NASA SEES: Weighing Where the Water Goes

AGU 2024 Washington D.C.

Mapping the Changing Distribution of Water in Polar Regions of Earth Using GRACE and GRACE-FO

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Abstract:
The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission, which tracks changes in Earth's water systems, is essential for monitoring long-term trends in ice sheet mass changes and their contributions to sea level rise. This study uses GRACE & GRACE-FO data to model ice sheet and glacial mass loss in three polar regions, along with their consequent sea level changes. Here, a subset of the raw data on the distance between the twin satellites was received in the form of K-Band Ranging (KBR) and Laser Range Instrument (LRI) measurements, which are collected and analyzed to help determine changes in gravity when the leading satellite was pulled towards areas of greater mass. The KBR/LRI data was converted to equivalent water height, then transformed to mass change in each region, which quantifies phenomena such as ice melt. To obtain the data for multiple data points over each region, a lat/long grid approach was used, which divides the world into segmented uniform square grids in order to store data. Analysis of the three regions show strong linear trends in ice mass changes, with Greenland and West Antarctica experiencing rates of approximately -237.63 ± 1.83 Gt/yr and -106.32 ± 0.99 Gt/yr respectively, while East Antarctica exhibited an increase in ice mass of 34.97 ± 0.93 Gt/yr. Collectively, these regions contribute to a mean sea level rise of 0.7982 mm/yr as a result of mass change. This research provides valuable insights into ice sheet loss in Antarctica and Greenland and its impact on global sea levels, including the uneven dispersion of melted polar ice influenced by factors such as crust deformation and shifts in Earth's rotational axis. These findings highlight the importance of continued satellite-based monitoring of Earth's water systems, demonstrating the potential of such data in advancing our understanding of climate change and its impacts.

GRACE-FO: Weighing Where the Water Goes

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Introduction

- Gravity Recovery And Climate Experiment Follow-On, or GRACE-FO, is a follow up mission, launched in 2018, to the original GRACE satellite launched by NASA and the German Aerospace Center in 2002.
- GRACE-FO's unique twin-satellite setup allows the system to measure gravity anomalies across the Earth caused by the movement and depletion of water with an accelerometer (Fig. 2).
- In a warming climate, tracking and monitoring the rates of ice sheet loss and glacial melt is crucial for understanding the impacts of sea level rise on our environment and for improving our projections of future sea level change.

Project Objective

Use GRACE-FO data to calculate ice loss in the polar regions of Greenland and Antarctica, model its effects on global sea level change, and project these metrics into the future.

Methodology

- From GRACE-FO residual accelerometer data, we can derive the equivalent water heights (EWH) of the anomalies using gravitational potential, spherical harmonic expansion, removing geophysical signals and considering elastic loading (Figs. 1, 2).
- A latitude and longitude grid approach is used, dividing the world into uniform grids of 0.25º latitude x 0.25º longitude.
- Mass loss of each grid within Antarctica and Greenland is calculated using Eq. 1.

$$\text{mass} = \text{surface area} \cdot \text{EWH} \cdot \text{density}_{\text{water}}$$

Equation 1

- Grid cells decrease in size towards the poles, so we account for this distortion by calculating a weighted average of mass anomalies, with each grid cell's contribution proportional to its area (Eq. 2).

$$\frac{\text{lwe}_1(\cos\rho_1)(\alpha)(d)(r) + \text{lwe}_2(\cos\rho_2)(\alpha)(d)(r) + \cdots + \text{lwe}_n(\cos\rho_n)(\alpha)(d)(r)}{(\alpha)(d)(r)(\cos\rho_1 + \cos\rho_2 + \cdots + \cos\rho_n)}$$

Equation 2, where lwe_n is the liquid water equivalent at grid n, ρ_n is the latitude of the grid, α is the grid longitude, d is the constant distance between longitudes (0.25º), and r is the radius of the Earth.

- Due to crust deformation, shifts in Earth's rotational axis, and gravity, sea level change is not distributed uniformly across the globe. A gradient fingerprint of Greenland, East Antarctica, and West Antarctica's contribution to 1mm of sea level change is used to scale sea level effects.

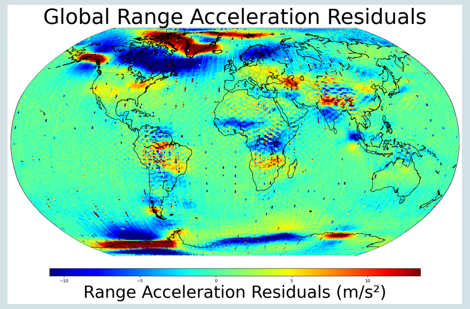

Fig. 1 – Map of GRACE-FO accelerometer residuals.

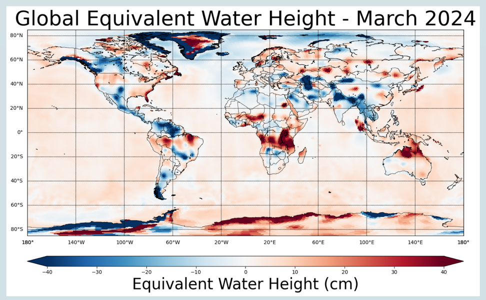

Fig. 2 – Converted map of liquid water equivalents.

Results: EWH

- The EWH of each of the three regions gives us a preliminary indication as to how mass is changing.
- Severe decrease in mass in LWE on the coasts of Greenland and Western Antarctica, with considerable gain in inland Greenland and the northern coast of East Antarctica.

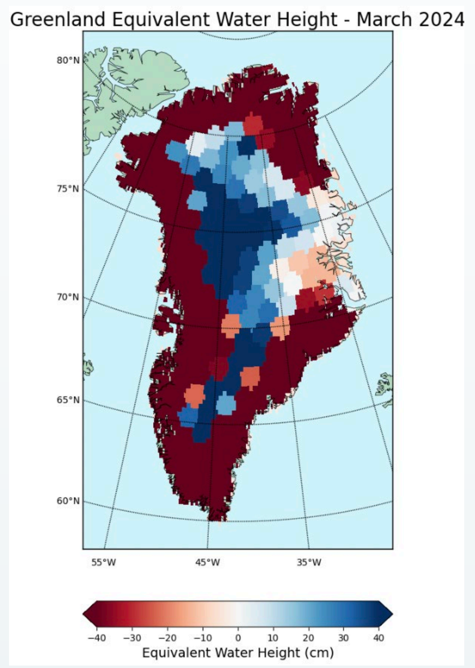

Fig. 3 – Equivalent water height of Greenland, March 2024.

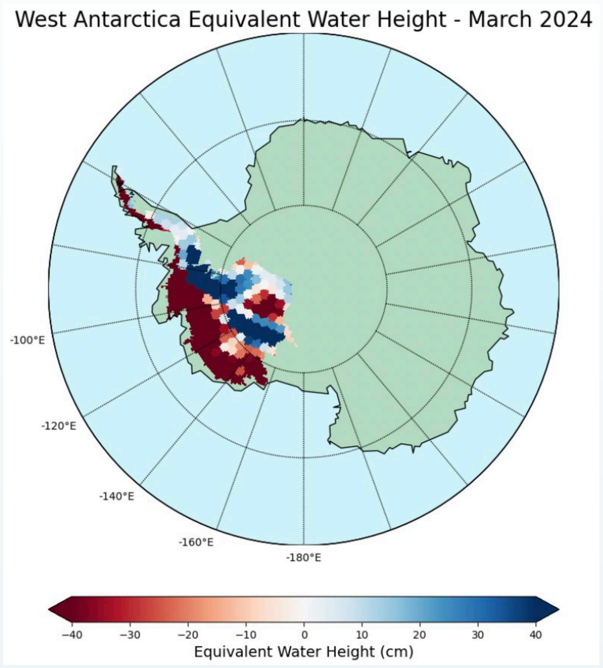

Fig. 4 – Equivalent water height of West Antarctica, March 2024.

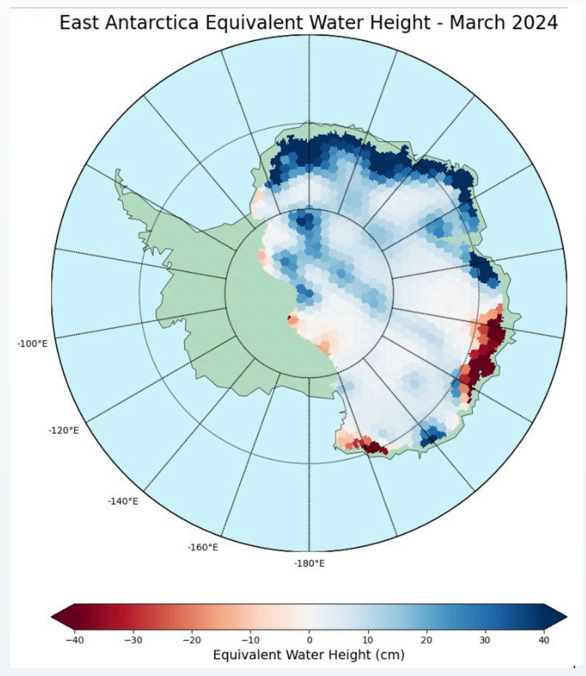

Fig. 5 – Equivalent water height of East Antarctica, March 2024.

Results: Average Mass Change

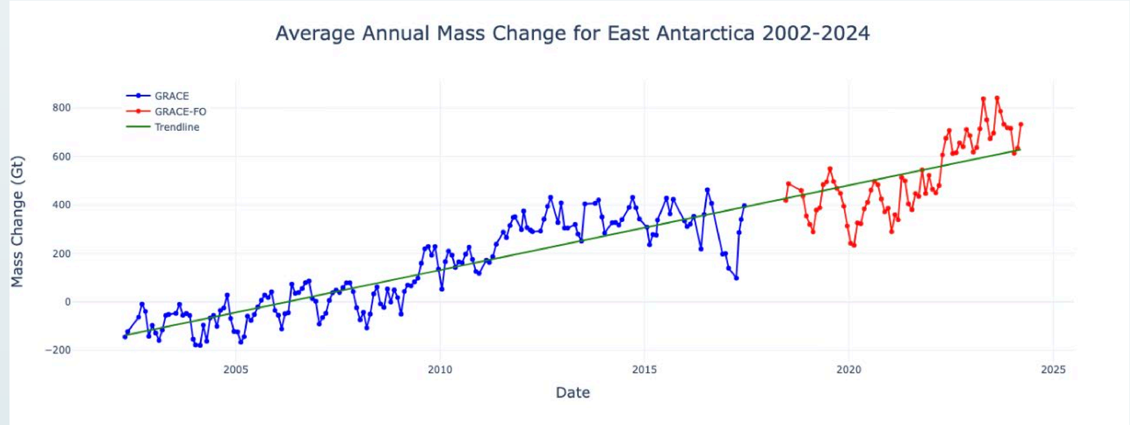

Fig. 6 – Average Mass change in Gigatons (Gt) of East Antarctica from 2002 – 2024 with trendline. GRACE and GRACE-FO data are displayed separately.

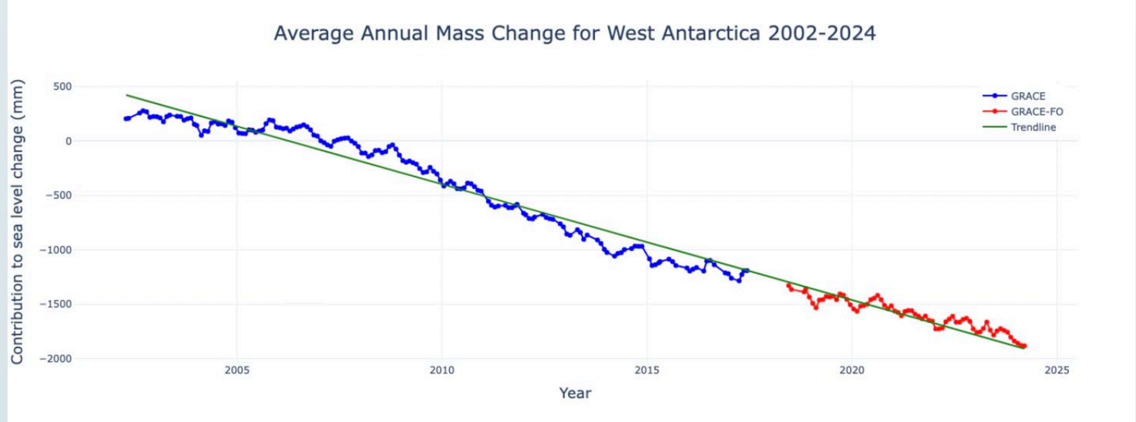

Fig. 7 – Average Mass change in Gigatons (Gt) of West Antarctica from 2002 – 2024 with trendline. GRACE and GRACE-FO data are displayed separately.

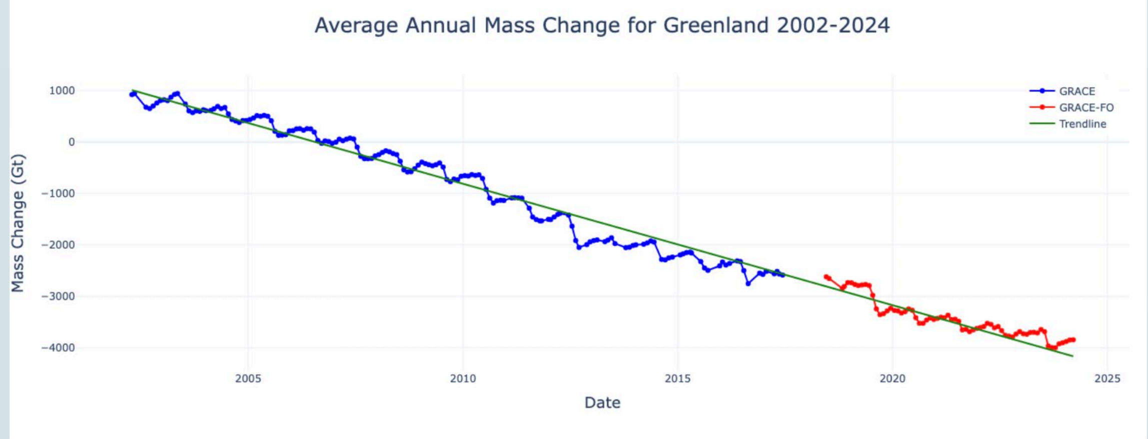

Fig. 6 – Average Mass change in Gigatons (Gt) of Greenland from 2002 – 2024 with trendline. GRACE and GRACE-FO data are displayed separately.

Results: Sea Level Change

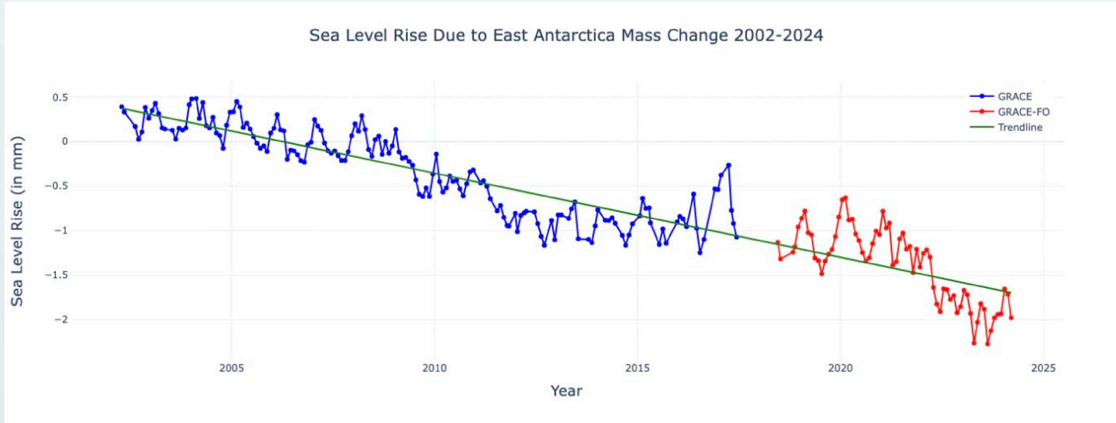

Fig. 9 – East Antarctica's contribution to global sea level rise from 2002-2024.

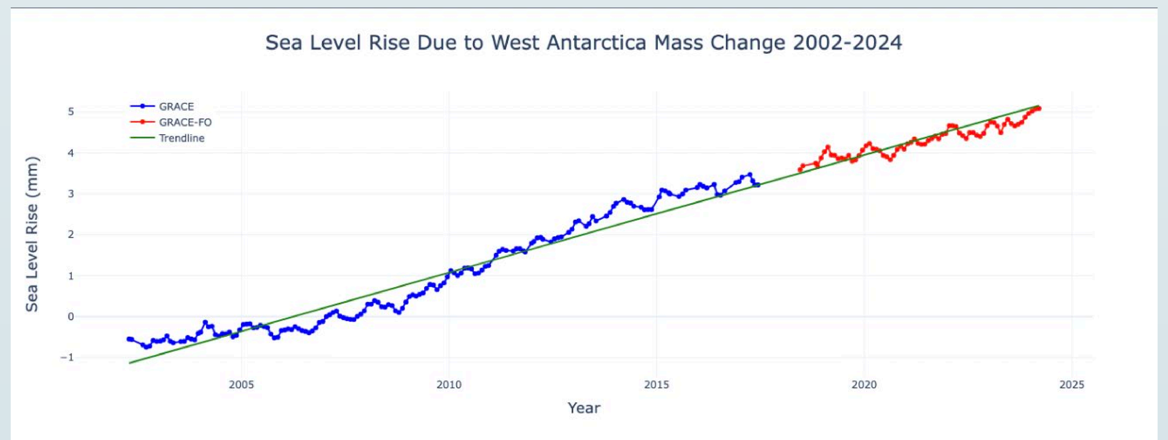

Fig. 10 – West Antarctica's contribution to global sea level rise from 2002-2024.

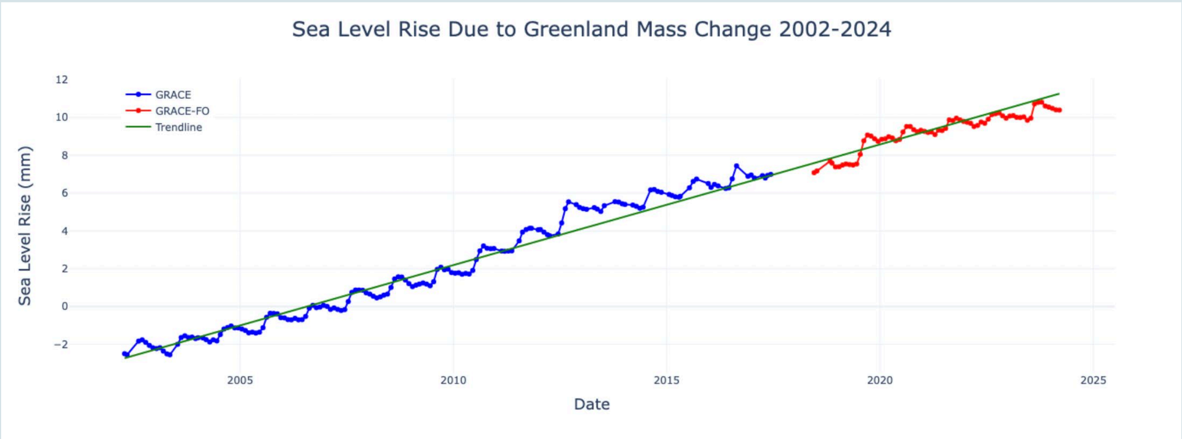

Fig. 11 – Greenland's contribution to global sea level rise from 2002-2024.

Distribution of Sea Level Rise and Future Projections

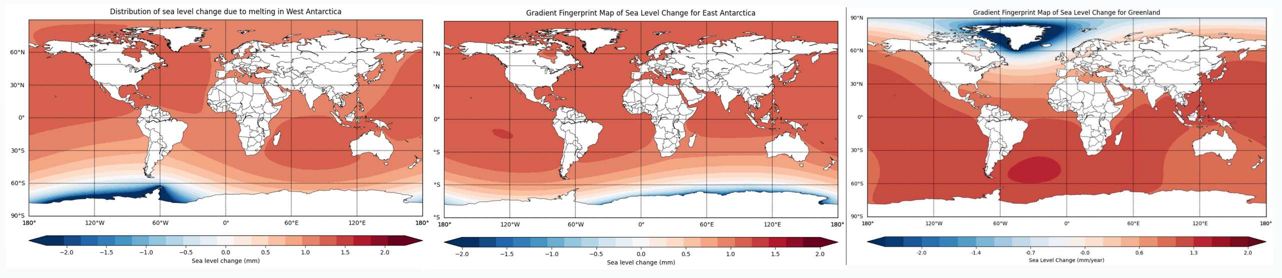

Fig. 12 –. Distribution of sea level change for each region (left to right; West Antarctica, East Antarctica, and Greenland)

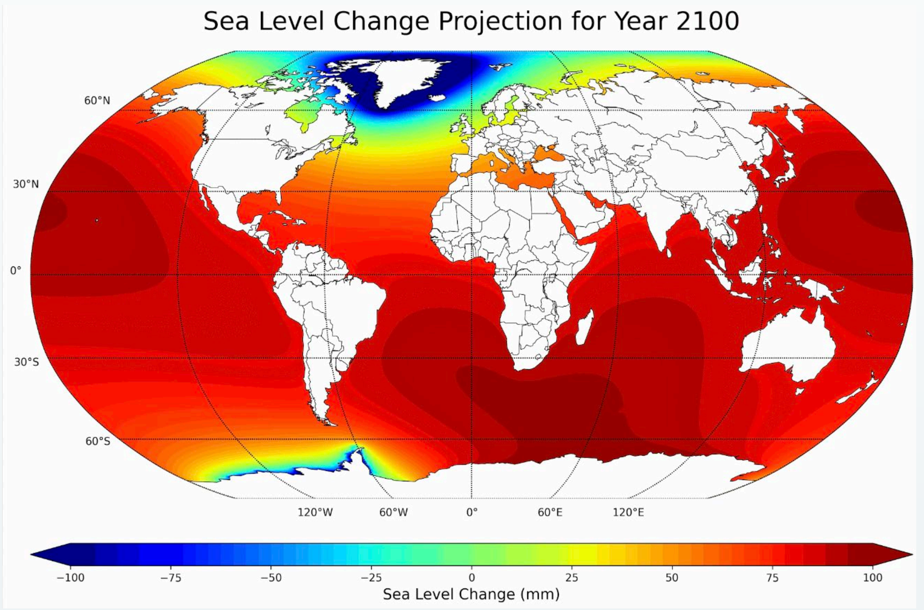

Fig. 13 – 2100 Projection of Sea Level Change

Discussion

- Greenland and West Antarctica are losing ice mass, on average, at rates of -236.13 ± 3.56 and -106.32 ± 0.99 Gigatons (Gt) per year, respectively.
- Greenland and West Antarctica are contributing to global sea level change, on average, by 0.64 ± 0.005 and +0.28 ± 0.002 millimeters (mm) per year, respectively.
- Conversely, East Antarctica is gaining ice mass, on average, at a rate of 34.97 ± -.93 Gt per year.
- East Antarctica is contributing to global sea level change, on average, by -0.09 ± 0.003 mm per year.
- Future projections calculate some regions experiencing 75-100 mm of sea level increase by the year 2100.

Conclusions

- EWH maps of each region indicate mass loss in Greenland and West Antarctica coasts.
- Conversely, there is considerable mass gain on Eastern Antarctica coast.
- The above is likely due to an increase in the magnitude of precipitation received by Greenland due to global warming, as well as changing atmospheric conditions.
- Variations in gravity, crust deformations, and shifts in the Earth's rotational axis contribute to an unequal distribution of sea level rise among equatorial, Pacific, and polar regions.

Acknowledgements

Thank you to our mentors, Chaoyang Zhang and Chirag Patel, for their guidance and support with throughout this project.
Thank you to the NASA STEM Enhancement in Earth and Space Science (SEES) and the Center for Space Research at UT Austin for the opportunity to conduct this research.