Monitoring the AMOC with GRACE/GRACE-FO – How far can we push the spatial resolution?

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Monitoring the Atlantic meridional overturning circulation (AMOC) with GRACE/GRACE-FO

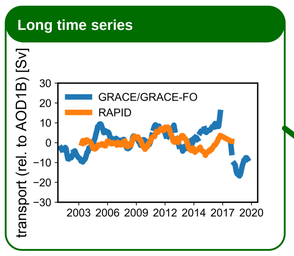
Previous Work

Landerer et al. (2015) have shown that satellite gravimetry has (some) skill at observing the lower limb of meridional transport.

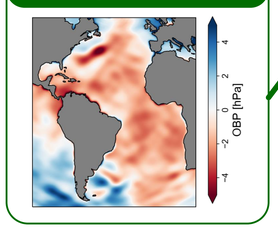
Why?

The AMOC is an important component of the Earth's climate system

Long time series



Full coverage of the Atlantic basin



How?

MOC is defined as the maximum of the streamfunction, it is therefore related to meridional transport.

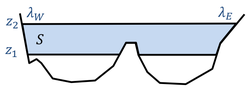
Transport through a basin cross-section is computed by integrating the velocity over the cross-section surface

$$\psi = \iint_S v(\lambda, z) d\lambda dz$$

ψ ... transport
v ... northward velocity
z ... elevation
λ ... longitude

geostrophic flow, neglect stress terms

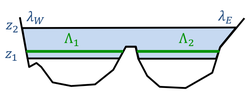
Topography of the Atlantic basin at 26°N



$$\psi = \iint_S \frac{1}{\rho_0 f} \frac{\partial p}{\partial \lambda} d\lambda dz$$

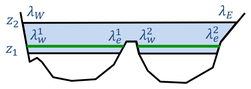
ρ_0 ... seawater density
f ... Coriolis parameter
p ... pressure

split integral into longitude/depth



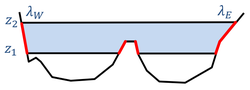
$$\rho_0 f \psi = \int_{z_1}^{z_2} \sum_k \int_{\Lambda_k} \frac{\partial p}{\partial \lambda} d\lambda dz$$

solve longitudinal integral



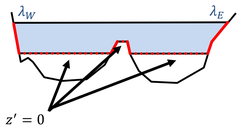
$$\rho_0 f \psi = \int_{z_1}^{z_2} \sum_k p\left(\lambda_e^k(z)\right) - p\left(\lambda_w^k(z)\right) dz$$

separate western and eastern boundary, change integration bounds



$$\rho_0 f \psi = \int_{z_2}^{z_1} \sum_k p\left(\lambda_w^k(z)\right) dz + \int_{z_1}^{z_2} \sum_k p\left(\lambda_e^k(z)\right) dz$$

substitute integration over depth with integration over longitude (assumes narrowing topography)



$$\psi = \frac{1}{\rho_0 f} \int_{\lambda_W}^{\lambda_E} p(\lambda) z'(\lambda) d\lambda$$

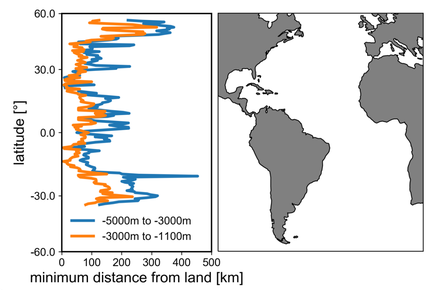
We can compute transport by integrating bottom pressure values from the western to the eastern depth layer boundary. Points outside the layer are excluded by setting the slope to zero.

Challenges

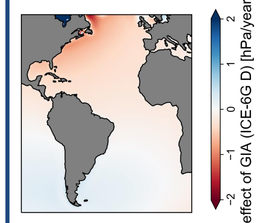
Signal Separation

Land Leakage

The distance of a depth layer from land gives us an indication if, for example, continental hydrology will leak into our transport estimates. Short answer: Yes, we must deal with signals like hydrology.



Glacial isostatic adjustment (GIA)



The effect of glacial isostatic adjustment (GIA) is small but visible. Disentangling it from secular trends in ocean bottom pressure is tricky but has been studied extensively in other GRACE/GRACE-FO applications.

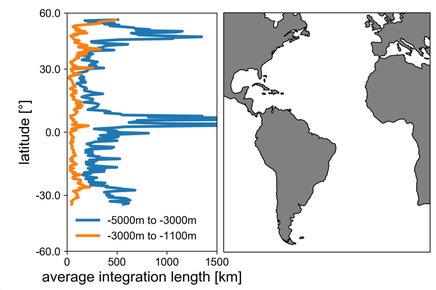
Signal separation on sensor measurement level: Why?

Models (for example continental hydrology) can be applied in their native spatial and temporal resolution.

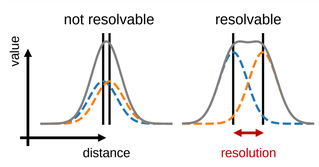
Model output is passed through the GRACE/GRACE-FO processing chain and therefore smoothed in the same way.

Spatial Resolution

Requirement: To compute transport from bottom pressure, we integrate over segments of the ocean floor. The spatial resolution should be in the same order of magnitude.



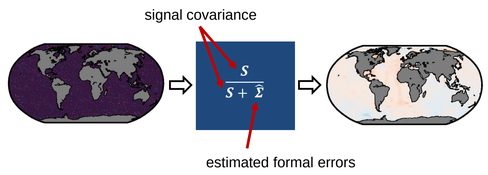
Definition (in this study): distance between two resolvable bottom pressure peaks



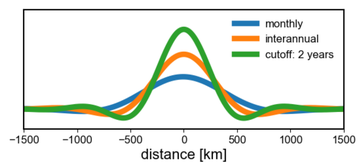
Resolution of GRACE and GRACE-FO

How can we derive the spatial resolution from a (constraint) GRACE/GRACE-FO solution?

A zero-constrained OBP estimate can be rewritten as a filter:



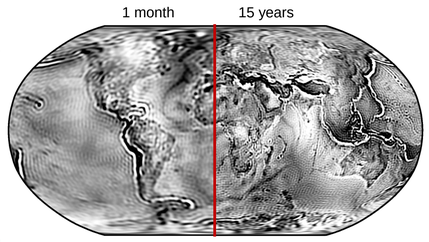
This filter has a kernel function, which shows how a single OBP peak is seen by GRACE/GRACE-FO and allows us to quantify the resolution:



Effect of temporal averaging

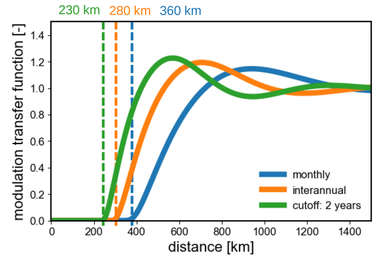
Averaging in time (before inversion) increases the spatial resolution. The same holds true for applying low-pass filters or constraining the difference between consecutive epochs.

Extreme example using GRACE data:



How far can we push it?

By looking at interannual and longer time scales we can increase the spatial resolution compared to a standard monthly solution.



We should be able to compute transport in the deeper layers (< -3000m) of the Atlantic. The depth layer -1100m to -3000m with a horizontal extent of 100km to 150km might be too narrow to properly resolve.

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