GREENLAND INLAND ICE MELT-OFF: ANALYSIS OF GLOBAL GRAVITY DATA FROM THE GRACE SATELLITES

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ABSTRACT

This paper gives an introductory analysis of gravity data from the GRACE (Gravity Recovery And Climate Experiment) twin satellites. The data consist of gravity data in the form of 10-day maximum values of 1° by 1° equivalent water height (EWH) in meters starting at 29 July 2002 and ending at 25 August 2010. Results focussing on Greenland show statistically significant mass loss interpreted as inland ice melt-off to the SE and NW with an acceleration in the melt-off occurring to the NW and a possible deceleration to the SE. Also, there are strong indications of a transition taking place in the mass loss in Greenland from mid-2004 to early 2006.

Index Terms— Regression analysis, statistical significance, temporal maximum autocorrelation factor analysis.

1. INTRODUCTION

Gravity data from the GRACE (Gravity Recovery And Climate Experiment) twin satellites launched in March 2002 with an expected life time of five years are analyzed by regression analysis and a temporal extension to principal component analysis called (temporal) maximum autocorrelation factor analysis. GRACE maps the Earth's gravity fields by making accurate measurements of the distance between the two identical spacecrafts (flying approximately 220 km apart and 500 km above the Earth in a polar orbit), using GPS and a microwave ranging system. It provides scientists from all over the world with an efficient and cost-effective way to map the Earth's gravity fields with unprecedented accuracy. The results from this mission yields crucial information about the distribution and flow of mass within the Earth and its surroundings. The gravity variations that GRACE studies include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the Earth. GRACE is a joint partnership between the National Aeronautics and Space Administration (NASA) in the United States and Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) in Germany, see http://www.csr.utexas.edu/grace/overview.html. Gravity field changes are related to mass changes and as a rule of thumb 2.4 cm of EWH change corresponds to 1 μGal gravity change, [4].

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2. DATA

Gravity data in the form of 10-day maximum values of 1° by 1° (the footprint of the measurements is actually around 400 km) equivalent water height (EWH) in meters are downloaded from http://grgs.obs-mip.fr/index.php/fre/Donnees-scientifiques/Champ-de-gravite/grace/release02, [1]. The EWH data consisting of 281 images with 180 rows and 360 columns each, span the period from 29 Jul 2002 to 25 Aug 2010. There are some gaps in the time series, fourteen 10-day periods are missing, see the above URL.

3. METHODS

Six interesting locations in Greenland were chosen for detailed investigation, Melville Bay, Upernavik and Ilulissat/Jakobshavn on the west coast, Kangarlussuaq, Helheim and Køge Bay on the east coast, see Figures 1 and 2. The global data set is analyzed by means of regression analysis and a latitude weighted orthogonal transformation; the weighting is applied to allow for the latitude dependent area of a 1° by 1° "spherical square". The transformation applied is much like principal component analysis in which variance is maximized. Here we instead maximize the temporal autocorrelation at each location in a temporal maximimum autocorrelation factor (MAF) analysis, [7, 8, 2, 5]. The maximum autocorrelation factors (MAFs for short) are found by solving the generalized eigenvalue problem

$$Sv = \lambda S_{\Delta} v,$$

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where S is the variance-covariance matrix of the data $x(t)$, t is time, and S_Δ is the variance-covariance matrix of the difference between the data and a (temporally) shifted version of the data $x(t + \Delta)$, followed by a projection of the data $x(t)$ onto the eigenvectors v; λ is the eigenvalue. Here the time lag Δ is chosen as one time step, i.e., 10 days. The (temporal) autocorrelation which is maximized is $1 - \lambda/2$.

4. RESULTS

The plots in Figure 2 show that mass, i.e., inland ice is lost at all six locations. Also, they indicate that to the NW this tendency is accelerating. In a regression model with cosines and sines of all frequencies from 1 cycle per year to the Nyquist frequency (1 cycle per 20 days), a constant, a linear and a quadratic term in time, the quadratic term (corresponding to acceleration) is negative and significant ($p < 0.0001$) in that area including the three locations Melville Bay, Upernavik, and Ilulissat/Jakobshavn. Also, the acceleration term is not significant for the SE region with the locations Kangarlussuaq, Helheim and Køge Bay.

Figure 3 shows the three MAF components with the highest temporal autocorrelations individually and combined as red, green and blue. Among other things these plots highlight regions in

- Greenland, Alaska and Antarctica,
- continental United States,
- South America including the Amazonas,
- central Africa,
- the NE part of the Indian Ocean (ringing artefacts relating to the 26 Dec 2004 earthquake/tsunami).

Figure 4 shows correlations between the first three temporal MAF components and the original data. The correlations are calculated over Greenland only (latitude $> 60°$ and $-75° <$ longitude $< -15°$). All three MAF components shown are strong indicators of a transition taking place in Greenland from mid-2004 to early 2006. The combined spatial and temporal behaviour of the MAF components in Figures 3 and 4 show

- MAF1: a strong transition from very high (~ 0.8) to extremely low correlation (~ -1.0) with EWH in the SE and the NW,
- MAF2: small and decreasing correlation with EWH to the NW from early 2005,
- MAF3: (since the spatial pattern is dark, i.e., negative to the SE) decreasing correlation with EWH from mid-2004 to early 2006 to the SE; negative but increasing correlation with EWH to the SE from 2007.

All three components are associated with little annual or other seasonal oscillation in Greenland.

5. CONCLUSIONS

The above analyses indicate tendencies of a mass loss to the SE and NW in Greenland with an acceleration occurring to the NW and a possible deceleration to the SE. These findings are supported by other studies, see [6, 3].

6. REFERENCES

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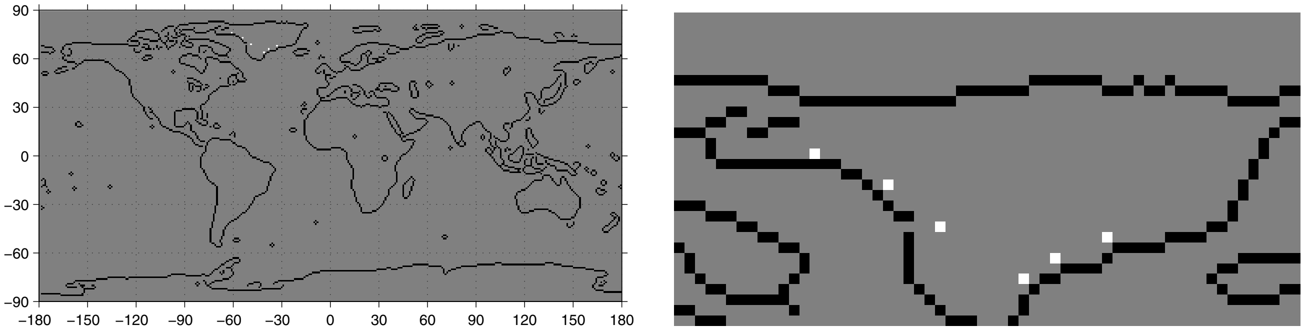

Fig. 1. Interesting locations in Greenland marked with small, white dots; on the west coast from north: Melville Bay, Upernavik, and Ilulissat/Jakobshavn; on the east coast from north: Kangarlussuaq, Helheim, and Køge Bay; zoom to the right.

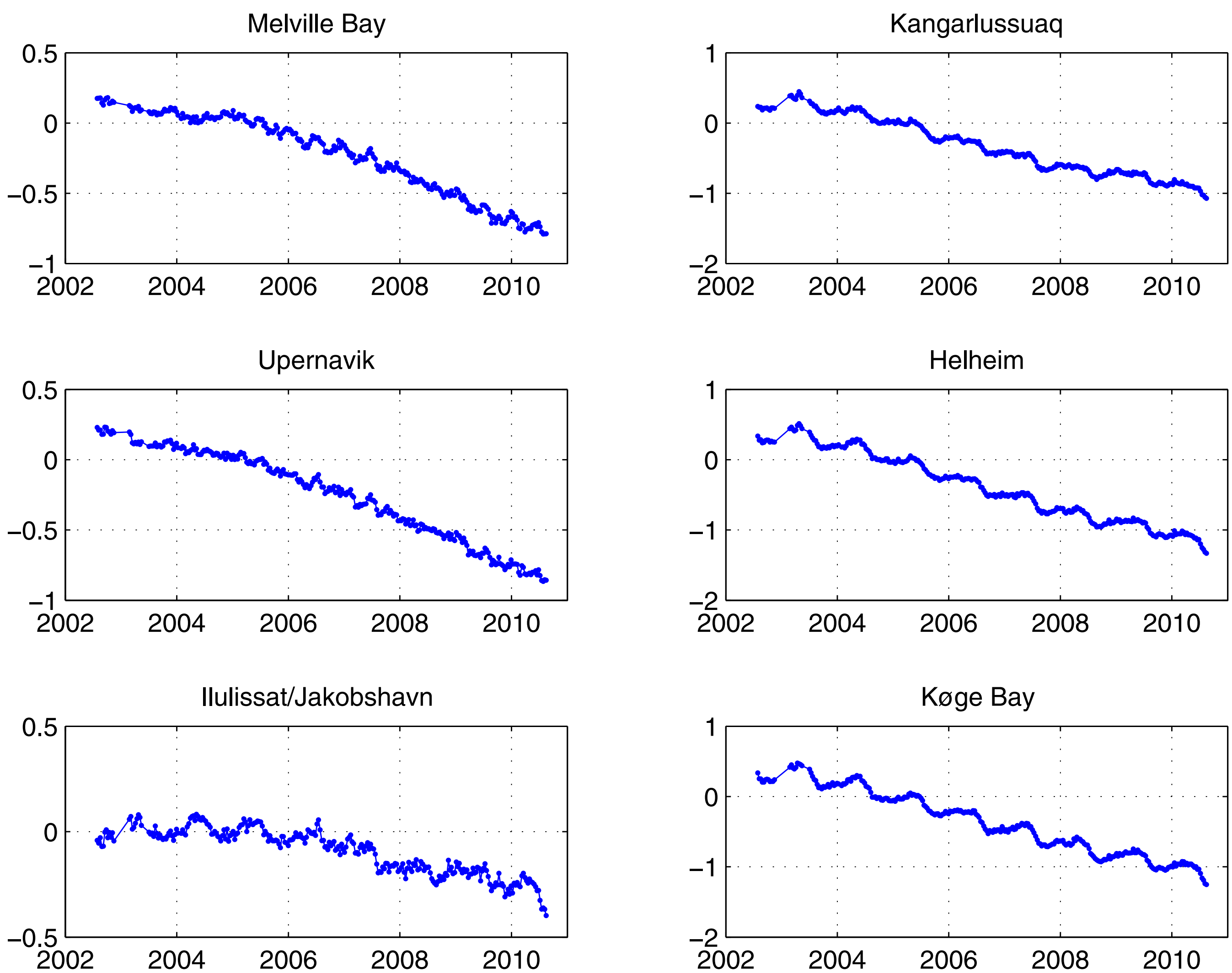

Fig. 2. EWH over time (in meters).

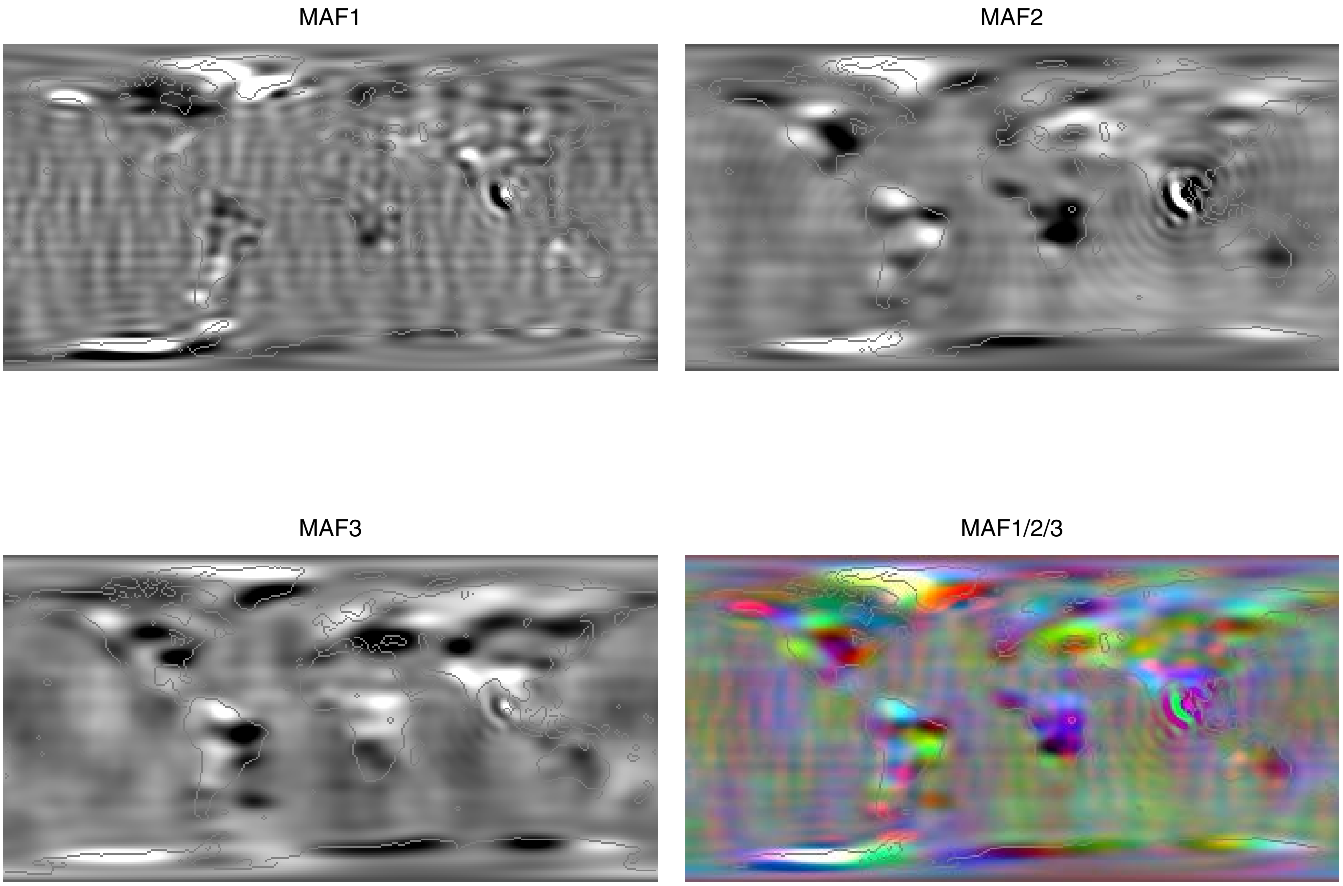

Fig. 3. Temporal MAF components 1, 2 and 3.

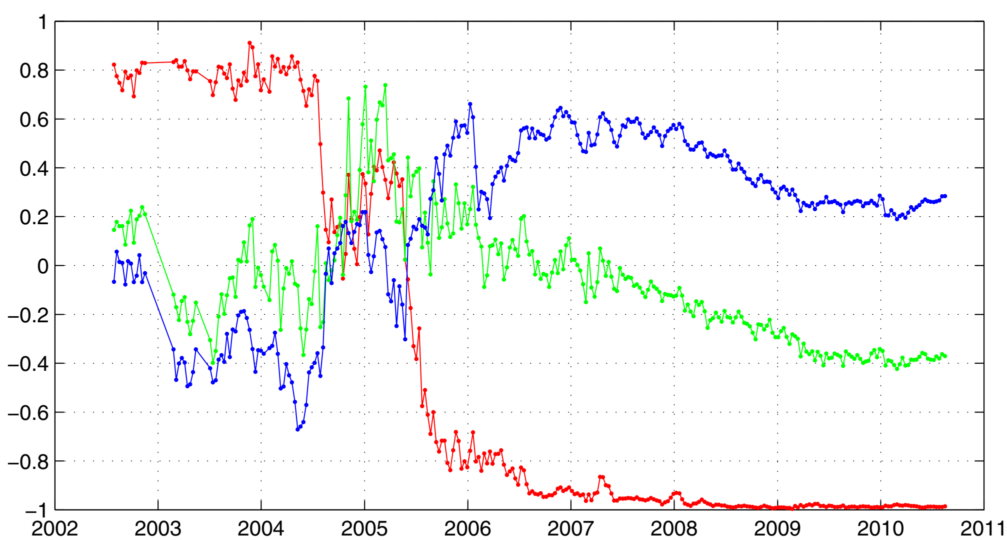

Fig. 4. Correlations between the first three temporal MAF components and the original data, for the first component in red, the second component in green, and the third component in blue; calculated over Greenland only (latitude $> 60°$ and $-75° <$ longitude $< -15°$).