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Analysis of time variable GRACE temporal models

Greenland ice mass loss

Shivam Pandey(170671) · Shivam Singh(170673) · Sarvesh Chaudhary(170637)

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Abstract The Greenland ice sheet is the second-largest ice sheet in the world after Antarctica, covering an area of 1.73 million square kilometers, and accounting for 10 percent of total global ice sheet volume The ice-mass change in the Greenland region is very important to study as the glaciers and the vast amount of ice-sheet covering a wide area contribute to the change in Global water level, oceanic structure, and temperature variation in the ocean currents. In this project, we have analyzed the change in ice-mass cover over Greenland. Here, we used Gravity Recovery and Climate Experiment (GRACE) data to retrieve the time series variations of ice-mass in Greenland from 2002 to 2018. The data obtained from the GRACE in the form of gravity value is smoothened by subtracting the mean from the monthly data obtained. This data contains a lot of noises that need to be filtered using Gaussian and Destriping filters in order to be used. As Gravity is directly proportional to mass so the surface mass density tells how much mass is concentrated in a confined space. Our method employs a non-isotropic filter. Since the GRACE noise structure has a non-isotropic nature, our method is used to decorrelate the GRACE data. From the surface mass density(SMD) anomaly time series we can see how the SMD has decreased consistently from 80.1632 Kg/m^2 on 1 January 2003 to -60.11265 Kg/m^2 on 13 January 2015.

Keywords GRACE · GRACE-FO · Spatio-temporal Analysis · Surface Mass Density · Gaussian Filter

1 Introduction

Over the years, the change in the ice-mass cover over Greenland has been quite significant and has attracted a lot of interest in the scientific community. The Gravity Recovery and Climate Experiment (GRACE) satellites have been providing us with monthly temporal models across the earth. With the help of this information, we can check the balances in the atmospheric properties, as these cause gravity to get degenerated and hence a clear relation between gravity field and the mass on the earth. The data provided by the GRACE mission provides us temporal models that can be used in the Spatio-temporal [Ding, Zhu, Feng, Zhang ChengDing .2020] study of any desired area. We know from the past the global warming and other factors cause the ice mass change [Bian .Bian .2019] over the Antarctic and Greenland [Bian .Bian .2019]. This change can be demonstrated by the disruption in the gravity field. In this project, we have analyzed the temporal variation of ice-mass over Greenland using 164 monthly GRACE observations provided by NASA-JPL GRACE through ICGEM portal 2002 - 2014. The environmental factors that are normal and secular in nature can be removed from the field information by subtracting the monthly temporal mean from the given data set. The anomaly is the best representation of the changes in the environment with local factors included, so we need to check the variation in the anomaly trends, and in results, it turned out to be decreasing ice mass, which directly implies the effect via global warming.

Address(es) of author(s) should be given

2 Data Processing

The data received from the Grace Satellite over the period of time gives gravity value which corresponds to the combined mass of the land and ice-mass over the land mass but we need only the anomalies for our model to do the computations. The data that we received from the satellite is quite noisy and contains constants which needs to be removed as our model only needs anomalies to compute mass change over an area. We also used filters like Destriping filter, Gaussian filter or cosine filter in order to smooth-en the data and remove the noises.

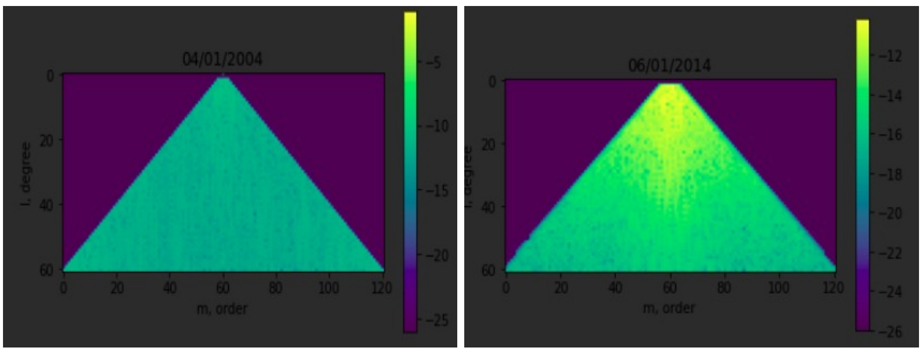
2.1 **Anomaly Detection**

The anomalies highlight variations in the data received over the period of time these anomalies arise due to unusually mass concentration/depletion in the Greenland region due to various factor like change of season, global warming etc [ChambersChambers2006]. through these anomalies we can detect or predict certain phenomena. In this project in order to calculate the anomalies, we have taken mean of the data over a certain period of time and then we have subtracted this mean from each monthly data. By this operation we have eliminated the constants like land mass under the ice which are not needed here.

$$\overline{K}_{lm} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} K_{lm}(t)dt \tag{1}$$

2.2 **Filtering**

In order to account for the noise in the signal, particularly for coefficients of high degree, it is necessary to filter the data set obtained from the GRACE. The limited spectral content of the gravity anomalies is properly accounted for by applying a low-pass filter and Gaussian filtering process act as a spatial low-pass filter on the spherical harmonic coefficients. The data received through remote sensing contains stripy noises so it needs to be filtered in order to be used, which can be achieved by destriping filters and Gaussian filter on spherical harmonic coefficients. The destriping filters removes the strips or streaks from the images which can be seen in the two images below. The image on the left which is unfiltered contains vertical stripes in the data representation while the image on the right which is filtered one shows smooth and non-noisy representation of data.



(a) Unfiltered (b) Filtered

$$\delta\overline{K}_{lm}(t) = B_l \sum_{n=m}^{L} B_{lm}^{nm} \delta K_{lm}(t) \tag{2}$$

3 SMD (Surface Mass Density)

The mass changes can be assumed to be located in a very thin layer of water concentrated at the surface and with variable thickness. This assumption is not far from reality, phenomenons like intensive melting of ice in Northwest and South-East region have been detected. Changes in ice-mass in Greenland region due to change in season and other factors like global warming, and by exchange of heat among oceanic currents have been shown to cause monthly changes in gravity signals. The gravity data obtained from the GRACE will give us gravity anomaly through which we will be able to calculate the ice-mass change which will be used in calculation of surface mass density. The vertical integrated mass changes are approximated by surface mass density i.e. surface mass density anomaly. [Tokuda, Komatani OgataTokuda .2013]

$$\Delta\sigma(\theta,\lambda,t) = \frac{a_e \rho_e}{3} \sum_{l=0}^{\infty} \frac{2l+1}{1+k_l} \sum_{m=-l}^{l} Y_{lm}(\theta,\lambda)\delta K_{lm}(\theta) \tag{3}$$

where ϕ and λ are the spherical latitude and longitude of the point of interest, a is the semi-major axis of a reference ellipsoid and P_{lm} is the normalized associated Legendre function of the first kind. ρ_e is the average mass density of the Earth is 5515 kg/m^3. K_l is the load Love number of degree [BryanBryan1998] l, $Y_{lm}(.)$ are the spherical harmonic coefficients and δK_{lm} are monthly anomalies of spherical harmonics with respect to a long-term mean.
The surface mass density can also be represented in terms of equivalent water height by dividing it with the density of water ρ.

$$h_w(\theta,\lambda,t) = \frac{\Delta\sigma(\theta,\lambda,t)}{\rho_w} \tag{4}$$

The quantity allows us to study changes in mass as changes in a column of water. For ice mass changes the density of ice can be used.

4 Results

We have obtained the temporal variations 1 for each 0.5x0.5 degree grid and plotted the variation for a single pixel and also for the mean over the complete area and in our case we have also shown the seasonal change for the year 2007.

From the results it is clear that the SMD is continuously decreasing throughout the year with a bit of fluctuations and that implies the melt of ice mass, which can be in sever regime. Even if taking the mean of the given whole are it is a clear trend and causes alarming situation. The data taken is from 2002-2018 and that shows a very significant change in these 16 years.

Models used in time series analysis:- In the results 1 you can see we have used Random Forest Regression(RFR), Linear Regression (LR) and polynomial Regression(2^{nd} order)(PR) models. In linear regression, the relationships are modeled using linear predictor functions whose unknown model parameters are estimated from the data whereas in polynomial regression is a form of regression analysis in which the relationship between the independent variable x and the dependent variable y is modelled as an nth degree polynomial in x. A Random forest is a meta estimator that fits a number of classifying decision trees on various sub-samples of the data-set and uses averaging to improve the predictive accuracy and control over-fitting.

5 Conclusion

The analysis described here shows that the GRACE measurement of time-variable gravity has been an excellent tool to study mass change over large areas. Our analysis shows that the mass loss over Greenland is not constant spatially. Due to factors like global warming, the SMD have constantly decreased over the years this has resulted in changing weathers, increased global water levels and uneven natural phenomena. The result of our analysis show a northward movement of ice mass loss along the west side of the Greenland simultaneously we also see a rapid ice melting in southwest Greenland. Global sea level still rises due to loosing mass at high rate streak of Southwest Greenland.

References

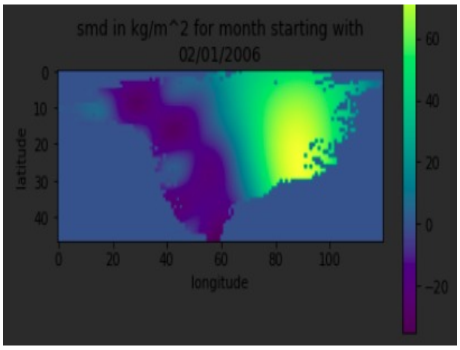
Bian .Bian .2019. Bian2019Bian, Y., Yue, J., Gao, W., Li, Z., Lu, D., Xiang, Y. Chen, J. 2019. Analysis of the spatiotemporal changes of ice sheet mass and driving factors in Greenland Analysis of the spatiotemporal changes of ice sheet mass and driving factors in Greenland. Remote Sens.1171–18. 10.3390/RS11070862

BryanBryan1998. Bryan1998Bryan, F. 1998. Pl . Pl . 103205–229.

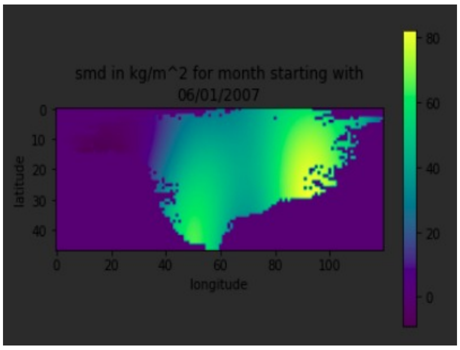
ChambersChambers2006. Chambers2006Chambers, DP. 2006. Evaluation of new GRACE time-variable gravity data over the ocean Evaluation of new GRACE time-variable gravity data over the ocean. Geophys. Res. Lett.33171–5. 10.1029/2006GL027296

Ding, Zhu, Feng, Zhang ChengDing .2020. Ding2020Ding, Y., Zhu, Y., Feng, J., Zhang, P. Cheng, Z. 2020. Interpretable spatio-temporal attention LSTM model for flood forecasting Interpretable spatio-temporal attention LSTM model for flood forecasting. Neurocomputing403348–359. `https://doi.org/10.1016/j.neucom.2020.04.110` 10.1016/j.neucom.2020.04.110

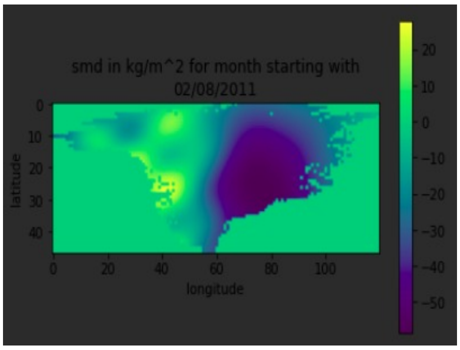
Tokuda, Komatani OgataTokuda .2013. Tokuda2013Tokuda, K., Komatani, K. Ogata, T. 2013. IPTalk DVD (1) (2) IPTalk DVD (1) (2). 212–3.



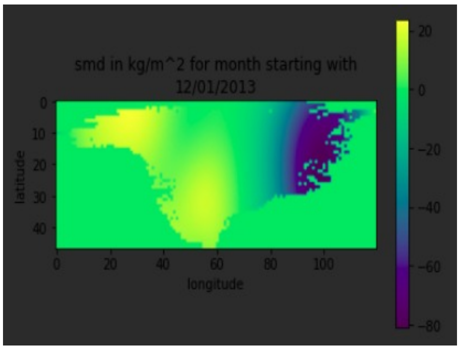
(c) sample-2006



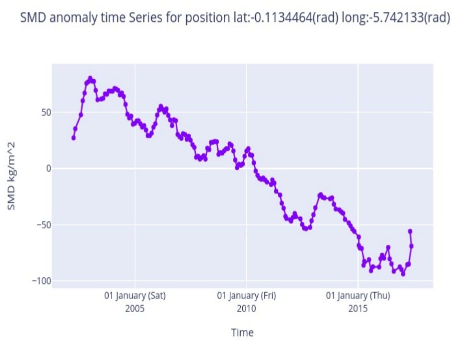
(d) Sample-2007



(e) Sample-2011



(f) Sample-2013



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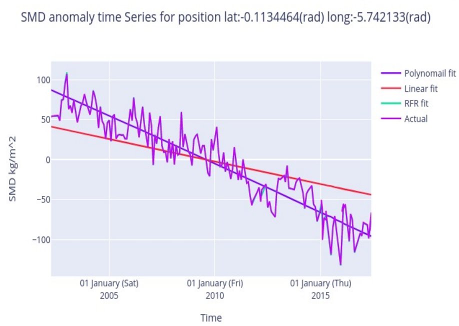

(h)

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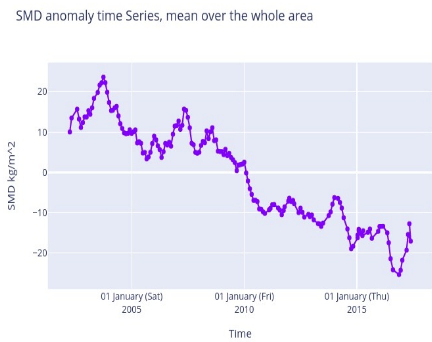

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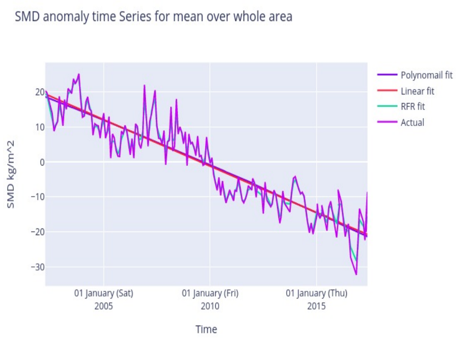

(k)

Fig. 1: Results