Churning the Ocean: Time variable gravity for ocean applications

Roelof Rietbroek, 28 Sept. 2022

Analogies with today's talk

Find this presentation on https://github.com/strawpants/grace-hackweek-ocean

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- Snake Vasuki: set the ocean in motion (e.g. forcing from wind stress)

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Analogies with today's talk

- Mount Mandara: Adding mass to the ocean (e.g. melt water)
- Snake Vasuki: set the ocean in motion (e.g. forcing from wind stress)
- Central Question: How can we use time variable gravity to observe ocean signals?

Find this presentation on https://github.com/strawpants/grace-hackweek-ocean

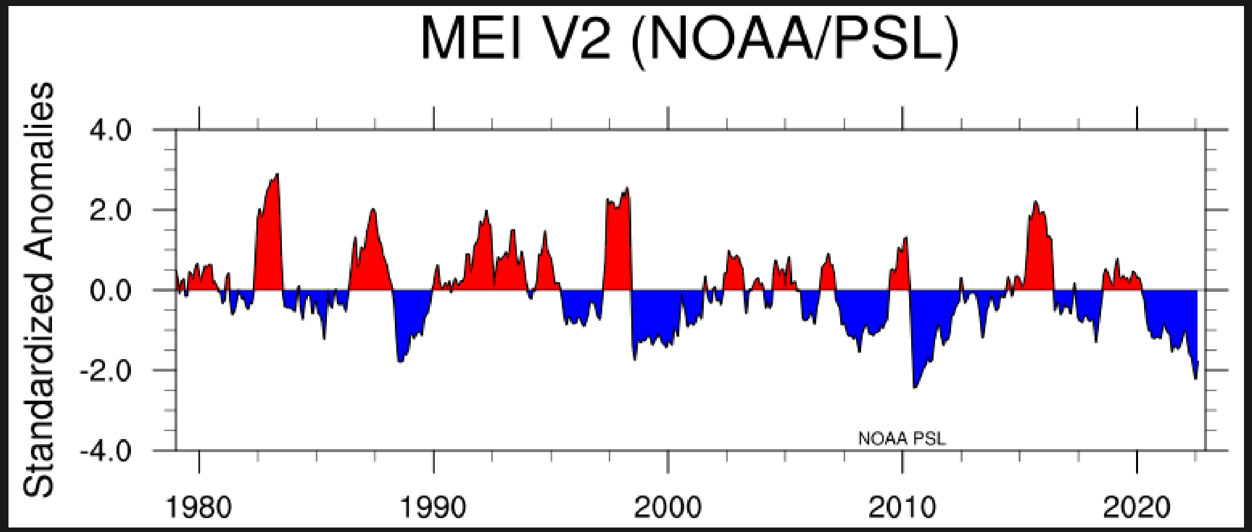
Adding mass to the oceans

Adding mass to the oceans

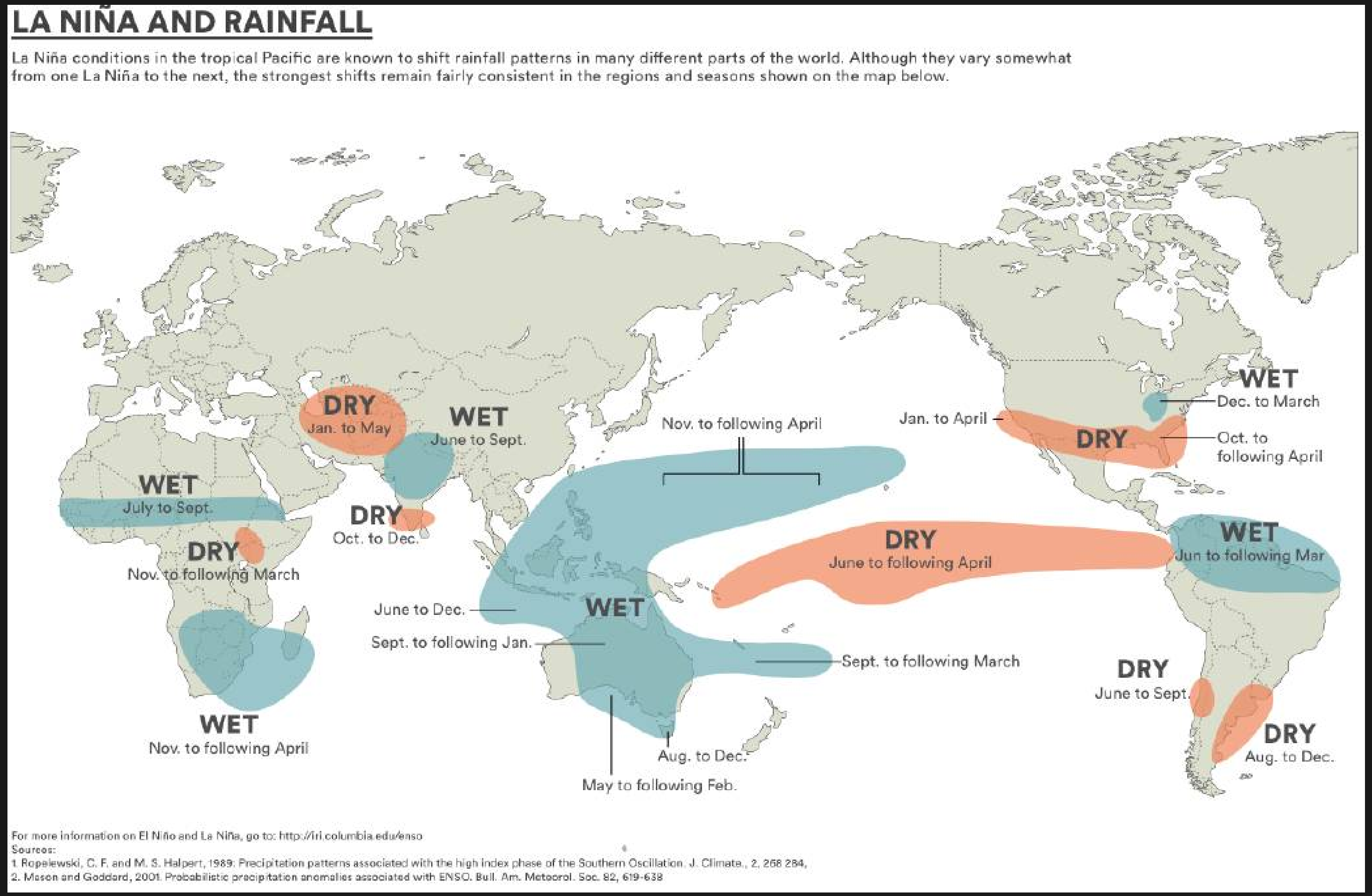
(or removing it)

2022 Floods in Pakistan, image: AFP

Does La Nina affect sea level?



Multivariate ENSO index,https://psl.noaa.gov/enso



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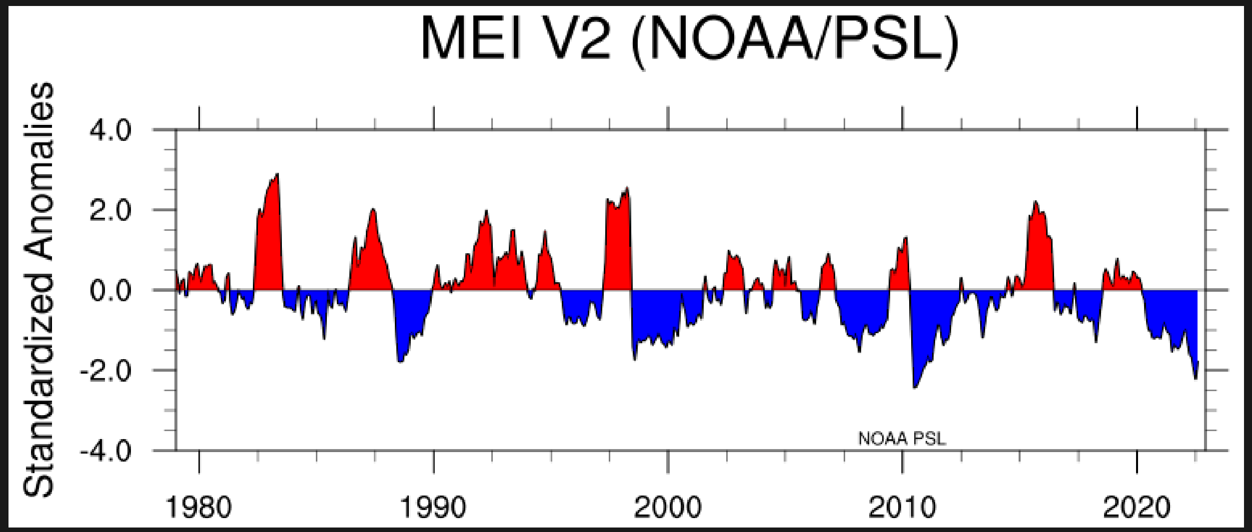

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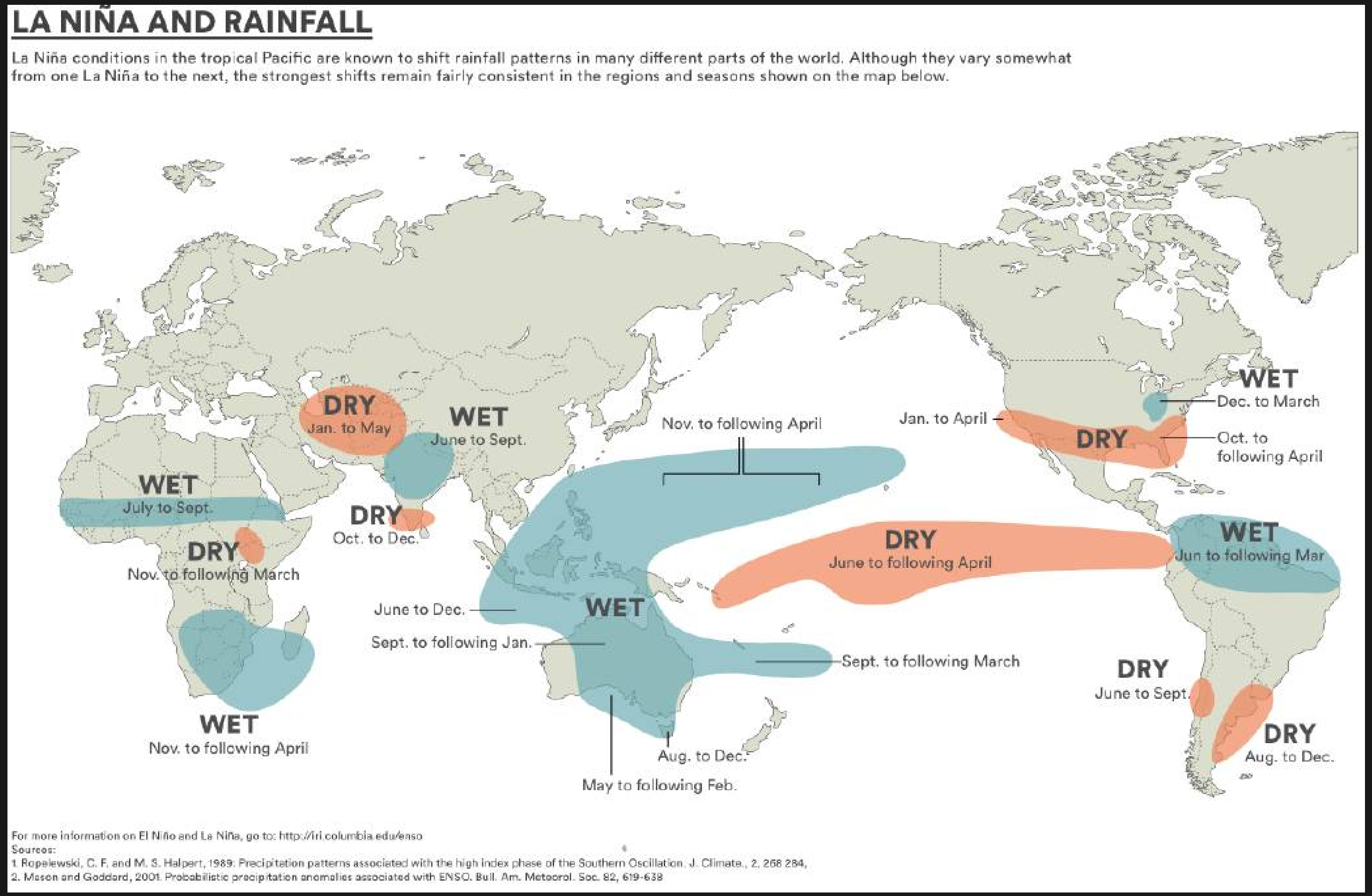

- Stronger trade winds -> warm/wet ocean blob in the western Pacific

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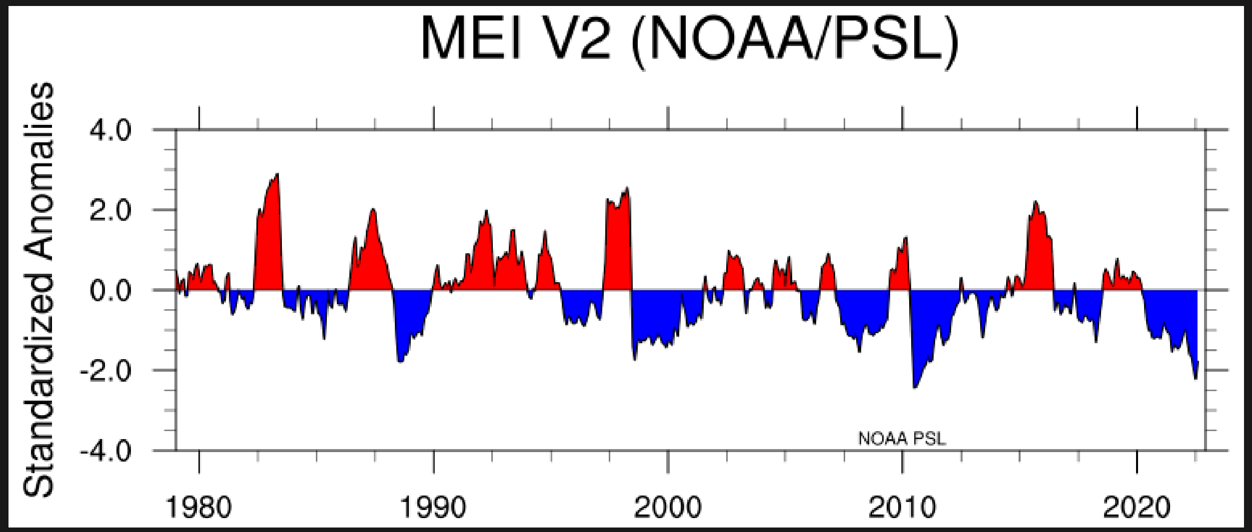

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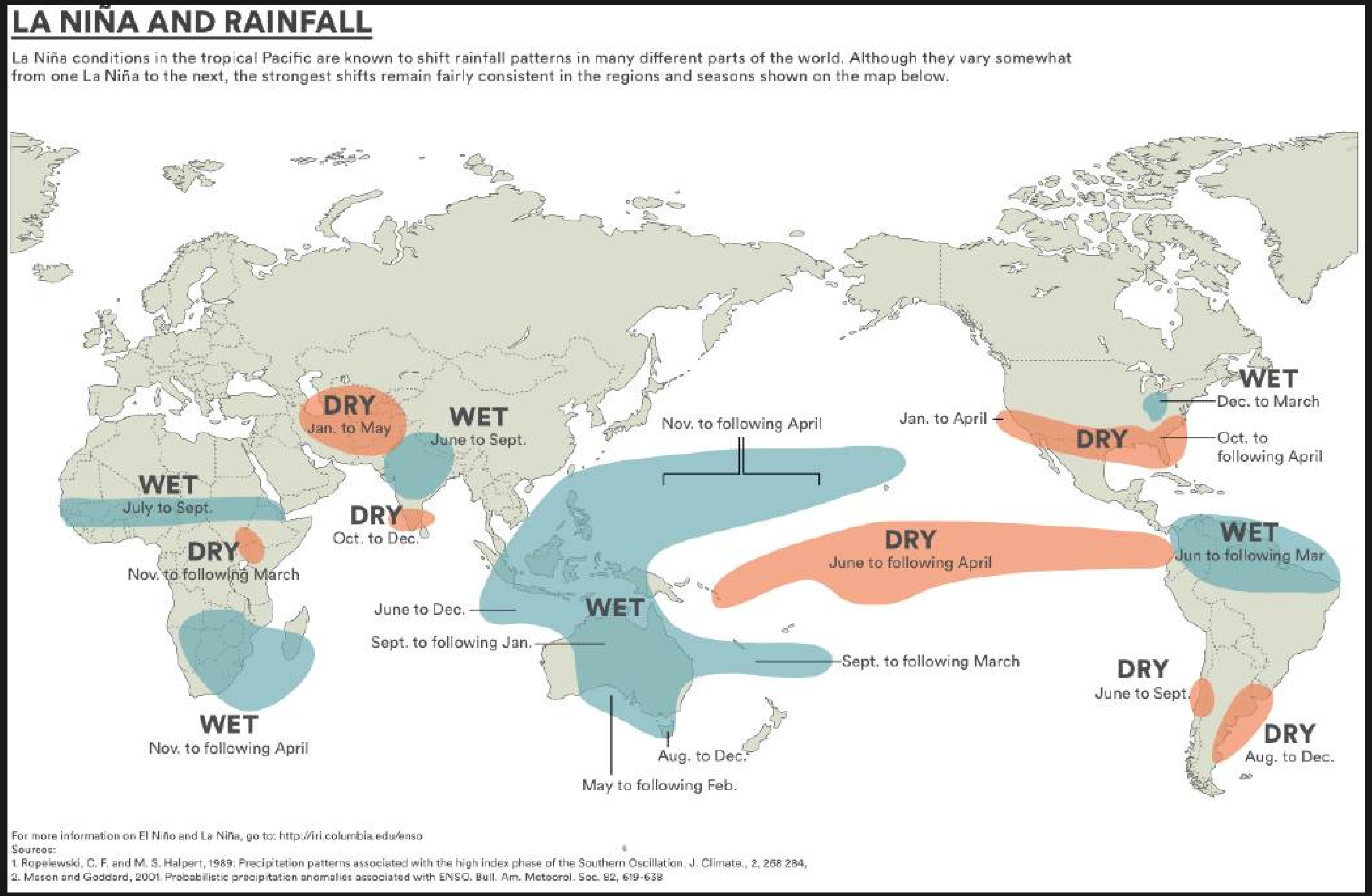

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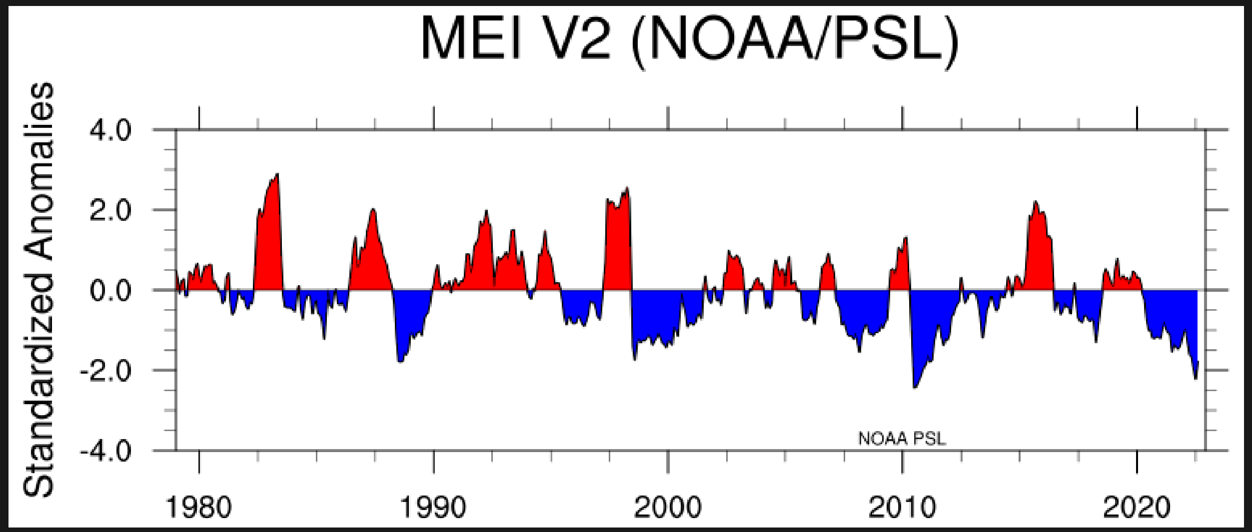

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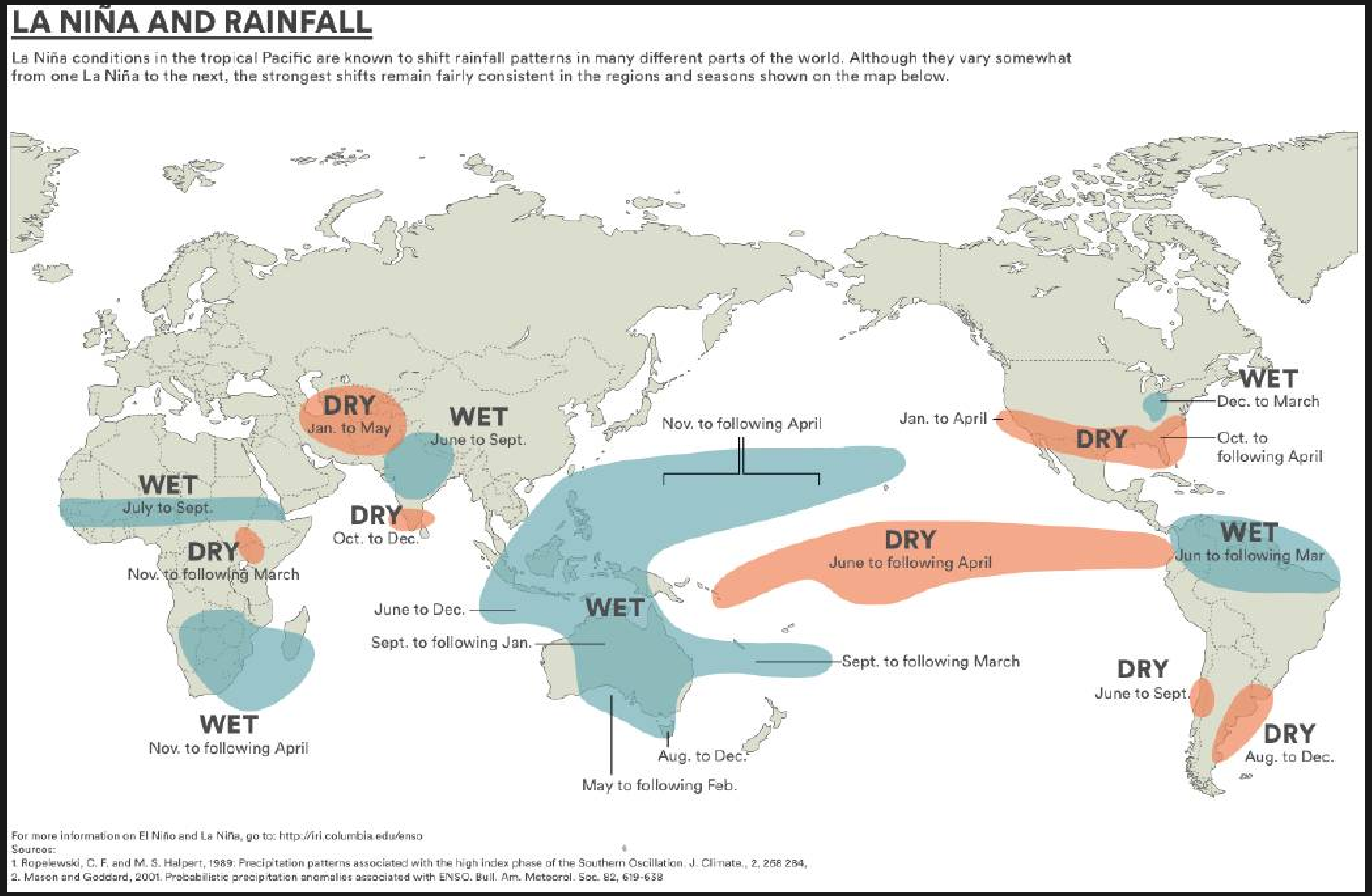

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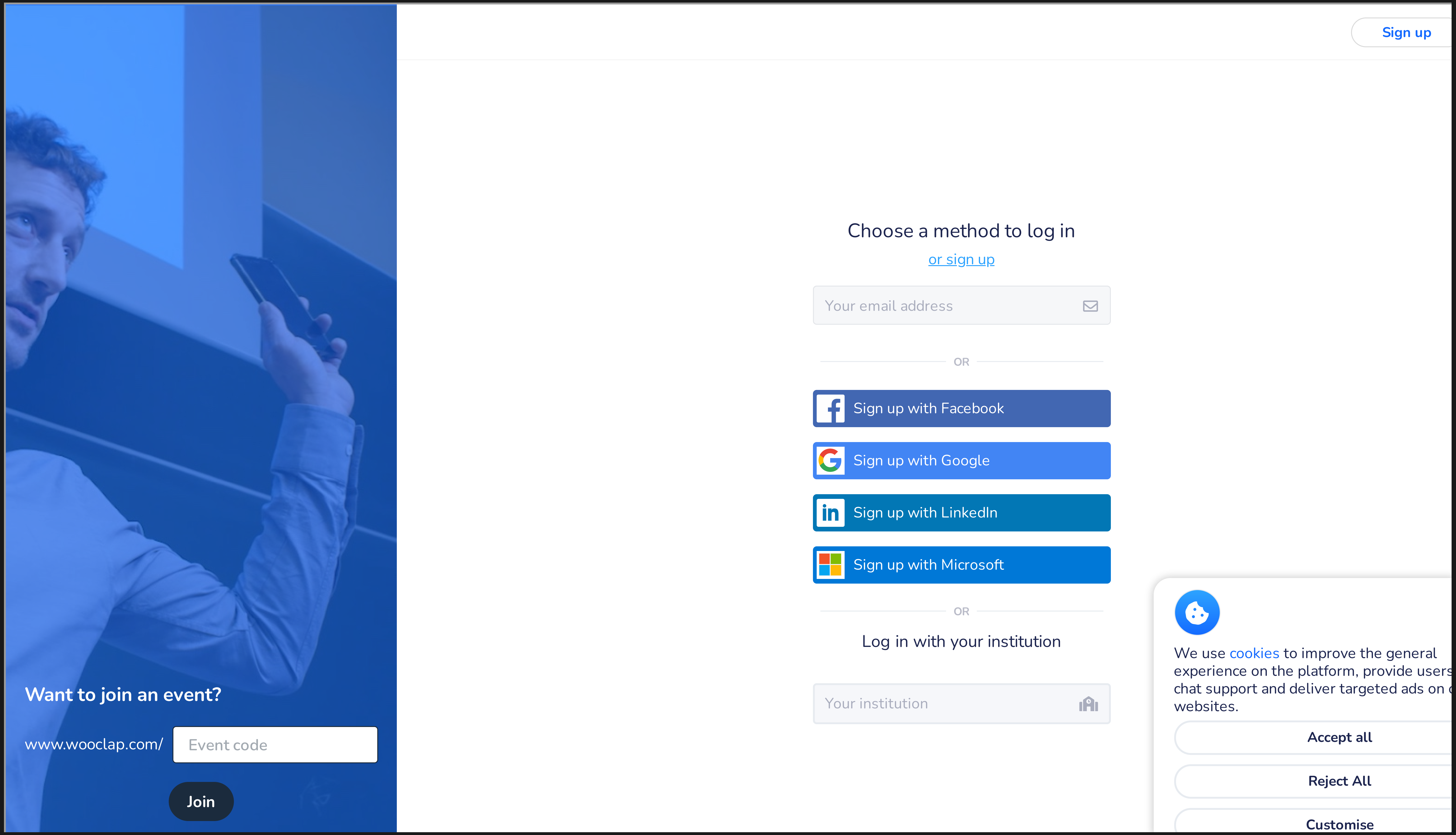
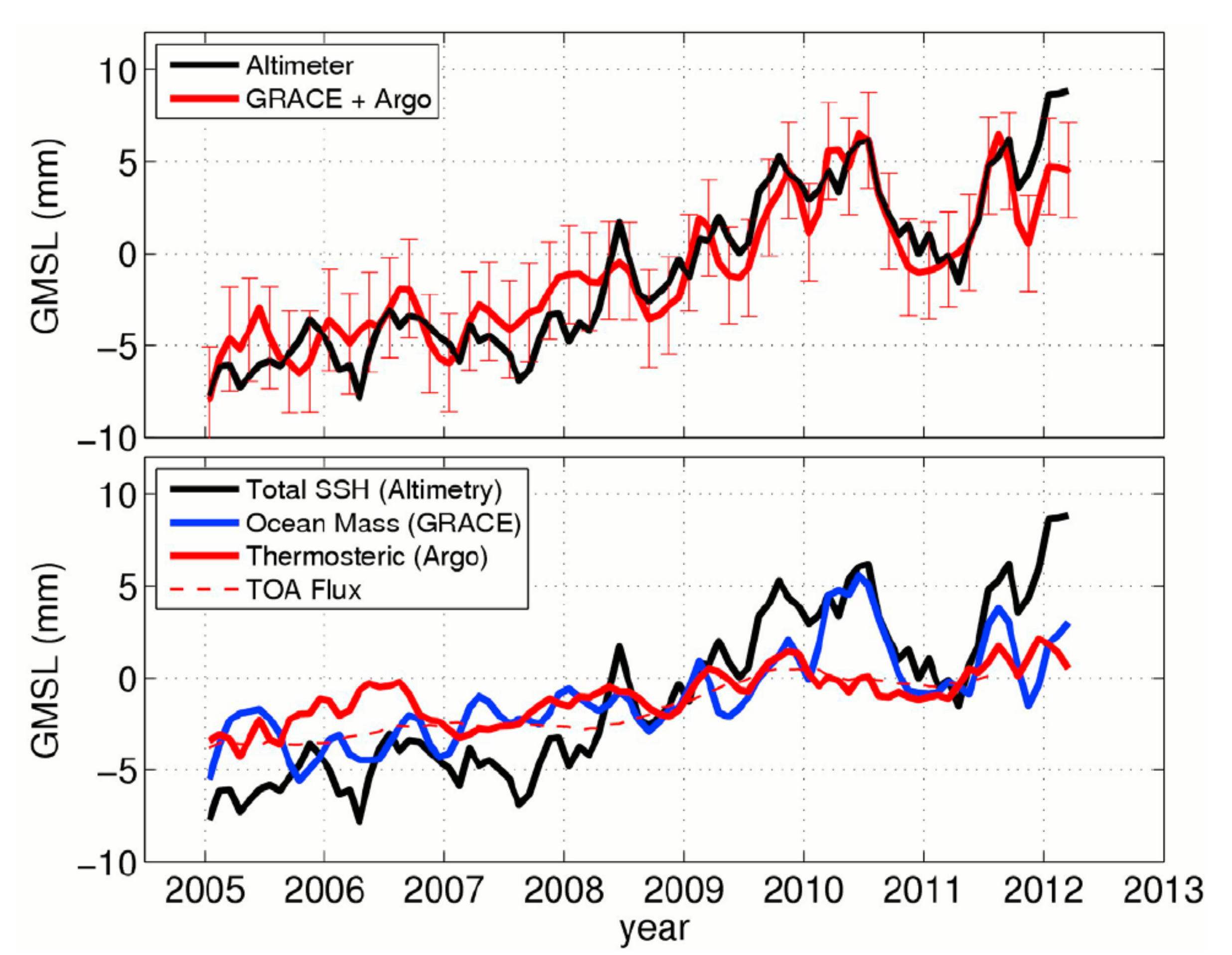
- Wet conditions in the West Pacific cause extreme precipitation
- Teleconnections with Monsoon, Africa..

Quiz time!

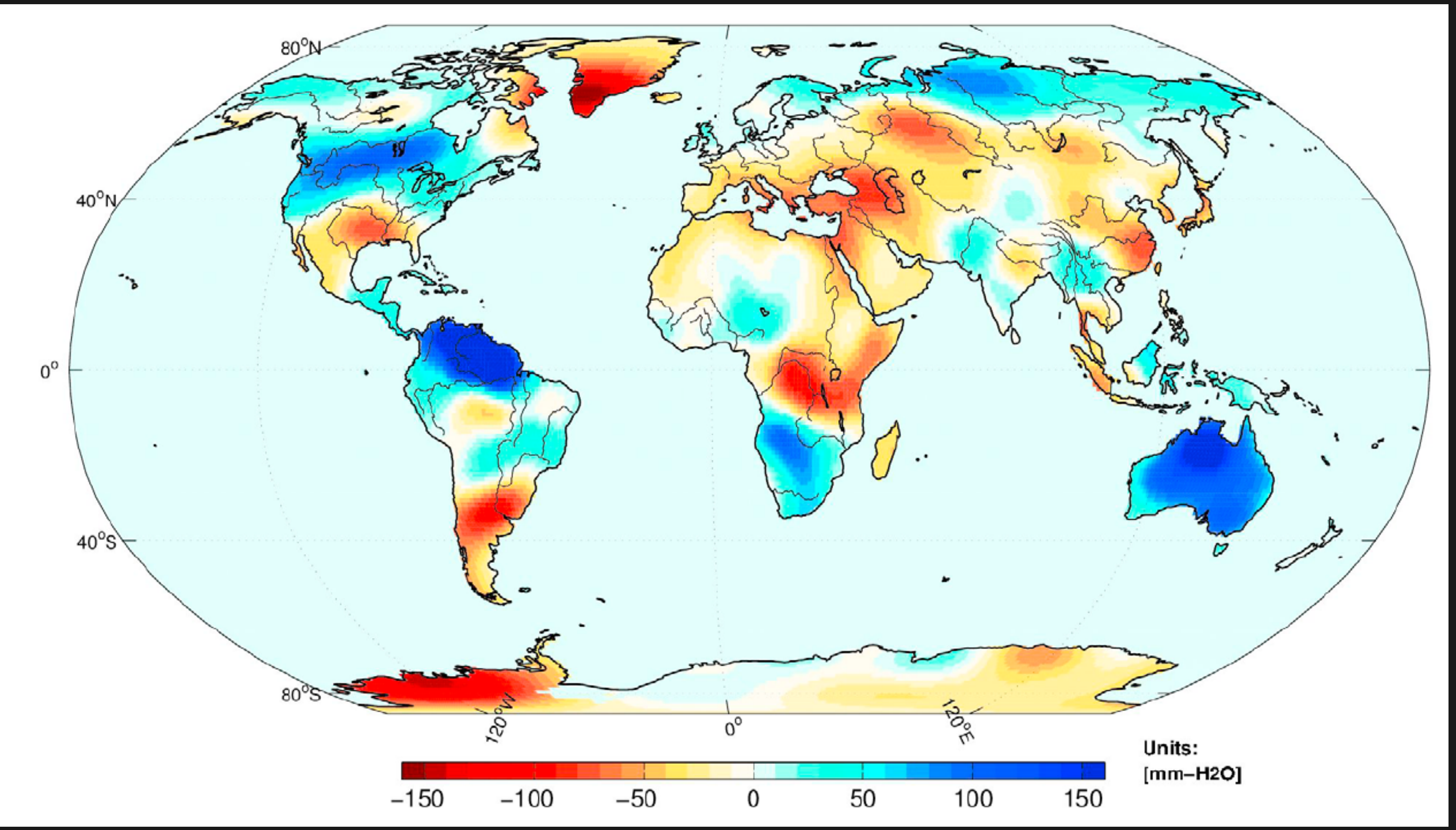


Sign up
Choose a method to log in
or sign up
Your email address
OR
Sign up with Facebook
Sign up with Google
Sign up with LinkedIn
Sign up with Microsoft
OR
Log in with your institution
Your institution
Want to join an event?
www.wooclap.com/
Event code
Join
We use cookies to improve the general experience on the platform, provide users chat support and deliver targeted ads on websites.
Accept all
Reject All
Customise

2010-2011 La Nina event



Global mean sea level variations (total, mass driven and 'steric'), From Böning et al. 2012



Terrestrial water storage change (2010-2011) from GRACE, From Böning et al. 2012

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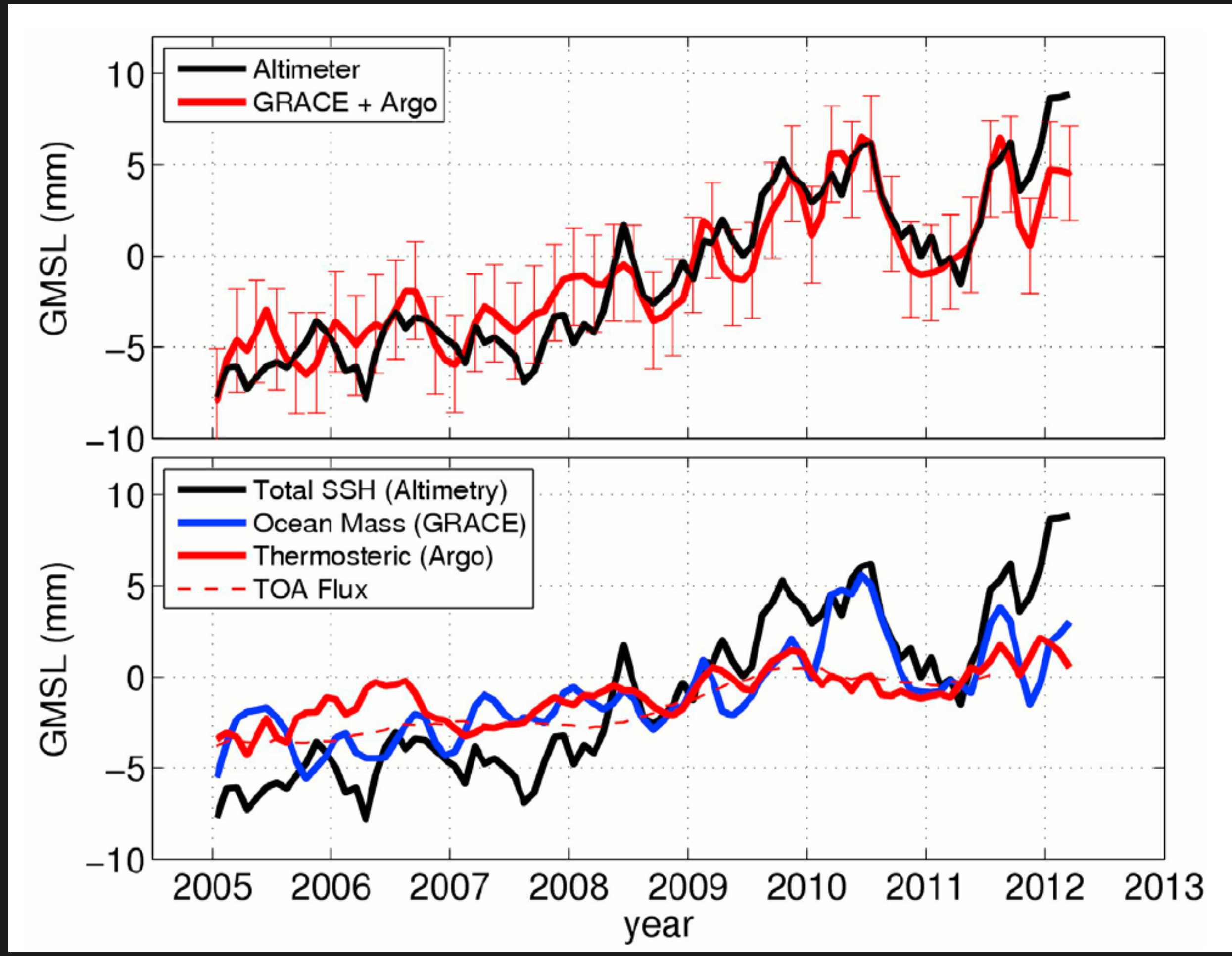

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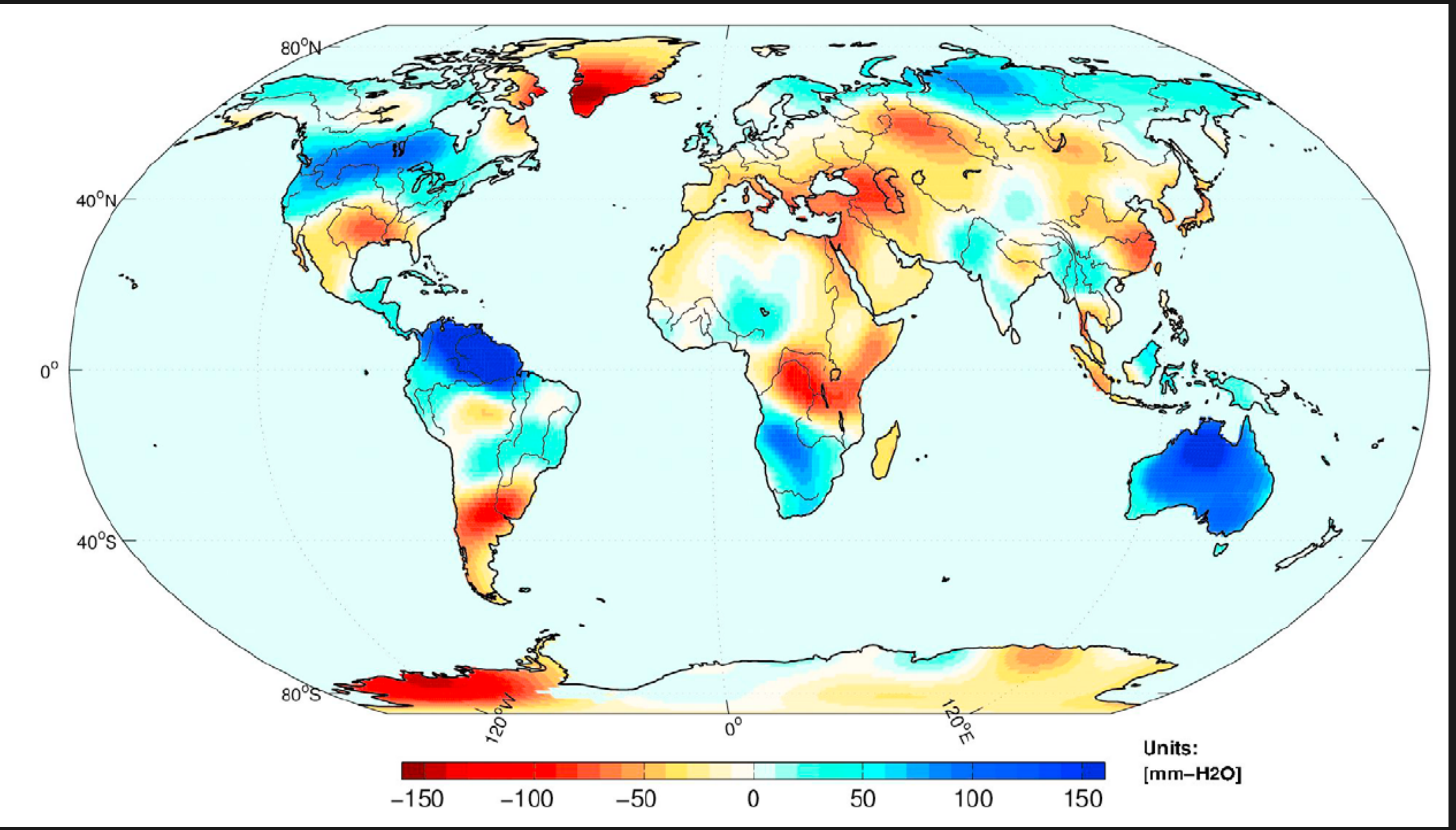

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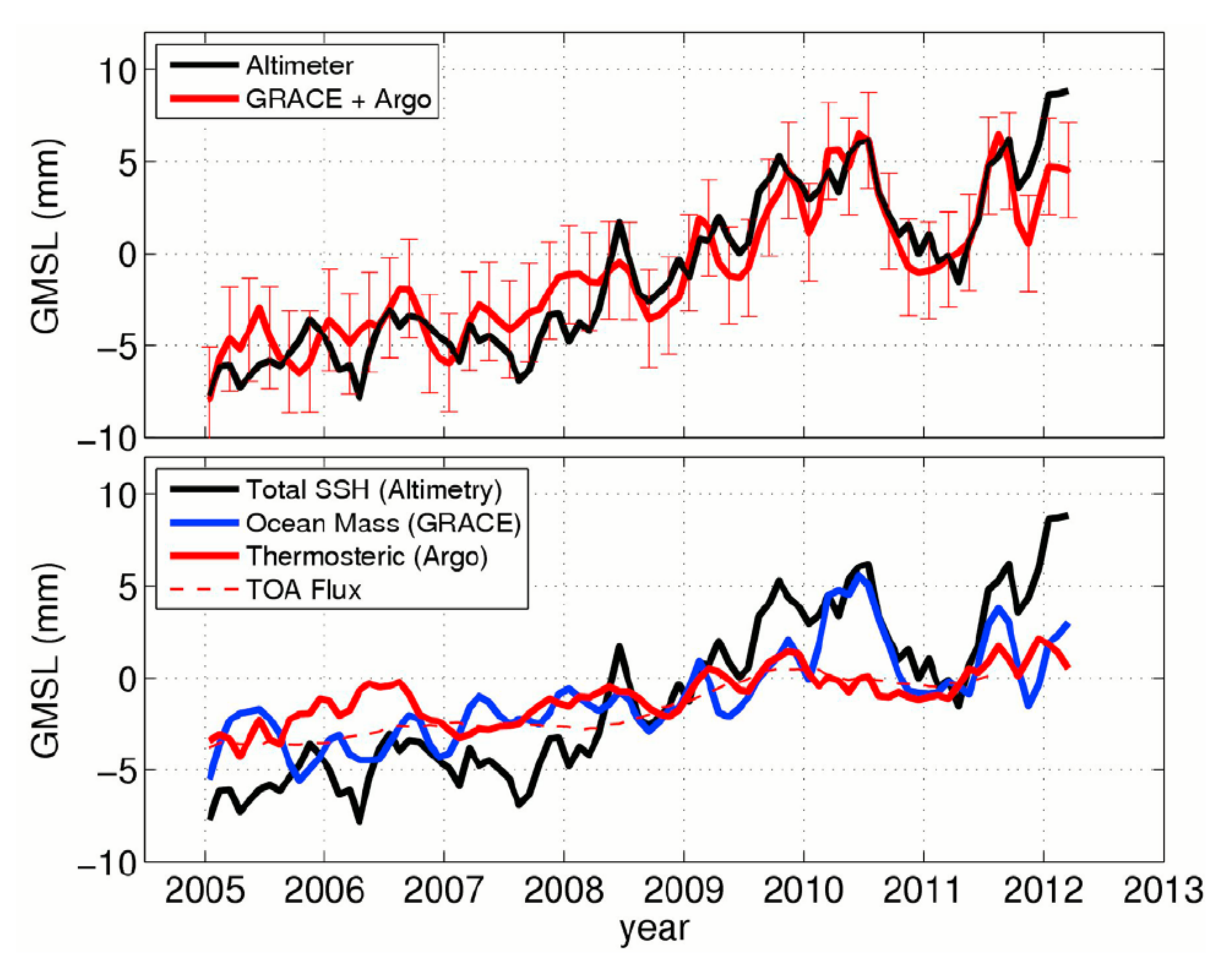

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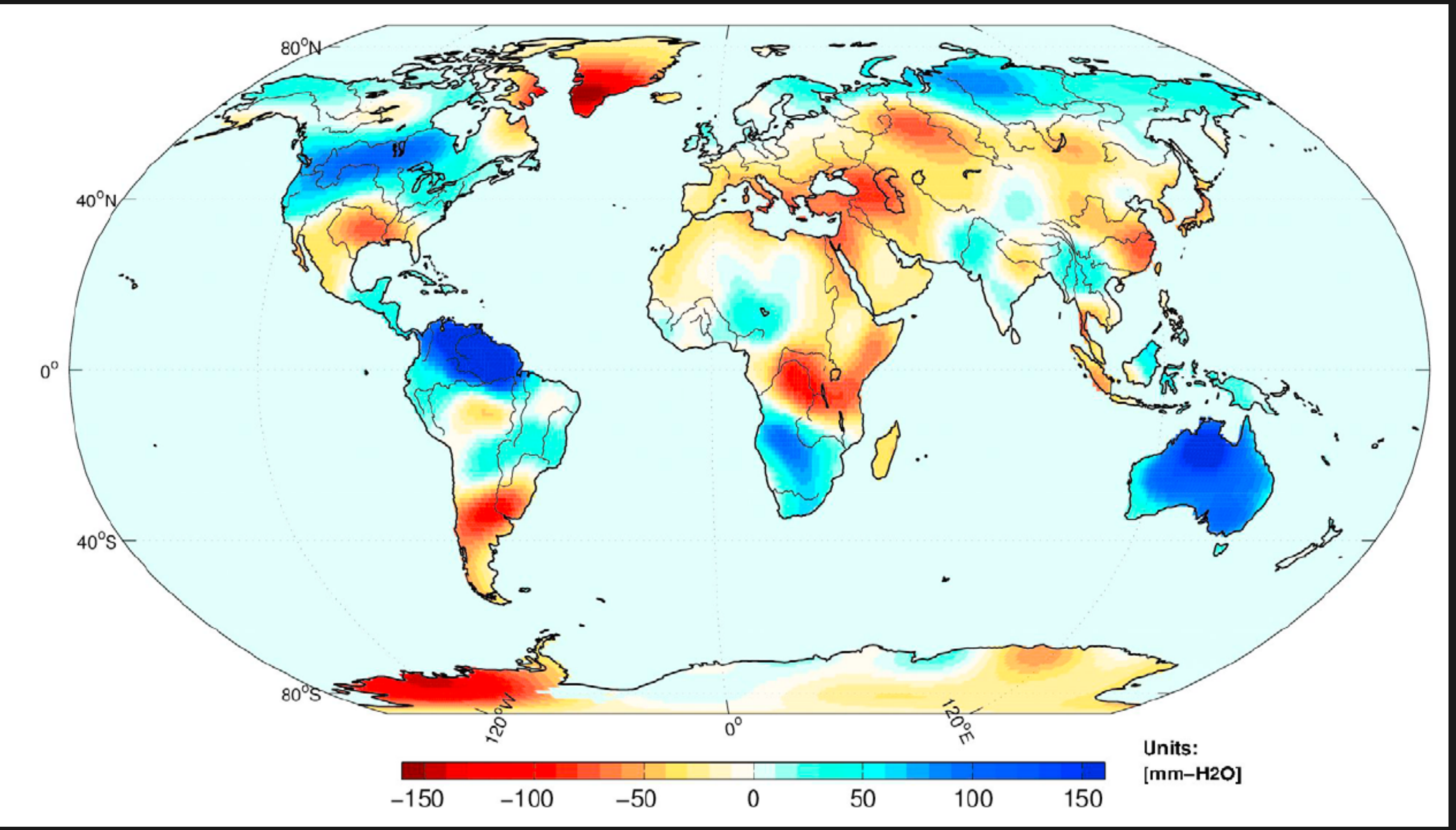

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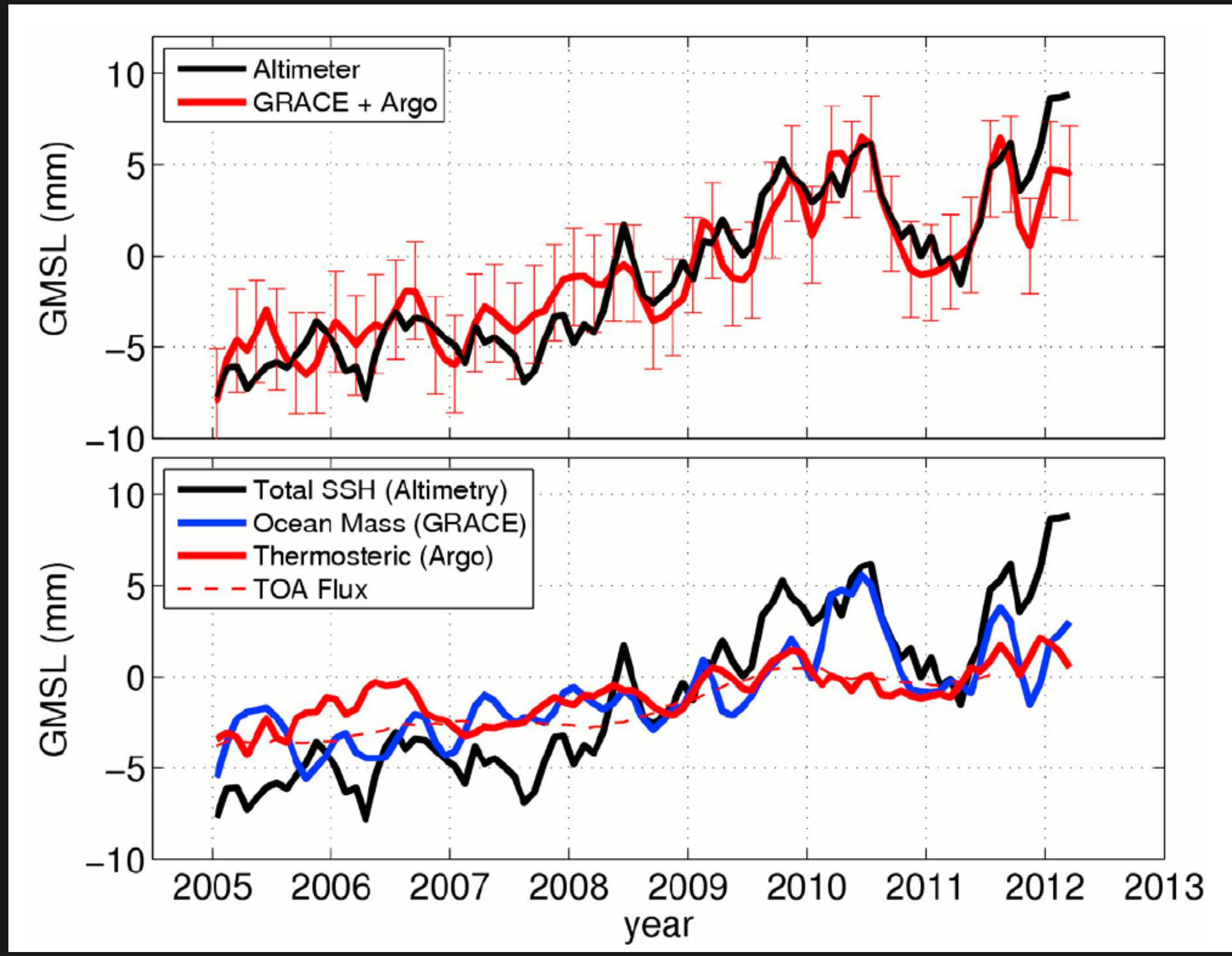

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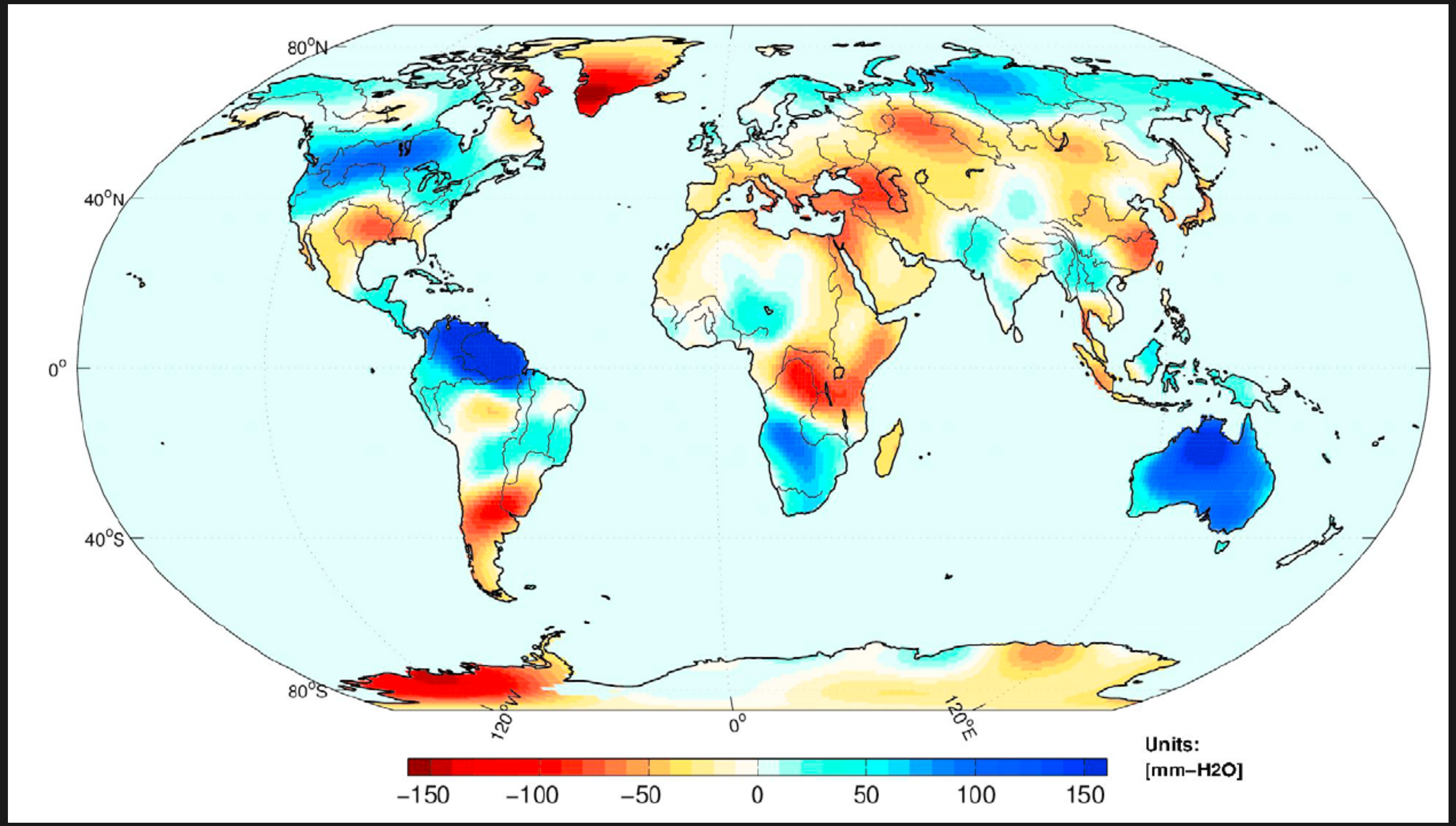

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- Detectable with radar altimetry
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- Hotspot:Australia

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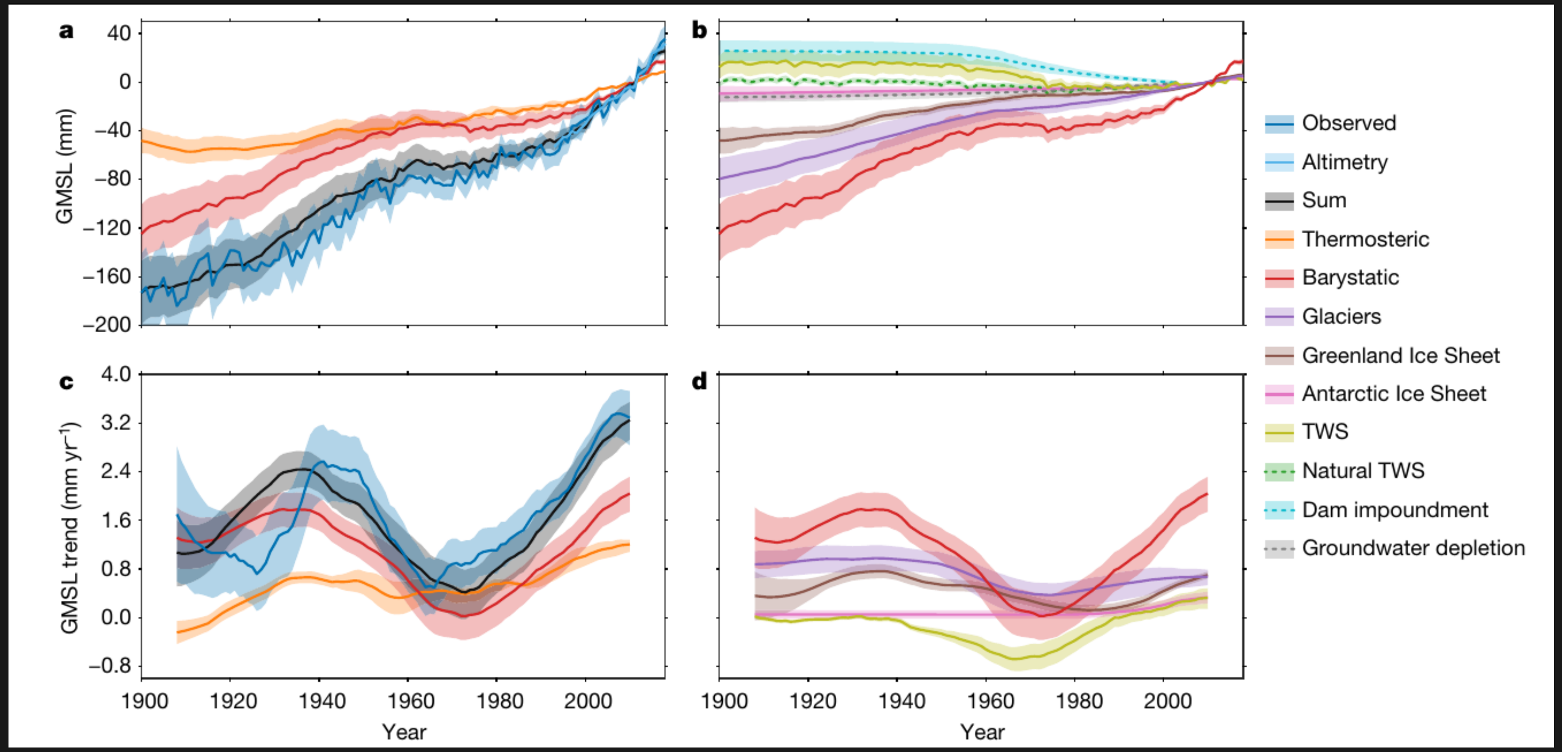
Sea level contributions since 1900



Historic sea level can be largely explained with different (modelled) sea level contributions. From Frederikse et al. 2020

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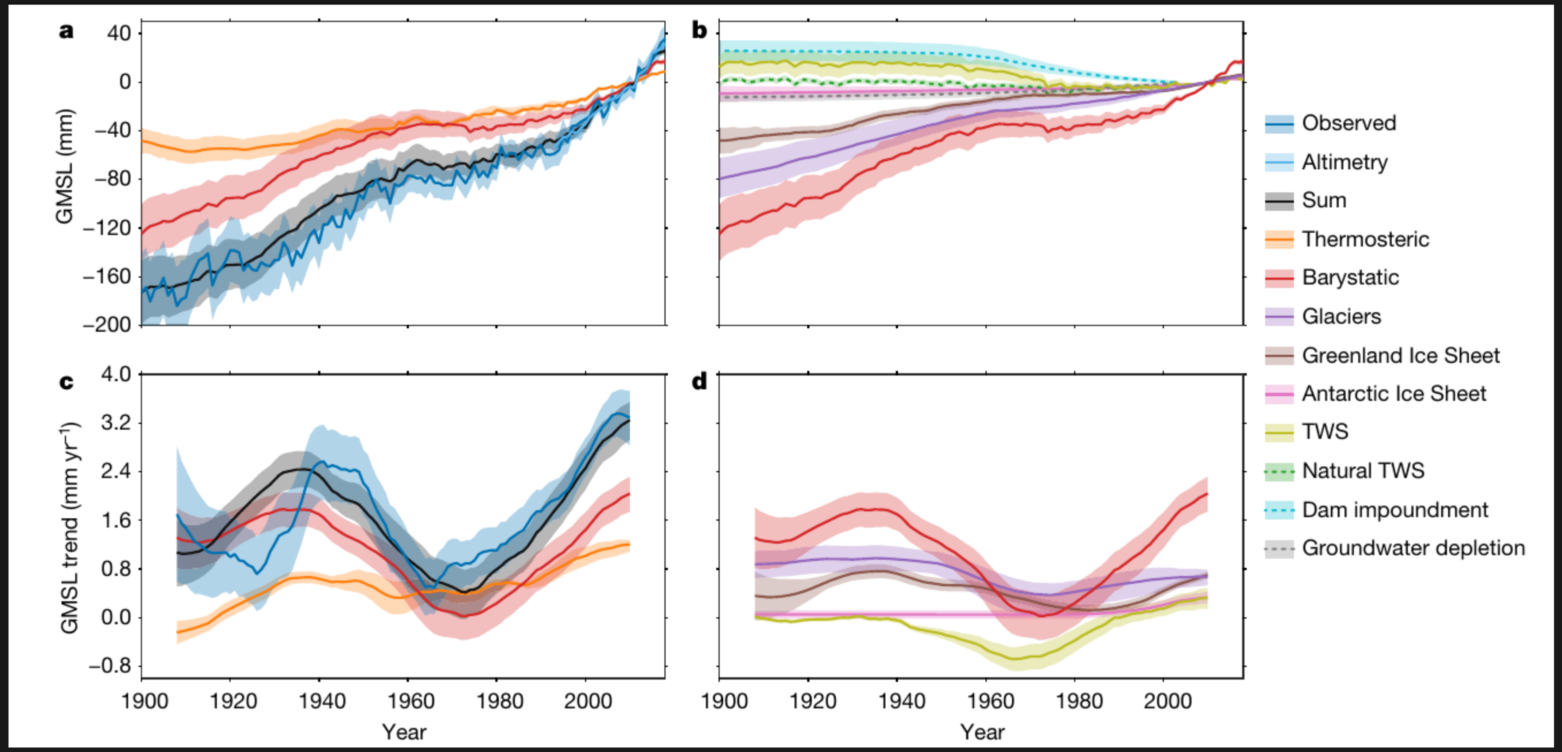

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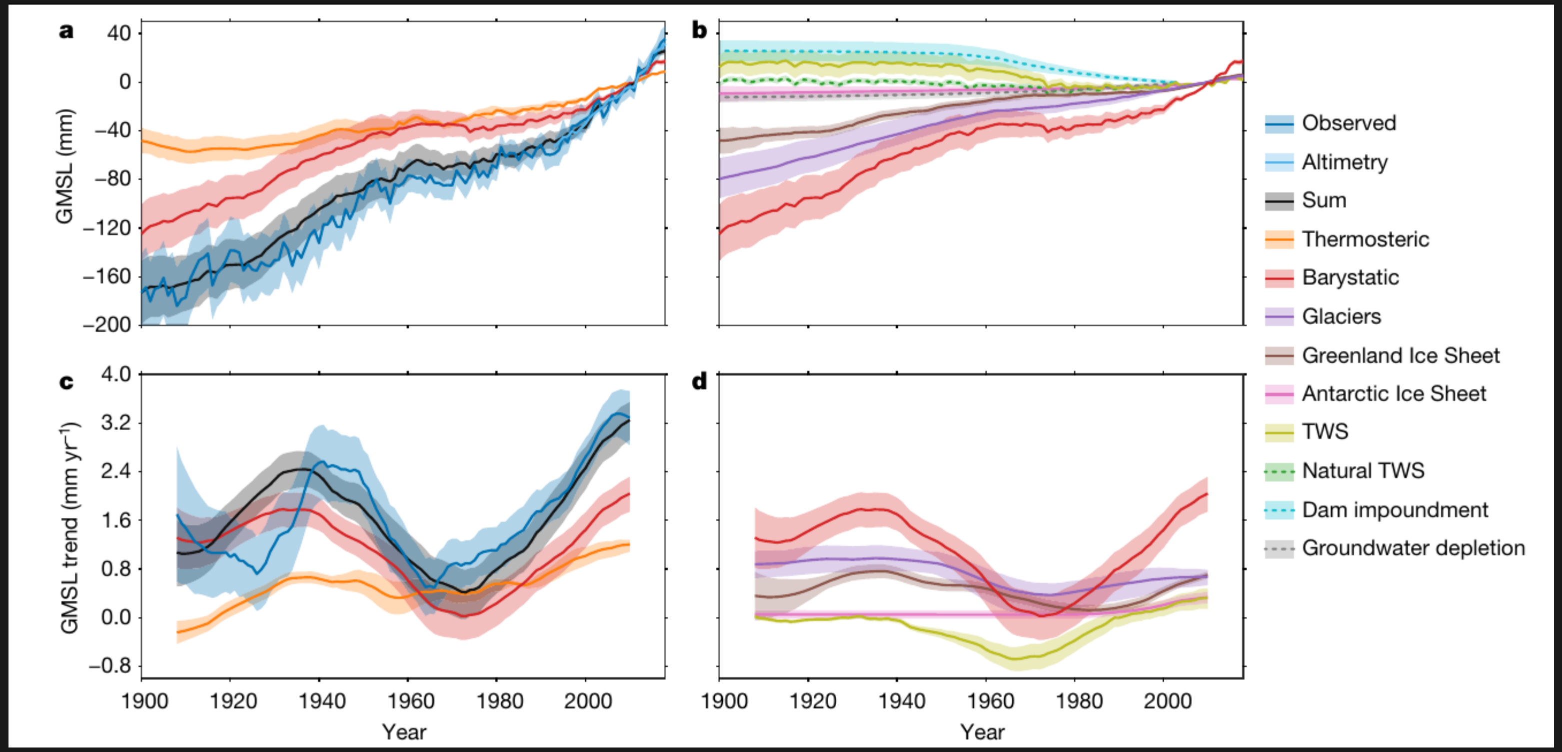

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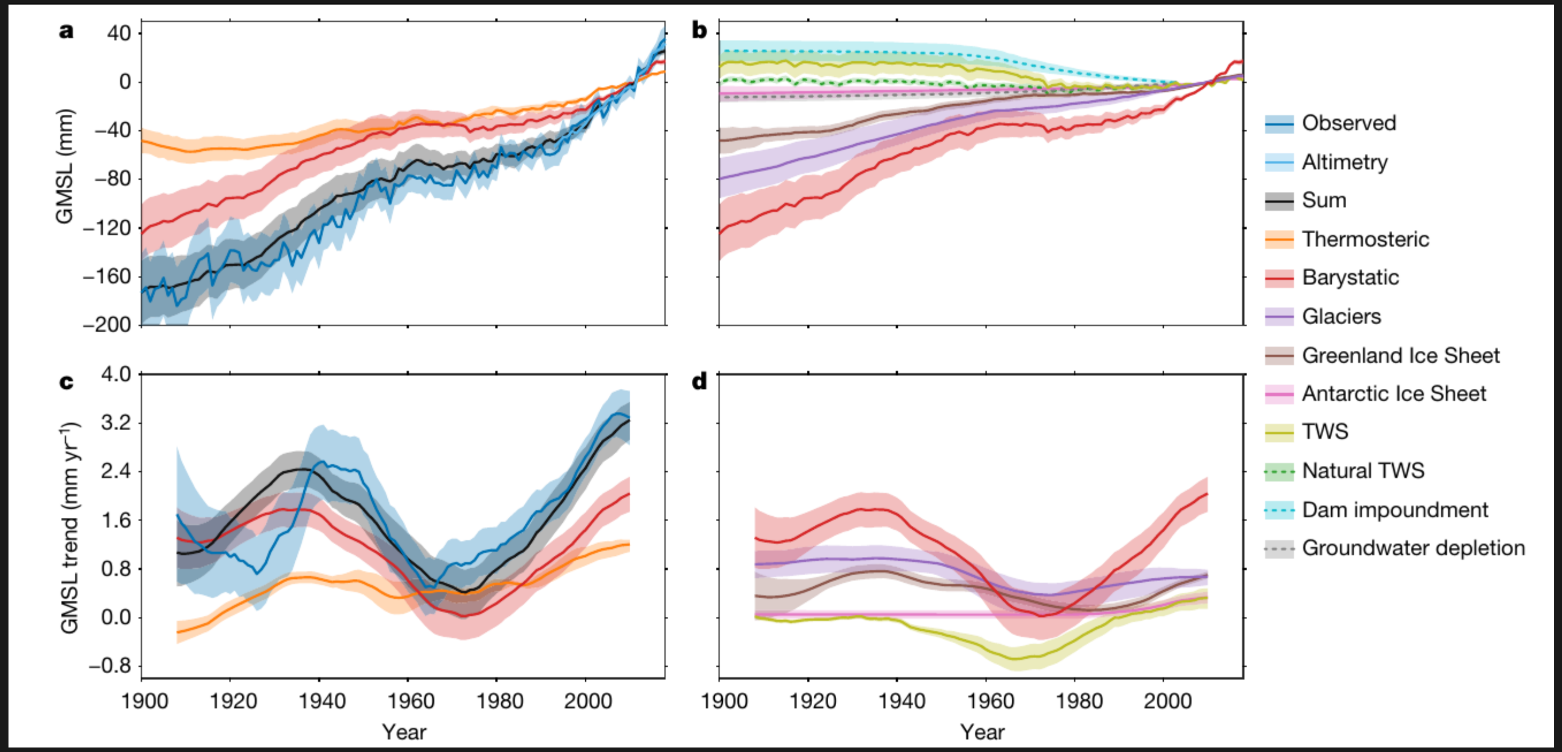

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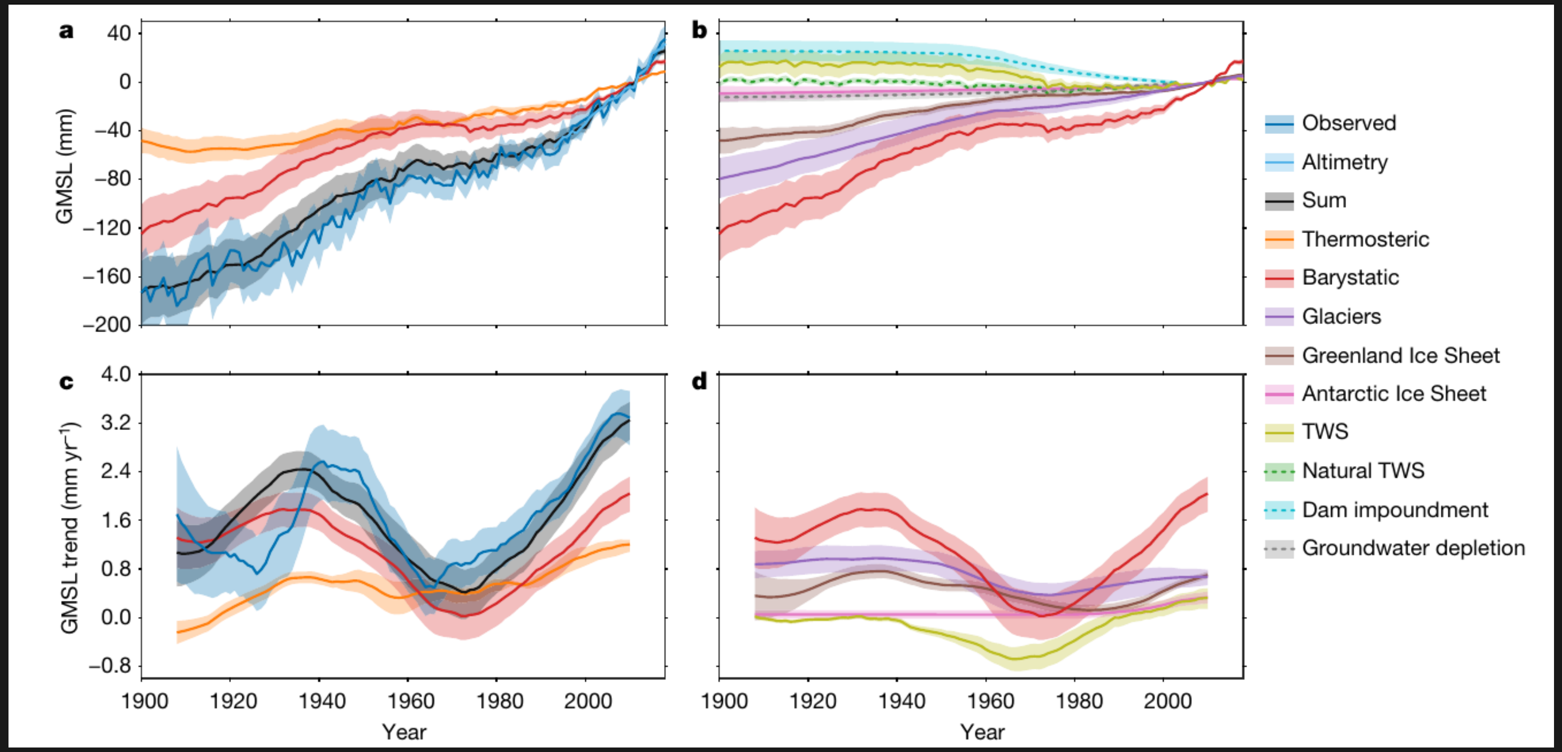

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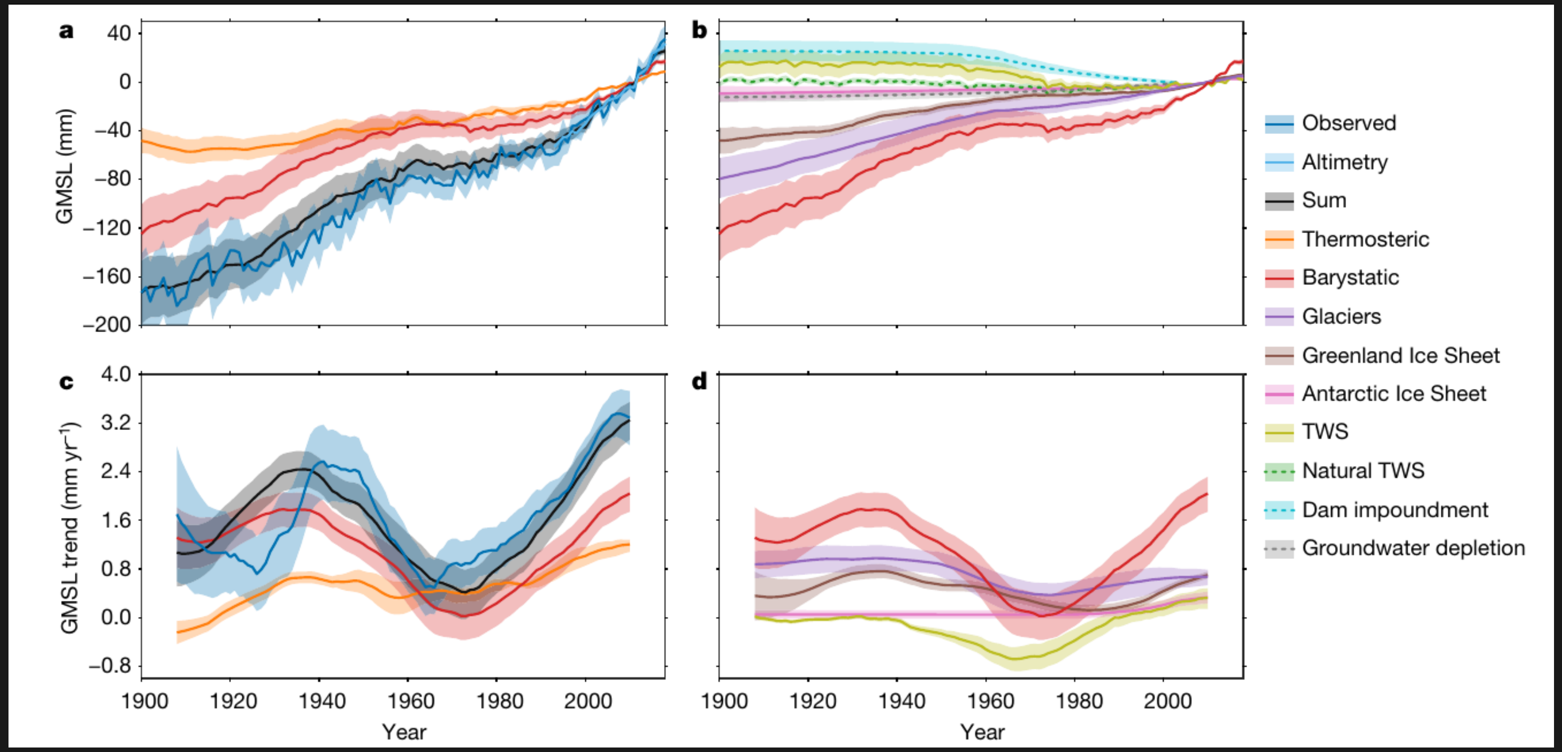

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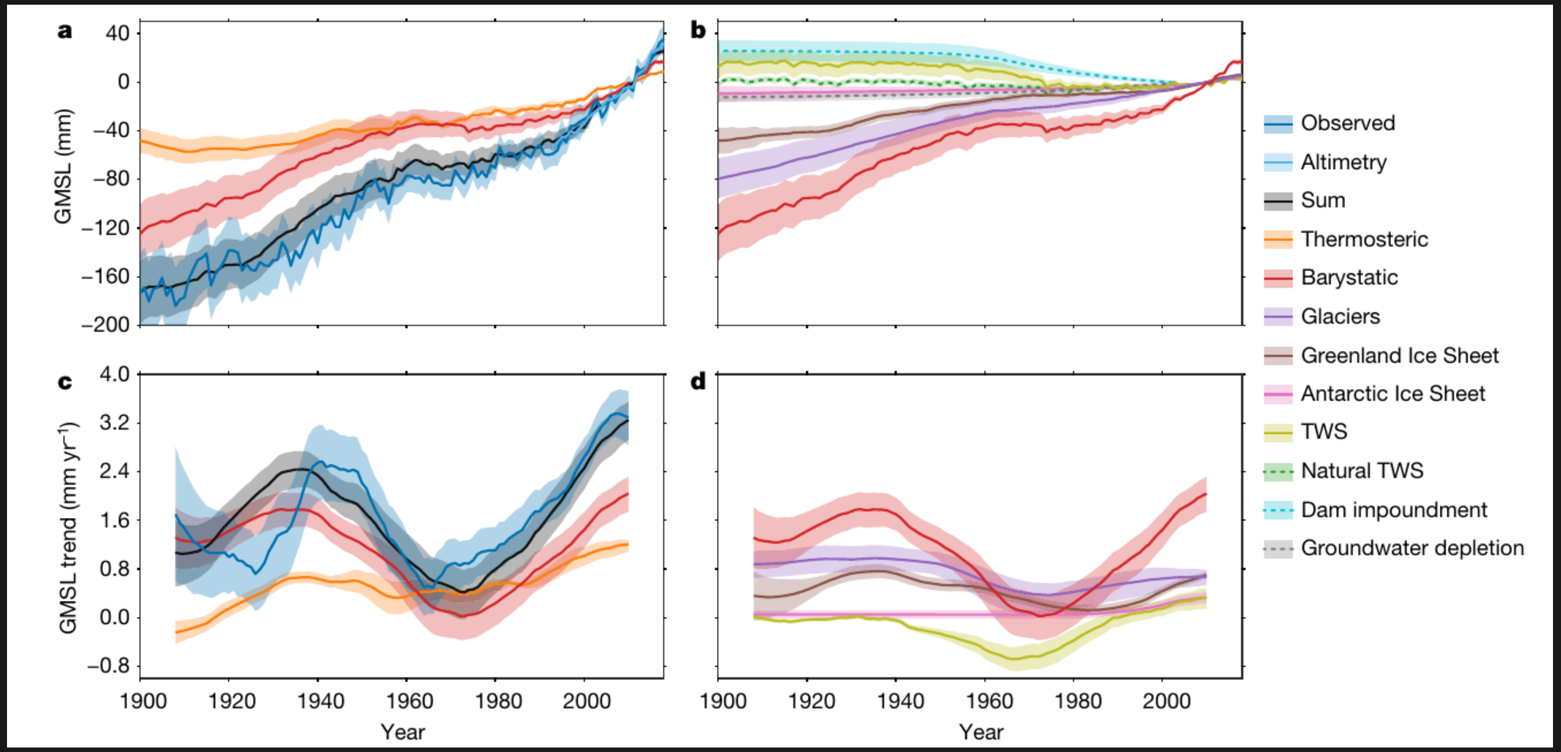

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- Recent accelerations from icesheets and glaciers -> (observable by GRACE since 2002)

Ocean mass from GRACE (Theory)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. B9, 2193, doi:10.1029/2001JB000576, 2002

Methods for inferring regional surface-mass anomalies from Gravity Recovery and Climate Experiment (GRACE) measurements of time-variable gravity

Sean Swenson and John Wahr
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Received 8 May 2001; revised 9 March 2002; accepted 14 March 2002; published 19 September 2002.

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$$\widetilde{\Delta\sigma}_{\text{region}} = \sum_{l,m} \frac{K_l}{\Omega_{\text{region}}} \left(W_{lm}^{c} \Delta C_{lm} + W_{lm}^{s} \Delta S_{lm} \right). \qquad (27)$$

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    - dot product of smoothed basin coefficients with GRACE-TWS coefficients

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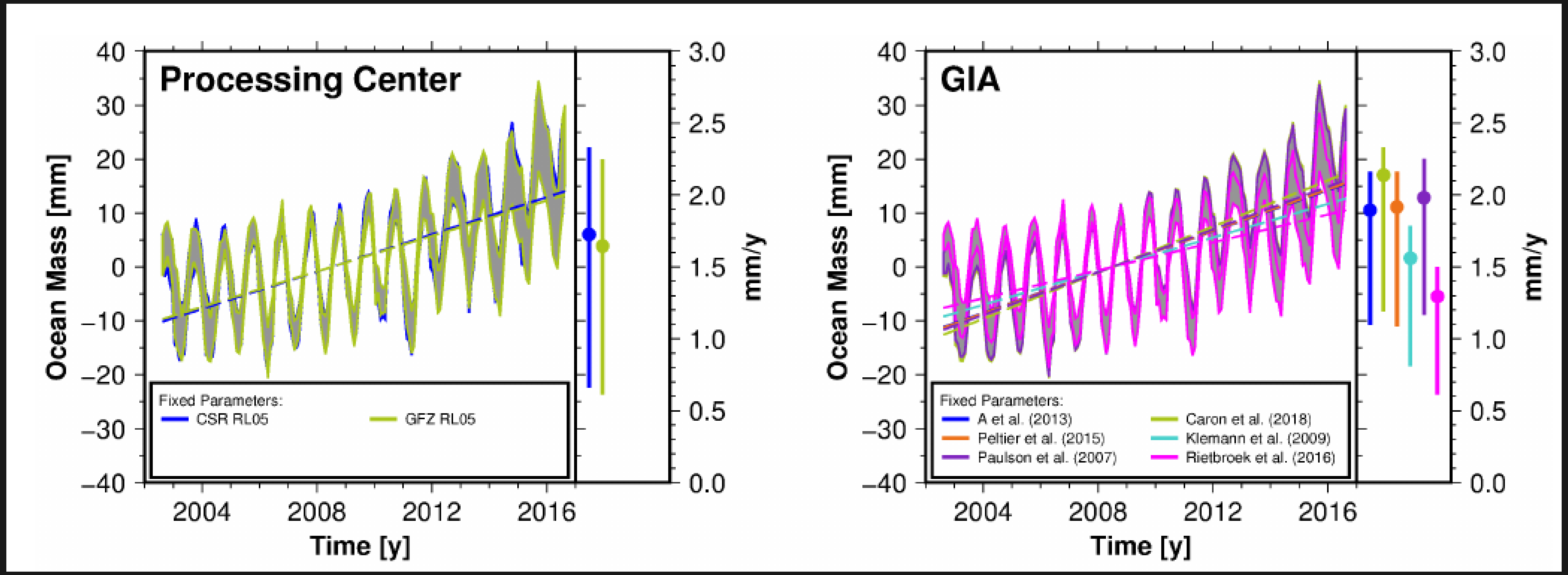

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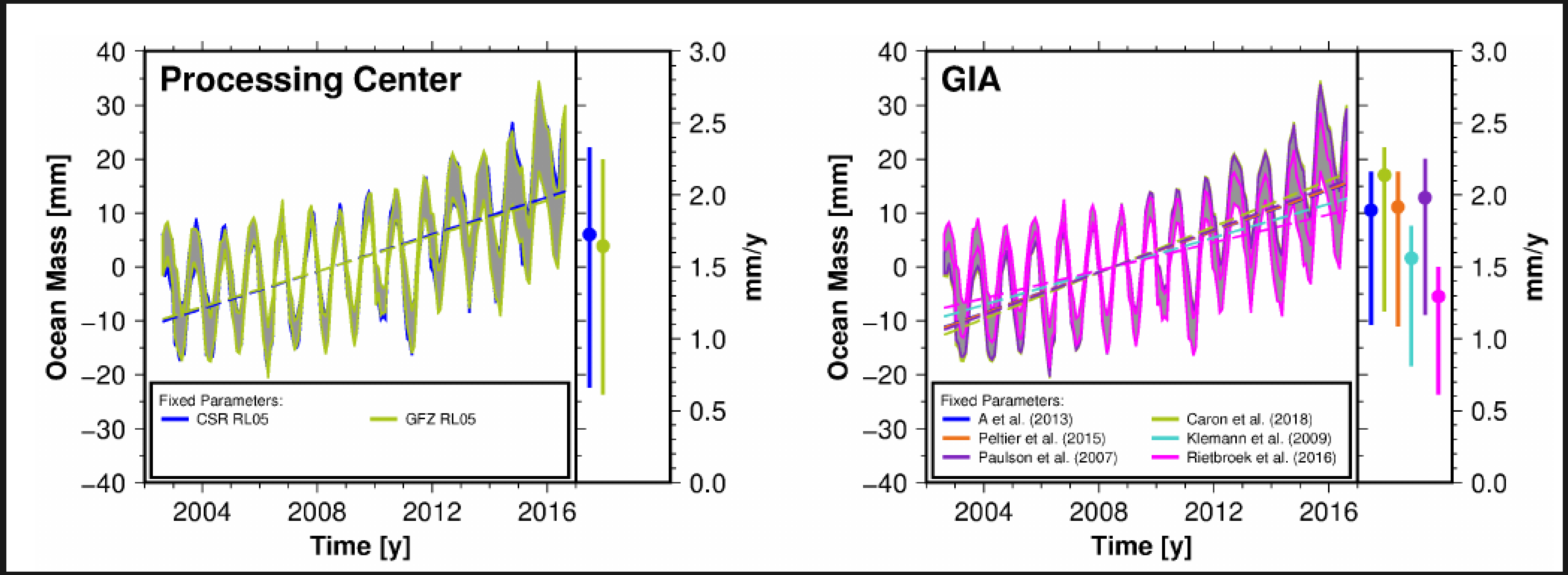

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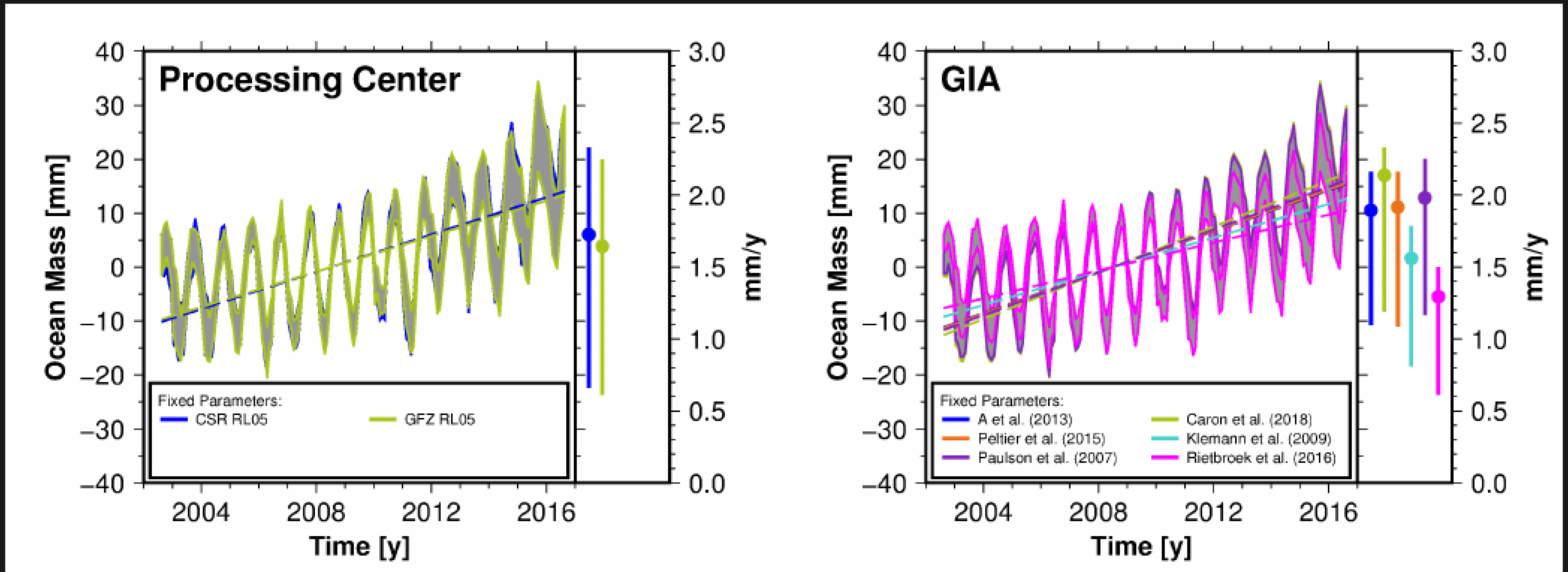

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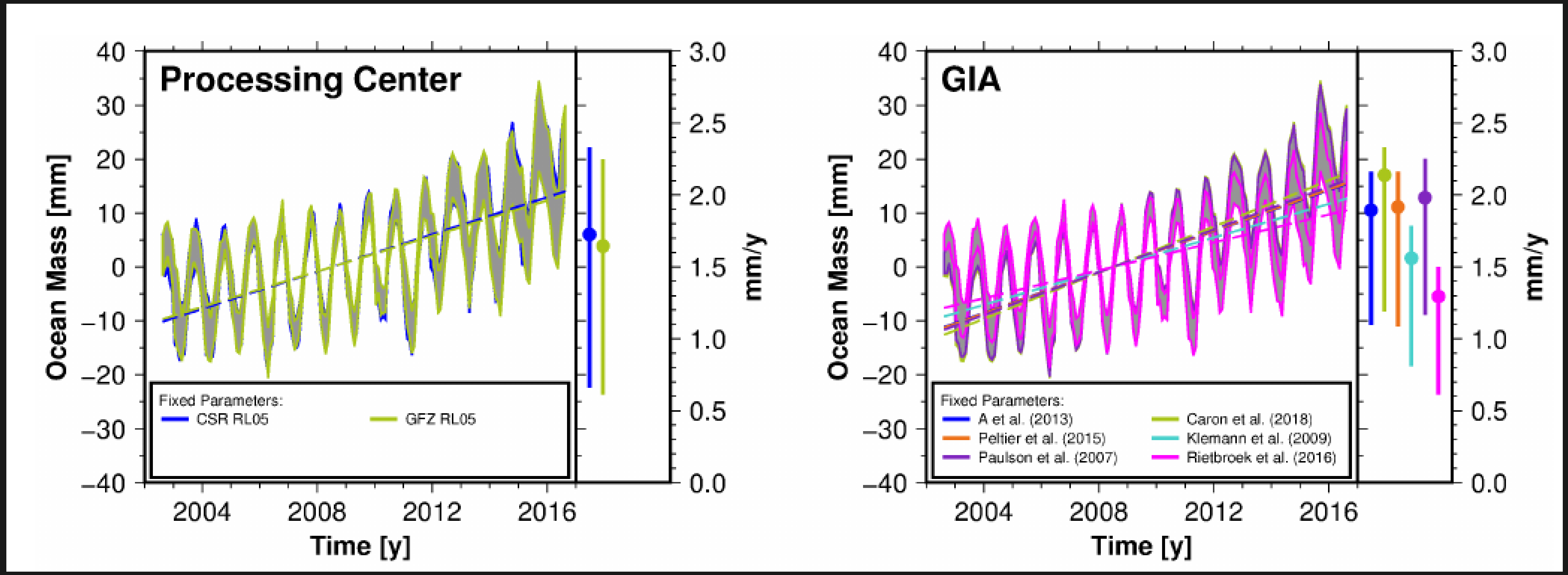

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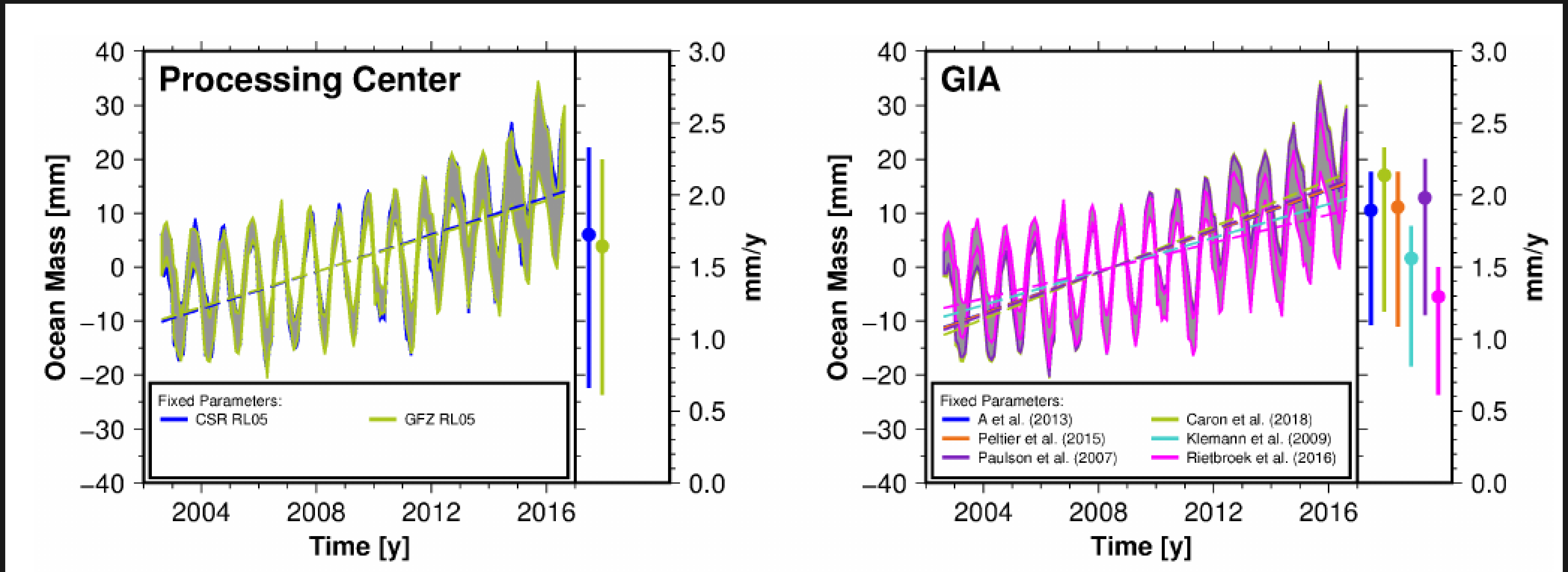

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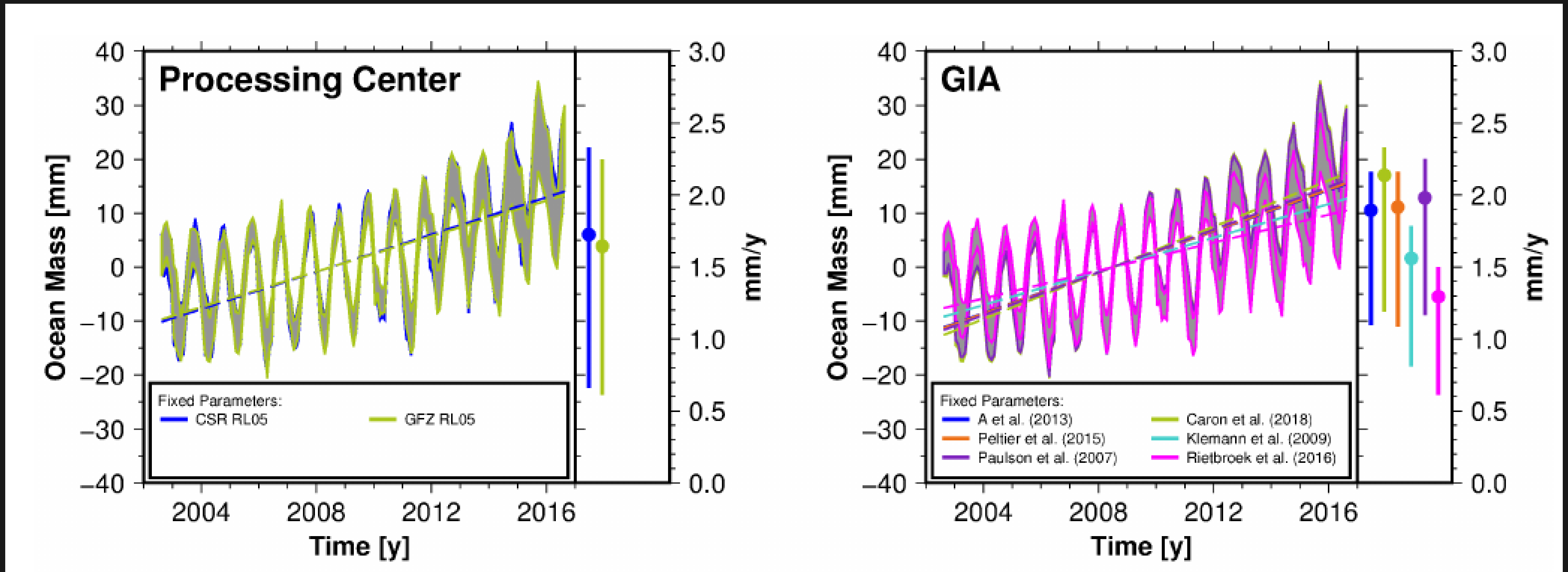

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  - restoring background models (GAC, GAD)
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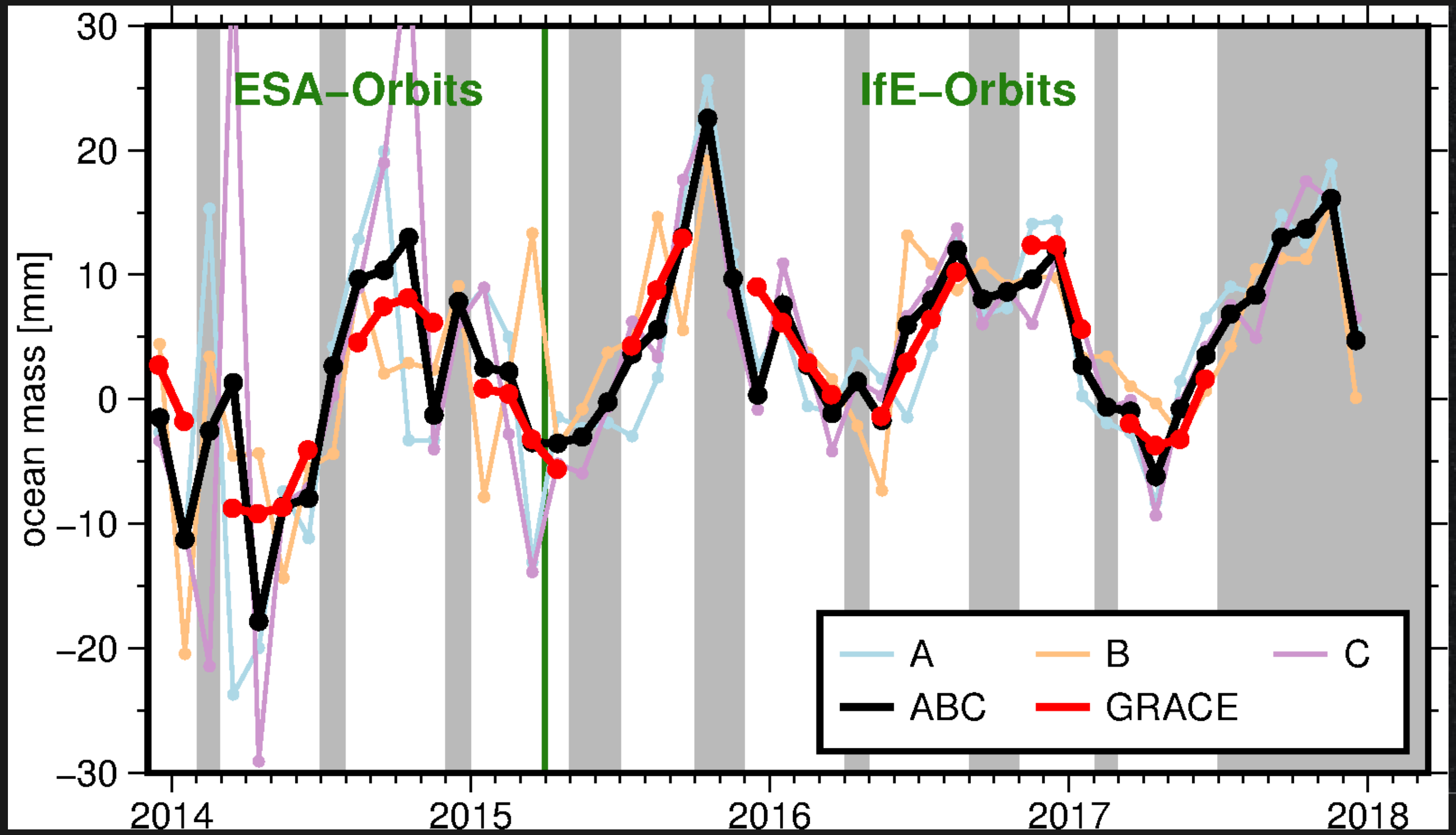
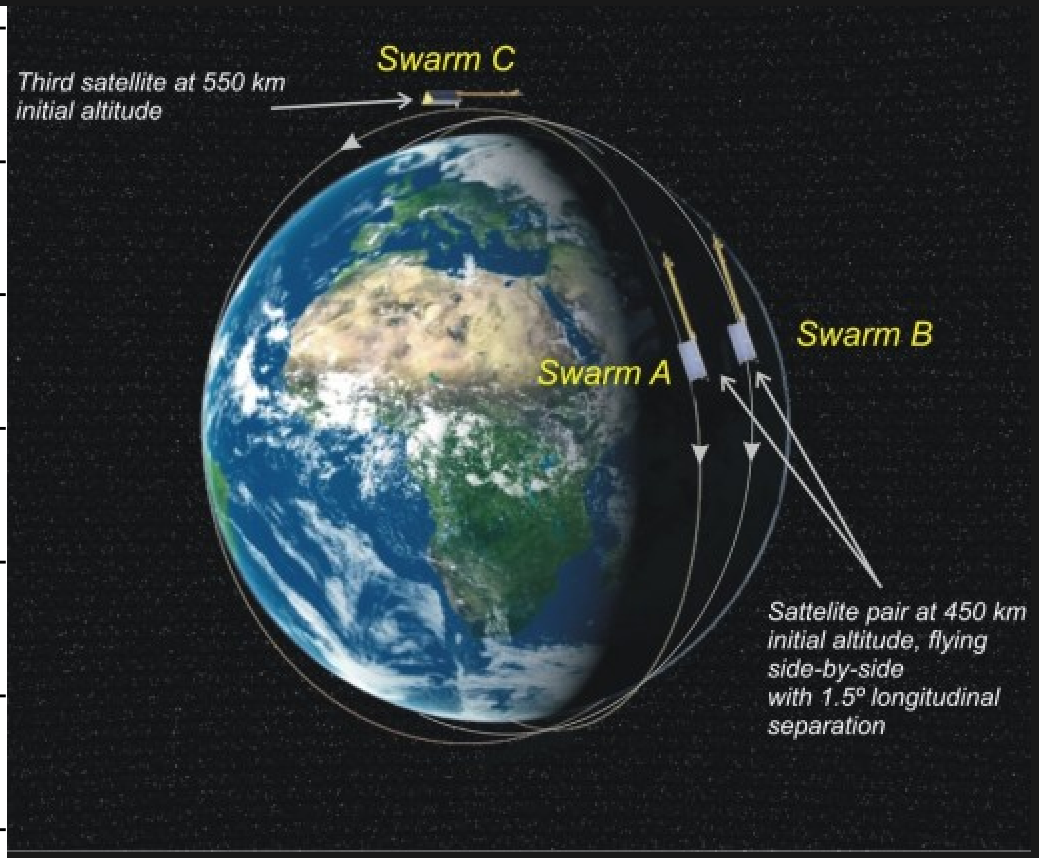
  - Current mass trends ~1.5-2mm/yr (c.f. total trend ~3.3 mm/yr)

Ocean mass from the SWARM Mission



Comparison of ocean mass from GRACE and the SWARM (A,B,C satellites). Update of Luck et al. 2018



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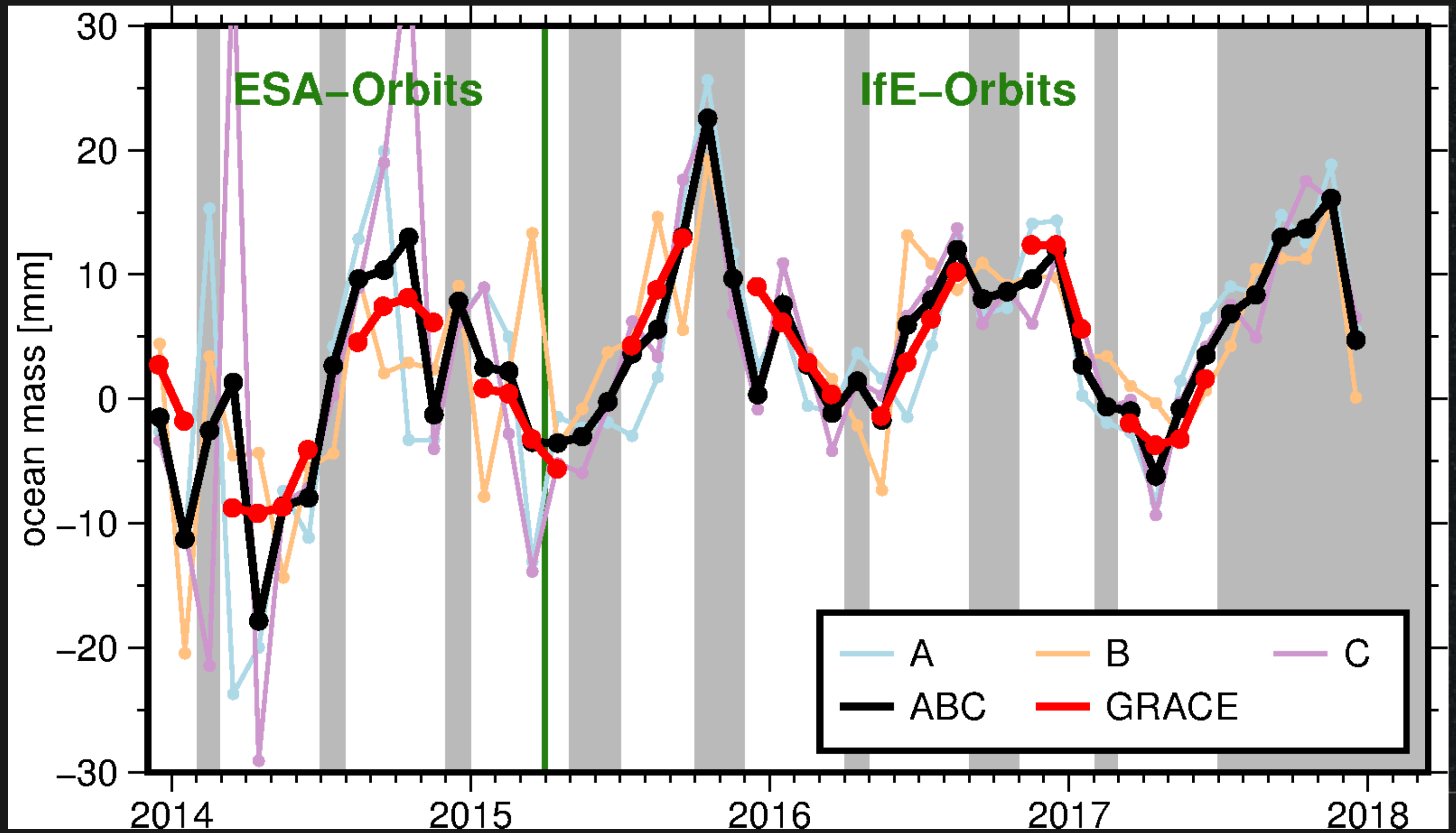

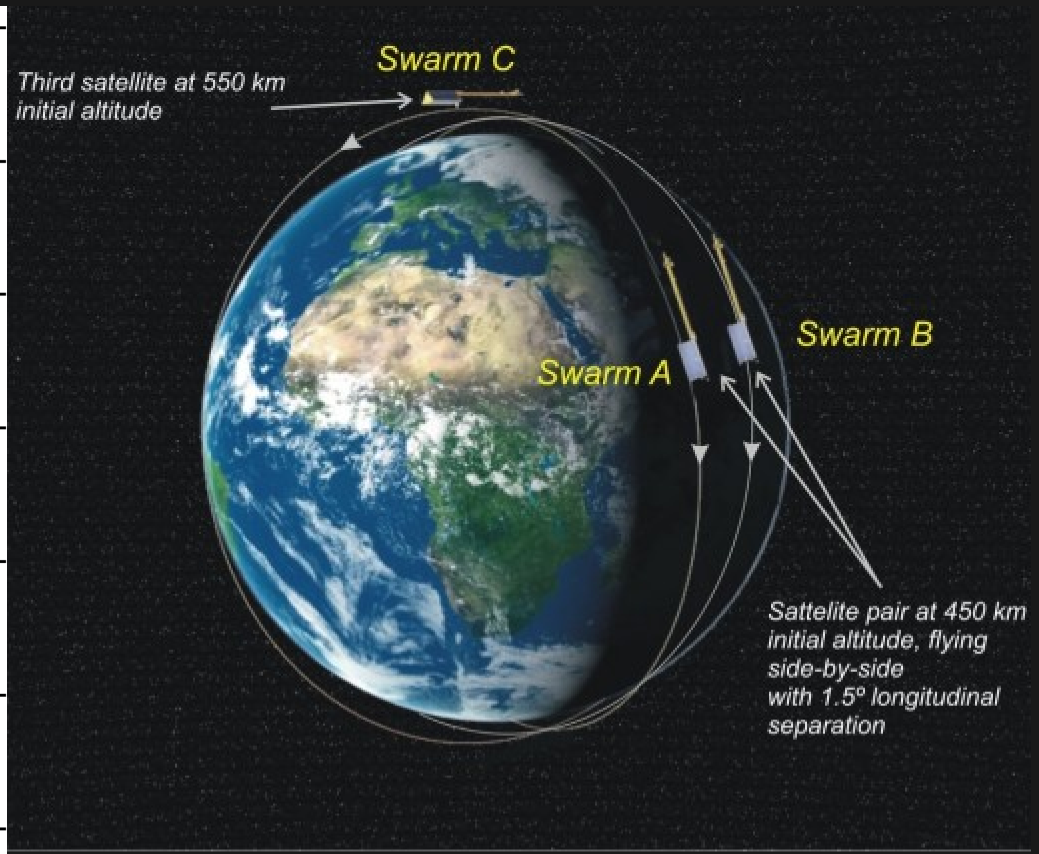

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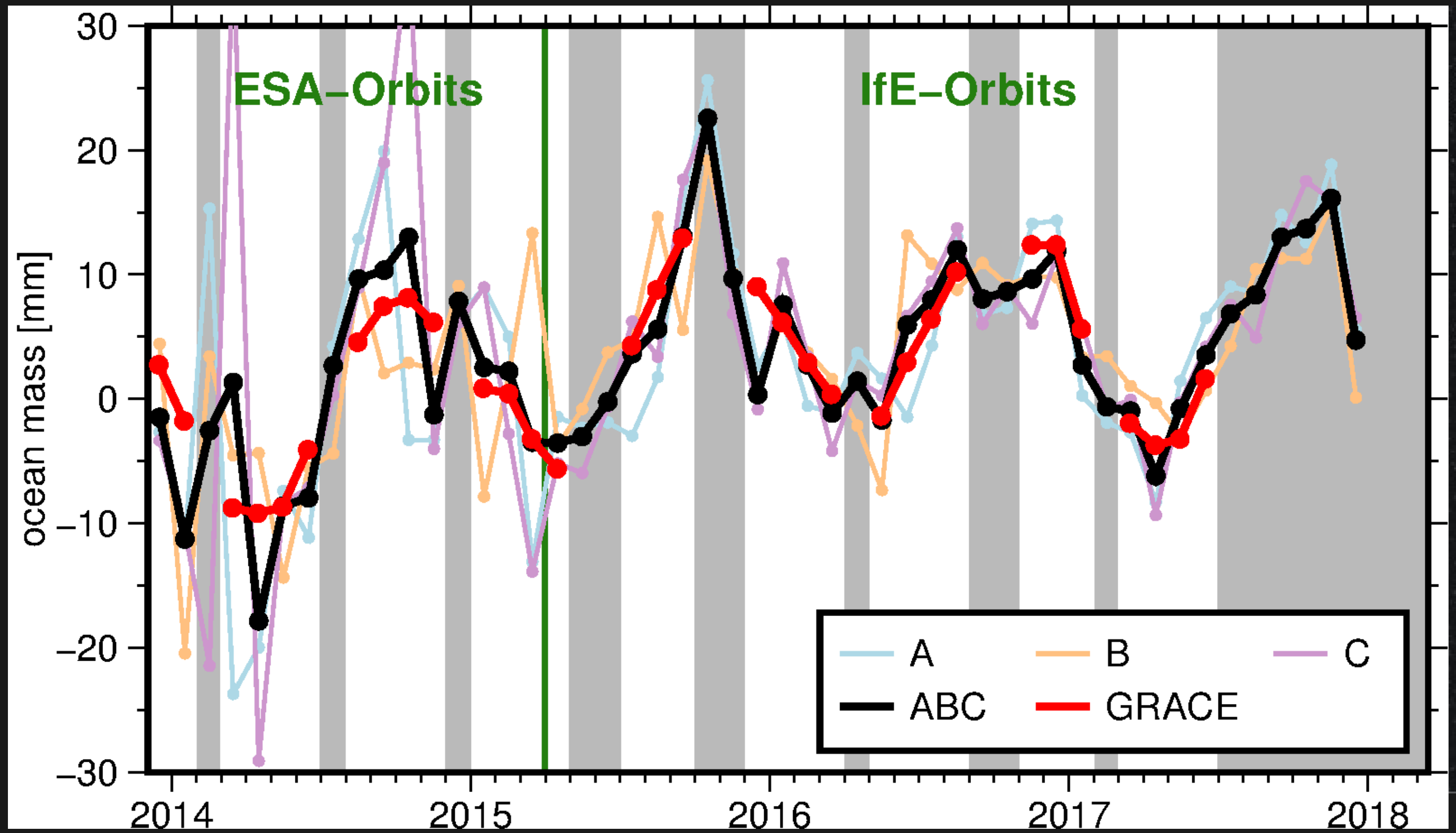

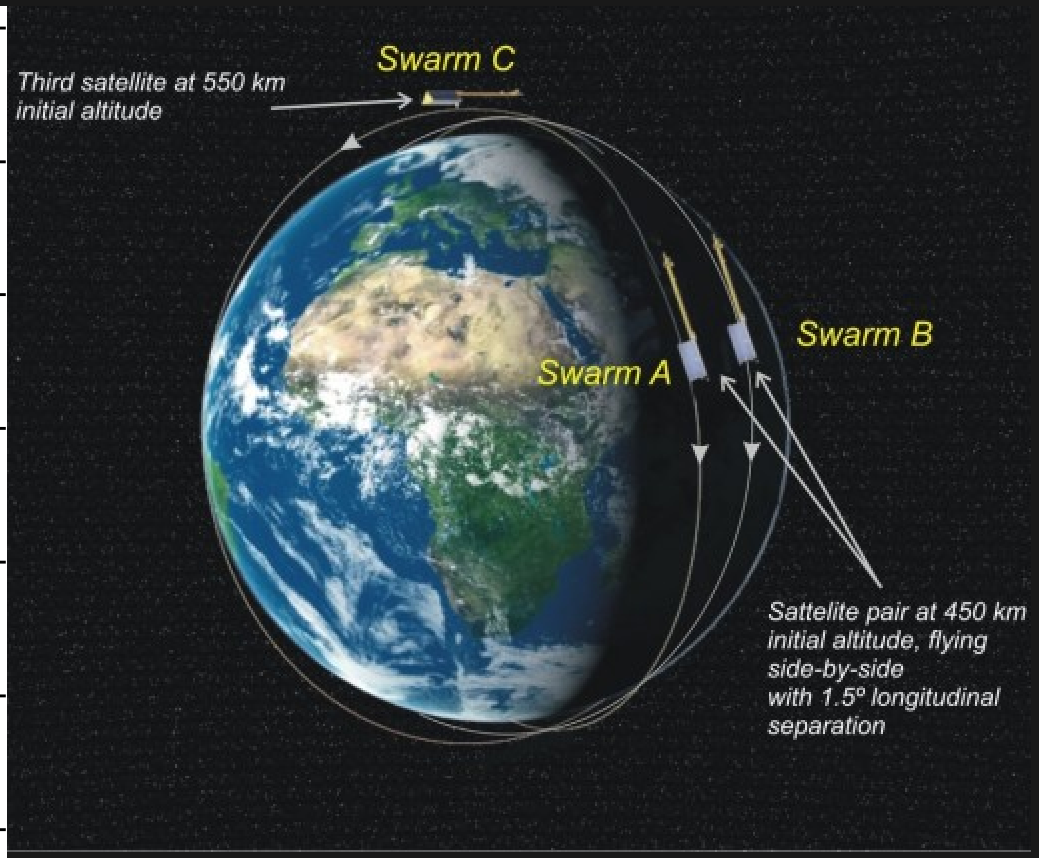

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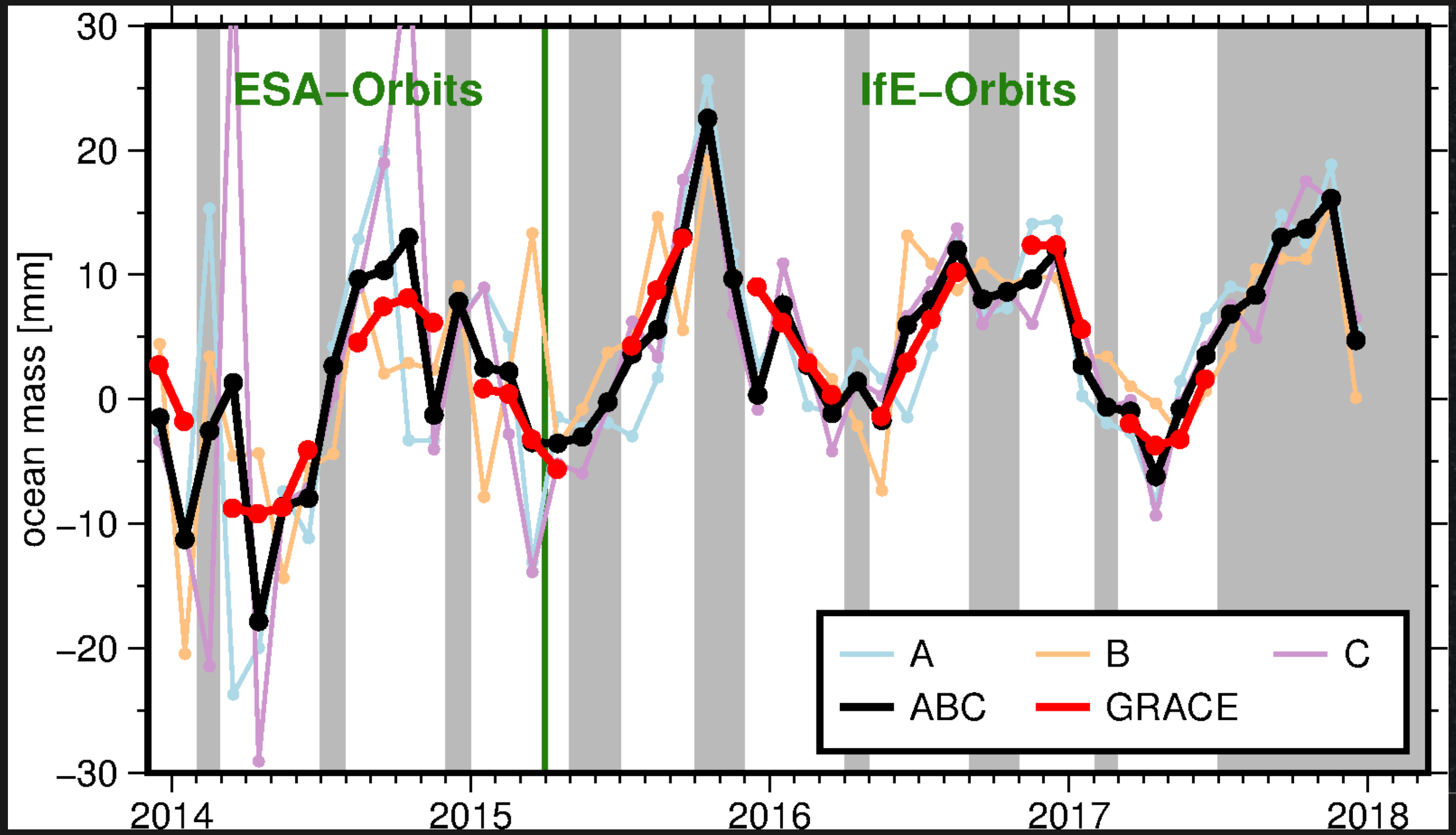

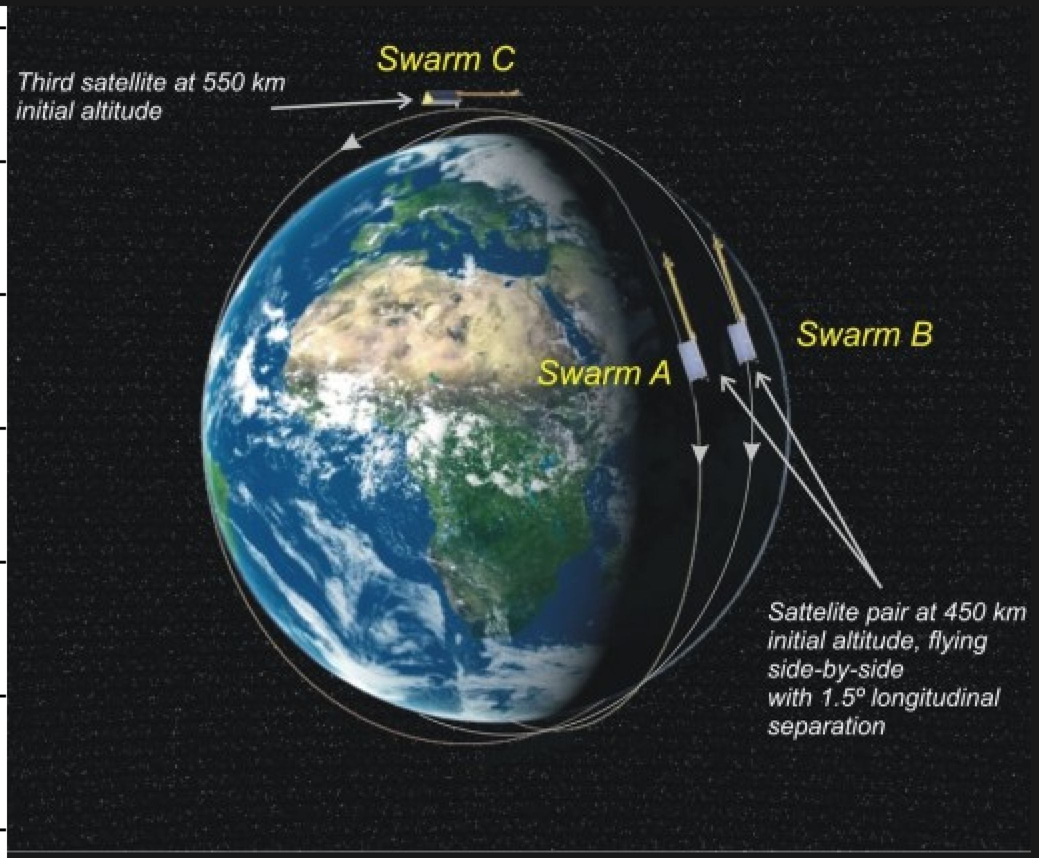

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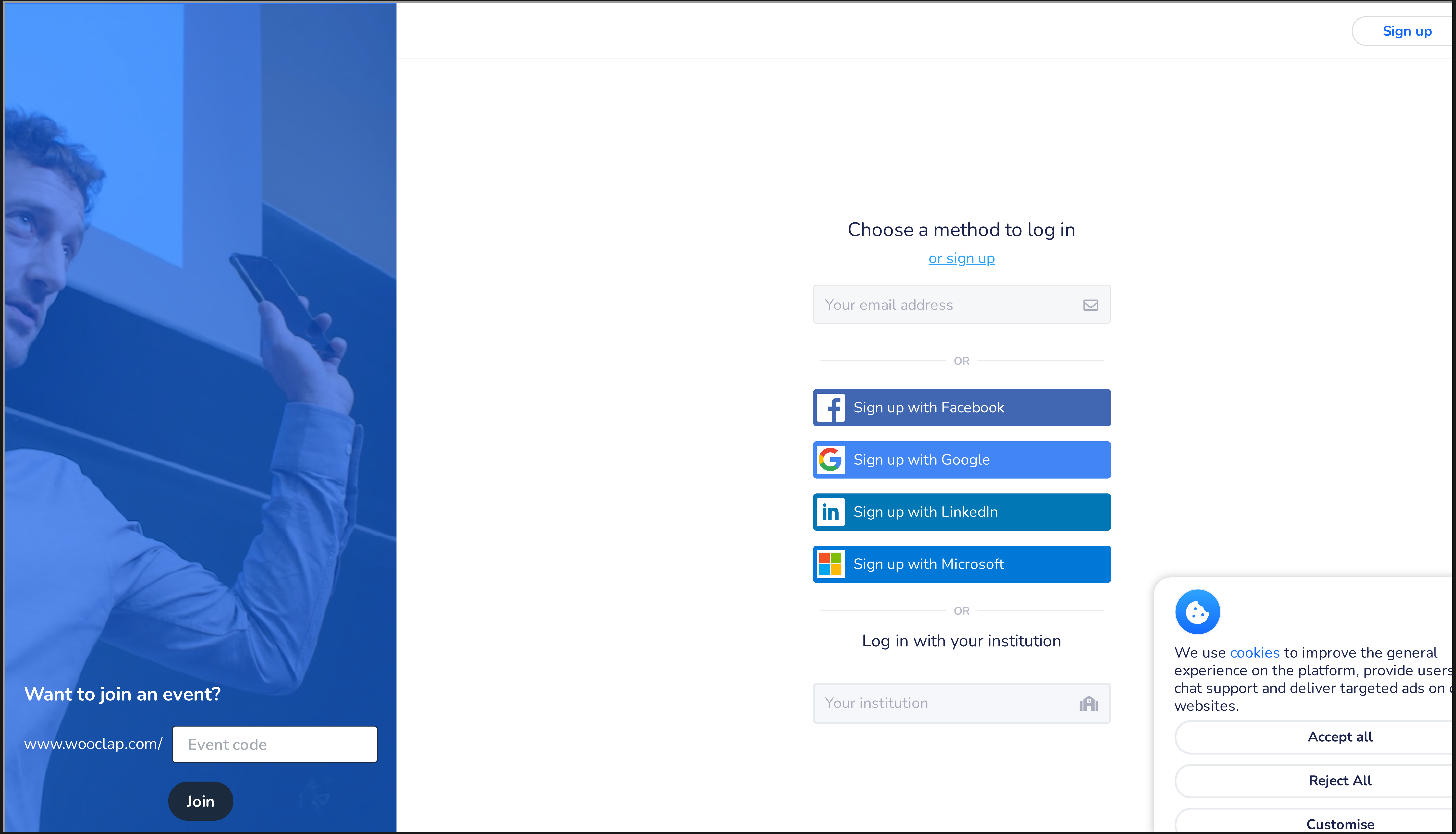
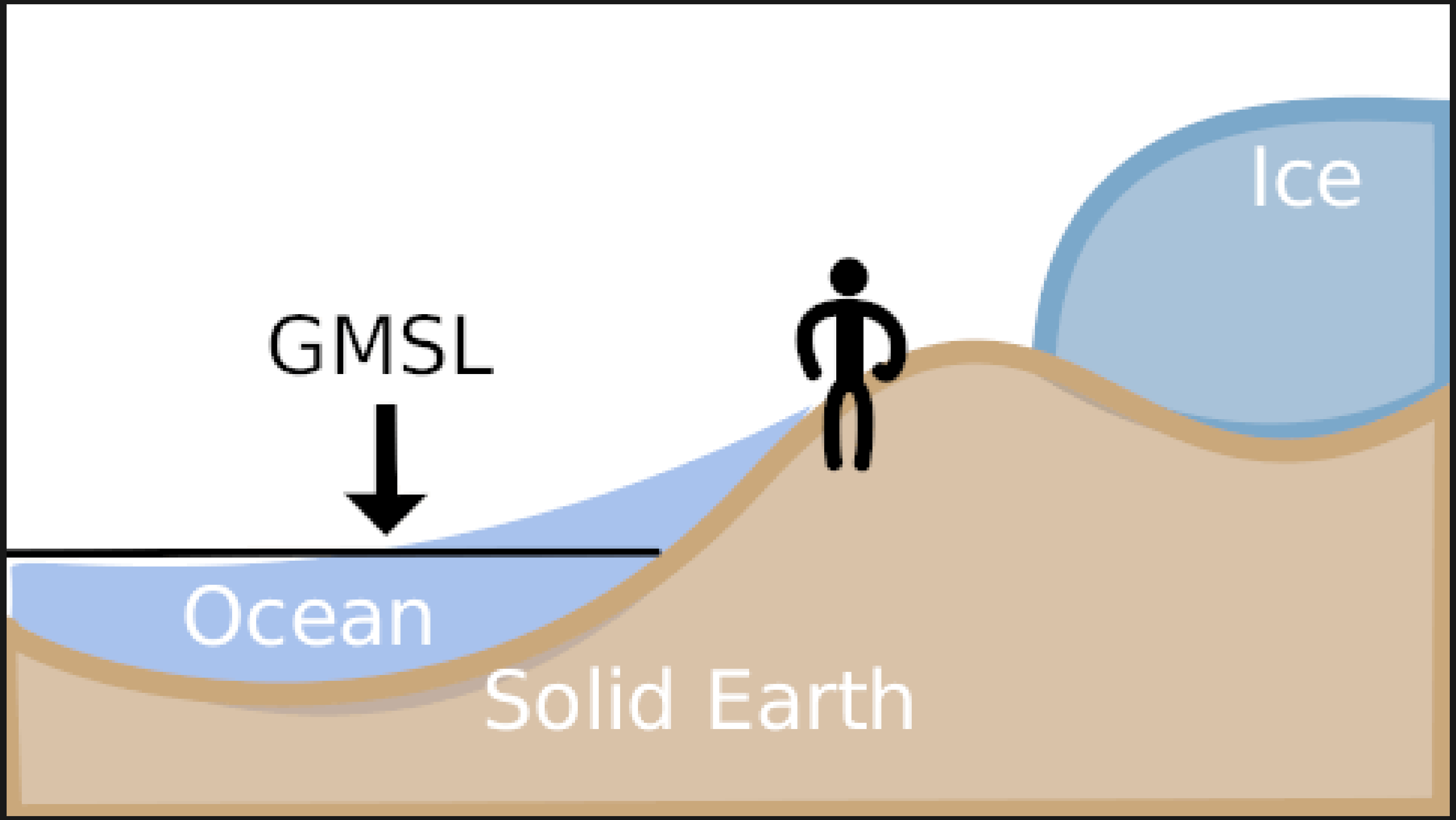
- Precise (kinematic) orbits contain information on low-resolution gravity changes -> ocean scales
- Principle is useful for filling gaps and potentially pre-GRACE era

Does Greenland induce regional sea level changes?



Relative sea level is affected by self attraction and loading (SAL)..



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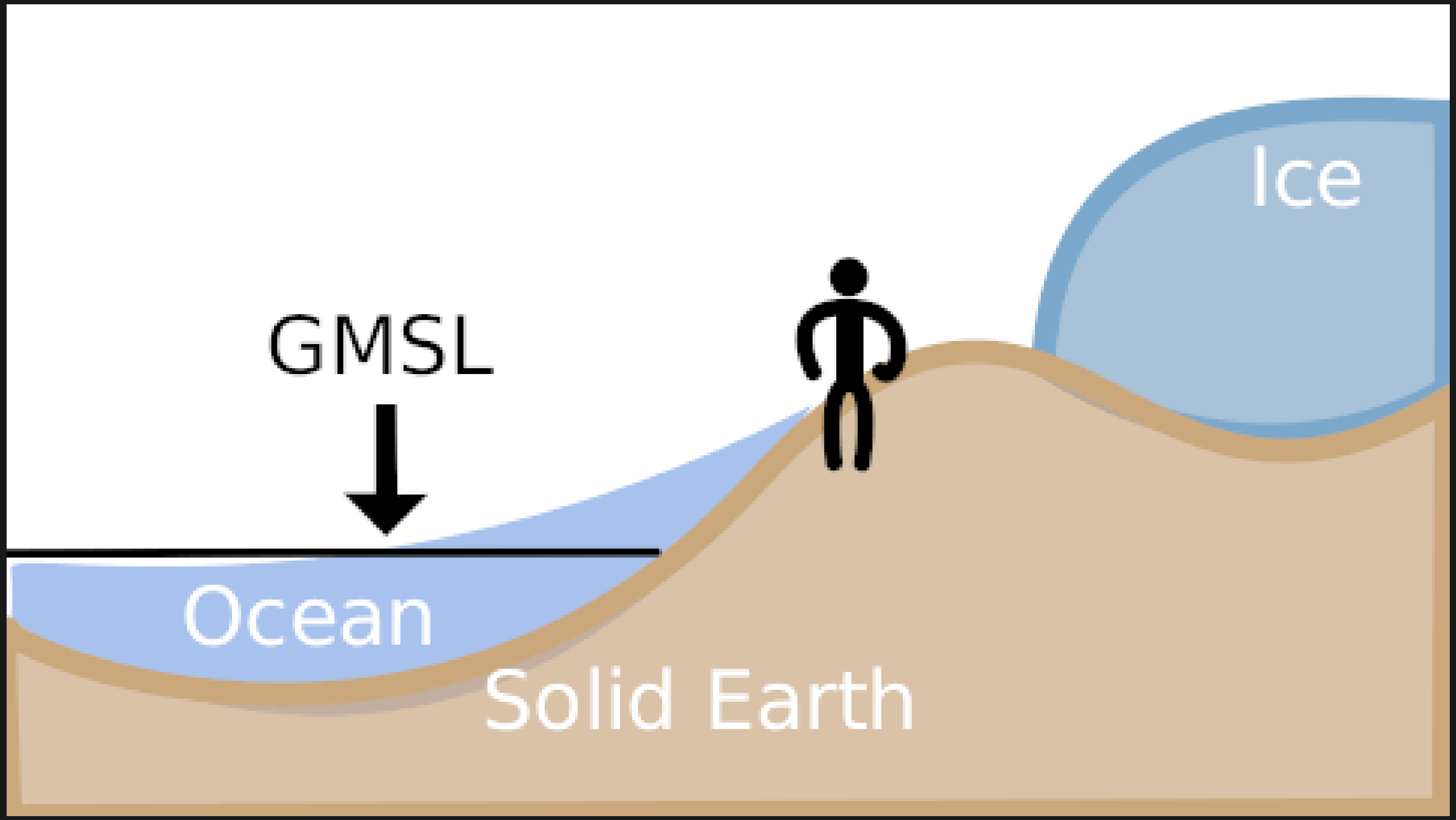

- Theory goes back to 1888 (Woodward)

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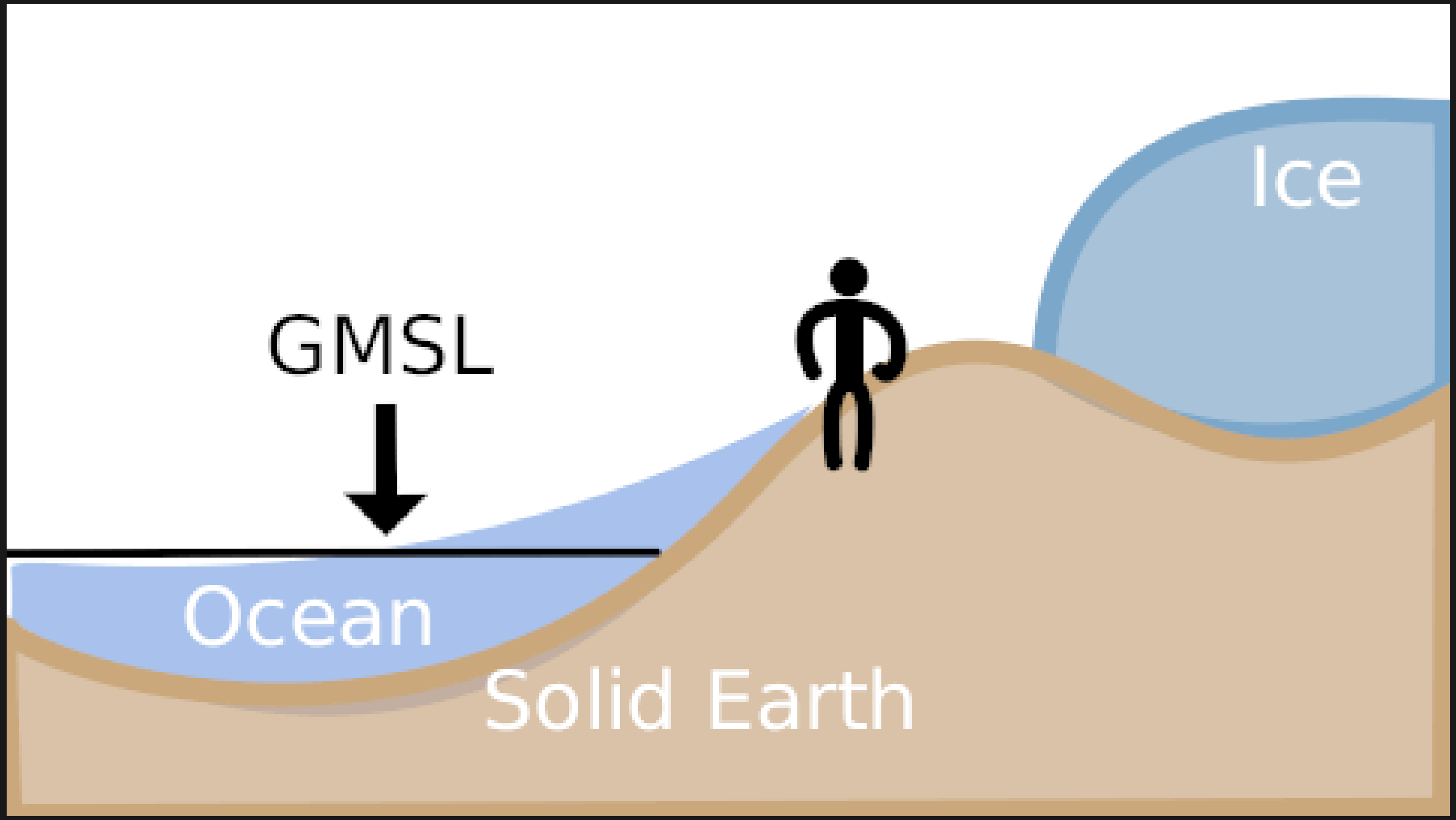

- Theory goes back to 1888 (Woodward)
- Modelled as a passive ocean response (no currents)

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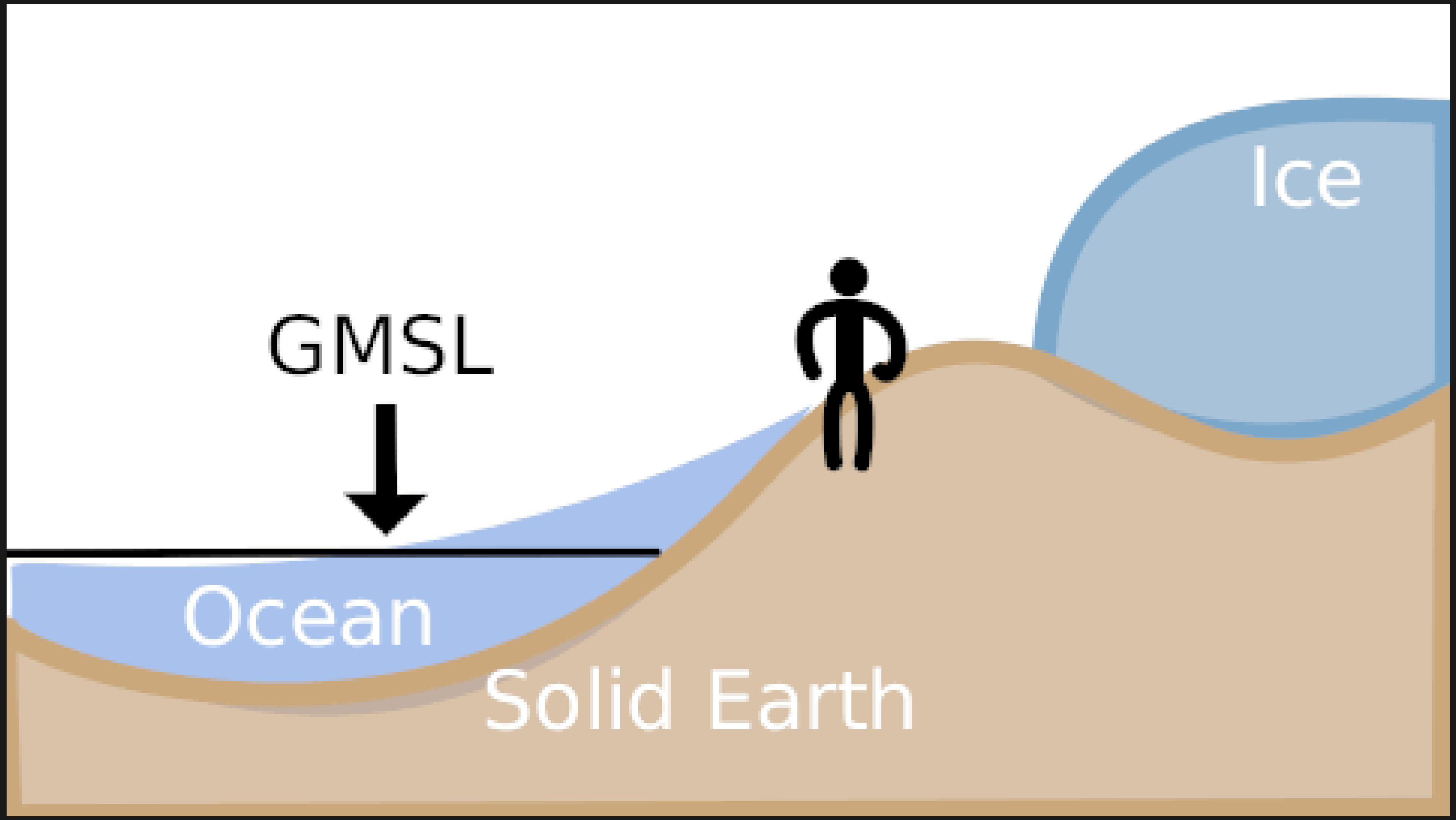

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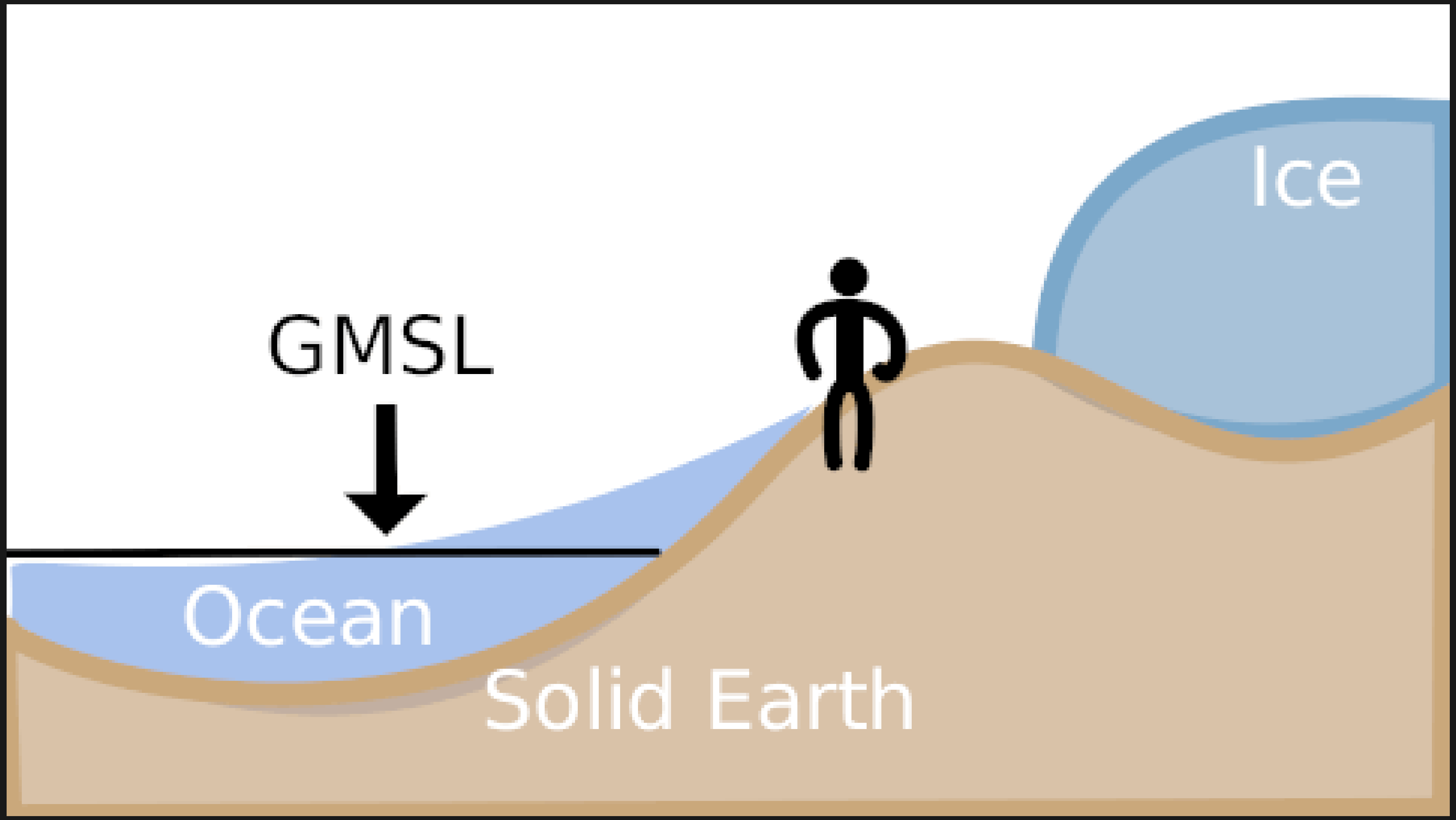
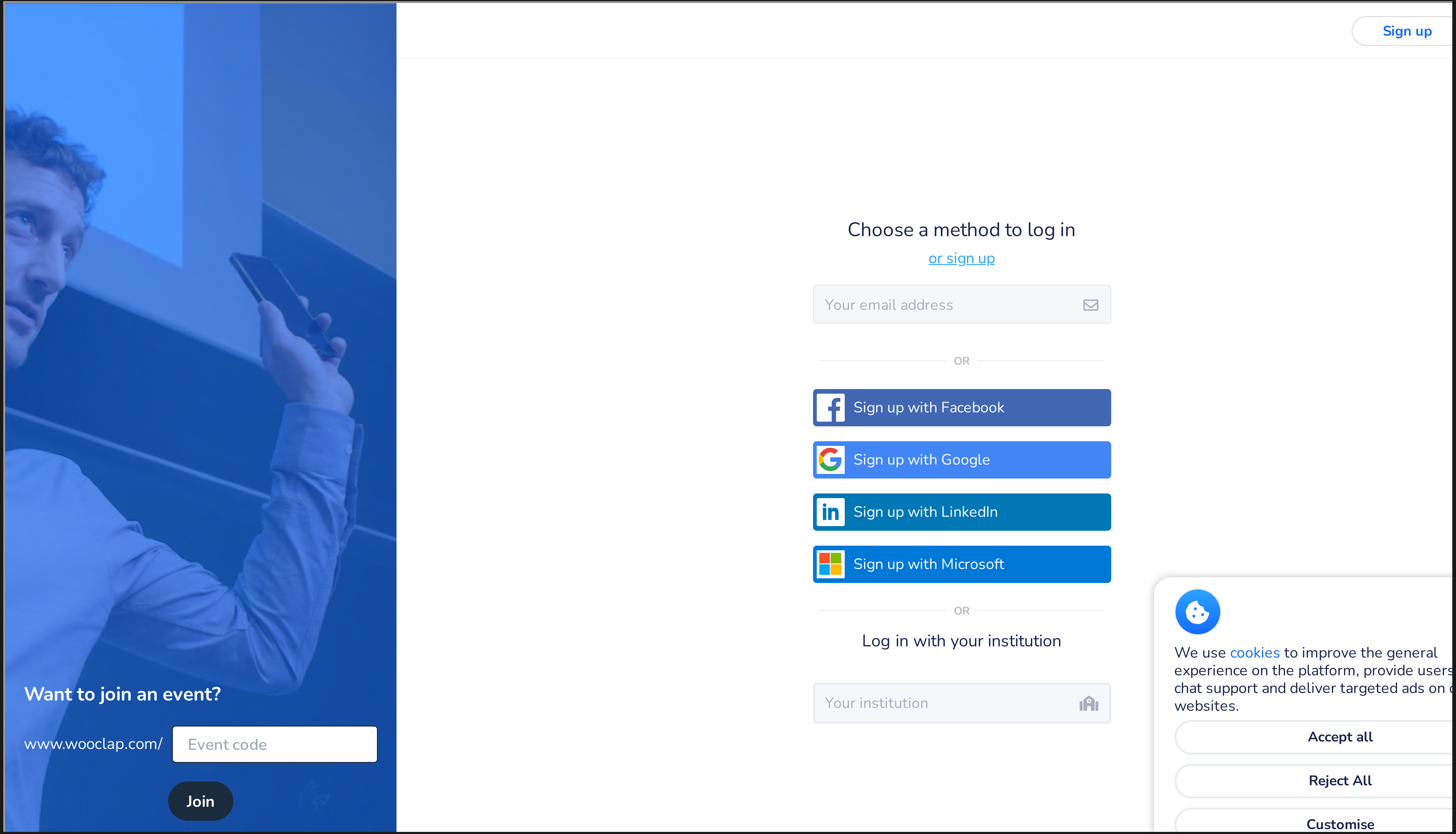
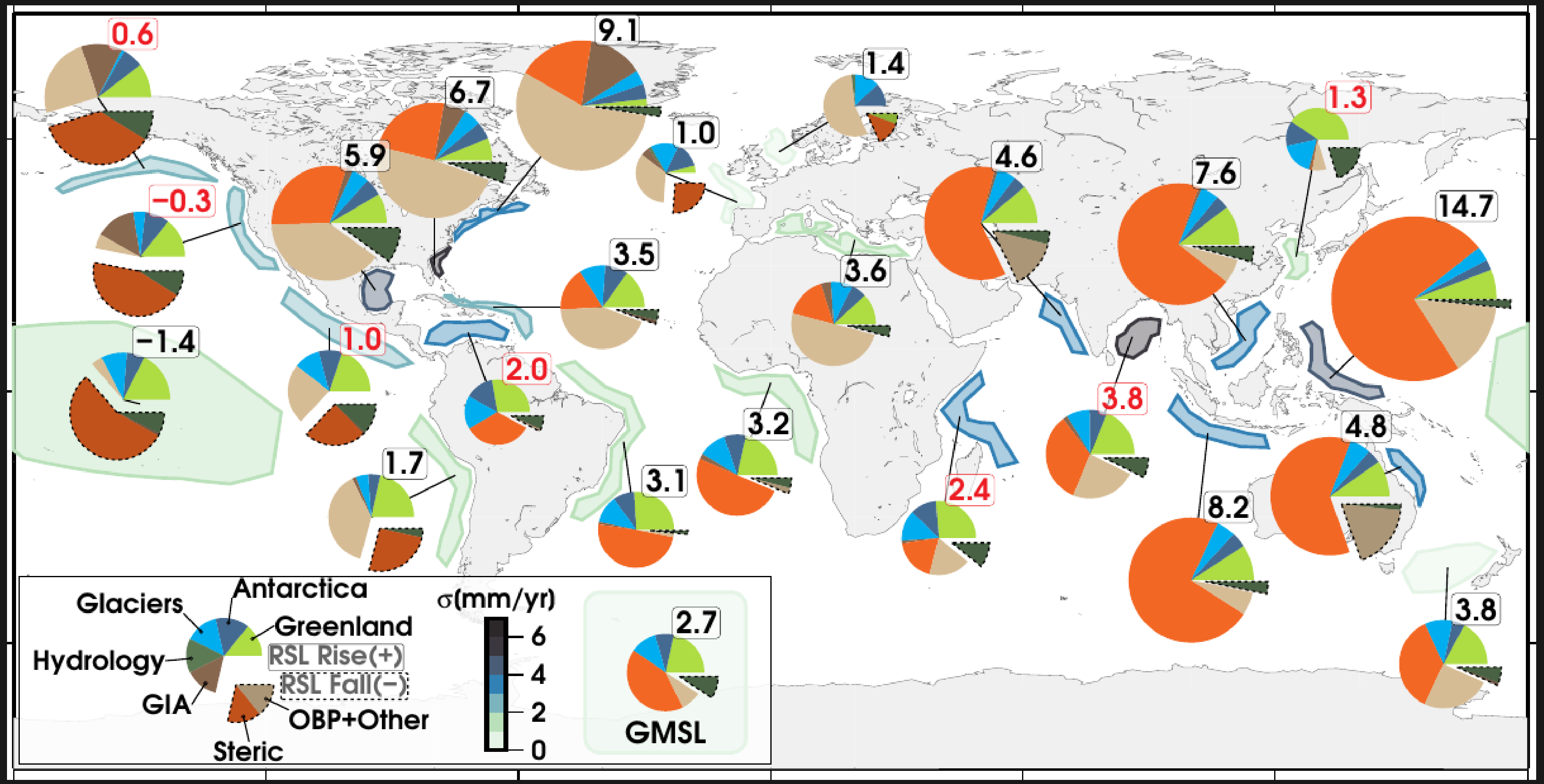


- Theory goes back to 1888 (Woodward)
- Modelled as a passive ocean response (no currents)
- mass conserving
- Takes into account the deformation of the Earth

Other factors affecting relative sea level?

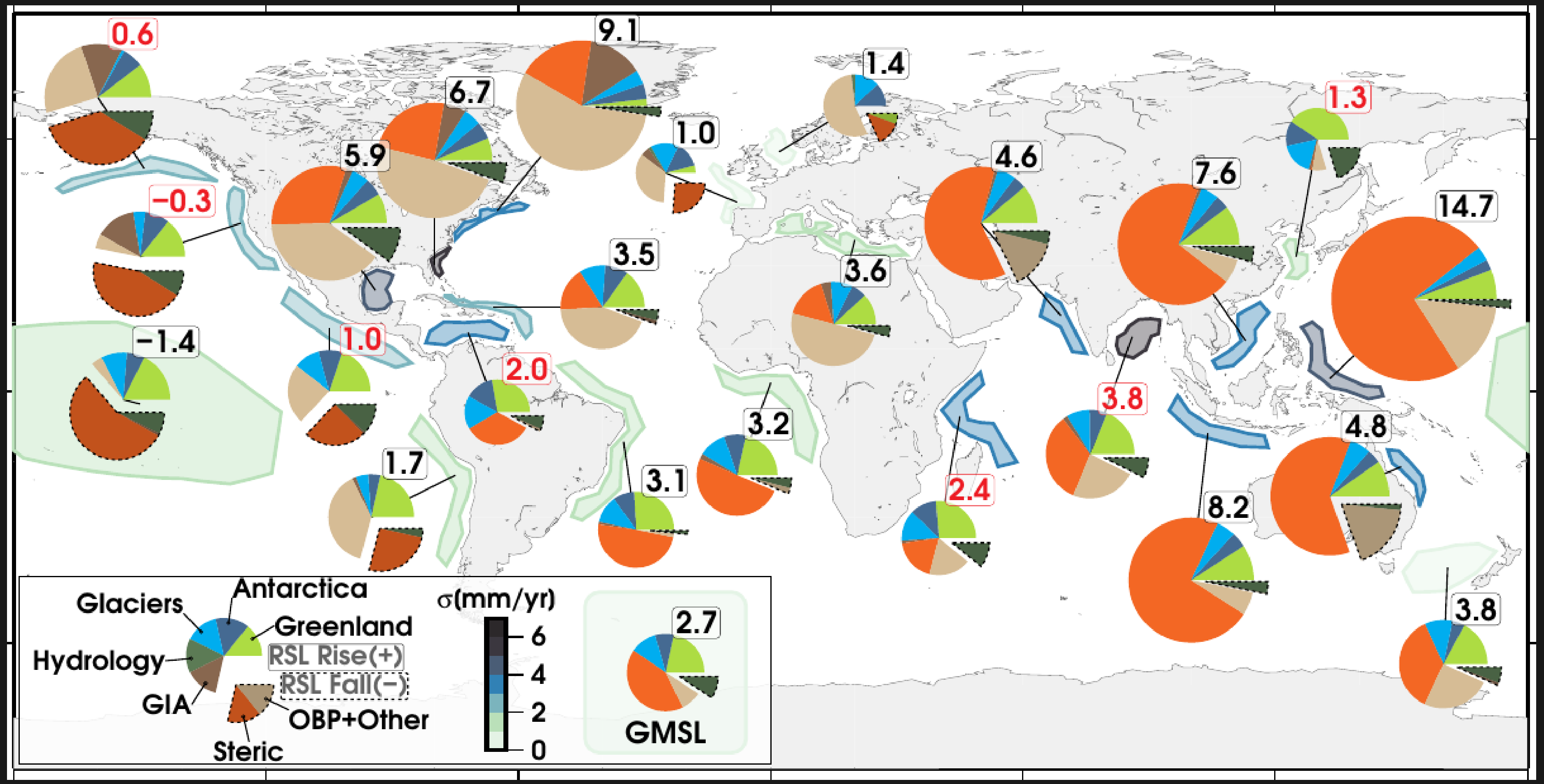


Regional sea level budgets



Regional sea level budgets from Rietbroek et al. 2016

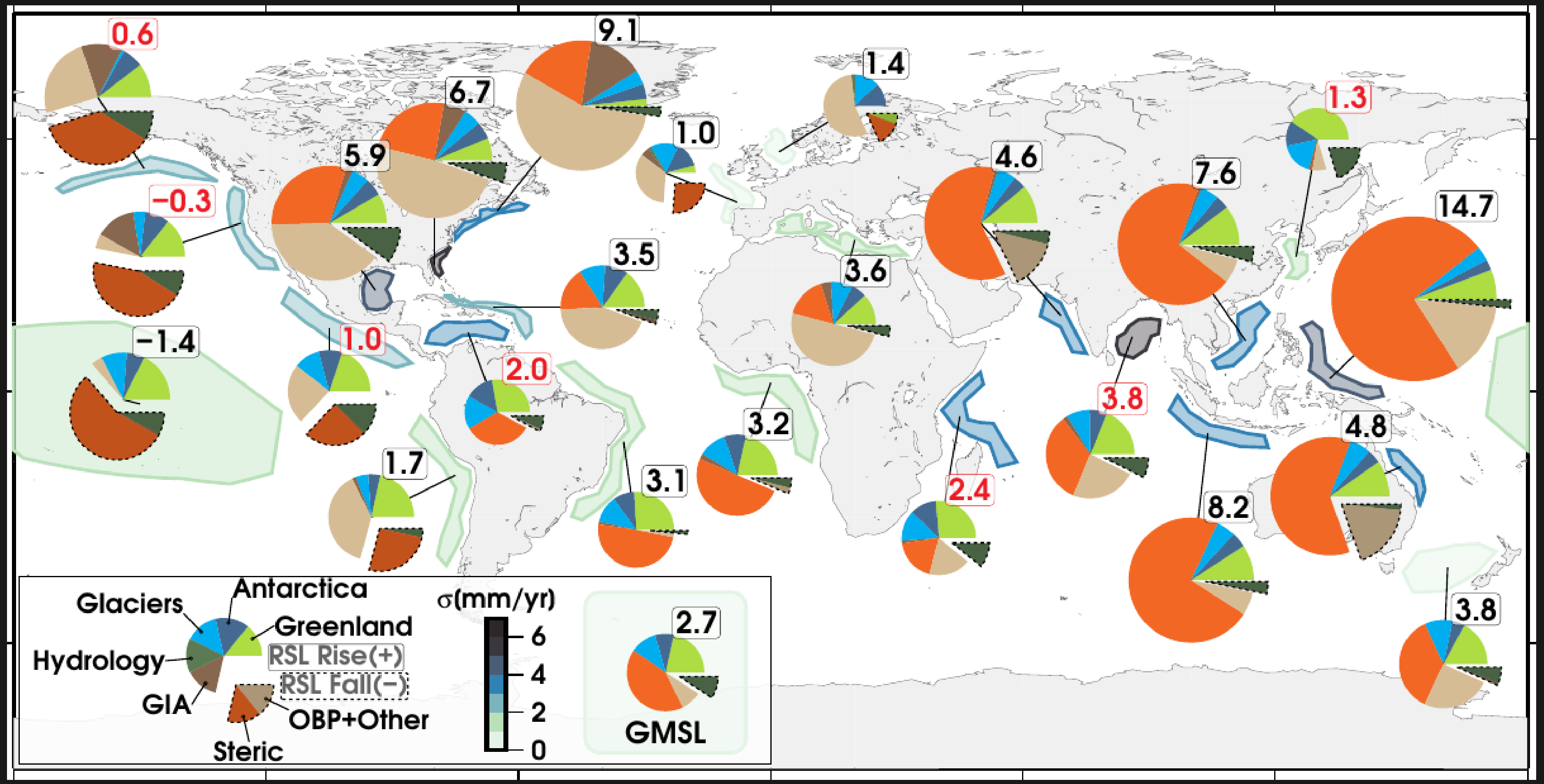
Regional sea level budgets



Regional sea level budgets from Rietbroek et al. 2016

- Sea level rise is not uniform

Regional sea level budgets



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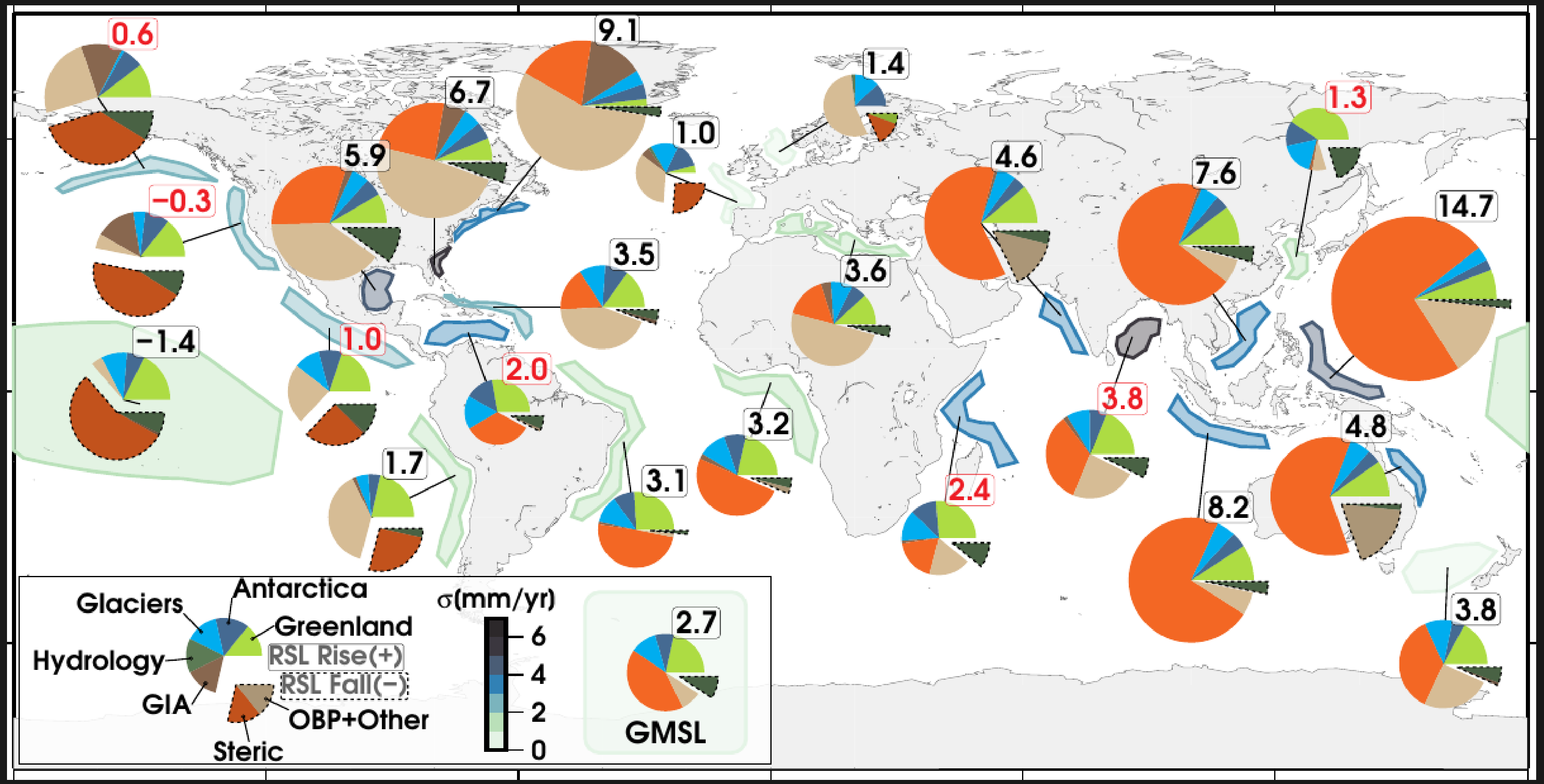

Regional sea level budgets from Rietbroek et al. 2016

- Sea level rise is not uniform
- SAL effects
- Thermosteric and ocean bottom pressure changes play a larger role in the regional budgets

Churning the ocean (forcing from wind stress, density contrasts)

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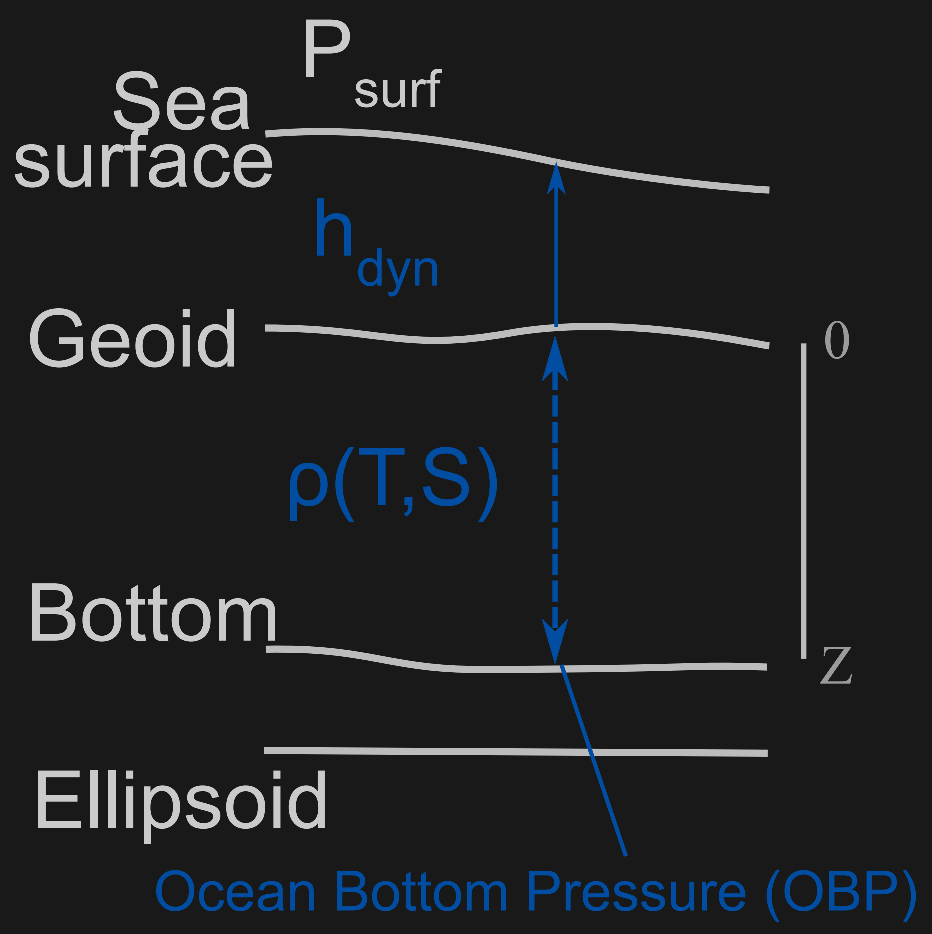
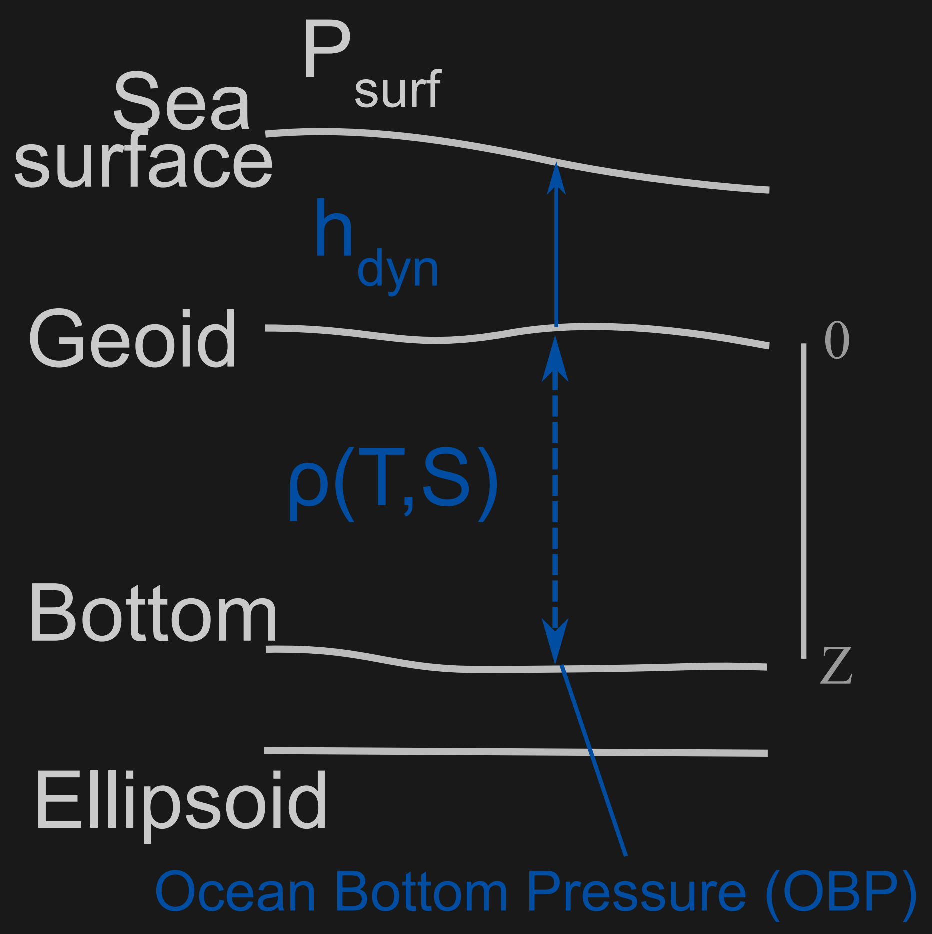
Integrating the water column to obtain ocean bottom pressure



Integrating the water column to obtain ocean bottom pressure

$$P_{OBP} = P_{surf} + g \int_{-Z}^{0} \rho(z, T, S) dz + g \rho_{sea} h_{dyn}$$



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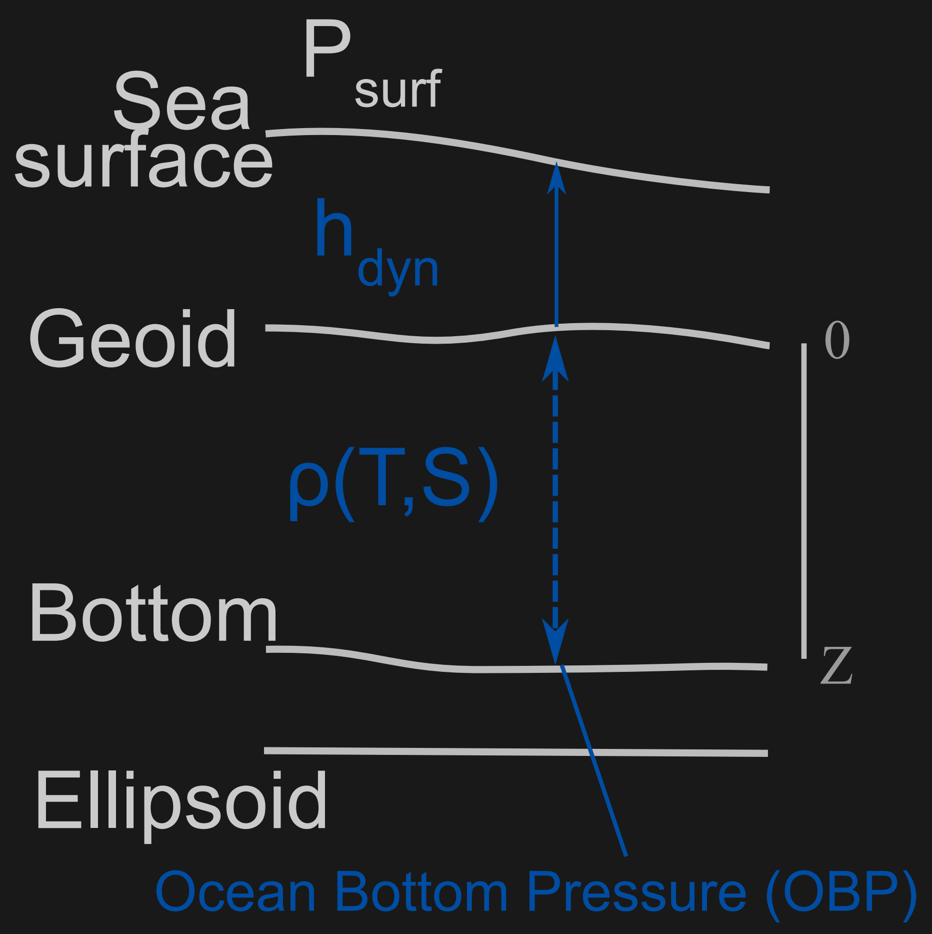

$$P_{OBP} = P_{surf} + g \int_{-Z}^{0} \rho(z, T, S) dz + g\rho_{sea} h_{dyn}$$

No OBP change → Steric **change** ($h_{dyn} = h_{ster}$

$$0 = g \int_{-Z}^{0} \delta\rho(z, T, S) dz + g\rho_{sea} h_{ster}$$

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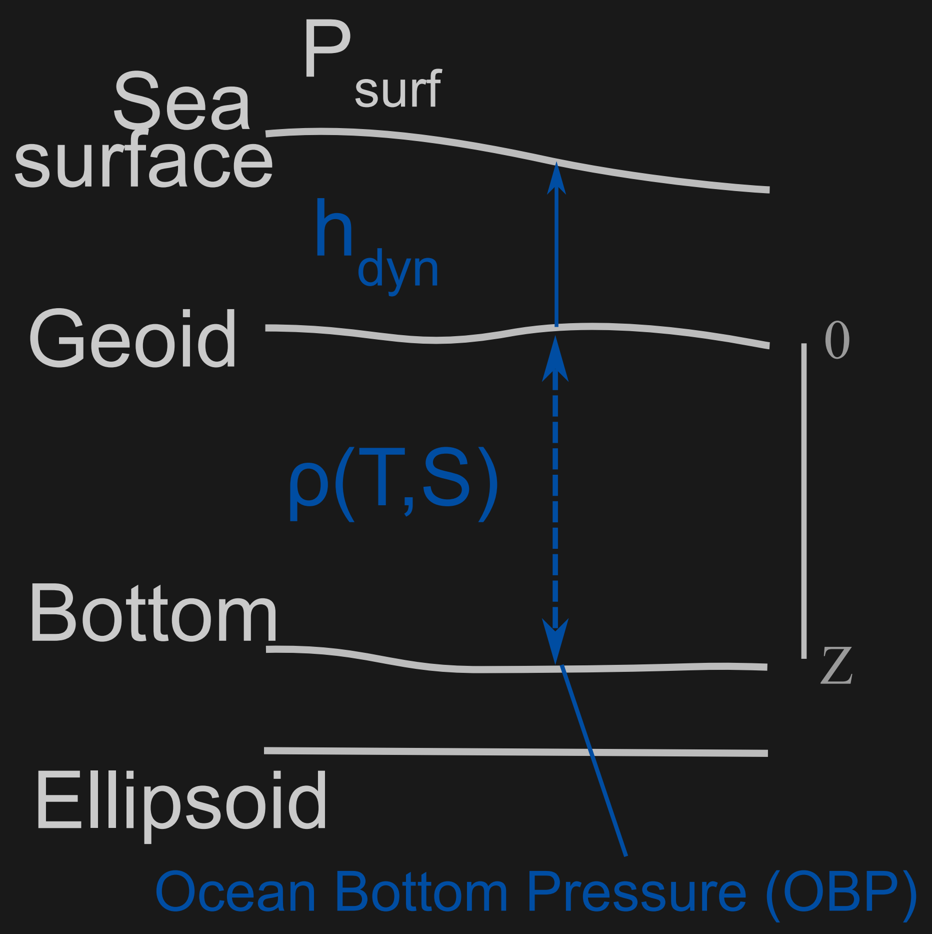

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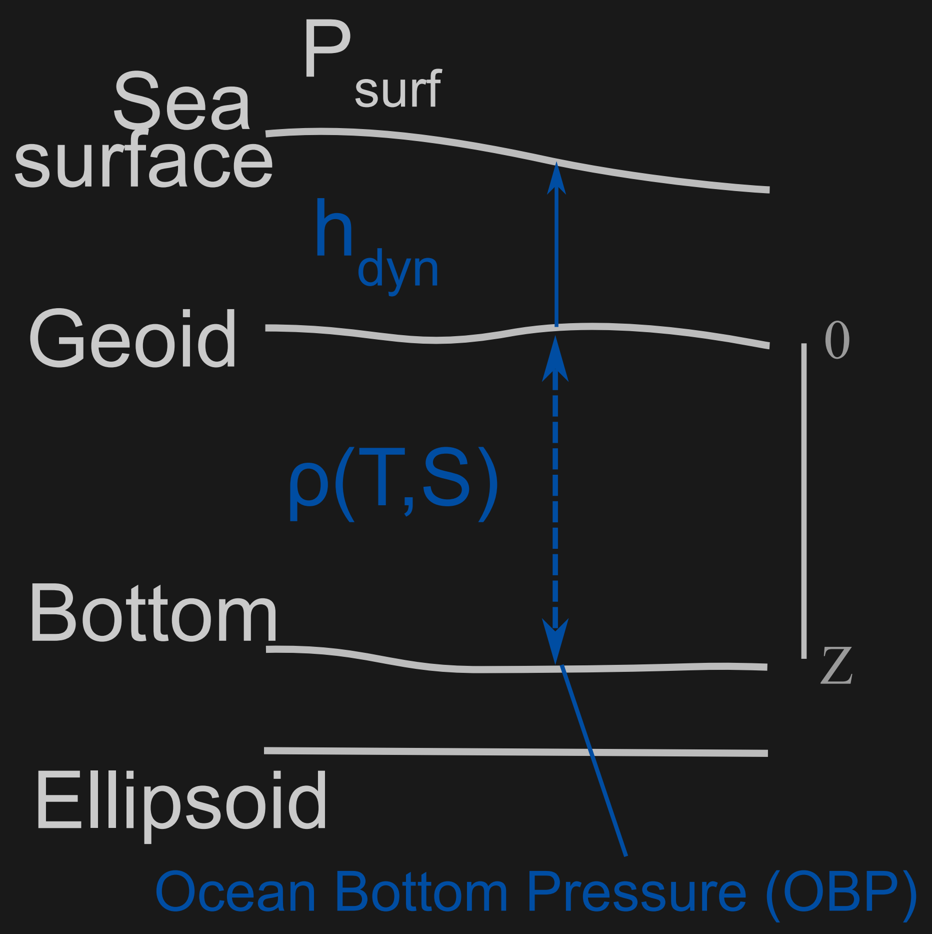

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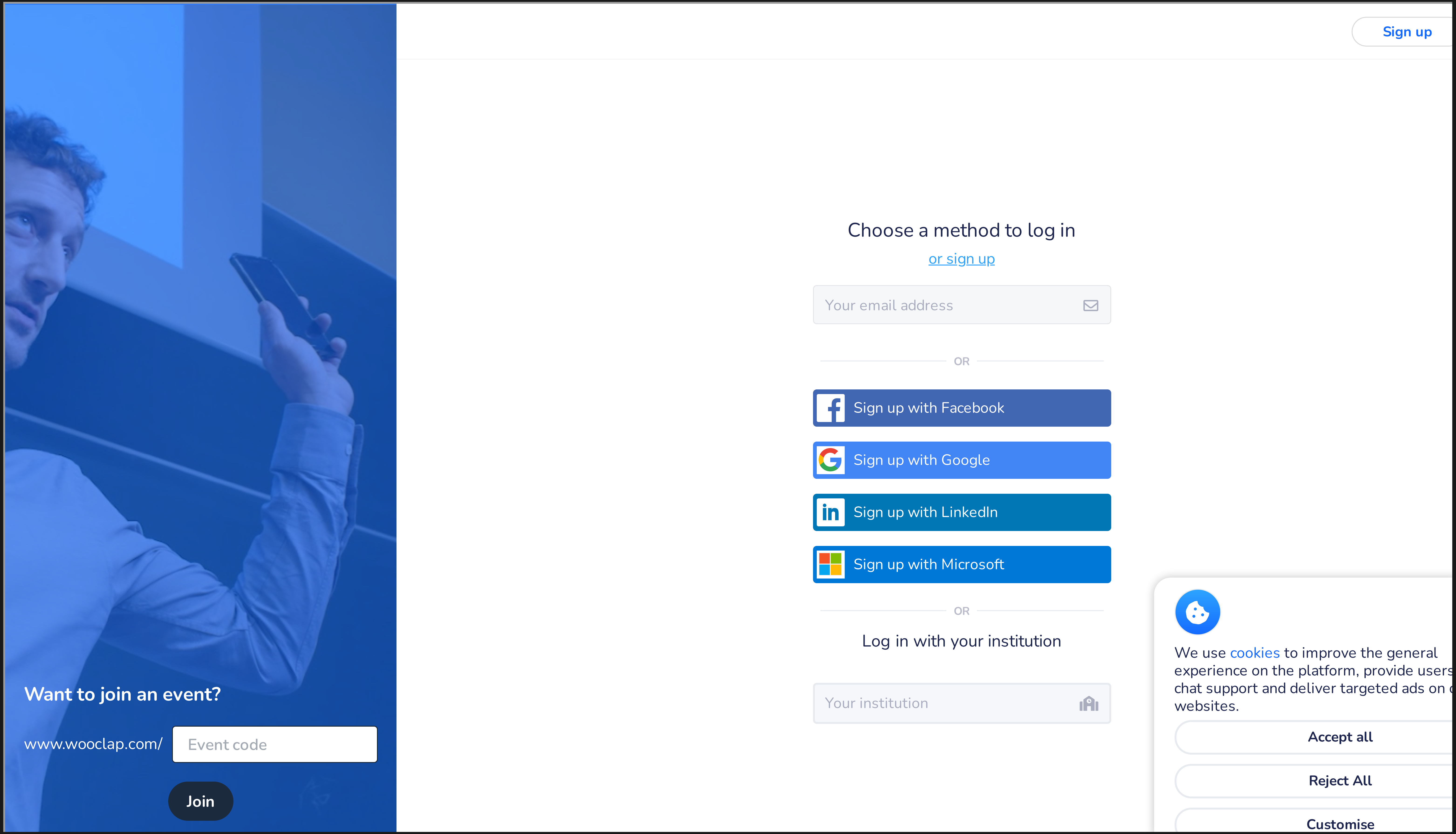
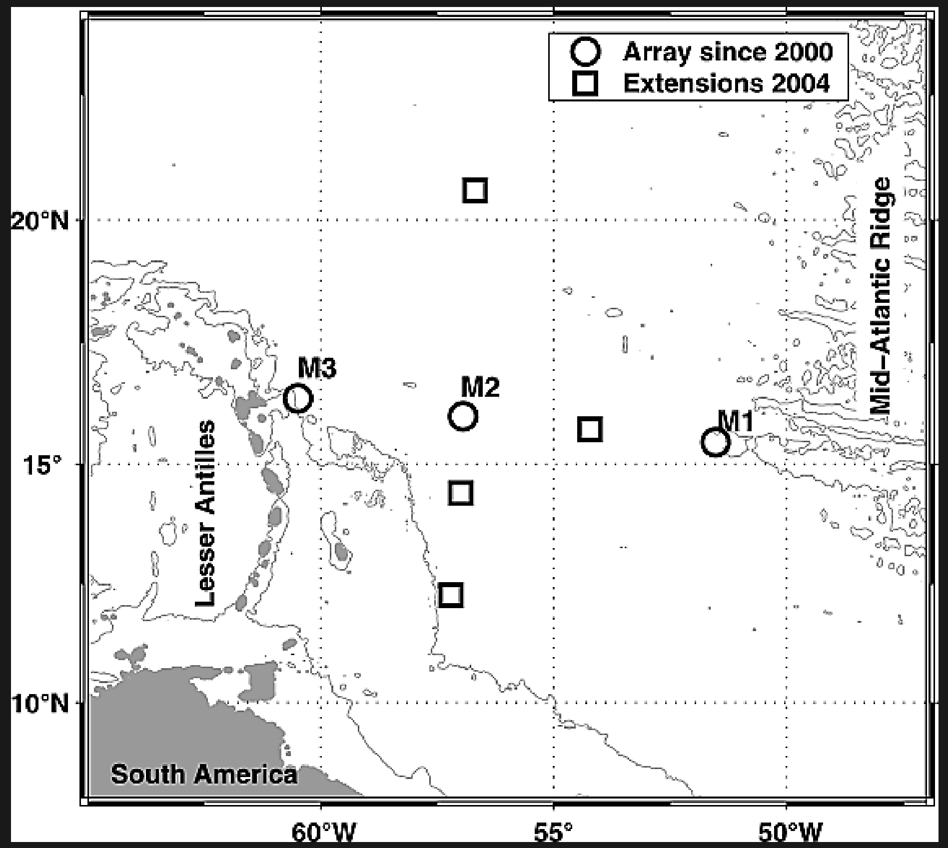
$$h_{ster} = -\frac{1}{\rho_{sea}} \int_{-Z}^{0} \delta\rho(z, T, S) dz$$

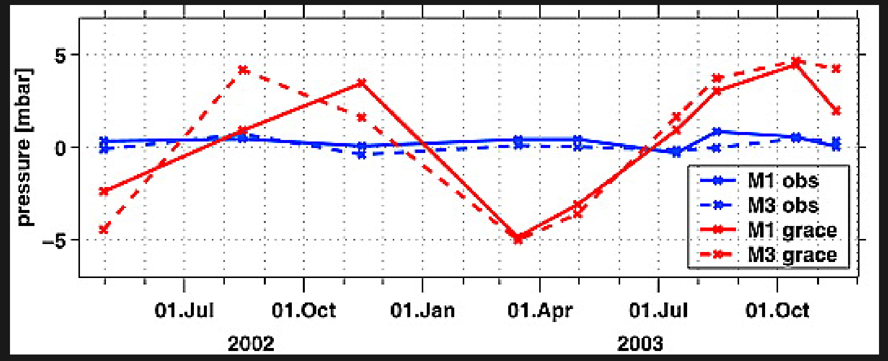
- h_{ster} invisible to GRACE! ($P_{OBP} = 0$)
- h_{ster} **is visible** by radar altimetry!
- Density ↑ results in ↓ of sea level
- Wind driven (quick) → change in h_{dyn}
- Density driven (slow)→ $h_{dyn} \approx h_{ster}$

Quiz time! (again)



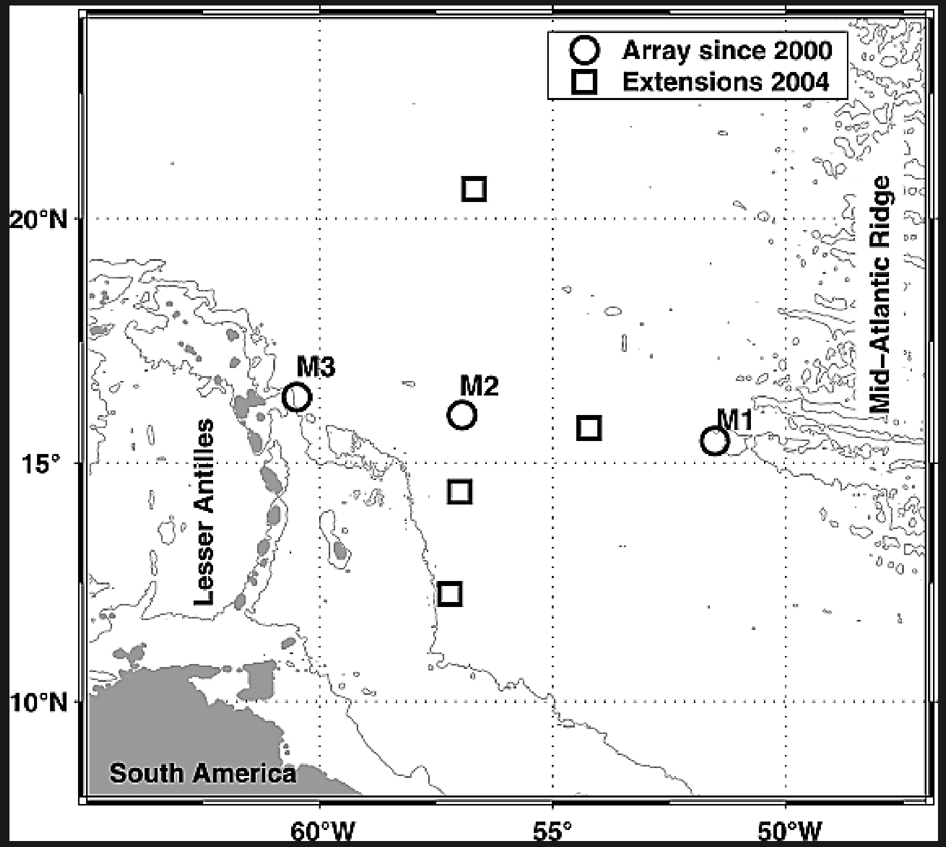
Early GRACE validation of ocean bottom pressure changes (Kanzow et al. 2005)

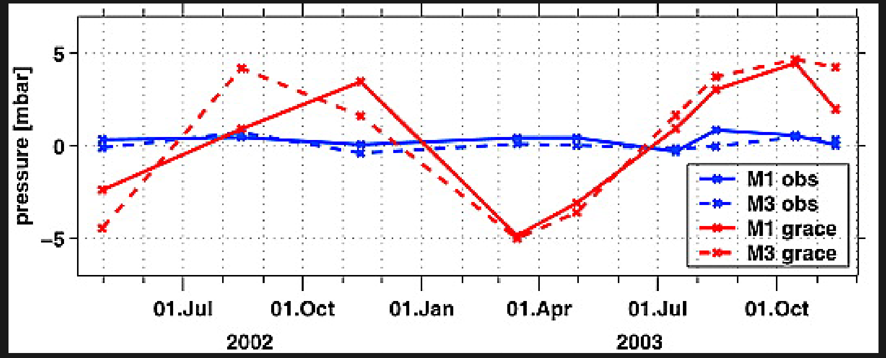




Early GRACE validation of ocean bottom pressure changes (Kanzow et al. 2005)

- In situ validation with pressure sensors





Early GRACE validation of ocean bottom pressure changes (Kanzow et al. 2005)

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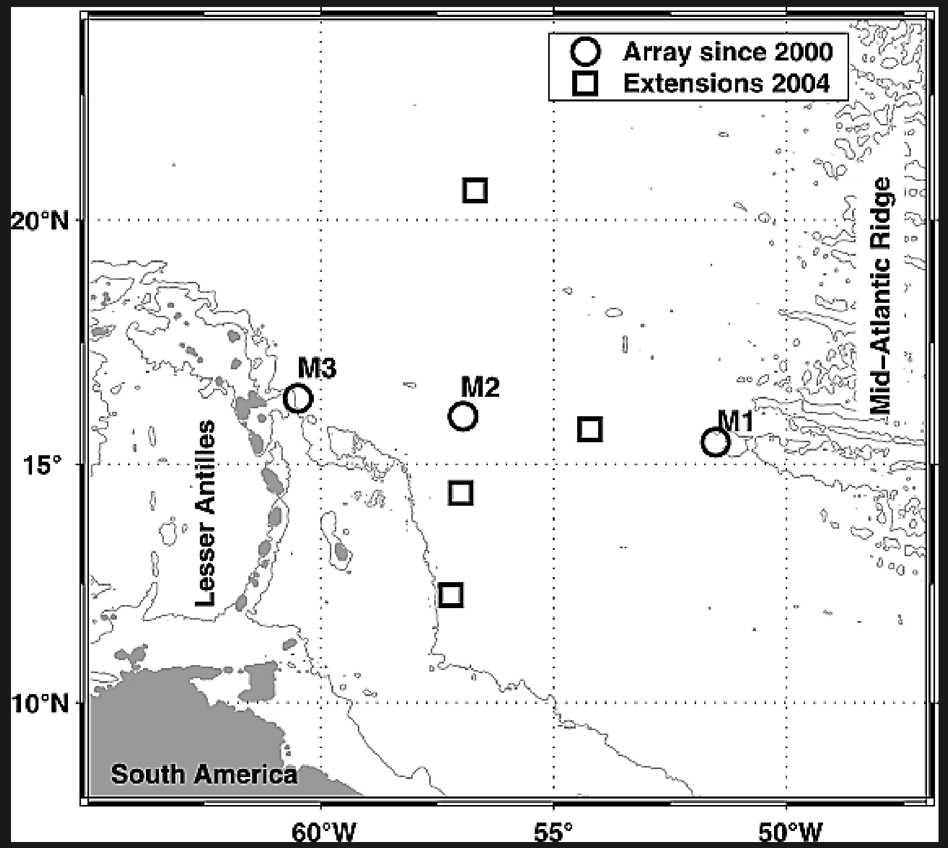
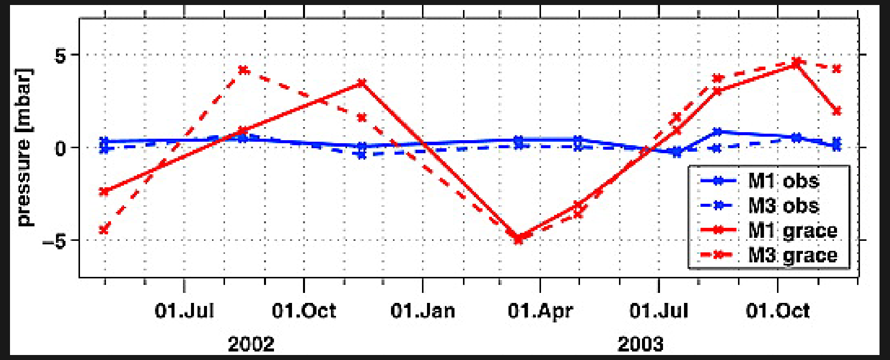
- GRACE fluctuations were too large





Early GRACE validation of ocean bottom pressure changes (Kanzow et al. 2005)

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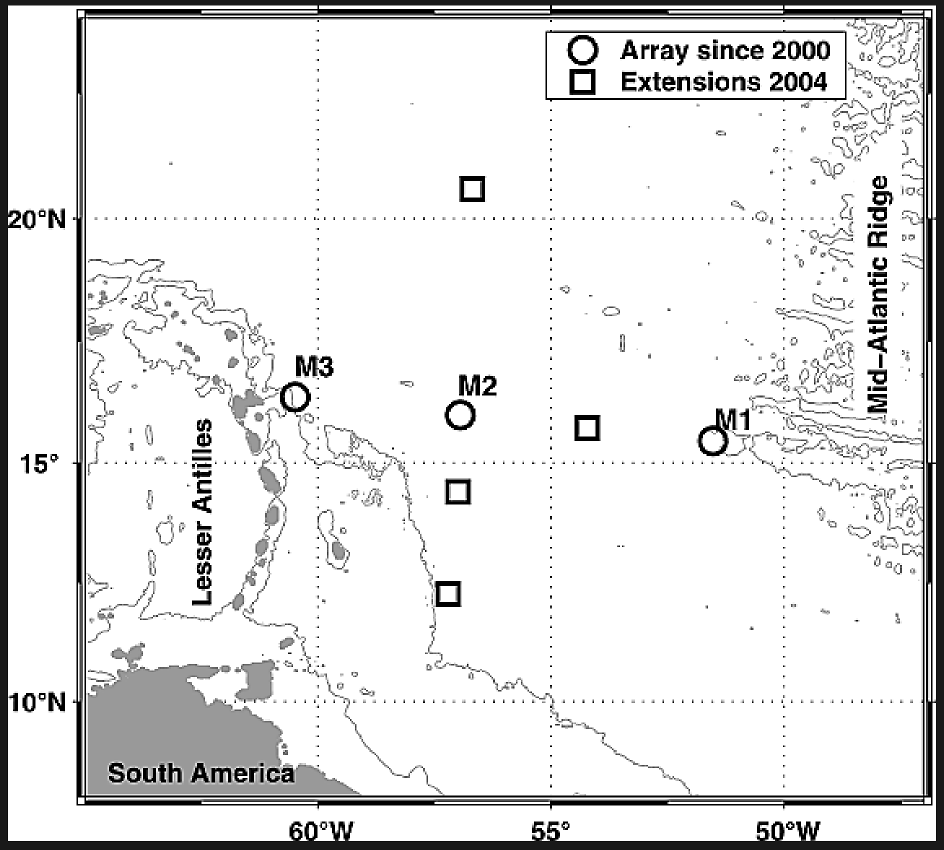

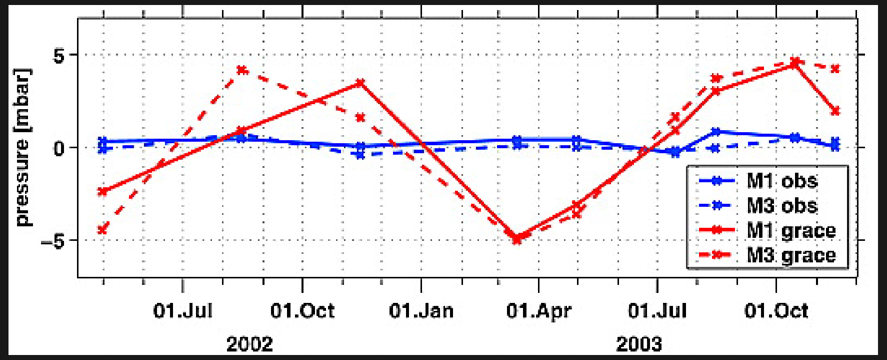

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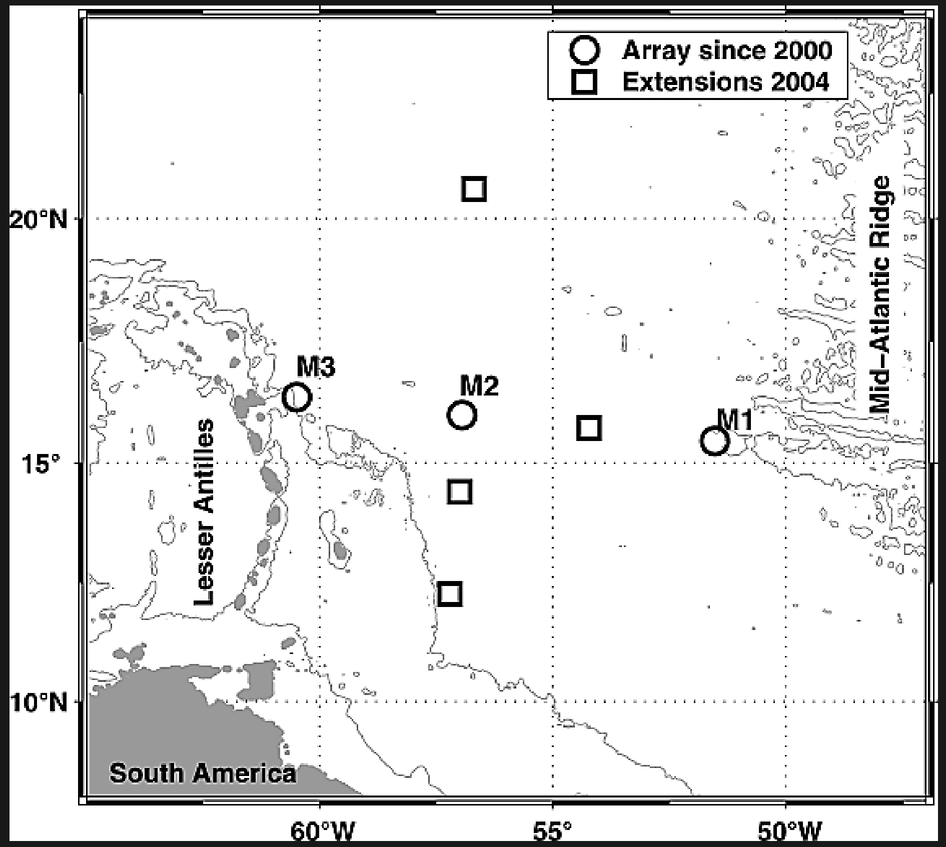
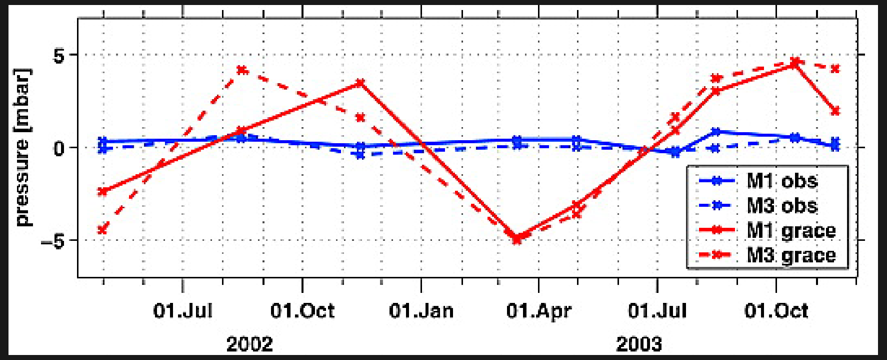
Early GRACE validation of ocean bottom pressure changes (Kanzow et al. 2005)

- In situ validation with pressure sensors
- GRACE fluctuations were too large
  - Signal leakage
  - Processing errors





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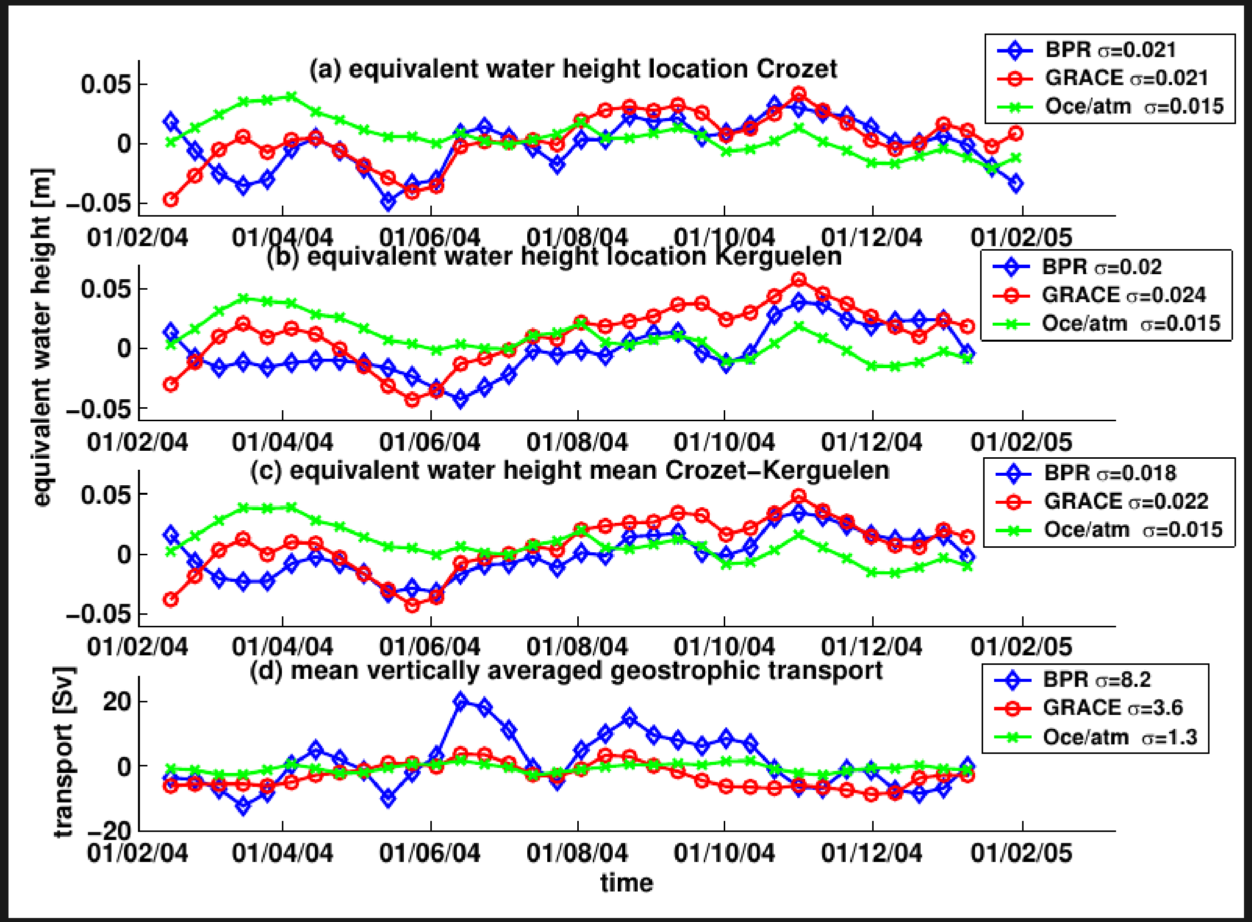
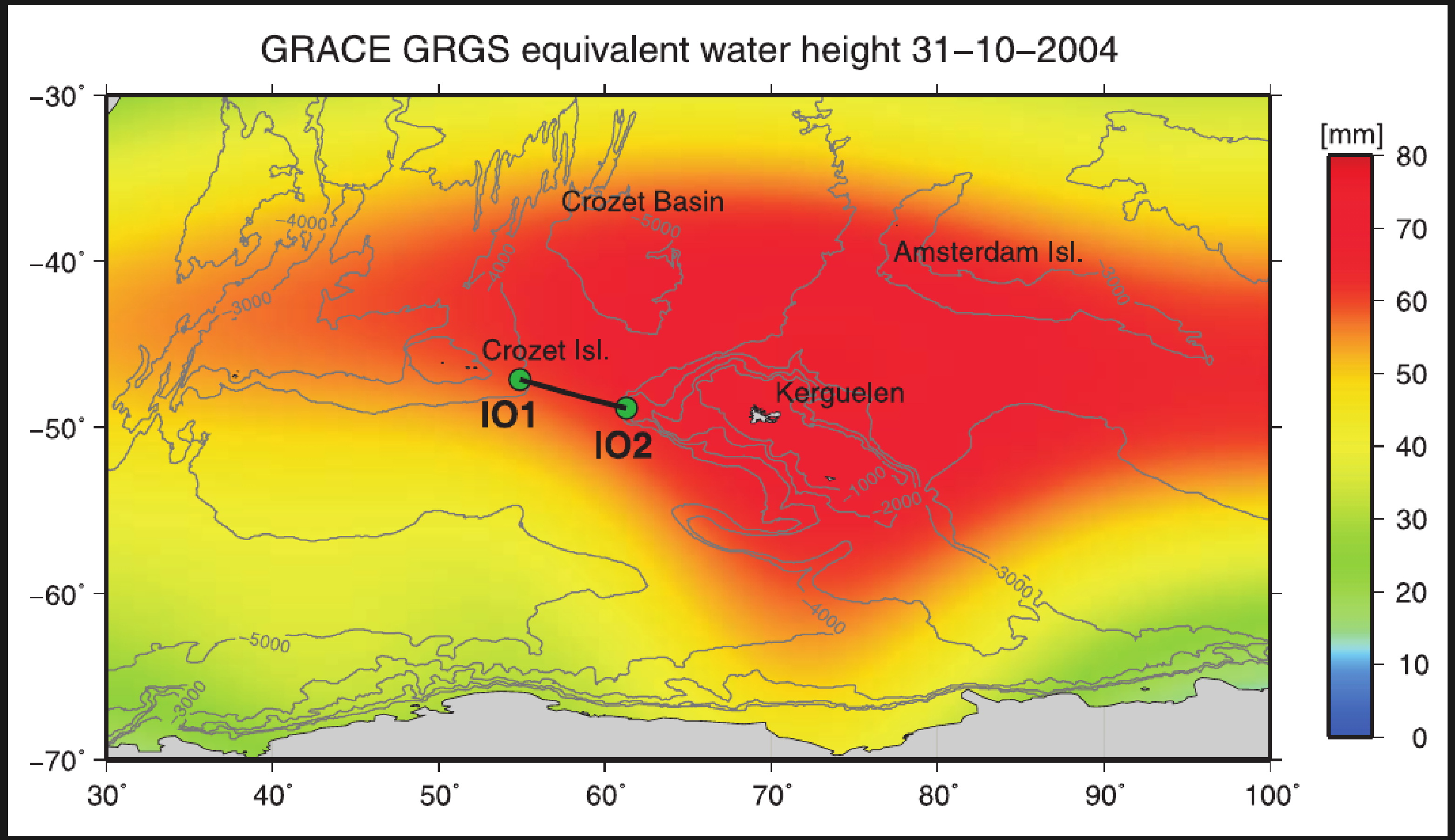
Validation in the Southern Ocean





From Rietbroek et al. 2006

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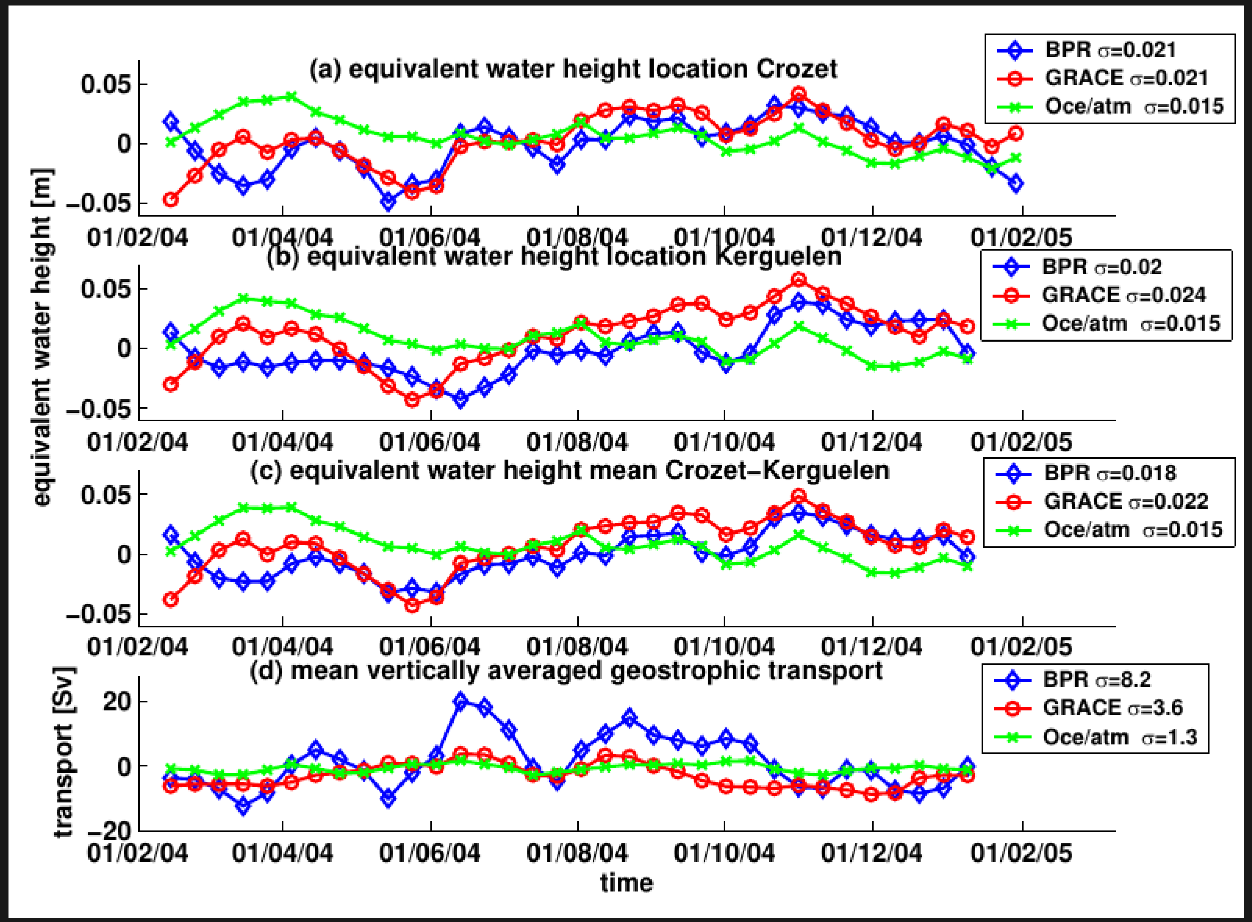

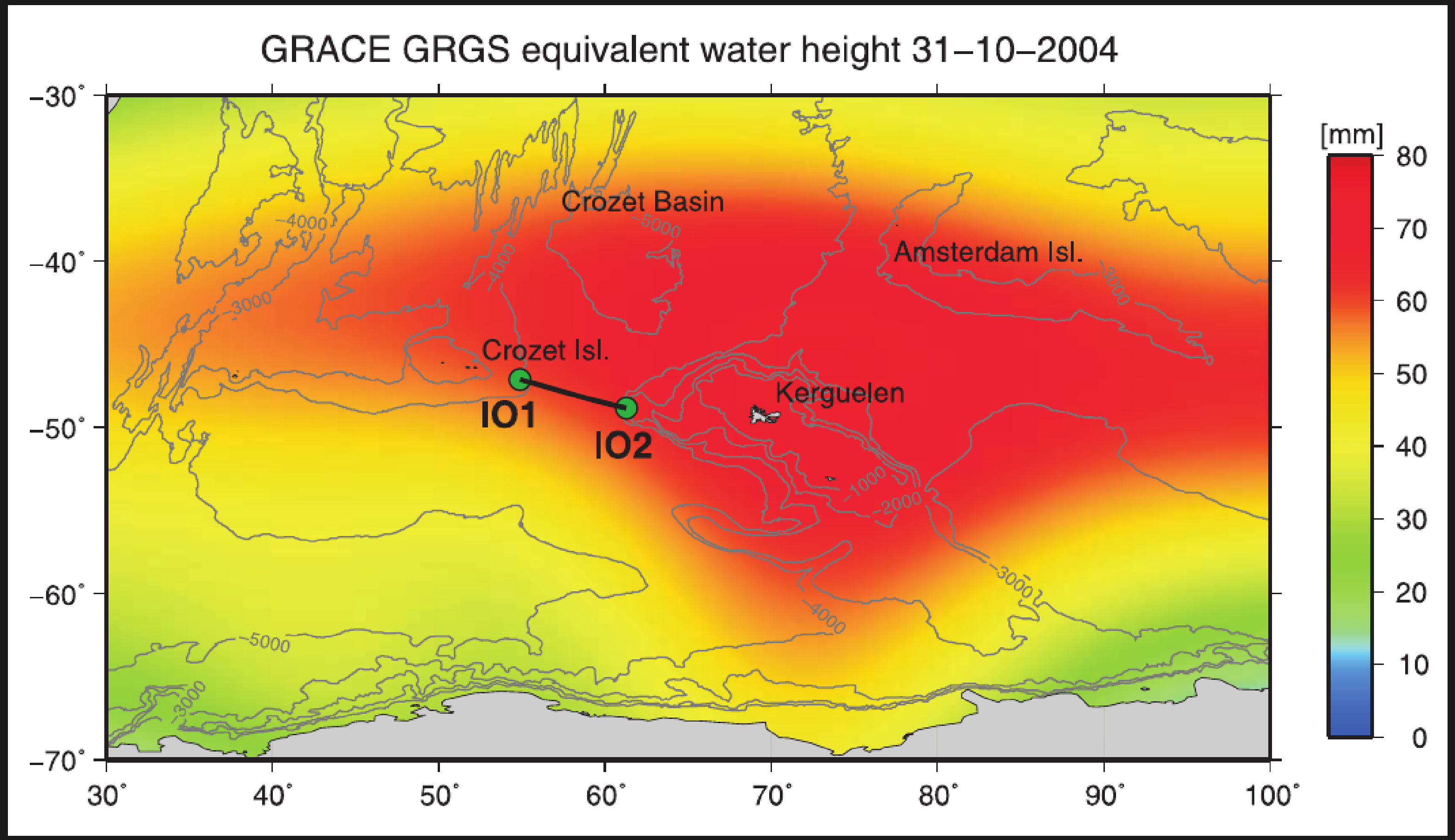

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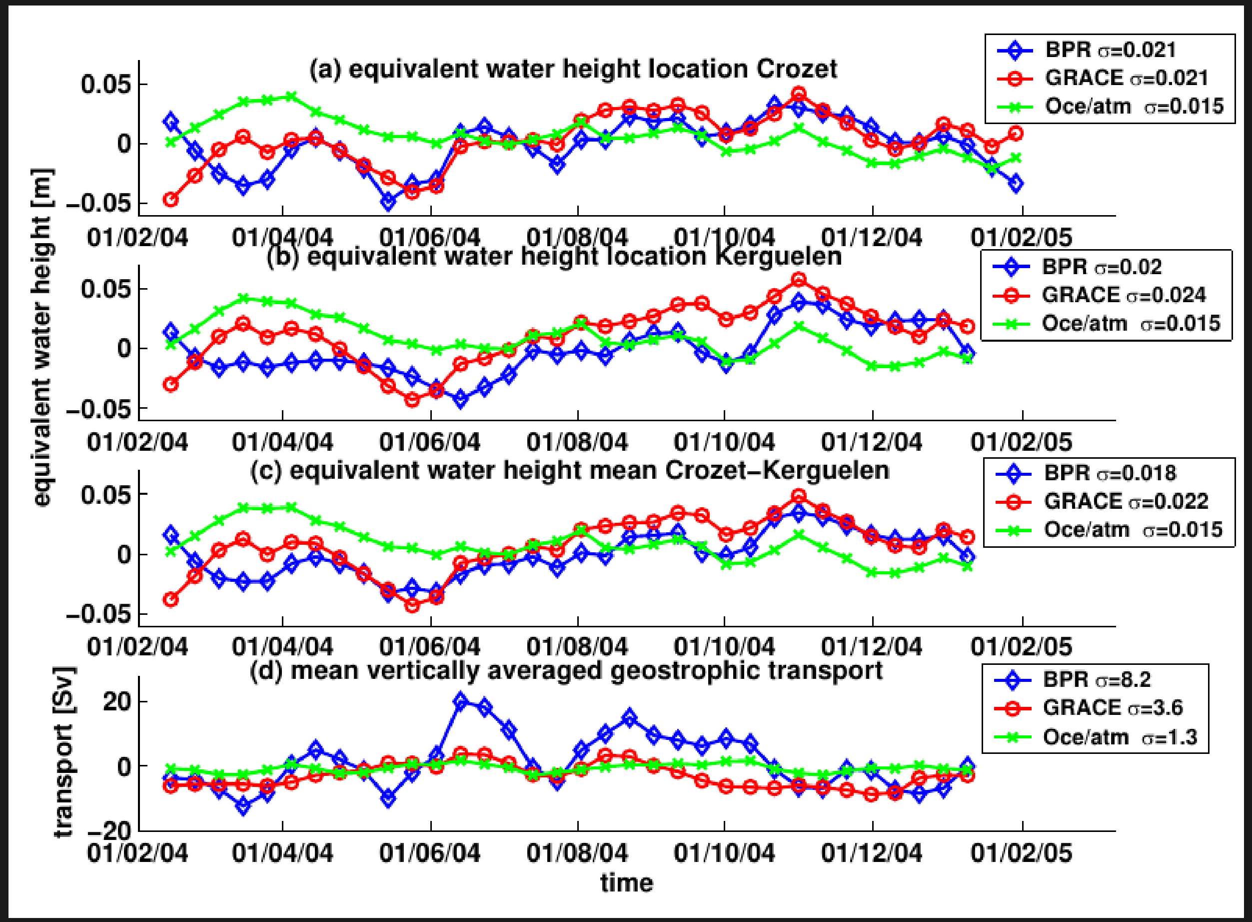

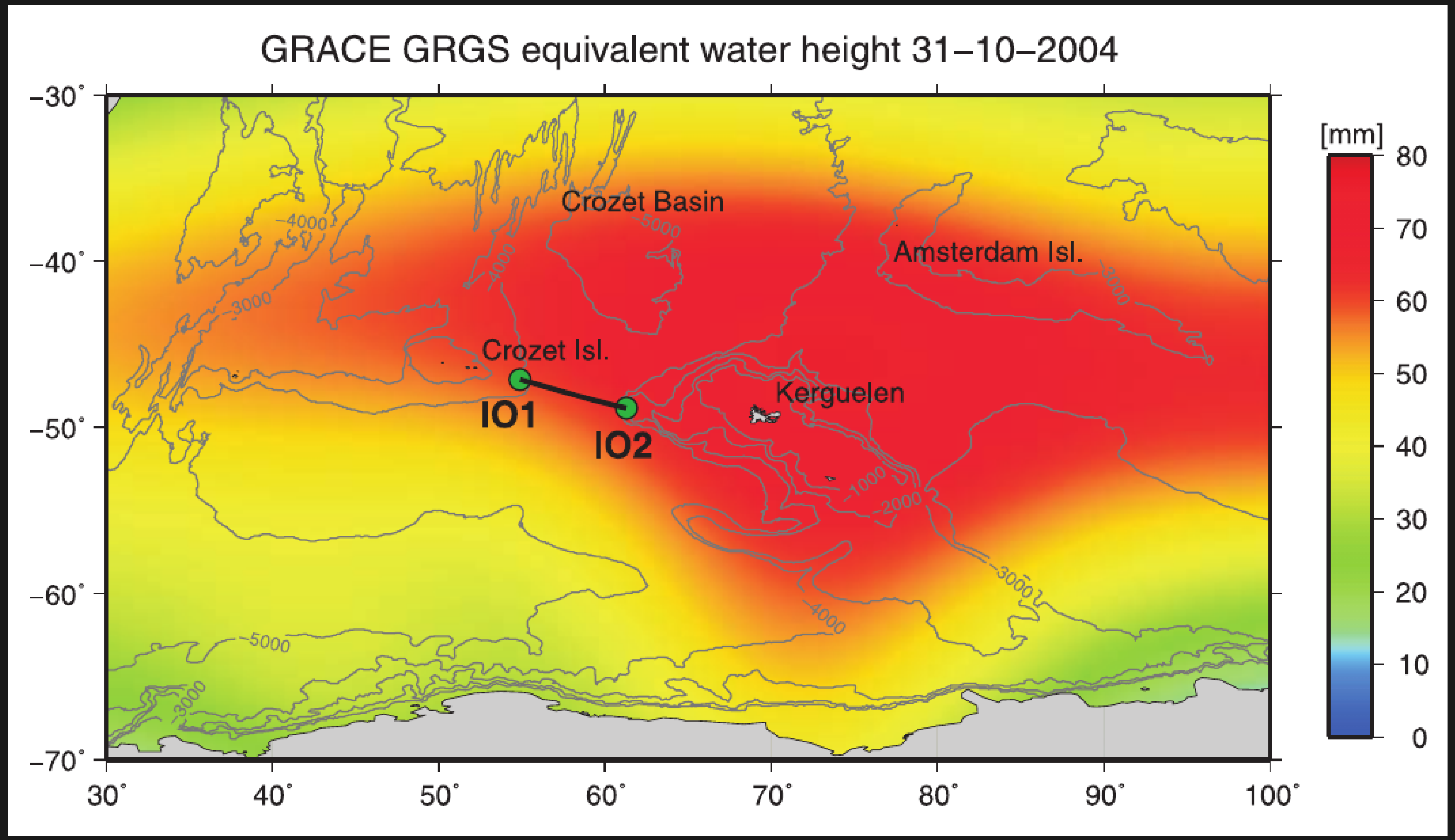

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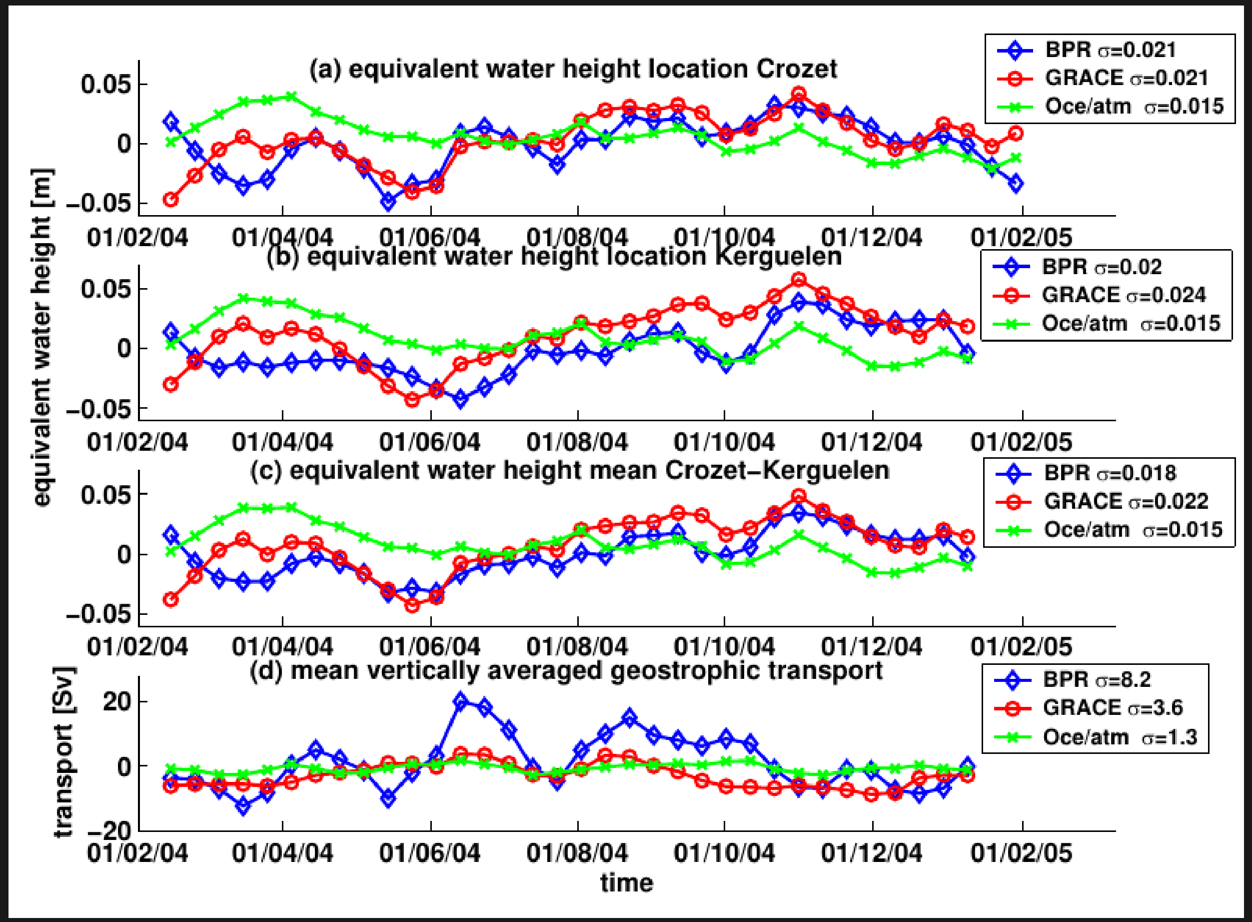

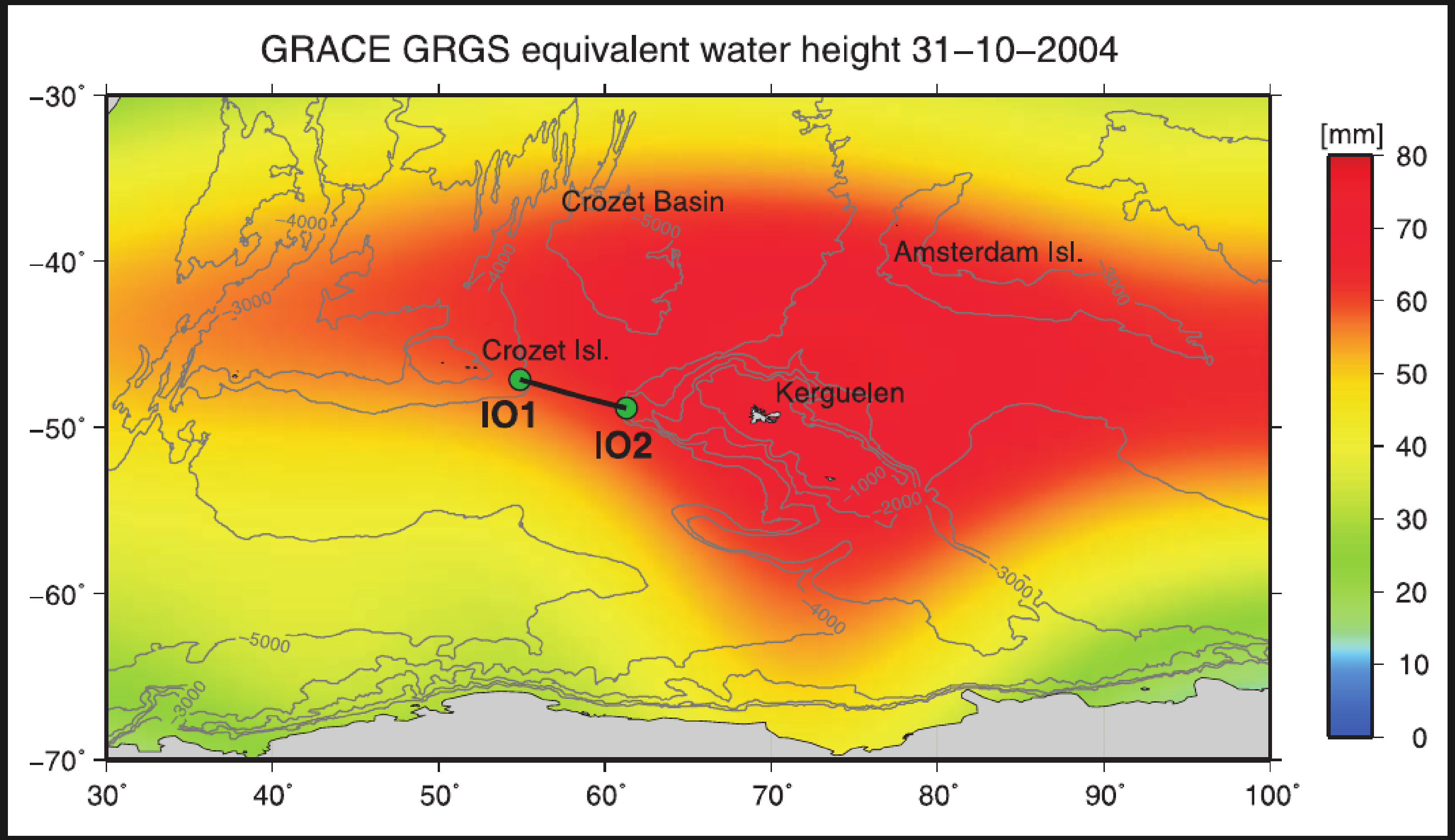

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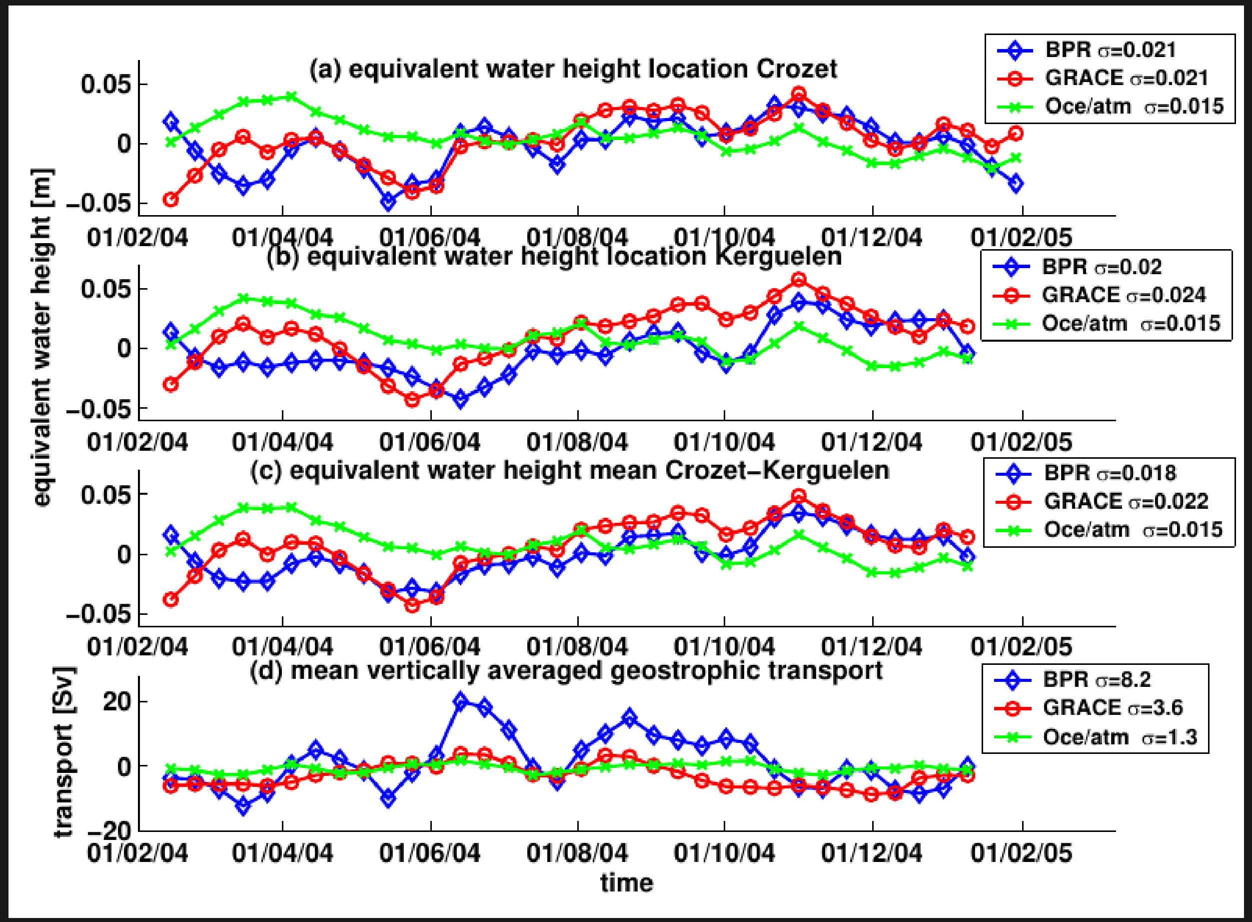

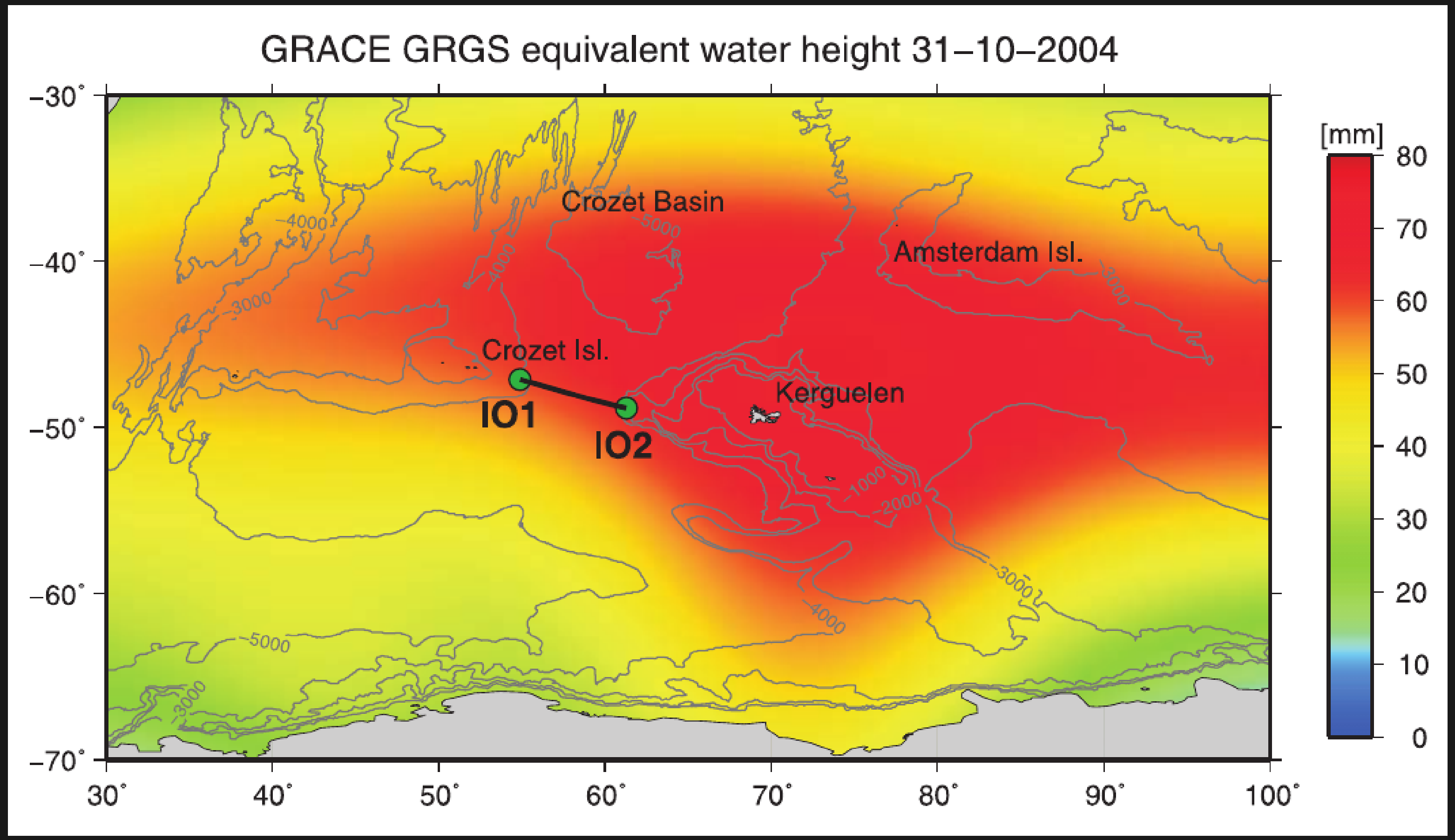

From Rietbroek et al. 2006

- In situ validation with pressure sensors
- 10-day GRACE solution was better than background model
- Large scale ocean signals picked up
- Due to smoothing geostrophic bottom currents not resolved

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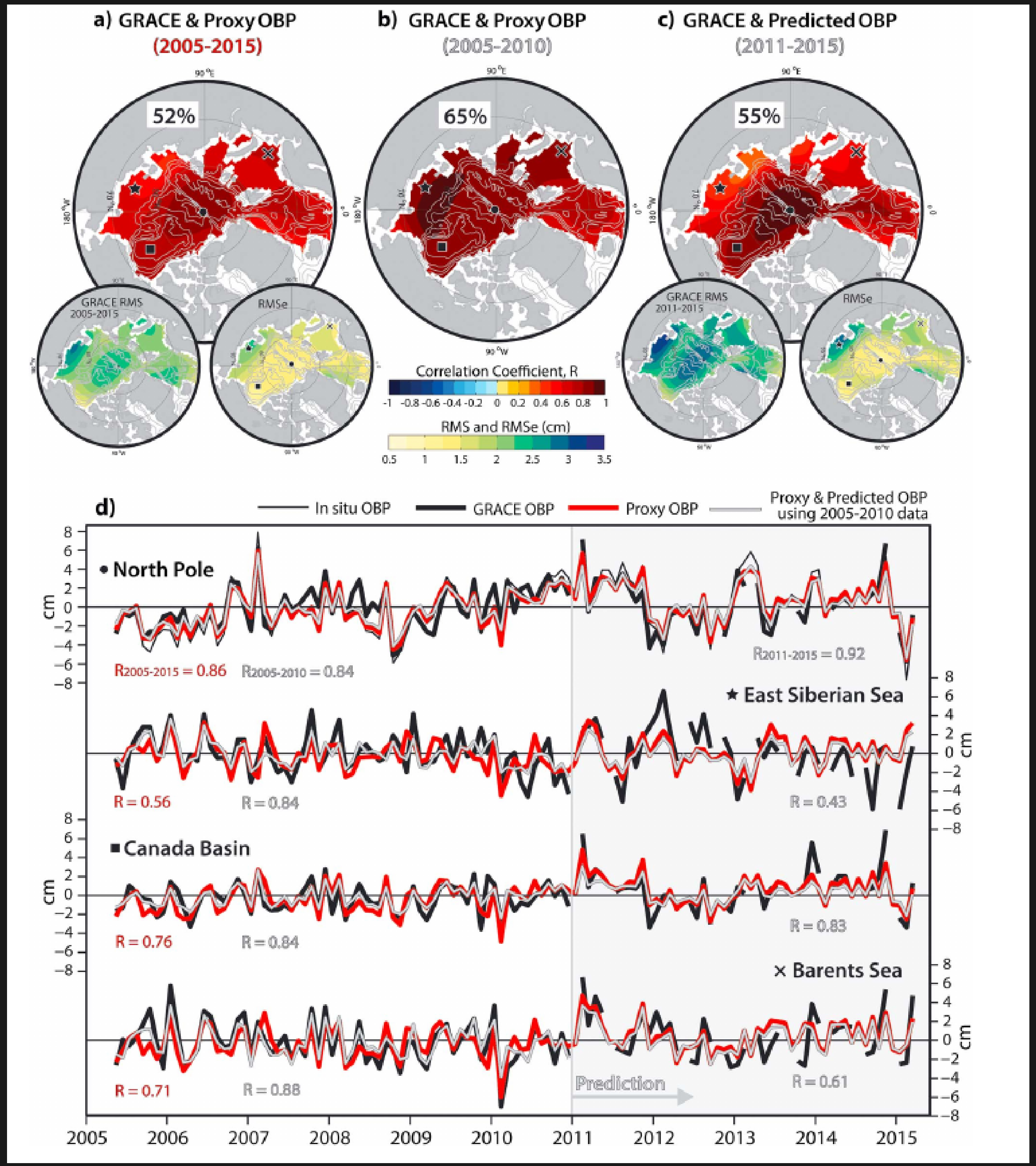
Arctic Ocean Bottom pressure variations well captured by GRACE



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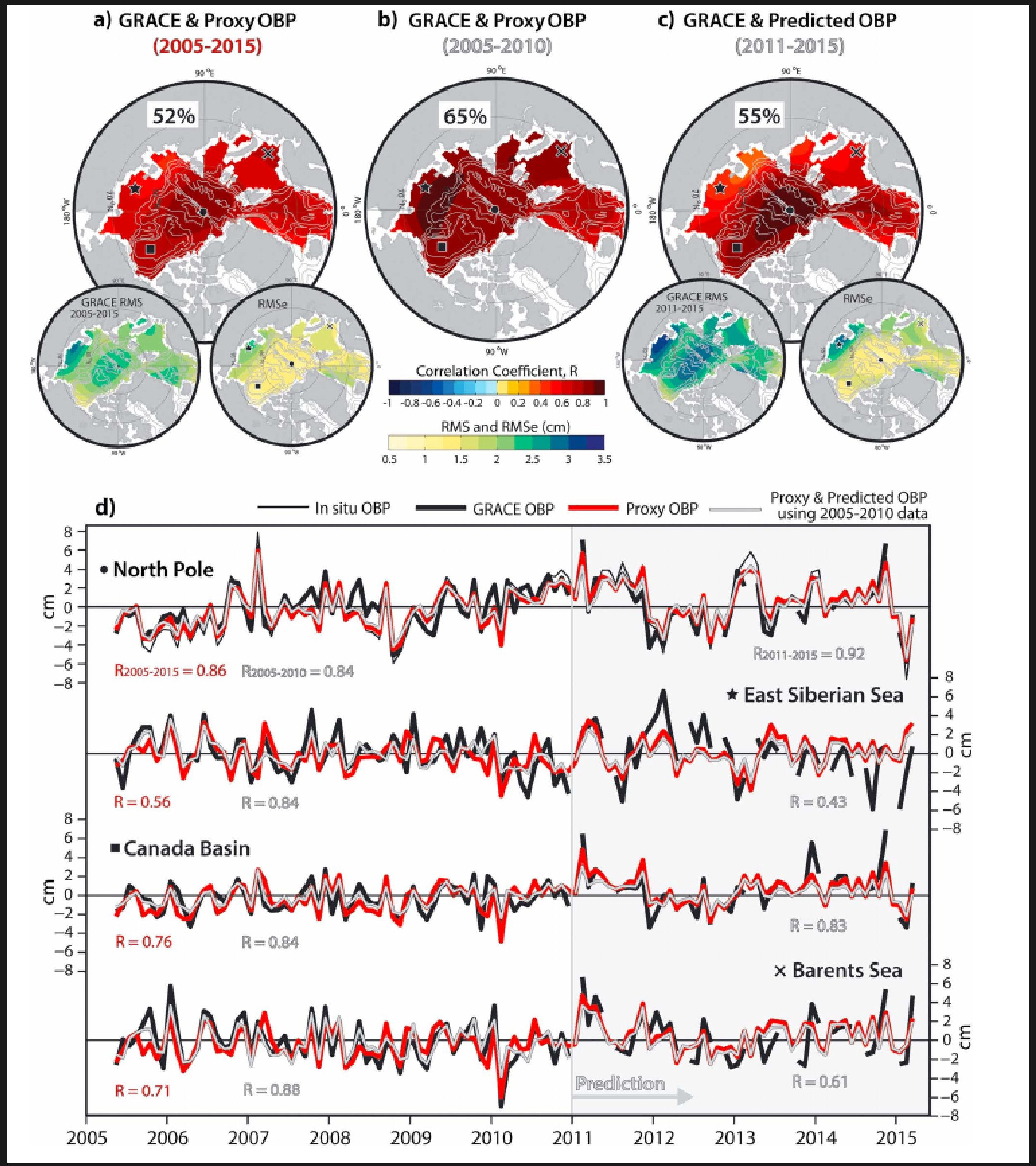

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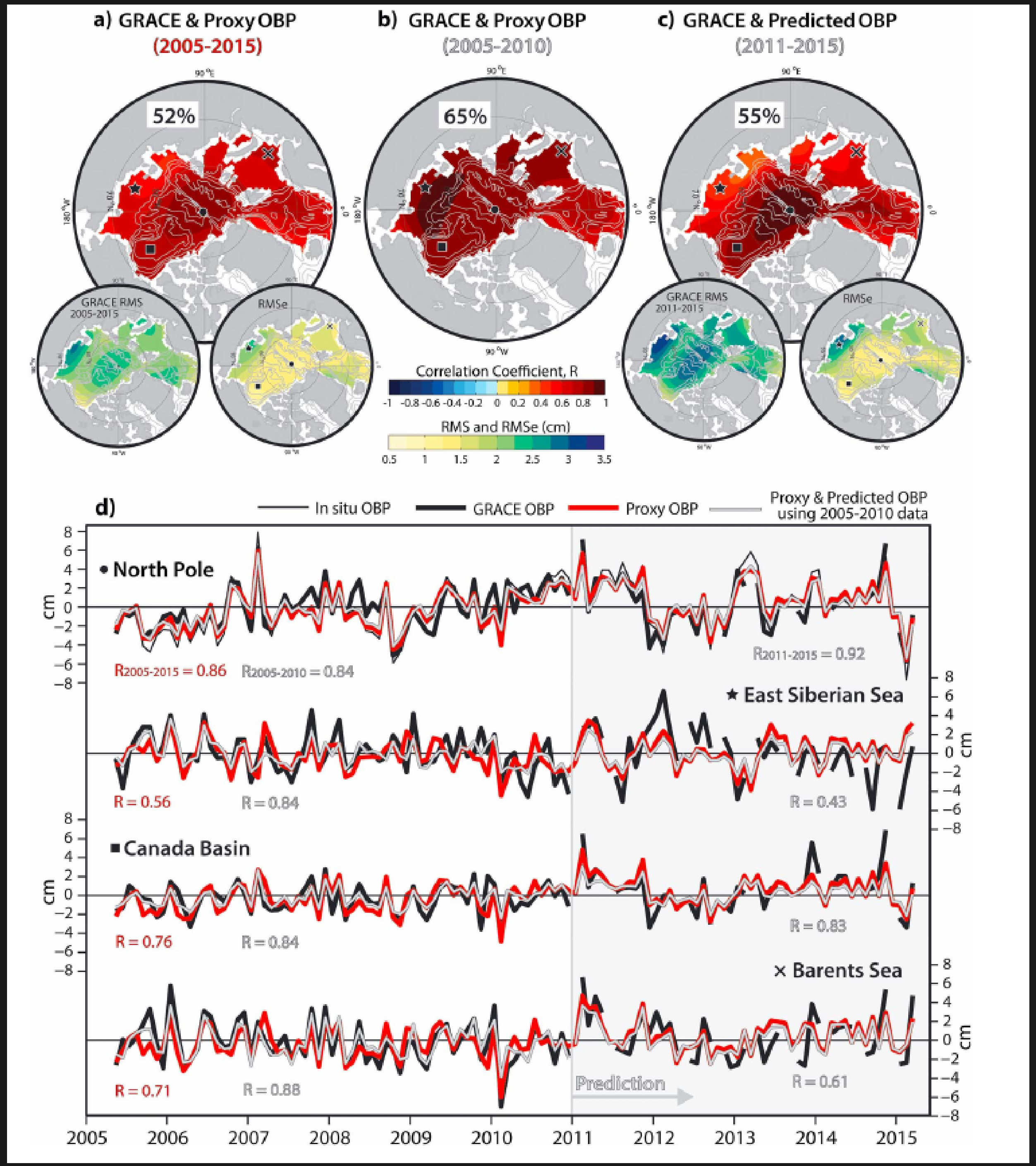

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- Coherent OBP signals in the Arctic

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ITC

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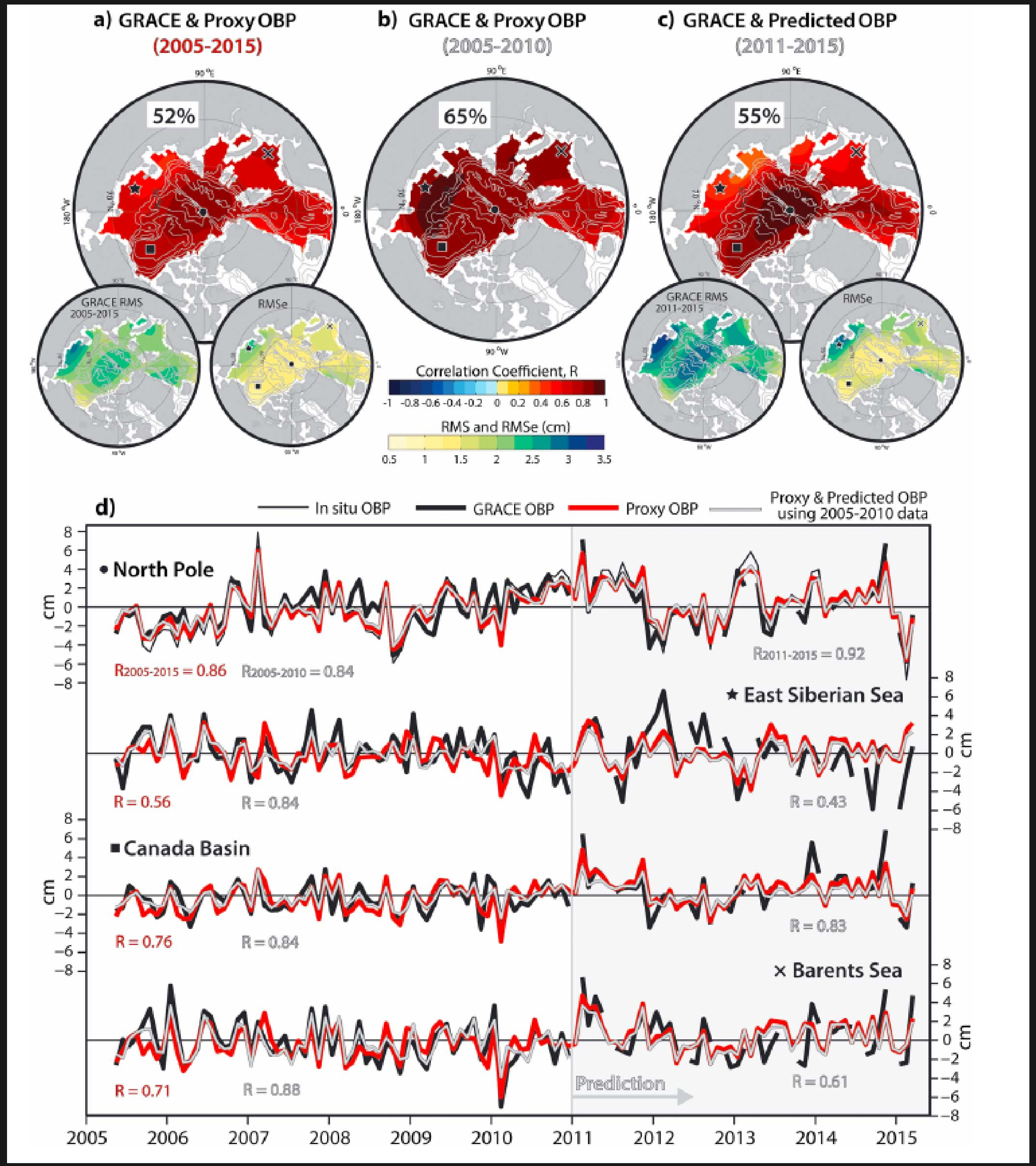

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- In situ OBP well captured by GRACE
- Coherent OBP signals in the Arctic
- Comparison showed that a single in situ OBP can serve as proxy for the entire Arctic

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Geostrophic currents from time variable gravity

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. C12, 3218, doi:10.1029/2001JC001274, 2002

A method of inferring changes in deep ocean currents from satellite measurements of time-variable gravity

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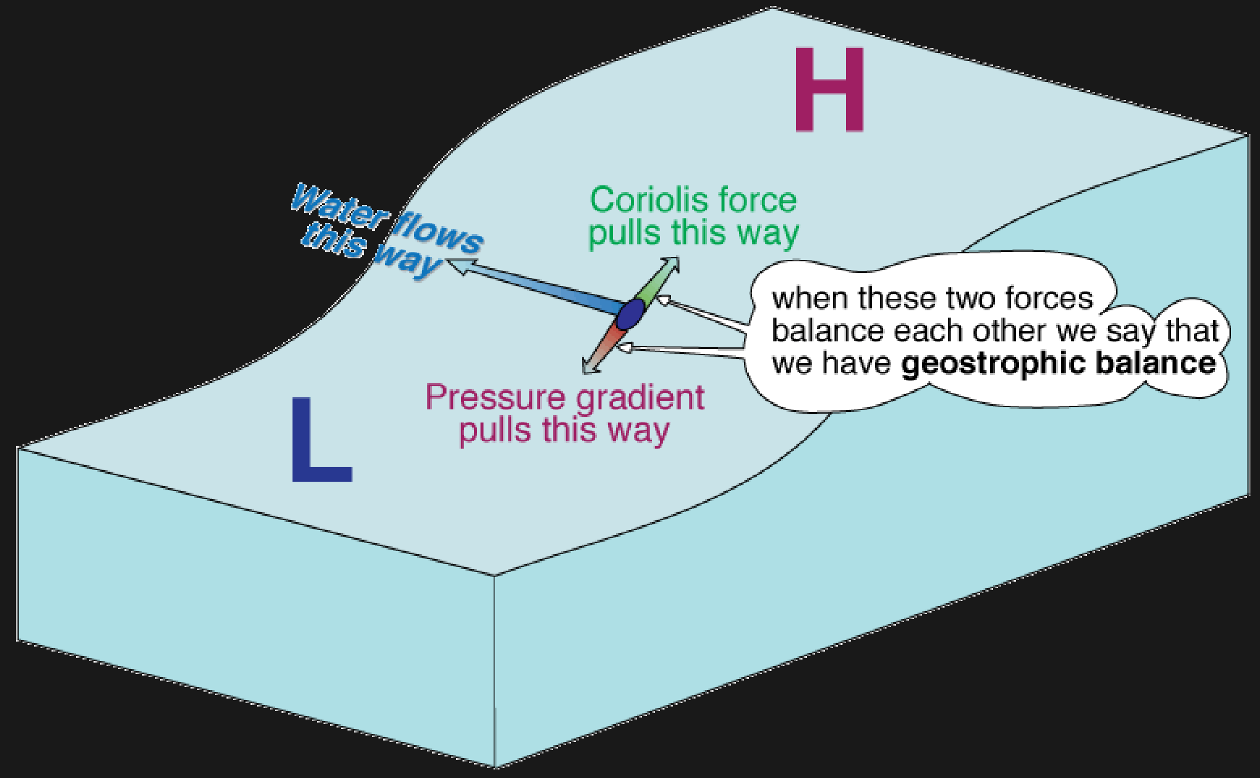

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the effects of friction and external forcing are less important, (1) reduces to the geostrophic approximation:

Pressure gradient

$$2\rho_0\Omega \times \mathbf{v} \approx -\nabla P \qquad (2)$$

Earth rotation vector

velocity

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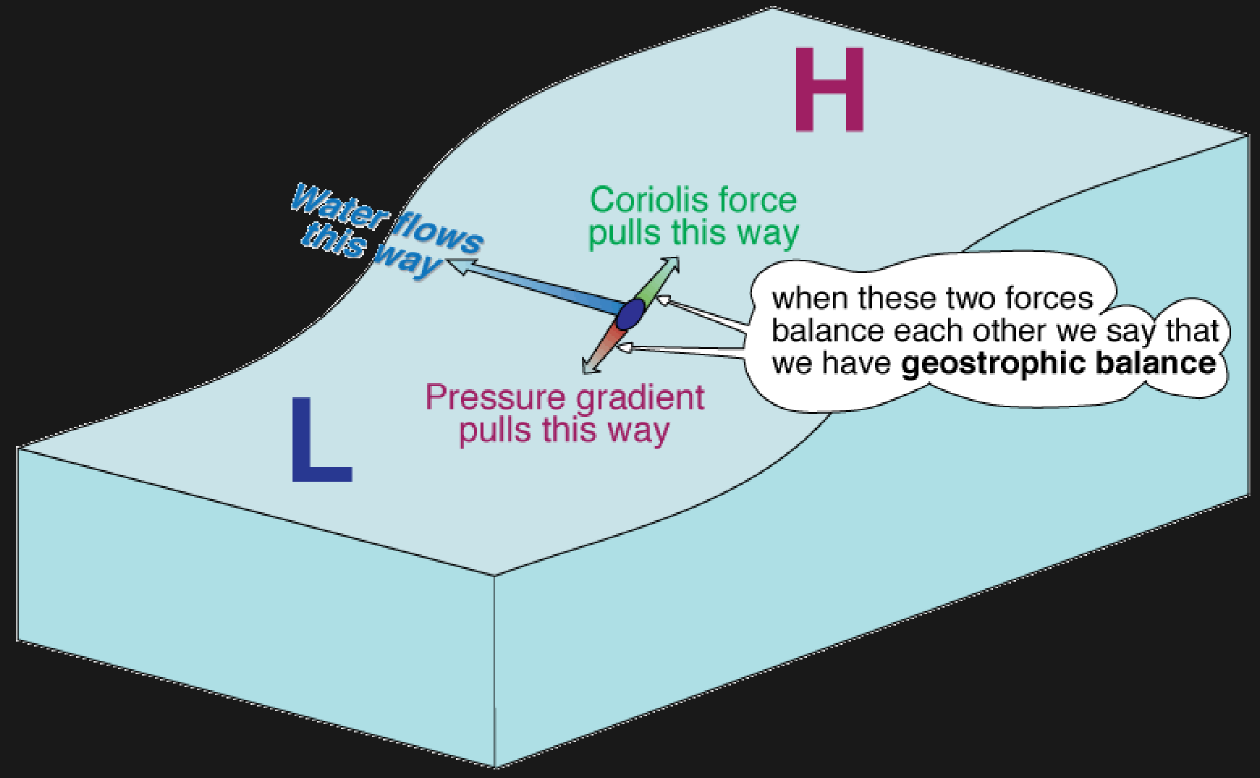

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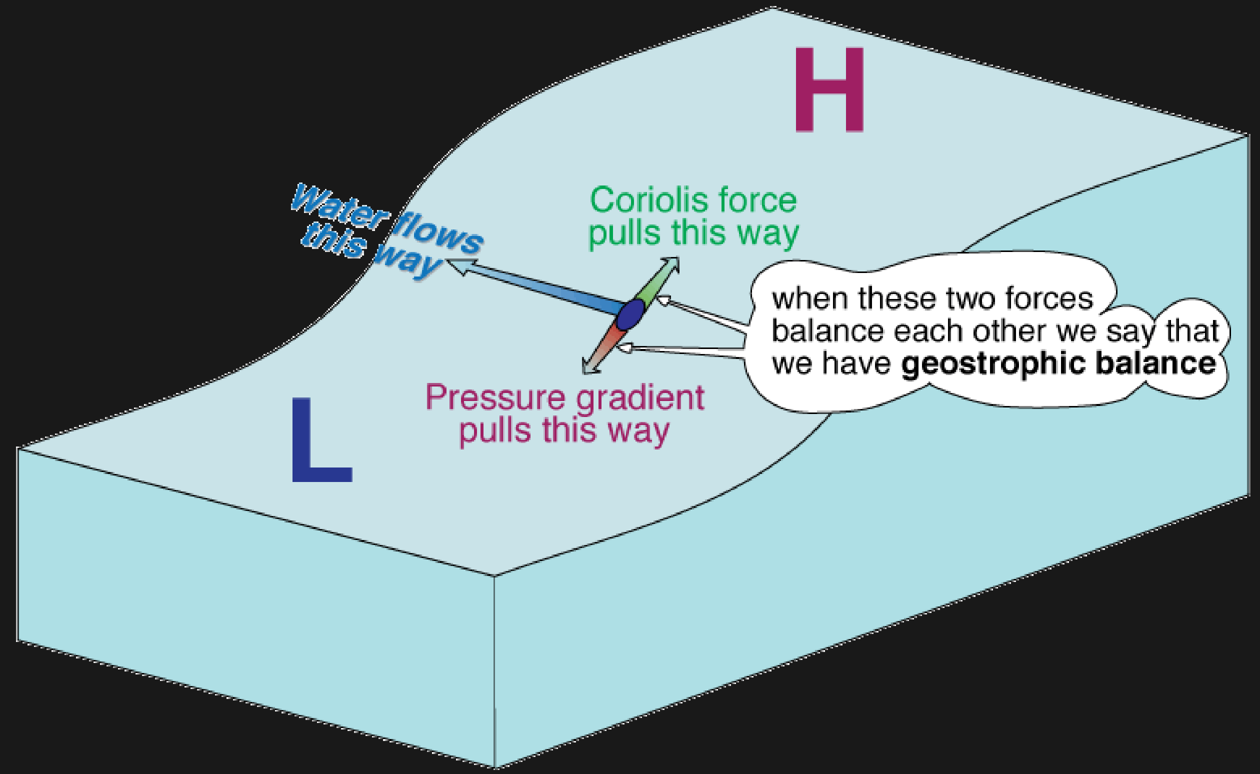

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- cross-product -> latitude dependency

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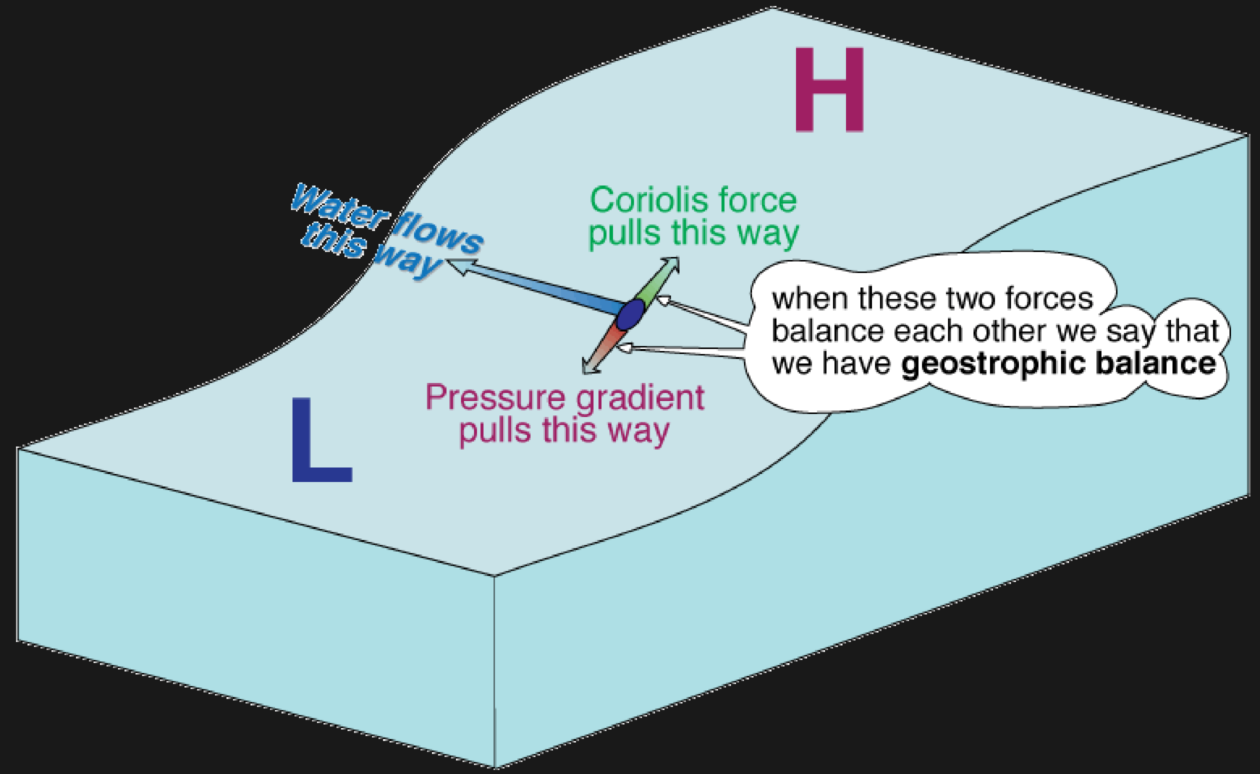

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Earth rotation vector

velocity

- Assume no accelerations
- cross-product -> latitude dependency
- Velocity is orthogonal to gradient!

What have you learned?

- Adding mass to the ocean
  - Observable in time-variable gravity
  - GRACE (1.5 - 2 mm/yr global mean ocean mass change)
  - Different causes have non-uniform contributions (Ice sheets, hydrology, dam impoundment,..)
  - Regional sea level also influenced by: Self attraction and loading
- Churning the Ocean (currents and wind)
  - Integration of the water column -> OBP
  - OBP changes due to dynamic height differences and column density change
  - Steric sea level: density driven dynamic height changes under the assumption of no OBP change
  - Pressure gradients cause circulation (surface gradient may be different from bottom)

Outlook

- Still many ocean applications unexplored (geostrophic currents!)
- Added value comes from combined data e.g. altimetry, Argo, etc.