



Spatio-temporal evolution of the Greenland ice sheet and associated deformation of the Earth: a multi-technic geodetic approach

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Context & Challenges

The melting of the Greenland ice sheet is one of the **major contributor of the global sea level rise** and is continuously monitored. The evolution of the Greenland Ice Sheet (GIS) is an important indicator of climate change and driver of sea level rise. However, providing accurate GIS ice mass balance **remains a challenge today**.

Goals

Combine **various geodetic data** and climate model to obtain better constraints on the ice mass variation.

Separation of the **different sources** of deformation

Isolate **GIA** signal in **GRACE** and **GNSS** data

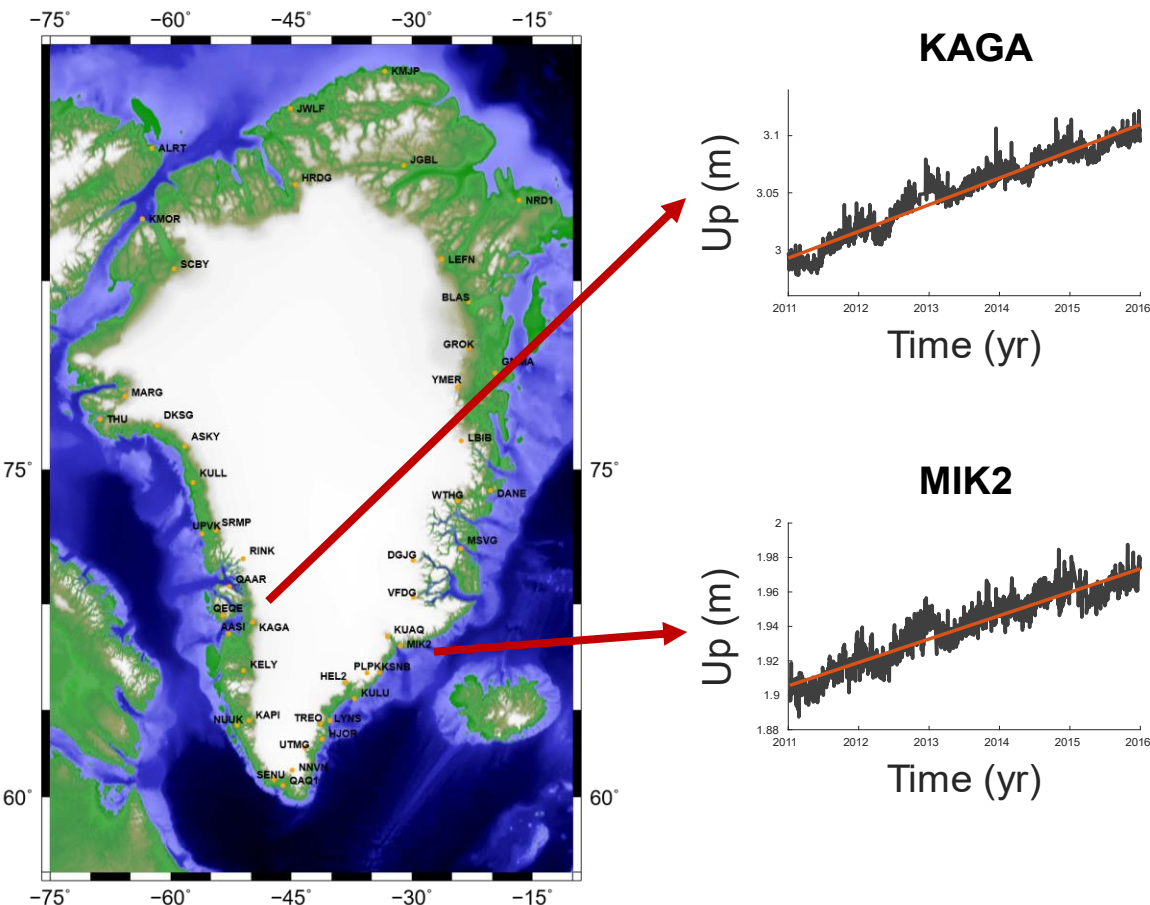
Recent ice melting

Glacial isostatic adjustment (GIA)

Data

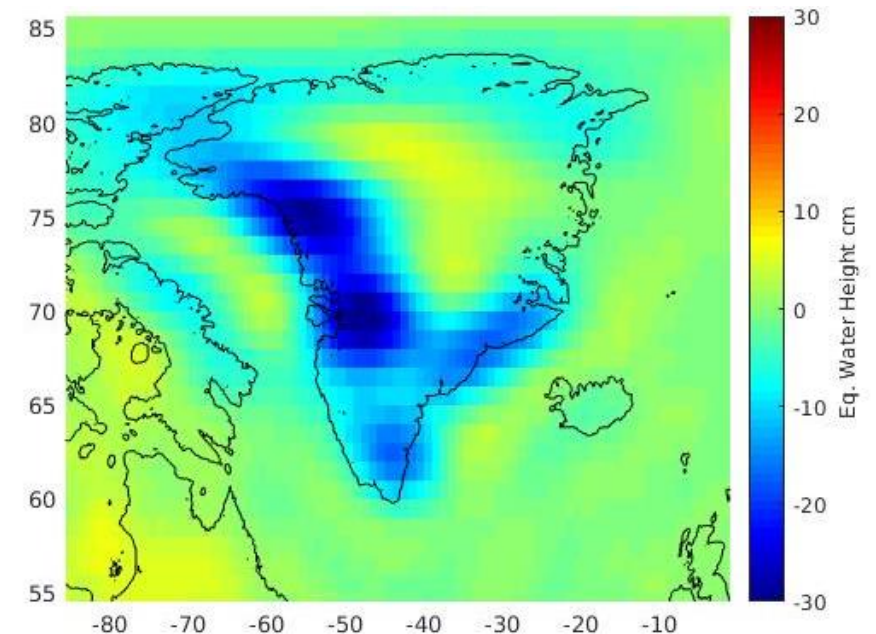
The time-span **2011-2015** offers a unique opportunity to compare mass loss estimates from Cryosat2 and GRACE, with an overall good quality of both datasets over this time period.

GNSS : 49 stations in the 2011-2015 period



GRACE : spatio-temporal mass variations

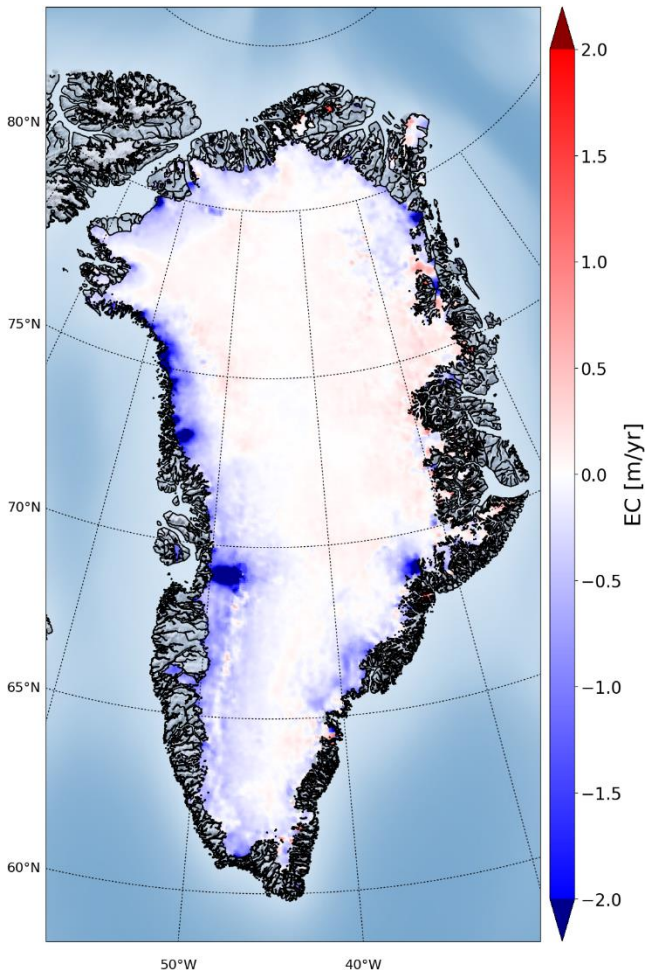
GRACE trend between 2011 and 2015



GRACE data, using **MSSA filtering method** applied to the spherical harmonic gravity field of 5 different GRACE solutions from Prévost, P. *et al* 2019

Altimetry data

Icesheet Simonsen, S. B., & Sørensen, L. S.
2017, Sørensen, L. S., et al 2018 : spatio-temporal
variations of surface elevations from Cryosat mission



2011-2015 volume
rate changes from
CryoSat-2 mission

Peripheral Glaciers, Hugonnet R, et al 2020:

All ASTER, ArcticDEM and REMA DEMs intersecting
glaciers worldwide:

- Stereo and bias-corrections
- 5 million CPU hours DEM coverage equivalent to 20 times the land area on Earth
- High resolution surface variations

The IMAU Firn densification model, FDM Noël, B. et al., 2015 & Steger, C.R. et al. 2017:

To convert the volume rate into mass, we consider
the firn compaction using the IMAU FDM model that
use RACMO climate model

Modelling Earth deformation

Load : CryoSat-2 and
peripheral glaciers mass
variations

HS decomposition



Decomposition of mass
variations into spherical
harmonics (SH) coefficients
up to degree 2700

$$\sigma_n^m$$

$$V_n^m = \frac{4\pi G a}{2n+1} \sigma_n^m$$


HS coefficients of the load
potential due to the
gravitational attraction of
the ice mass V_n^m

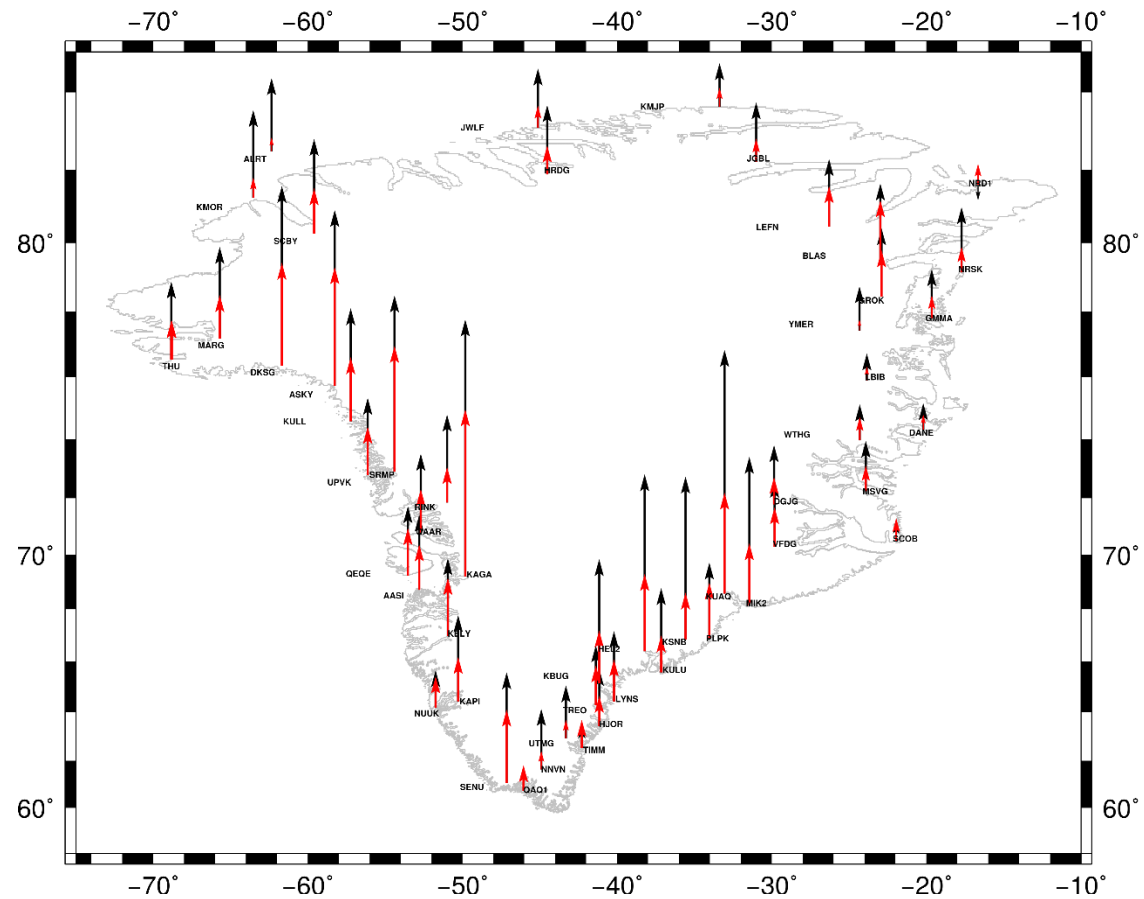
Load Love number h_n
compute for a 1D PREM
+ CRUST1 Earth model



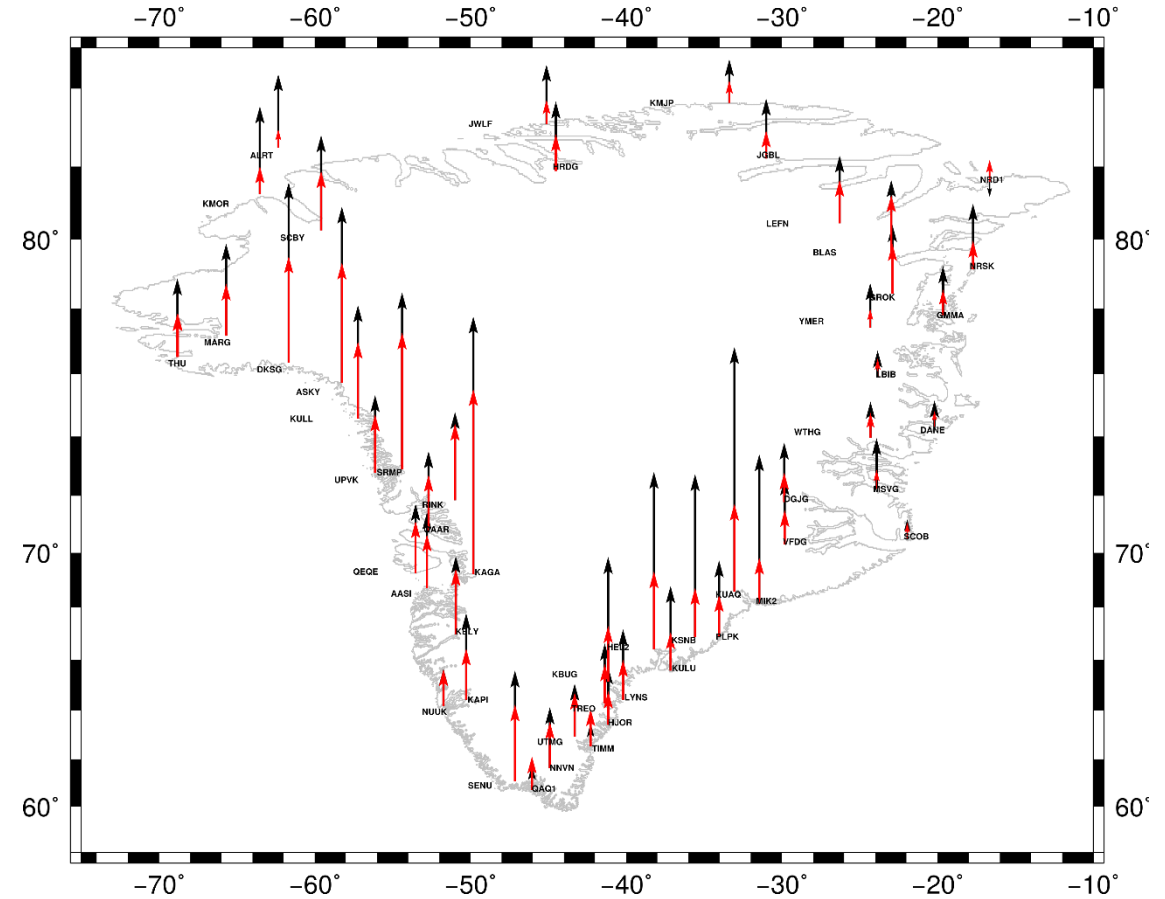
Radial displacement:

$$u_r(a, \theta, \varphi) = \frac{1}{g_0} \sum_{n=1}^{\infty} \sum_{m=-n}^n V_n^m h_n Y_n^m$$

Altimetry vs GNSS



Model with FDM



Model with average density = 850 kg/m^3

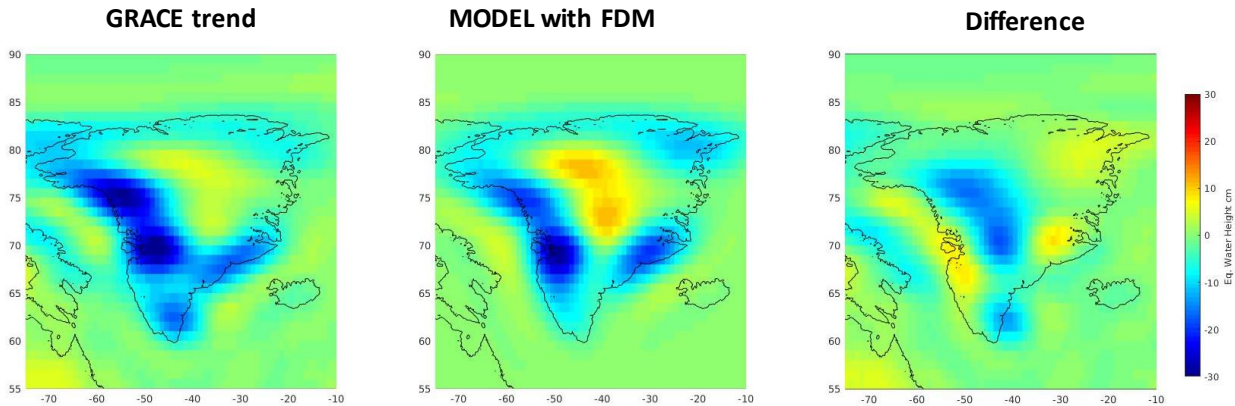
$\uparrow$ 1cm/yr $\uparrow$
 GNSS MODEL

Altimetry vs GNSS

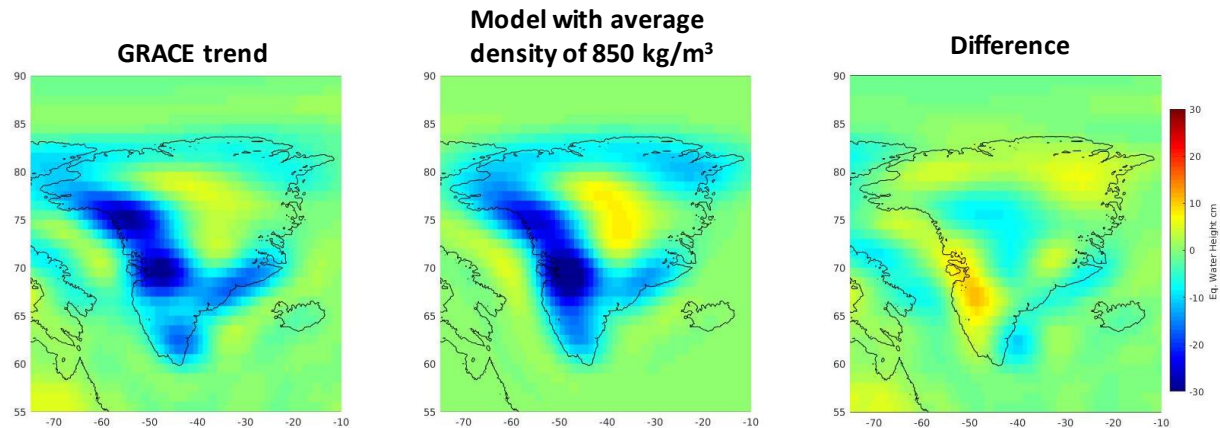
- ❄ In both models most of displacements predicted using altimetry data underestimate GNSS displacements.
- ❄ Other differences can be due to a lack of resolution in the deformation modelling which cannot fully account for peripheral glaciers melting
- ❄ Many differences between GNSS observations and altimetry predictions, up to a few mm/yr, are well explained by GIA models.
- ❄ But there are large uplift rates from GNSS in the southeast region, with differences with altimetry predictions above 1cm/yr.

Altimetry vs GRACE

Model with FDM



Model with average density = 850 kg/m^3



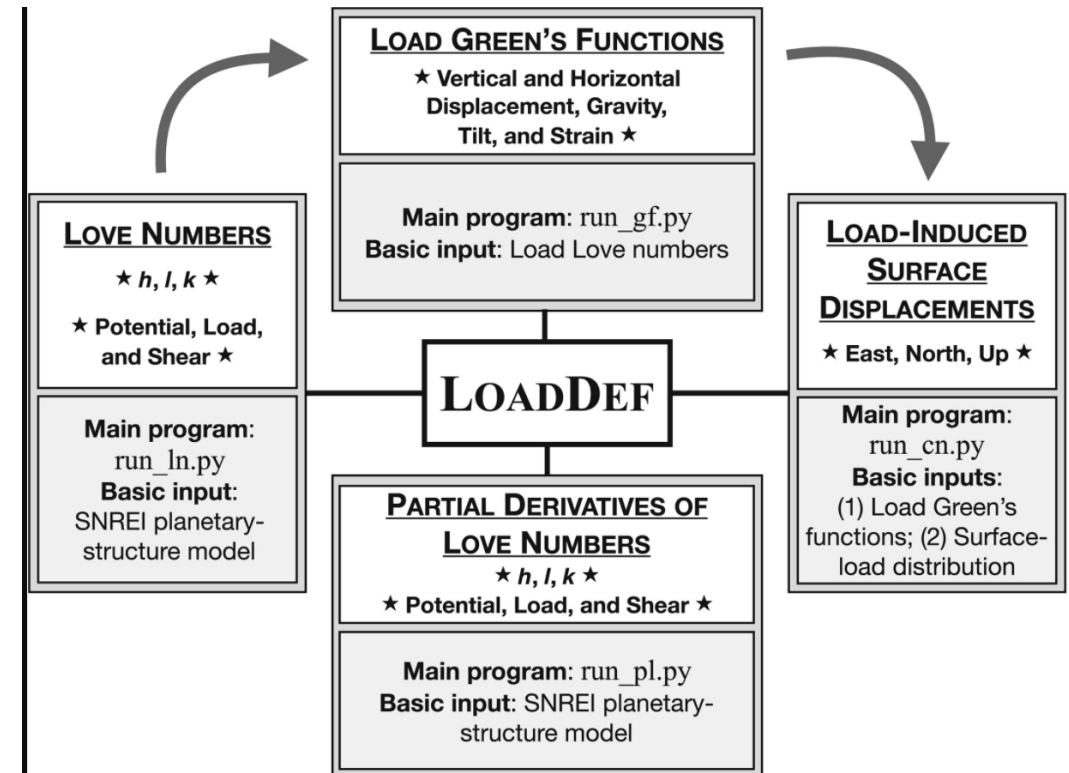
- ✈ The model **with FDM**, underestimates a lot the ice loss in the southeast and central regions.
- ✈ We can see that if we take a constant density of 850 kg/m^3 the predicted signal using altimetry data is closer to the GRACE signal.
- ✈ Discrepancies could be due either to a flaw in the altimetry model (inaccuracies in observations or FDM) or to GIA.

Conclusion

- ✈️ GNSS, altimetry and GRACE data are not **directly** comparable in Greenland and datasets should be combined carefully, due to the different applied corrections and the different resolutions in time and space.
- ✈️ Understanding why **GNSS** observations show a strong signals in certain regions **that neither the altimetry nor GRACE** detect is of importance.
- ✈️ Due to the lack of resolution in radar altimetry, it is necessary to account for **peripheral glaciers**.
- ✈️ We aim to separate different sources of deformation by combining the different types of data with different resolutions.

What's next ?

- **Use LoadDef**, Martens, H. R., *et al* (2019). code to compute local effects of melting in earth deformation.
- **Calibrate** altimetry data with GRACE data to estimate vertical velocities.
- Investigate possible constraints on the **short-term rheology** of the mantle.



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