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S10 Subglacial aquatic environments

Potential subglacial lakes derived from a new DEM from Cryosat-2 and satellite optical image in the David Glacier, Antarctica

Choon Ki Lee[1], Nowook Park[2], Byeonhoon Kim[3], Yoncheol Park[1], Hyun Jae Yoo[1], Wonsang Lee[1]
[1] Division of Polar Earth-System Sciences, Korea Polar Research Institute, Incheon, Korea
[2] Department of Geoinfomatic Engineering, Inha University, Incheon, Korea
[3] Department of Earth Science Education, Seoul National University, Seoul, Korea

Abstract The potential subglacial lake locations and melt water path ways can be simply determined from the hydraulic potential surface in the Antarctica. The hydraulic potential is usually calculated using ice thickness and bedrock topography. However, the current data sets of ice thickness and bedrock topography (e.g. BEDMAP2) are not accurate enough to predict correct subglacial lake locations in the David Glacier, Antarctica. In order to improve the quality of hydraulic potential estimates, we constructed a new high-resolution digital elevation model (DEM) by means of combining the Cryosat-2 measurements and the satellite optical images geostatistically. The Cryosat-2 has a disadvantage that the ground tracks are quite irregular over an area with rough topography so that the radar altimetry often fails to measure the elevations in topographic hollows. To overcome this limitation, we generate a relative elevation distribution from a single satellite optical image and a method called as "shape from shading" and combine it with the Cryosat-2 measurements using the simple Kriging with local mean. The new DEM model corresponds well with the ICESat measurements. The improved DEM is used to map the hydraulic potential. As a result, the active subglacial lake David 1 (D1), already discovered by the ICESat measurements, has several hydraulic sinks indicating that the lake D1 is not a single lake. In addition, the ICESat tracks with large elevation change rates well agree with the potential subglacial lake locations. The GPS measurements for more than 5 months at two sites in the lake D1 also support this result.

Study area

- David Glacier
  - Smith et al. (2009) have observed 6 subglaical lakes in the David Glacier. D1 is the largest lake.

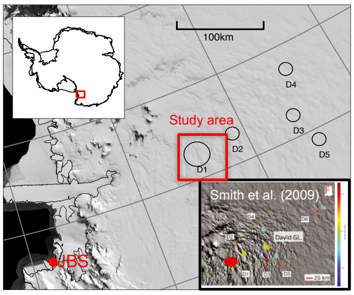


Figure 1 Location of study area. The D1-D6 indicate the locations of subglacial lakes identified by a previous research (Smith et al., 2009). JBS indicates the Jangbogo Station in the Terra Nova Bay. Red rectangle indicates the study area

DEM generation from Cryosat-2 and Landsat image

- Cryosat-2 SARin elevation measurements (2013-2014)
- Topography generation from a single Landsat image (Dec. 2013) using a shape from shading method Pentland (1990)
- Merging Cryosat-2 elevations and topography from Landsat
  - Remove a regional slope using 5th order polynomial fitting
  - Estimation of the linear relationship between the Cryosat-2 elevations and topography from Landsat
- Simple Kriging with local mean (Goovaert, 1997)

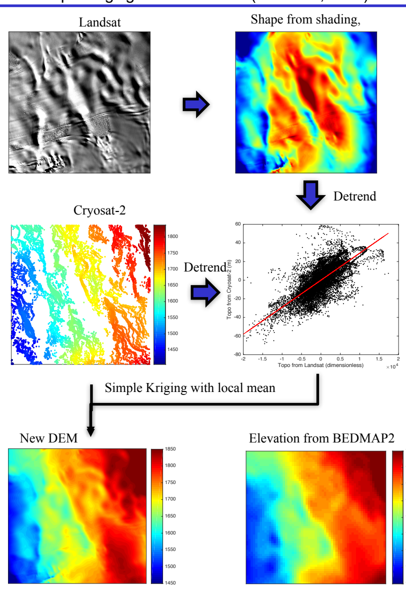


Figure 2 Procedure of DEM generation from Cryosat-2 and Landsat image

Ice thickness

- We use the ice thickness from BEDMAP2 currently.
- Enhancement of the quality of Ice thickness using the mass balance method (Morlighem et al., 2011): under construction

Hydraulic potential

- Shreve (1972)

$$P_h = \rho_w g z_b + \rho_i g z_i$$

- where ρ_w and ρ_i are density of water (1000kg/m^3) and ice (917kg/m^3), z_i and z_b are ice thickness and bedrock elevation with respect to geoid, and g is gravitational acceleration

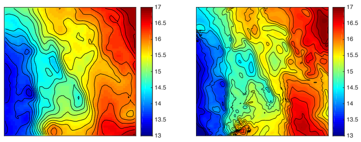
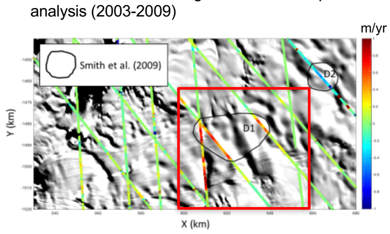


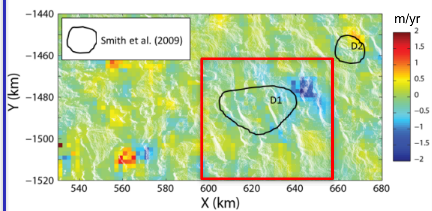
Figure 3 Comparison of the hydraulic potentials derived using (left) BEDMAP2 and (right) new DEM. The unit of hydraulic potential is MPa and the contour interval is 200 kPa.

Elevation changes from altimetry measurements

- ICESat
  - Linear elevation change rate from repeat track analysis (2003-2009)



- Cryosat-2
  - Linear elevation change rates estimated in 10 km * 10 km regions (2010-2014)



- Cryosat-2 does not detect the elevation changes in D1 clearly
  - The L2 product of SARin mode rarely contains the elevations on the concave area in this region.

Localized hydraulic potential lows

- Several localized hydraulic potential lows are identified near the lake D1.
- Hydraulic barriers (>100 kPa equivalent to >10m hydraulic head) divide the potential lows.
- The elevation changes measured by ICESat is correlated with the location of potential lows.
- The lake D1 probably consists of more than 5 small lakes.

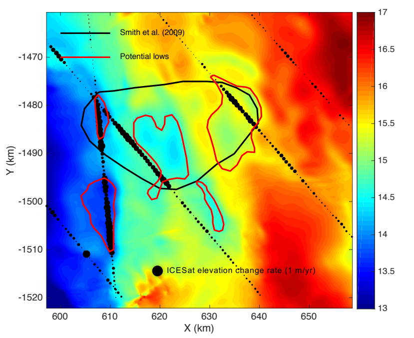


Figure 4 Localized hydraulic potential lows (red line). The color shading shows the hydraulic potential in MPa, derived using new DEM. The black circles indicate the elevation change rate from ICESat and the circle size denotes the absolute value of elevation change rate in the range of 0 m/yr and 1 m/yr.

In situ GPS observations

- GPS observations (2015)
  - Two GPSs in the lake D1: the elevation lowering of ~0.4 m/yr at a site (KGPS06) in D1 but no elevation change at another site (KGPS07) in D1
    => The lake D1 may be not a single lake.

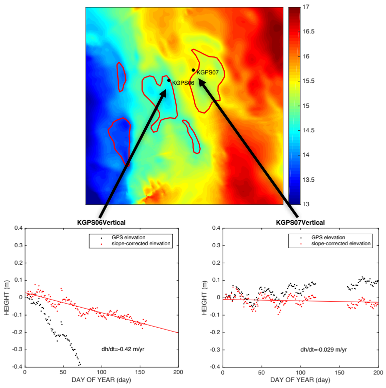


Figure 5 Elevation monitoring at GPS stations on the lake D1. The upper panel shows the location of GPS stations and the lower panels shows the elevation changes measured at KGPS06 (left) and KGPS07 (right). The effect of surface slope on the elevation change measured by GPS was corrected by leveling survey data.

- A GPS in the lake D2: the elevation lowering of ~0.6 m/yr (not shown here)

Dense GPS array installation

- Denser GPS array (2016~)
  - 12 GPS is recording since early 2016 => We could recover the GPS data next year.

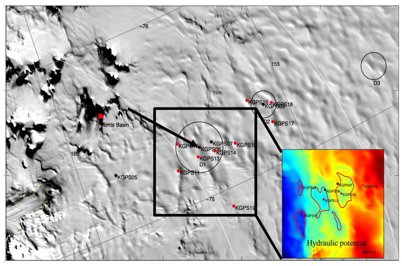


Figure 6 GPS stations on the lake D1 and D2 lakes. The black dot indicate the GPS sites operated during 2015. The red dot indicate the GPS sites installed in 2016 (the data will be recovered next year).

Summary

- We generate a high-resolution DEM using the Cryosat-2 and Landsat image.
- The relative topography from Landsat image successfully fills the gaps in the Cryosat-2 elevation measurements.
- Several localized potential lows are identified from the hydraulic potential map derived using new DEM.
- The elevation changes measured by ICESat is correlated with the location of potential lows.
- The in situ GPS measurements in the lake D1 represent the elevation change rates different site by site.
- Consequently, we suggest the lake D1 in the David glacier may consist of several small lakes.

Further researches

- Accurate mapping of bedrock topography is required: the ice thickness estimation based on the mass conservation (Morlighem et al., 2011) or dense ice radar survey.
- Currently operating GPS measurements on a dense GPS array might reveal the connections among the several potential lakes.

Reference

- Goovaert, P. (1997), *Geostatistics for Natural Resources Evaluation*, 496 pp., Oxford, New York.
- Morlighem, M., Rignot, E., Seroussi, H., Larour, E., Ben Dhia,H., and Aubry, D.: A mass conservation approach for mapping glacier ice thickness, Geophys. Res. Lett., 38, L19503,doi:10.1029/2011gl048659, 2011.
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