Geophysical Research Abstracts
Vol. 17, EGU2015-6721, 2015
EGU General Assembly 2015

Antarctic ice sheet mass loss, glacio-isostatic adjustment and surface processes from ENVISAT, ICESat, CryoSat-2, GRACE and GPS

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Constraining past ice mass changes, identifying their cause(s) and determining rigorous error estimates, is important for closing the sea level budget and as an input for and test of numerical models. For the Antarctic ice sheet, considerable uncertainty remains between different methods and groups. Estimates obtained from altimetry, gravimetry, and mass-budget methods can yield conflicting results with error estimates that do not always overlap, while the, commonly adopted, use of different forward models to isolate and remove the effects of glacio-isostatic adjustment (GIA) and surface mass balance (SMB) processes introduces another source of uncertainty which is hard to quantify. To address both these issues, we present a statistical modelling approach to the problem. We combine the observational data, including satellite altimetry, GRACE, GPS and InSAR, and use the different degrees of spatial and temporal smoothness to constrain the underlying geophysical processes. This is achieved via a spatio-temporal Bayesian hierarchical model, employing dimensionality reduction methods to allow the solution to remain tractable in the presence of the large number (> 10̂7) of observations involved. The resulting trend estimates are only dependent on length and smoothness properties obtained from numerical models, but are otherwise entirely data-driven. As a consequence, the solutions provide a valuable independent test of the forward models.

Here, we present the annually-resolved spatial fields for i) dynamic ice loss, ii) SMB anomaly, iii) firn compaction and iv) (the time invariant) GIA, using a combination of GRACE, ICESat, ENVISat, CryoSat 2 and GPS vertical uplift rates, for 2003-2013. The elastic flexure of the crust is also determined simultaneously. We focus here primarily on the mass trends rather than solid earth effects. We obtain a mean rate of -97+-16 Gt/yr for the 11 year period with a statstically significant positive trend for East Antarctica and negative values for the WAIS and Peninsula. We present the spatial pattern of evolving dynamic ice loss in these areas and contrast that with a significant positive SMB anomaly in East Antarctica since 2009 and other parts of the ice sheet. We also compare our SMB anomalies with those from the regional climate model, RACMO-2.3 to test its ability to capture the spatio-temporal structure of inter-annual variability in snowfall.