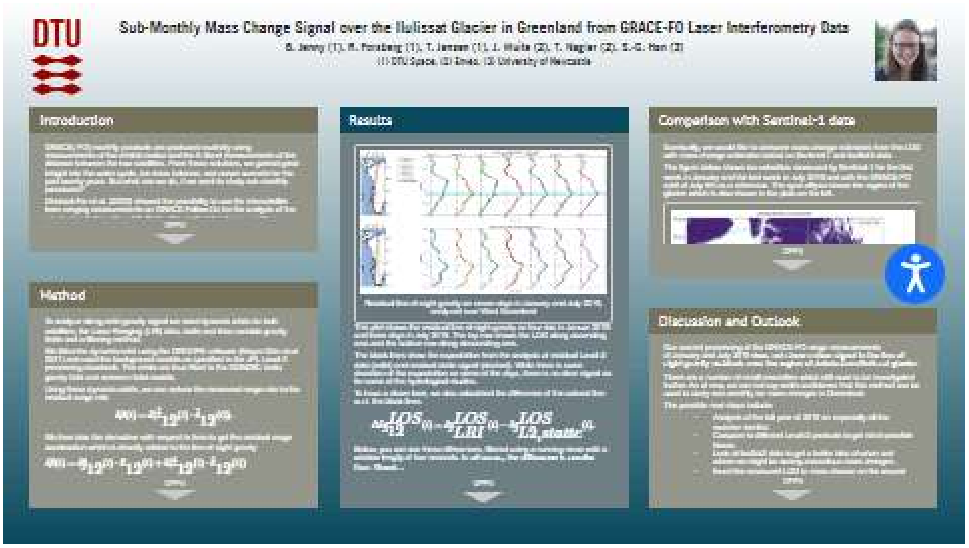
Sub-Monthly Mass Change Signal over the Ilulissat Glacier in Greenland from GRACE-FO Laser Interferometry Data



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INTRODUCTION

GRACE(-FO) monthly products are produced routinely using measurements of the orbital motion and the K-Band measurements of the distance between the two satellites. From these solutions, we gained great insight into the water cycle, ice mass balance, and ocean currents for the past twenty years. But what can we do, if we want to study sub-monthly processes?

Ghobadi-Far et al. (2022) showed the possibility to use the intersatellite laser ranging measurements on GRACE Follow-On for the analysis of the gravity signal along the orbit. So far, this method has been used to e.g. study the mass change in the Amazon or to study storm surges over the northern sea (Weigelt et. al. 2023).

In this study, we focus on the Greenland Ice Sheet and especially the region around Jakobshavn/Ilulissat glacier.

METHOD

To analyze along-orbit gravity signal we need dynamic orbits for both satellites, the Laser Ranging (LRI) data, static and time-variable gravity fields and a filtering method.

We fitted the dynamic orbit using the GROOPS software (Mayer-Gürr et.al 2021) and used the background models as specified in the JPL Level-2 processing standards. The orbits are thus fitted to the GGM05C static gravity field and common tidal models.

Using these dynamic orbits, we can reduce the measured range rate to the residual range rate

$$\delta\dot{\rho}(t) = \delta(\dot{\vec{x}}_{12}(t) \cdot \vec{e}_{12}(t)).$$

We then take the derivative with respect to time to get the residual range acceleration which is directly related to the line-of-sight gravity

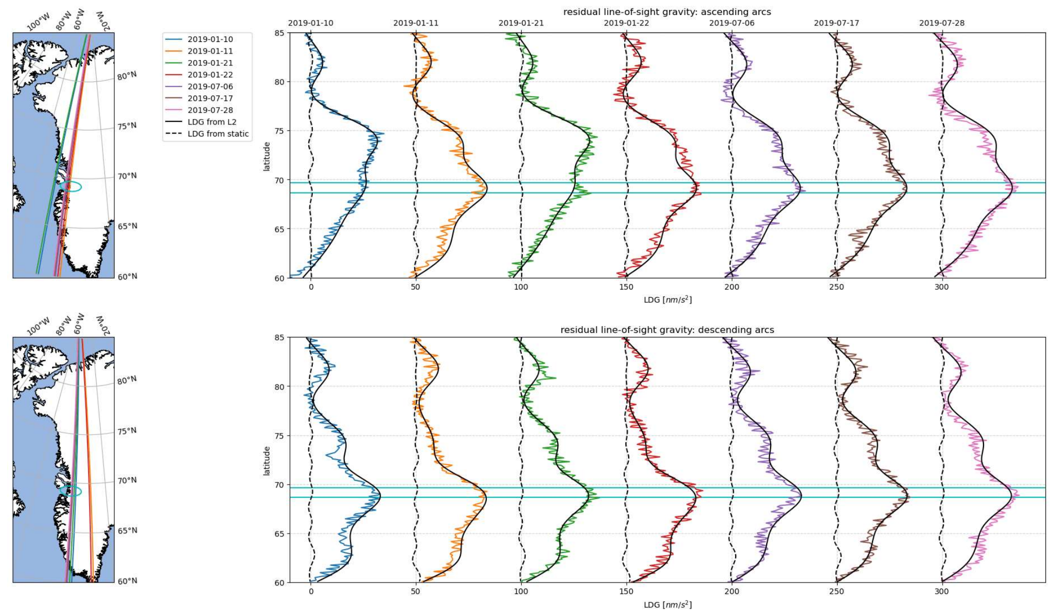
$$\delta\ddot{\rho}(t) = \delta\vec{g}_{12}(t) \cdot \vec{e}_{12}(t) + \delta(\dot{\vec{x}}_{12}(t) \cdot \dot{\vec{e}}_{12}(t)) = \delta g_{12}^{LOS}(t) + \Delta_0(t).$$

The second term is the residual centrifugal acceleration and it has been shown by Weigelt (2017) that this contributes to the range acceleration mainly at the low-frequency part of the spectrum. We are using the transfer function developed by Ghobadi-Far et. al. (2018) to extract the residual line-of-sight gravity (LGD) from the residual range acceleration.

We compare the LGD to the expectation of the Level-2 gravity fields. This is done by calculating the residual gravity signal along the dynamic orbits using the monthly gravity field models ITSG-Grace2018 up to d/o 96 and reducing them by the static model GGM05C. To account for the static signal, we also compute the LGD based on GOCO06S above d/o 97 reduced by the GGM05C.

All gravity field models were downloaded from the ICGEM website.

RESULTS



Residual line-of-sight gravity on seven days in January and July 2019, analyzed over West Greenland

This plot shows the residual line-of-sight gravity on four das in Januar 2019 and three days in July 2019. The top row shows the LGD along ascending arcs and the bottom row along descending arcs.

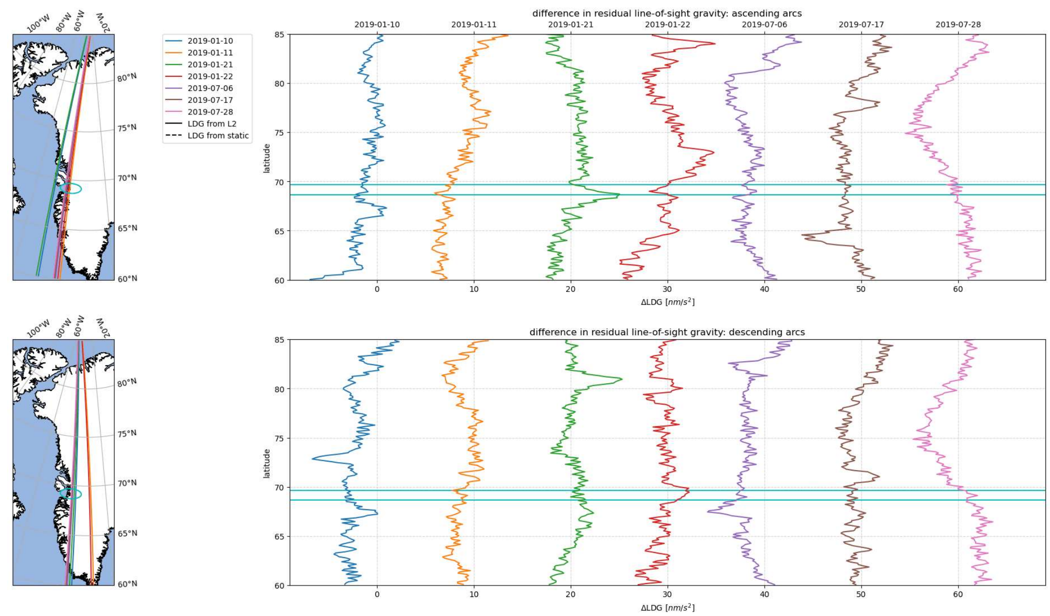
The black lines show the expectation from the analysis of residual Level-2 data (solid) and residual static signal (dashed). While there is some deviation of the expectation on some of the days, there is no clear signal as for some of the hydrological studies.

To have a closer look, we also calculated the difference of the colored line w.r.t. the black lines

$$\Delta\delta g_{12}^{LOS}(t) = \delta g_{LRI}^{LOS}(t) - \delta g_{L2,static}^{LOS}(t).$$

Below, you can see these differences, filtered using a running mean with a window length of four seconds. **In all cases, the difference is smaller than 10nm/s^2.**

On July 28th, both arcs show similar pattern with a negative anomaly around 75^{o}N. Both the ascending arc on January 11th and the descending arc on January 10th show a negative values for latitudes belwo 72^{o}N which is not the case ten days later.

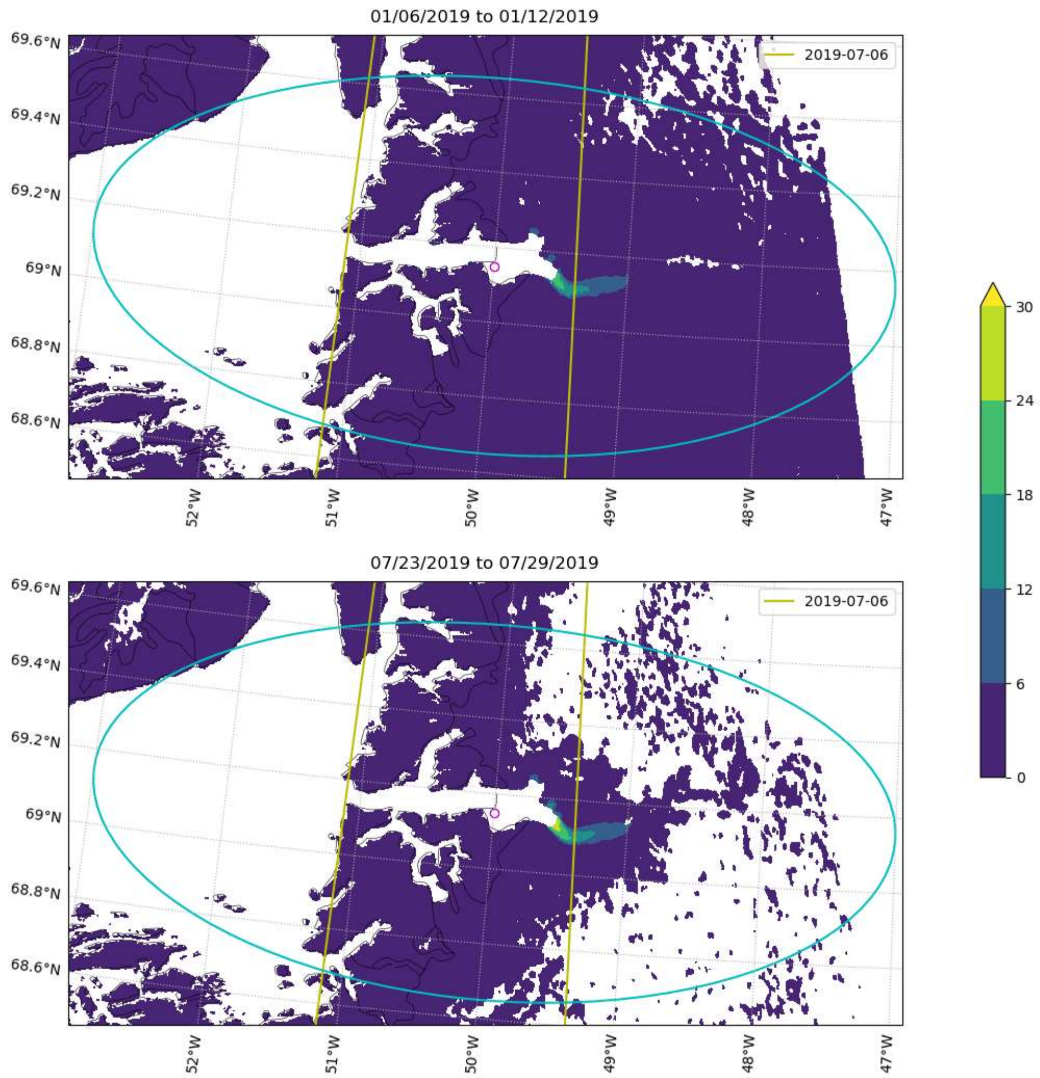


Difference in LDG on seven days in January and July 2019, analyzed over West Greenland

COMPARISON WITH SENTINEL-1 DATA

Eventually, we would like to compare mass change estimates from the LGD with mass change estimates based on Sentinel-1 and IceSat2 data.

The figure below shows ice-velocities measured by Sentinel-1 for the first week in January and the last week in July 2019 and with the GRACE-FO orbit of July 6th as a reference. The cyan ellipse shows the region of the glacier which is also shown in the plots on the left.



Ice velocities from Sentinel-1 data

DISCUSSION AND OUTLOOK

Our current processing of the GRACE-FO range measurements of January and July 2019 **does not show a clear signal in the anomalous line-of-sight gravity residuals over the region of Jakobshavn/Ilulissat glacier**.

There are a number of small anomalies which still need to be investigated further. Further work is needed to be able to look at sub-monthly ice mass changes through this method.

The next steps include:

- Analysis of the full year of 2019 an especially all the summer months
- Compare to different Level-2 products to get rid of possible biases
- Look at IceSat2 data to get a better idea of when and where we might be seeing anomalous mass changes.
- Use IceSat2 data to estimate LGD signal at orbit height
- Invert the measured LGD to mass change on the ground which then can be compared to mass change from height and velocity changes.

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I am Barbara Jenny, a PhD student at the Technical University of Denmark and I specialize in Satellite Gravimetry with a focus on the cryosphere and next generation missions.

In my presentation, I am discussing the possibility of studying along track gravity residuals to extract sub-monthly signal over West Greenland. I am presenting the first results looking at January and July 2019. If you are interested in sub-monthly ice mass change or would like to discuss which region and time period I should look at next, please stop by my poster and have a chat with me or contact me via e-Mail.

TRANSCRIPT

ABSTRACT

GRACE(-FO) monthly products are produced routinely using measurements of the orbital motion and the K-Band measurements of the distance between the two satellites. From these solutions, we gained great insight into the water cycle, ice mass balance, and ocean currents for the past twenty years. But these monthly solutions are not the full picture. More information about sub-monthly processes can be extracted from the Level-1B data. Currently, the data used to extract the GRACE-FO orbits contains the K-band ranging (KBR) measurements but not the data from the Laser Ranging Interferometer (LRI). It has been shown several times that using orbits and LRI data, one can calculate residual Line-of-sight gravity signals. These studies mainly focused on the Amazon River region to study changes in the water storage which happen faster than over one month.

We use this approach to look at the changes in the speed of the llulissat glacier in Greenland. This is one of the biggest and fastest glaciers in Greenland and significant changes in its speed can happen over as little as one week during exceptional summer melt periods, as demonstrated a.o. by SAR interferometry. We demonstrate how LRI can help to give further constraints on when these changes in speed happen, within the restrictions of the limited spatial resolution.

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