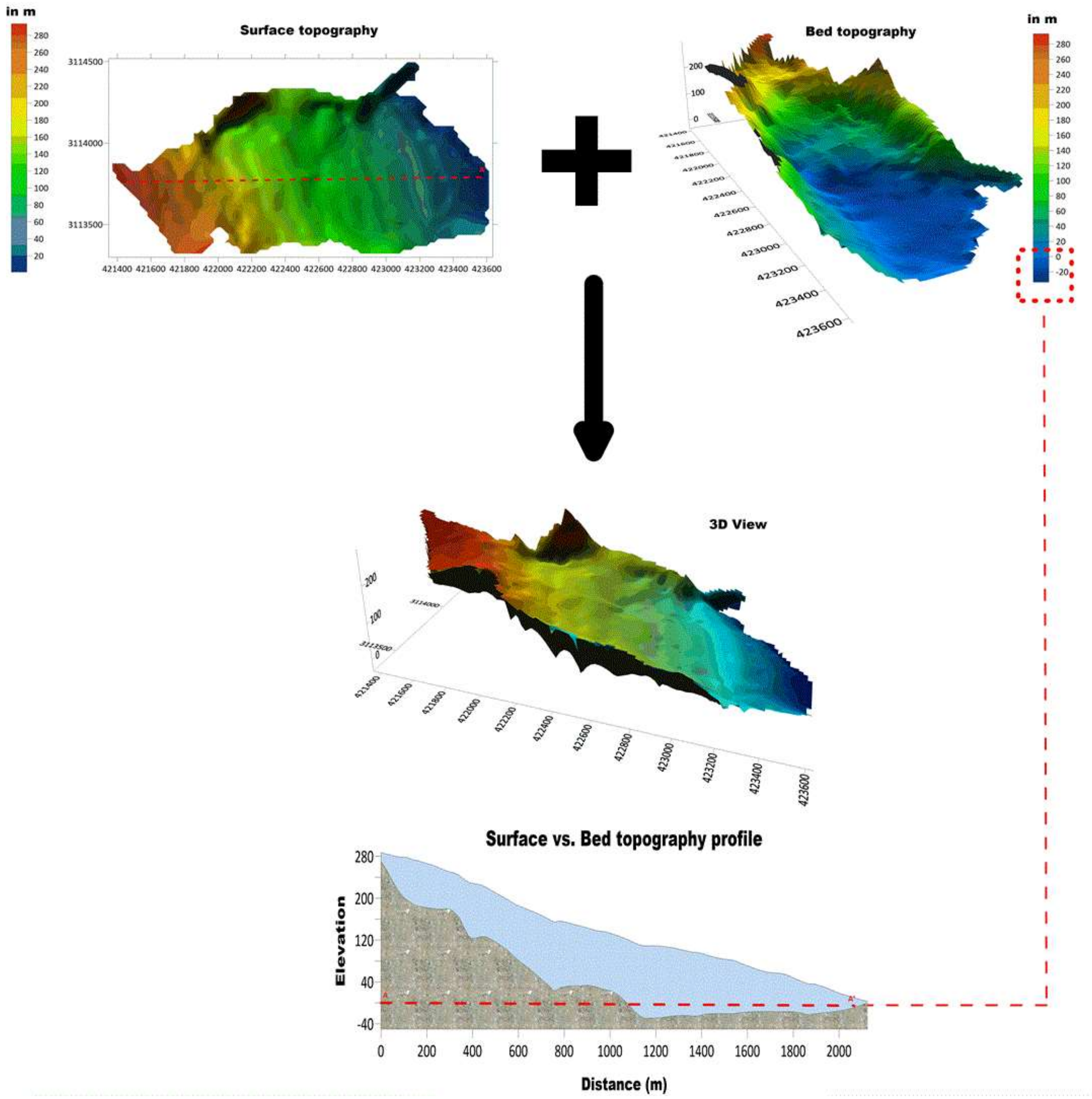


Figure 7: Cross-sectional profiles of the glacier thickness (Glabtop model).

CONCLUSIONS

Ice thickness (GPR) distribution varies (heterogeneously distributed) at different parts in the tongue of the glacier, ranging from a minimum at the glacier borders to a maximum value of 155 m at the central part. The total volume has been estimated to be 0.11 km^3. Most of the ice volume and thickness are concentrated in the elevation range of 100–200 m a.s.l. We bounded areas in the bed topography below sea level (Glabtop model), which can be seen as potential sites for future lake formation. Sensitivity analysis reveal that Glabtop model with a shape factor (f) = 0.5 gave best results when compared with ground penetrating radar (GPR) data measured on Znosko glacier and has an uncertainty range of ± 20.5%.



AUTHOR INFORMATION

I am biologist with a MSc. in Integrated Watershed Management, currently a PhD student at National Agrarian University La Molina in Peru. My research uses remote sensing tools and field data measurements to understand the glaciers dynamics on the King George Island ice cap. Since 2013, I am working as an environmental specialist in the Division of Antarctic Affairs under the Ministry of Foreign Affairs of Peru body in charge of the National Antarctic Program, and I have had the opportunity to participate in different Peruvian expeditions to Antarctica. I am a member of the International Association of Cryospheric Sciences (IACS) and individual council member of APECS Council 2020-2021.

ABSTRACT

Around the world there is a consensus of the importance of knowladge the ice thickness distribution and total ice volume for estimating future glacier change for both glaciological and hydrological application, especially the Polar Regions for being important regulators of the global climate system and response rapidly to climate change. This work aimed to estimate the ice thickness distribution and total ice volume of Znosko glacier (King George Island, Antarctic Peninsula) using Glacier Bed Topography (Glabtop) model and ground data. Ground penetrating radar (GPR) measurements were collected in two field campaigns. GPR measurements were used to validate, calibrate (shape factor) and improve the accuracy of the ice thickness distribution model. The ice thickness (GPR) distribution is not uniform over the glacier, which varies from 0 to 155 m. The total stored ice volumen of Znosko glacier in 2020 is estimated to be 0.11 km^3. Additionally, the model bounded areas in the bedrock topography below sea level, as a sign of future lake formation. Sensitivity analysis reveal that Glabtop model with a shape factor (f) = 0.5 gave best results when compared with ground penetrating radar (GPR) data measured on Znosko glacier and has an uncertainty range of ± 20.5%.

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