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Spherical and ellipsoidal surface mass change from GRACE time-variable gravity data

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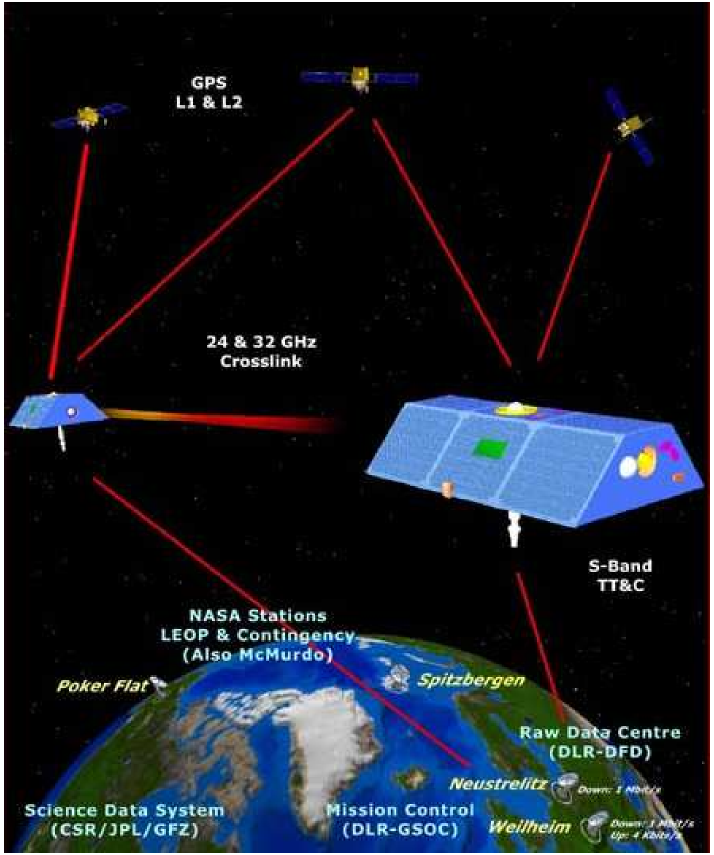
1. Motivation:

- **GRACE** (Gravity Recovery and Climate Experiment),
- Mapping the Earth's **time-variable** gravitational field (**2002-2017**),
- Altitude: **~460 km** (above the Earth's surface),
- Spatial resolution: **several 100 km**,
- Temporal resolution: **~1 month**.



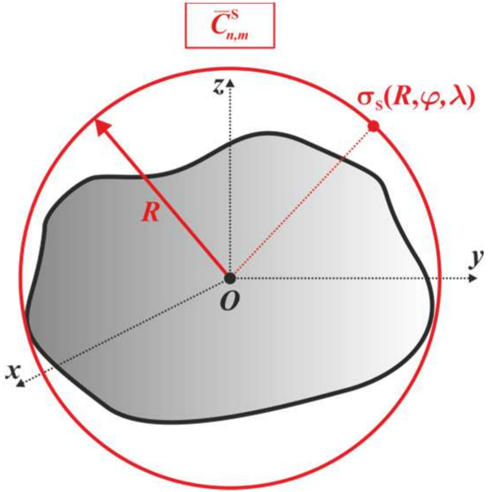
- Revolutionary applications (geodesy, geophysics, hydrology, glaciology, oceanography, …),
- **GRACE-FO** launched in 2018 to extend GRACE time series,
- Methodology, processing, and background geophysical models continuously improve,
- Standard approach for surface mass determination by Wahr et al. (1998) is based on the spherical approximation of the Earth,
- More realistic geometry, such as ellipsoidal, has to be considered for accurate modelling and geoscience applications.

2. Theory:

A) Spherical surface mass (Wahr et al. 1998):

$$\sigma_S(R,\varphi,\lambda) = \frac{R\,\rho_{ave}}{3} \sum_{n=0}^{\infty} \sum_{m=-n}^{+n} \frac{2n+1}{1+k_n^S} \bar{C}_{n,m}^S \, \bar{Y}_{n,m}(\varphi,\lambda)$$

Geometry:



Notation:

σ_S – spherical surface mass,

R, φ, λ – spherical geocentric coordinates,

ρ_{ave} – average density,

k_n^S – spherical Love number,

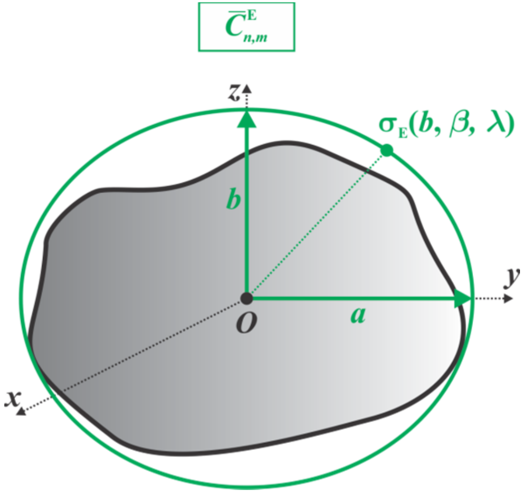
$\bar{C}_{n,m}^S$ – spherical harmonic coefficient,

$\bar{Y}_{n,m}$ – surface (spherical) harmonic function.

B) Ellipsoidal surface mass (Ghobadi-Far et al. 2019):

$$\sigma_{\mathrm{E}}(a,b,\beta,\lambda)=\frac{a\,b\,\rho_{\mathrm{ave}}}{3\sqrt{b^2+(a^2-b^2)\sin^2\beta}}\sum_{n=0}^{\infty}\sum_{m=-n}^{+n}\frac{2n+1}{1+k_{n,m}^{\mathrm{E}}}\frac{1}{T_{n,m}(a,b)}\bar{C}_{n,m}^{\mathrm{E}}\,\bar{Y}_{n,m}(\beta,\lambda)$$

Geometry:



Notation:

σ_{E} – ellipsoidal surface mass,

a – semi-major axis,

b, β, λ – ellipsoidal geocentric coordinates,

$k_{n,m}^{\mathrm{E}}$ – ellipsoidal Love number,

$T_{n,m}$ – auxiliary function,

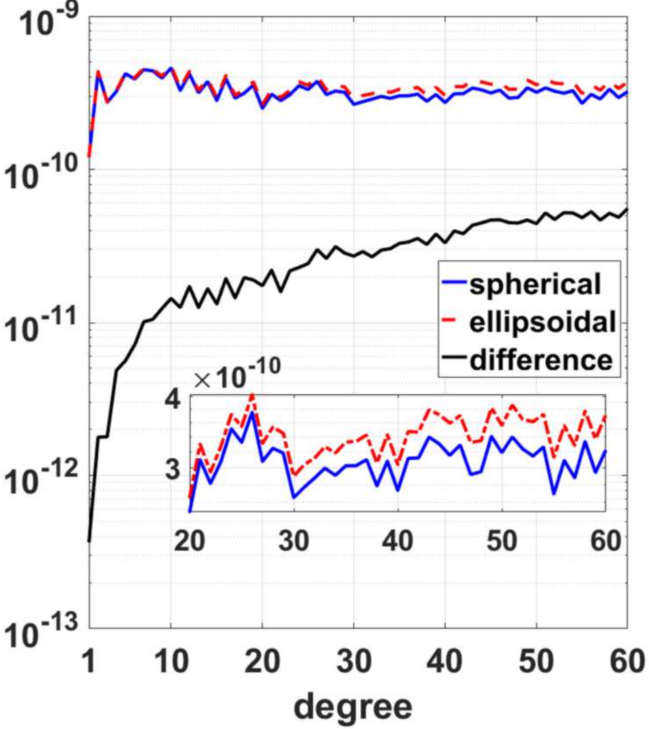
$\bar{C}_{n,m}^{\mathrm{E}}$ – ellipsoidal harmonic coefficient.

3. Numerical experiments:

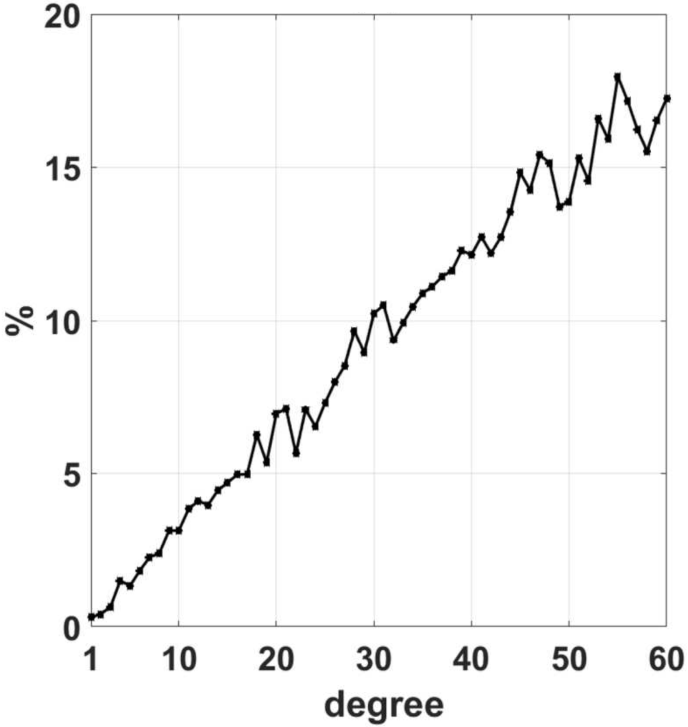
- Spherical vs. ellipsoidal approach for computing surface mass **change rate** (linear trend),
- GRACE Level 2 monthly gravitational fields by the Center for Space Research (Bettadpur 2012), 2003-2015, RL06, up to d/o 60,
- Corrected for GIA (A et al. 2012), geocenter motion (Swenson et al. 2008), $\bar{C}_{2,0}$ from SLR (Cheng et al. 2013),
- Spherical surface mass changes calculated @ R = 6378136.3 m,
- Ellipsoidal surface mass changes calculated @ EGM08 reference ellipsoid (a = 6378136.3 m, b = 6356751.6 m).

A) Spectrum of the surface mass change rate

Degree amplitudes

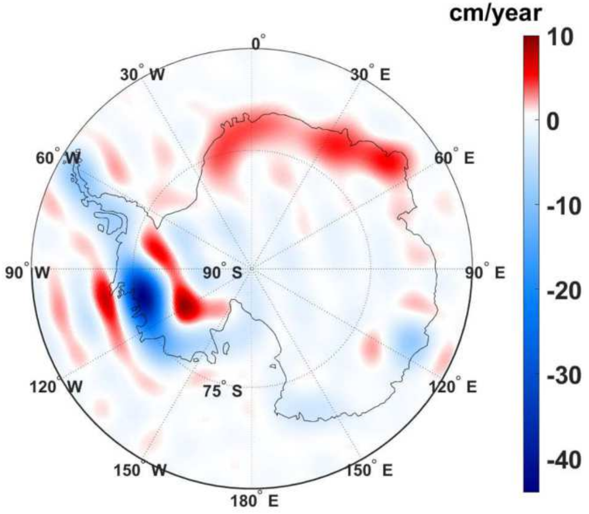


Relative difference

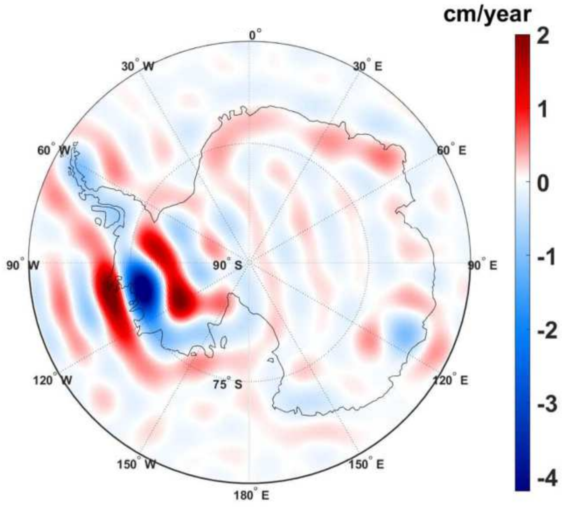


B) Surface mass change rate in Antarctica

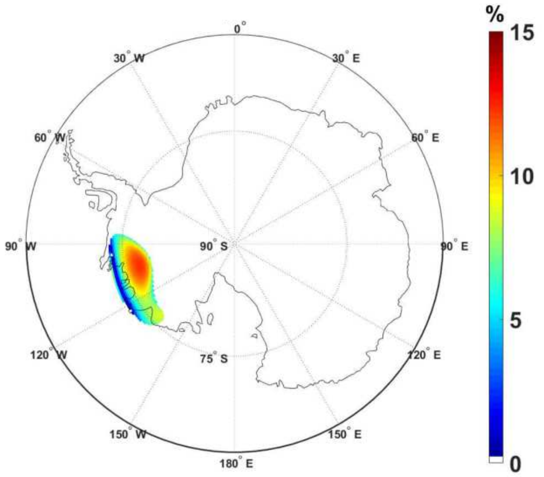
Spherical approach



Ellipsoidal minus spherical



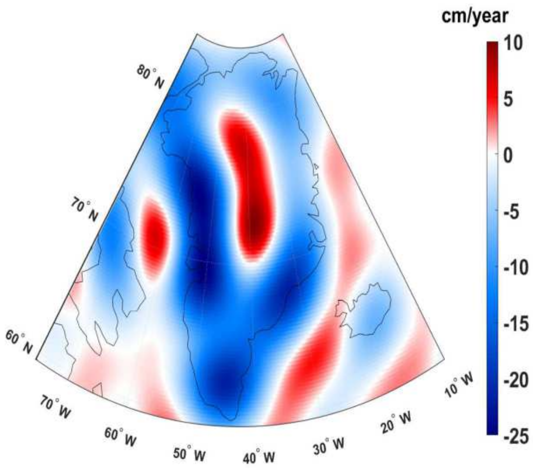
Relative difference



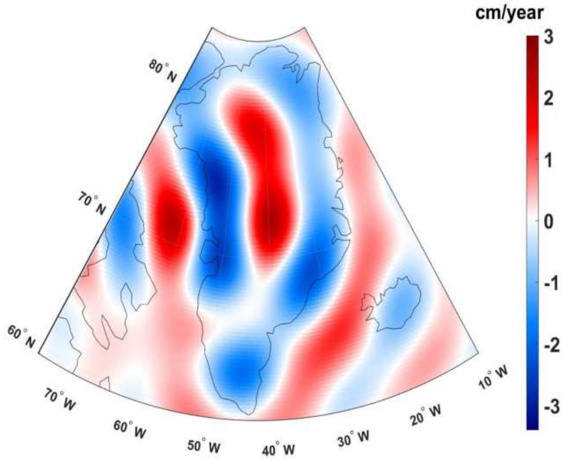
Absolute value of the signal
> 10 cm/year

C) Surface mass change rate in Greenland

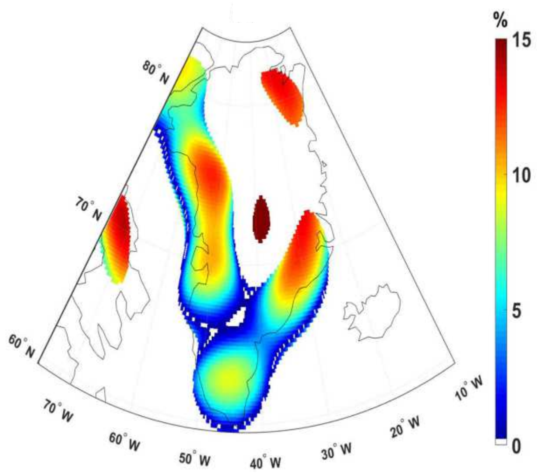
Spherical approach



Ellipsoidal minus spherical



Relative difference



Absolute value of the signal
> 10 cm/year

4. Conclusions:

- We developed a **rigorous ellipsoidal** approach for the determination of the surface mass from the external gravitational field,

- The spherical approach by Wahr et al. (1998) underestimates the surface ice mass change by **10-15%** in Antarctica and Greenland,

- Source codes implementing the ellipsoidal approach are available to potential users.

More details can be found in:

Ghobadi-Far K, Šprlák M, Han S-C (2019) Determination of ellipsoidal surface mass change from GRACE time-variable gravity data. Geophysical Journal International 219(1):248-259.

Thank you for your attention!!!

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