An integrated approach for estimating global isostatic adjustment, land ice, hydrology and ocean mass trends within a complete coupled Earth system framework

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1. Introduction to the GlobalMass project

Motivation:

- Future sea level rise (SLR) is one of the most serious consequences of climate change.
- Understanding the drivers of past sea level change is crucial for improving predictions.
- SLR integrates many Earth system components including oceans, land ice, terrestrial water storage, as well as solid Earth effects.
- Traditionally, each component has been tackled separately, which has often led to inconsistencies between discipline-specific estimates of each part of the sea level budget.
- Our project aims at producing a physically-based, data-driven solution for the complete coupled land-ocean-solid Earth system that is consistent with the full suite of observations, prior knowledge and fundamental geophysical constraints.

Approach:

- Global data-driven solution for glacial isostatic adjustment (GIA) based on mass changes from the Gravity Recovery And Climate Experiment (GRACE) mission and vertical land motions from permanent GPS stations
- Combination of in-situ and satellite observations with prior information on physical principles such as mass conservation and characteristic spatial and temporal length scales within a Bayesian Hierarchical Model (BHM)
- Simultaneous global and consistent partitioning of the integrated SLR signal into its steric (thermal) and barystatic (mass) component for the satellite era within the BHM. The latter component is induced by hydrological mass trends and melting of land ice.
- Re-evaluation of the 20th Century sea level record
- The BHM was tested on Antarctica and will be further developed in this project to tackle geophysical, computational, and statistical challenges on a global scale

2. Data

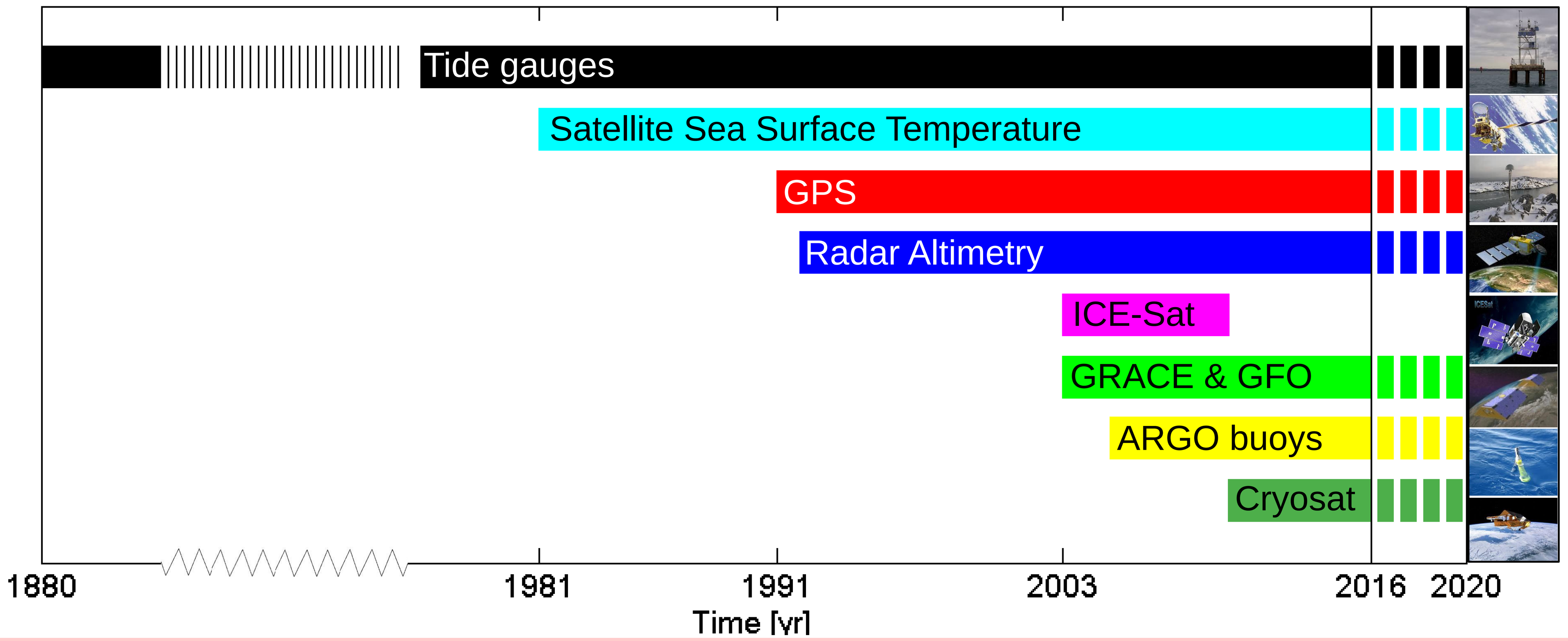

Figure 1: Temporal coverage of the observations that will be merged in the statistical framework. Their combination with model-derived spatial and temporal length scales can be used to separate different geophysical processes.

Challenges:

- Volume, diversity and uncertainty of data sets.
- In-situ and satellite measurements exhibit various spatial resolutions.
- The data sets are not consistent with each other or the integrated sea level signal.

3. Methodology: a Bayesian Hierarchical Model (BHM)

Global mean sea level (GMSL) can be separated in various individual sources:
GMSL = Steric + Mass = Argo + GRACE (+GIA) = Altimetry; Mass = Ice + Hydrology

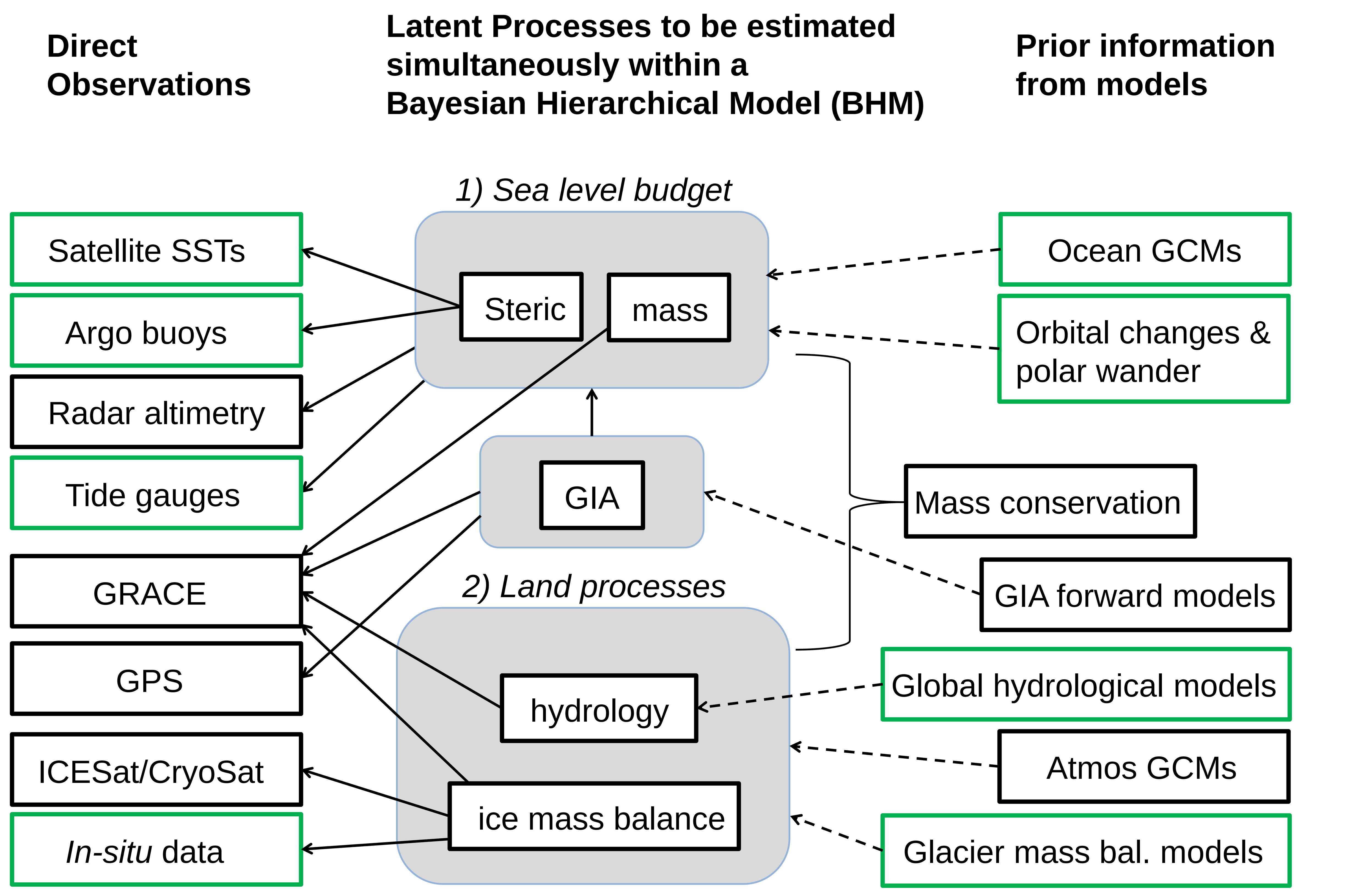

Figure 2: Schematic diagram showing the links between the observations, the latent processes, and the main priors that can be used to aid source separation. The boxes in green indicate data sets and models that have not been used in the existing Bayesian Hierarchical Model (BHM) developed for Antarctica (Zammit-Mangion et al., 2015).

4. Examples from Antarctica

GRACE, altimetry, and GPS data have been combined with prior information that incorporates the physics of the coupled Earth system such as conservation of mass and characteristic length scales of different processes in both space and time, e.g. from MODIS, InSAR, RACMO, and a firn model. The BHM was applied to solve simultaneously for a) glacial isostatic adjustment (GIA), b) ice dynamics, and c) surface mass balance (SMB; c.f. Fig. 2).

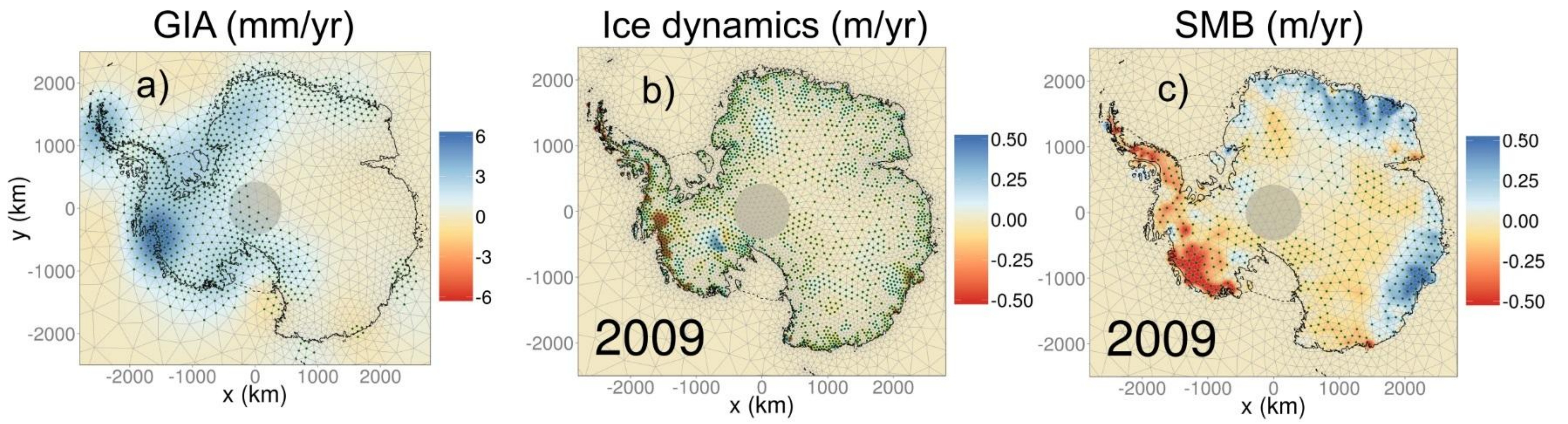

Figure 3: Separation of geophysical signals in Antarctica into a) GIA, b) ice dynamics, and c) surface mass balance (SMB) using the Bayesian Hierarchical Model (BHM). In a) the elastic model REAR has been used to correct GPS data. Figures are taken from Martín-Español et al. (2016).

5. Conclusions and outlook

The Bayesian Hierarchical Model (BHM) has been tested on Antarctica and showed that the three processes (i) surface mass balance, (ii) ice dynamics, and (iii) GIA can be successfully separated. In the GlobalMass project, we aim in separating five latent processes based on satellite and in-situ data combined with prior information from geophysical models (c.f. Fig. 2).

Outlook on the GlobalMass project

- Five year ERC project (started in 08/2016)
- Aim 1: developing the methodology and software to undertake multi-variate spatio-temporal modelling at a global scale.
- Aim 2: estimating a completely data-driven solution of GIA that is consistent with the full suite of observations and physical principles, such as mass and volume conservation. The solution can be used to test GIA simulations from forward modelling, which exhibit high uncertainties due to poorly known lower mantle velocity, ice loading histories and the 3-dimensional structure of the Earth.
- Aim 3: closing the sea level budget for the last four decades using sea surface temperature and satellite altimetry data, as well as re-evaluating the 20th Century sea level rate for which tide gauge data only provide spatially limited information.
- Aim 4: estimating spatially distributed land ice mass balance for the last three decades making use of a suite of satellite observations (e.g., ICE-Sat, CryoSat, GRACE and its follow-on missions) and in-situ glacier mass balance data.
- Aim 5: estimating land hydrology trends for the last two decades and assessing their contribution to global mean sea level (GMSL).

Updates and further information about the project can be found at https://www.researchgate.net/project/Global-ice-and-ocean-mass-trends.

References

Martín-Español, A., et al. (2016), Spatial and temporal Antarctic Ice Sheet mass trends, glacio-isostatic adjustment, and surface processes from a joint inversion of satellite altimeter, gravity, and GPS data, J. Geophys. Res. Earth Surf., 121, 182–200, doi:10.1002/2015JF003550

Schoen, N., A. Zammit-Mangion, J. C. Rougier, T. Flament, F. Rémy, S. Luthcke, and J. L. Bamber (2015), Simultaneous solution formass trends on the West Antarctic Ice Sheet, The Cryosphere, 9(2), 805–819, 10.5194/tc-9-805-2015

Zammit-Mangion, A., J. Rougier, N. Schoen, F. Lindgren, and J. Bamber (2015), Multivariate spatio-temporal modelling for assessing Antarctica's present-day contribution to sea-level rise, Environmetrics, 26(3), 159–177, 10.1002/env.2323

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