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Gravity changes in mid-west Greenland from GOCE gravity model and gradient data using ground and airborne gravity

Carl Christian Tscherning[1], Matija Herceg[2], Joanna Fredenslund Levinsen[3]

(1) University of Copenhagen, Niels Bohr Institute, Denmark, (2) University of Copenhagen, IGN, Denmark, (3) DTU Space, Denmark

Introduction

GOCE TRF (terrestrial reference frame) vertical anomalous gradients (Tzz) from two periods have been used to determine gravity anomalies changes in mid-west Greenland, where a large mass-loss has been detected using GRACE (Fig. 1). As additional data were used the GOCE DIR-3 model and ground gravity at the coast on solid rock, where no mass loss is expected.
The methods of Least-Squares Collocation (LSC) and the Reduced Point Mass (RPM) methods have been used, however only LSC included the ground data.

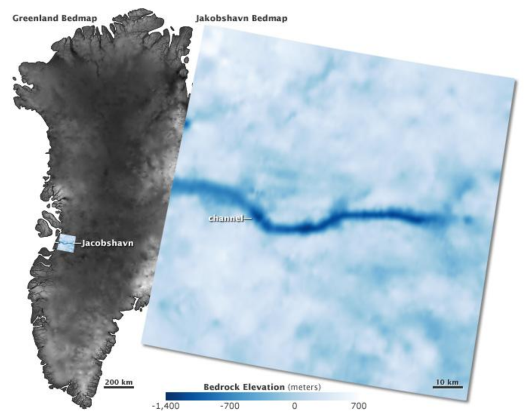

Figure 1: Greenland and Jakobshavn Isbrae bedmap elevations. Figure credit:NASA Earth Observatory

Data used

In this study, we have used GOCE Tzz gravity gradient component data from two periods (from October 2010 to September 2011, and from October 2011 to September 2012) to predict gravity anomaly.
The GOCE DIR-3 [Brusima et al., 2010] model was also used in the remove-restore procedure, where the contribution from the DIR-3 model up to sph. harm. d/o 120 has been subtracted and later added back to the calculated gravity anomalies and GOCE gravity gradients.
In order to enhance the calculation of gravity anomalies, ground gravity from Western-Greenland [Kejlsø, 1958; Svejgaard 1959] was used. The data have been measured at sites (solid rock), where we do not expect any gravity change due to the mass changes (see Fig. 4).
Furthermore data from the airborne gravity survey project (GAP) 1991-1992 [Brozena et al., 1992] was compared to the DIR-3 model.

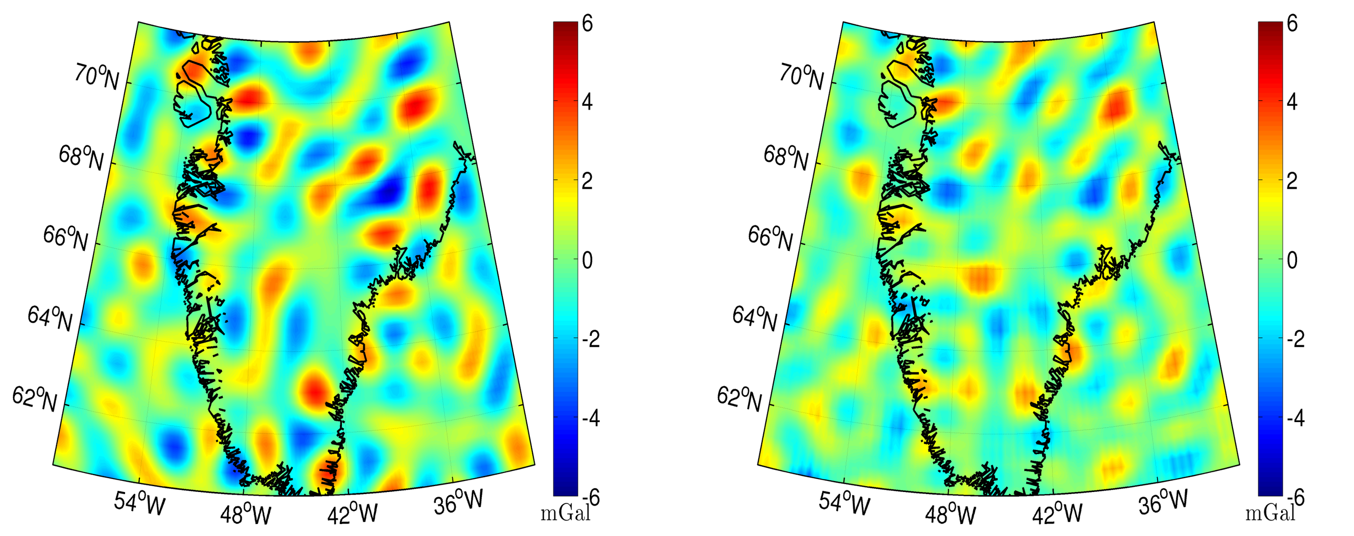

Figure 2: Comparison of predicted gravity anomaly found using LSC (left) and the RPM (right) respectively. The observation period is from 2011 to 2012.

Calculations

Using the gravity gradients, gravity anomalies have been computed at height of 2km from each of the two data sets using either LSC or RPM. The two methods give nearly identical results if only gradients are used (see Fig. 2). But the estimated error (from LSC) is between 12 and 15 mgal. This is much larger than the gravity change expected using the known mass-loss at the Jacobshavn Isbrae [Levinsen et al., 2013], which is approximately 2 mgal (corresponds to the ice height change of 50 m) for the period 04.08.2007 to 02.08.2008 (Fig 3.), and yearly trend is shown on figure 5..)

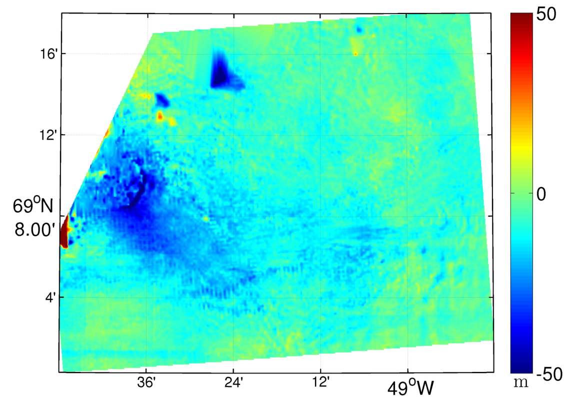

Figure 3: Surface elevation changes over Jacobshavn Isbrae drainage basin. Obtained by co-registering stereoscopic imagery from SPOT-5 to laser scanner. The observation period is from 04.08.2007 to 02.08.2008.

Results

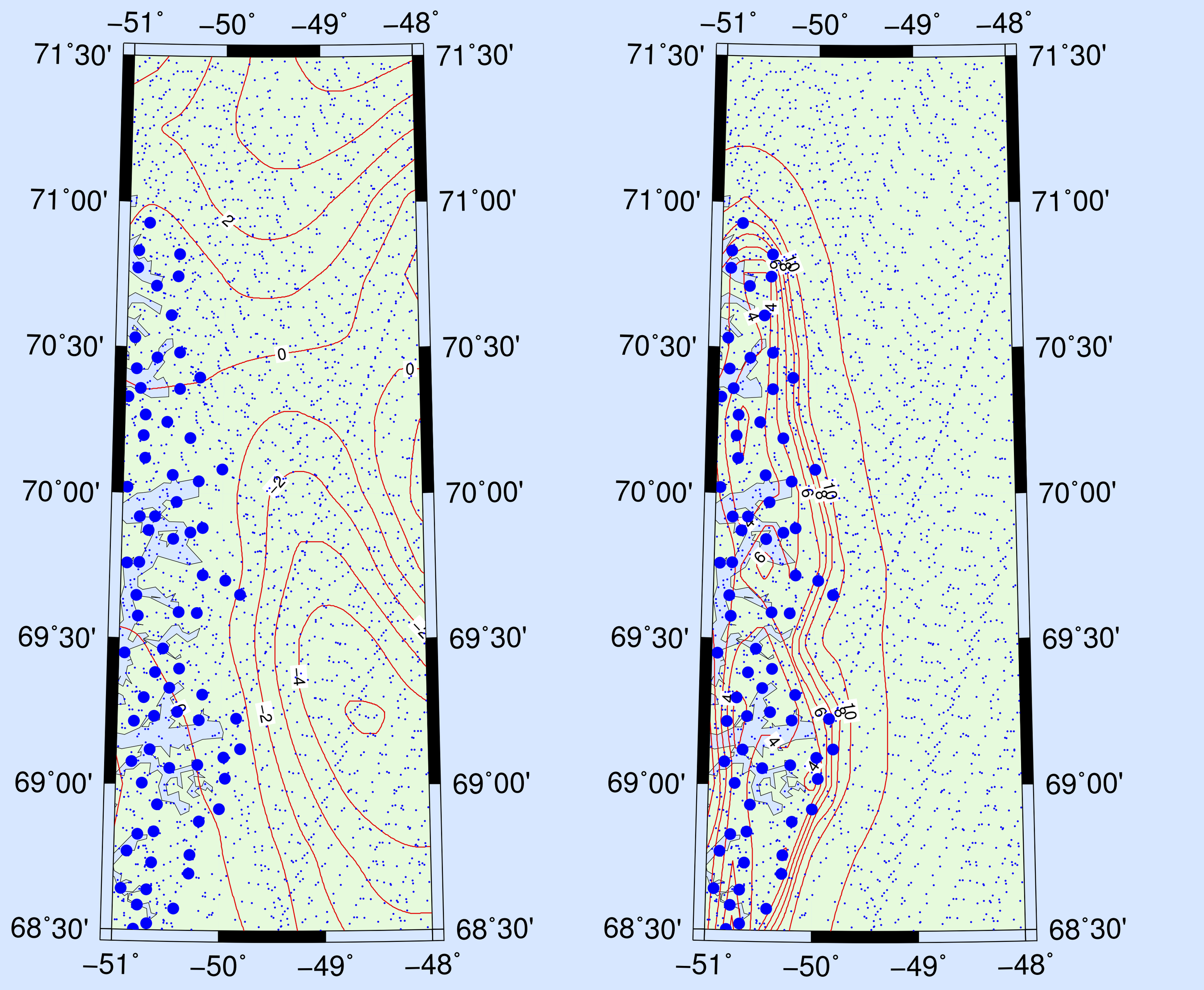

Figure 4: Differences between gravity anomalies (mgal) from 2011 to 2012 (left), and (right) error estimates of predicted anomalies (mgal). The location of GOCE data used is shown as small blue dots and ground gravity data as large blue dots.

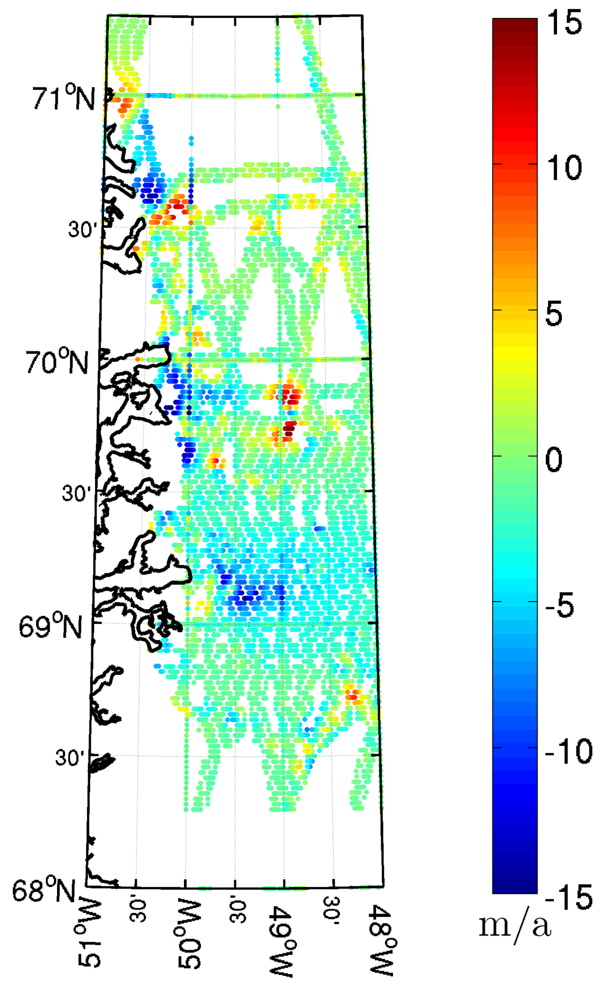

Figure 5: Surface elevation changes over Jacobshavn Isbrae. Obtained from ATM and PROMICE (2009-2012).

Results

The gravity anomaly differences vary from -4 to 2 mgal (Fig 4., left). It is negative, -2 mgal, (showing mass loss) around the Jacobshavn Isbrae (latitude 69°15', longitude 49°-50° W, where the yearly mass-loss has been estimated to correspond to -2 mgal (Fig 3.). The computed change range has estimated error from 2 to 10 mgal from West to East. This shows the capability of using GOCE Tzz and ground gravity to determine mass changes.

By introducing extra ground gravity observa-tions (108 values) from West Greenland the prediction error was significantly reduced close to the coast, see Fig. 4. The differences be-tween the gravity anomaly prediction for 2011 and 2012 are also shown in Fig. 4 (right).

Additional results

The GOCE DIR-3 model was also used to evaluate gravity values in the points of the Greenland airborne gravity survey performed in 1991 and 1992. The differences had a mean value of 0.9 and a standard deviation of 17.3 mgal for all of Greenland. In the South-West area the mean of the differences was 0.15 mgal and the standard deviation 7.14. This indicate that possibly no total mass loss has occurred in Greenland from 1992 to 2012.

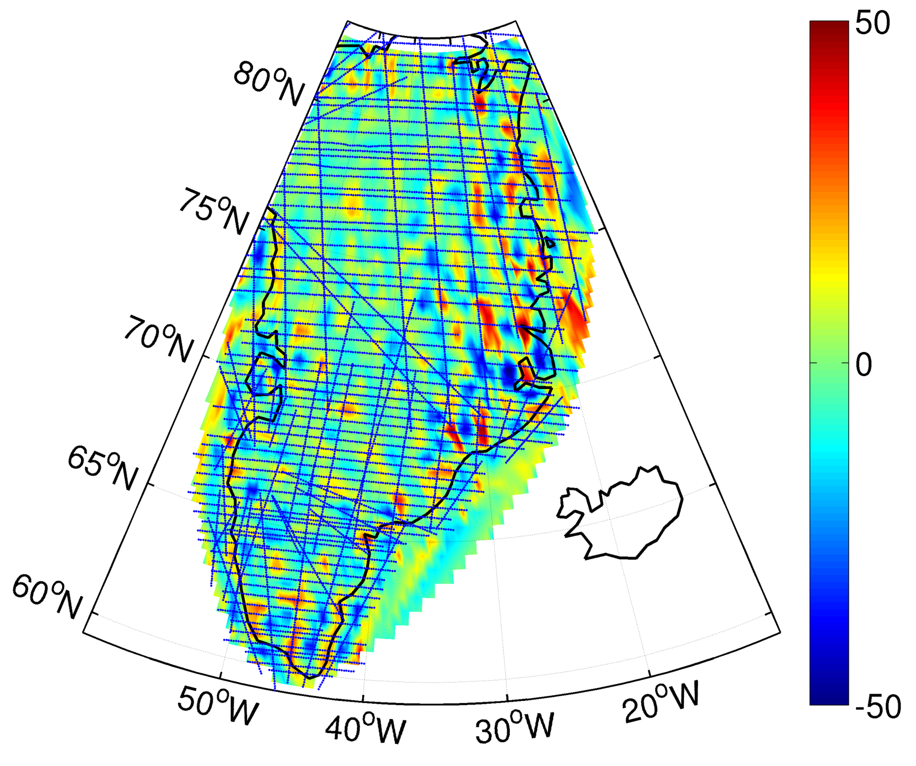

Figure 6: Differences of gravity anomalies calculated using the GOCE DIR-3 model with the observed GAP airborne gravity anomalies. Units are mgal.

Conclusions

- The use of GOCE data for the determination of mass changes is very difficult due to the data error of 5 to 10 mE, which propagates to an error of estimated ground gravity anomalies in an area like Greenland of 15-20 mgal. If gravity data located at points where no changes of gravity can be expected is added to the GOCE gradient data, improvement in the prediction of gravity anomaly changes caused my ice mass can be made. In this study, the largest mass changes have been detected close to the west Greenland cost, as it was reported by results based on GRACE [Sørensen [2010]. We have seen that mass loss of the expected order of magnitude for the period 2011-2012 in the Jacobshavn Isbrae area have been detected.

- Predicted ice mass loss inside the area of Jacobshavn Isbrae glacier and increase outside of the area was be verified using ATM data.
- Further improvement can be made by removing the gravity effect of topography from GOCE Tzz gradients.

- Improvements may be also expected by using data from the final part of the GOCE mission during 2013 where the satellite was in a lower orbit. - Gravity anomalies calculated from the GOCE DIR-3 solution and compared with existing airborne data from 1991 and 1992 indicates that the total mass changes may be zero in this 20 year period.

- Older high quality gravity data observed at points, where no mass changes are expected, may as shown be used to enhance the use of satellite gravity data (and to reduce prediction error) for the study of other phenomena like ground-water changes in other areas.

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cct@gfy.ku.dk