

Regional seafloor topography variations mapped by gravity gradients

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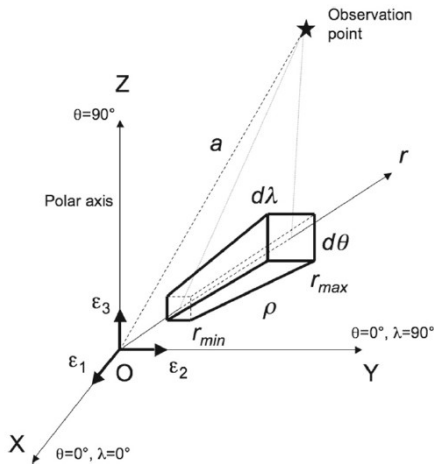
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OBJECTIVES

We propose a Kalman Filter (KF) approach to integrate different types of geophysical data, i.e. geoid height, free-air gravity anomalies, **gravity gradients**, single beam sounding ship tracks, etc, for refining seafloor topography estimation.

In this presentation, we focus on introducing the inversion of gravity gradients.

- ✓ The analytical solution is estimated by radial integration.

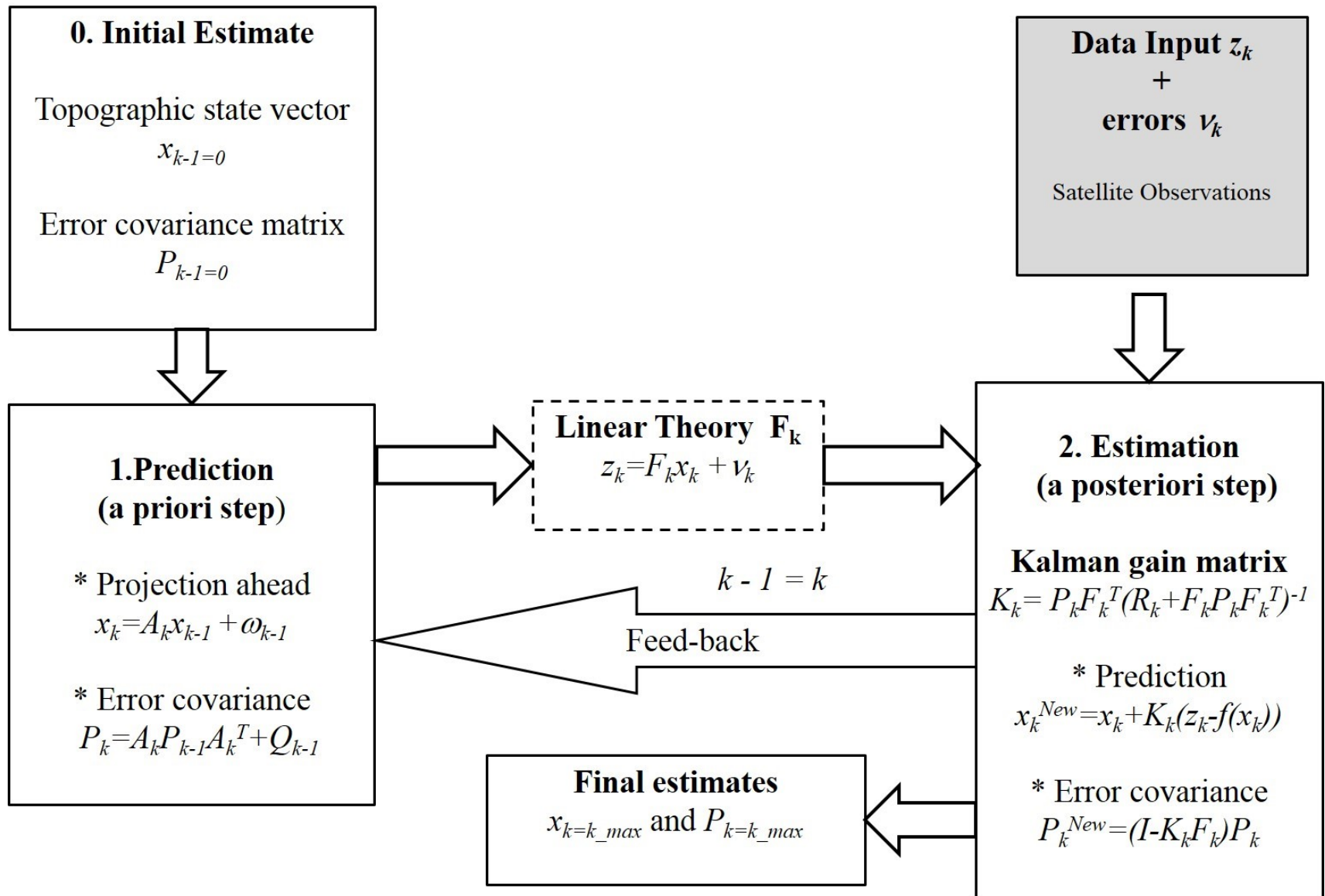


$$\frac{d^2V(a, h, \varphi)}{dr^2} = G(\rho_h - \rho_w) \Delta\lambda \Delta\theta \cos \theta \int_R^{R+h} \zeta(a, r', \varphi) dr'$$

$$\zeta(a, r', \varphi) = r'^2 \left[\frac{3(r' \cos \varphi - a)^2}{(a^2 + r'^2 - 2ar' \cos \varphi)^{5/2}} - \frac{1}{(a^2 + r'^2 - 2ar' \cos \varphi)^{3/2}} \right]$$

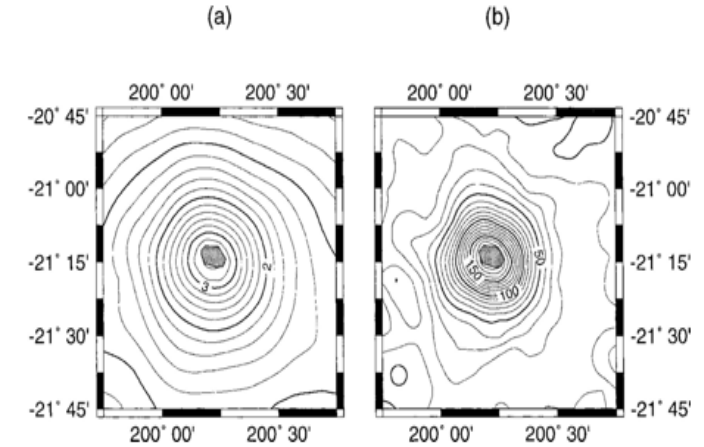
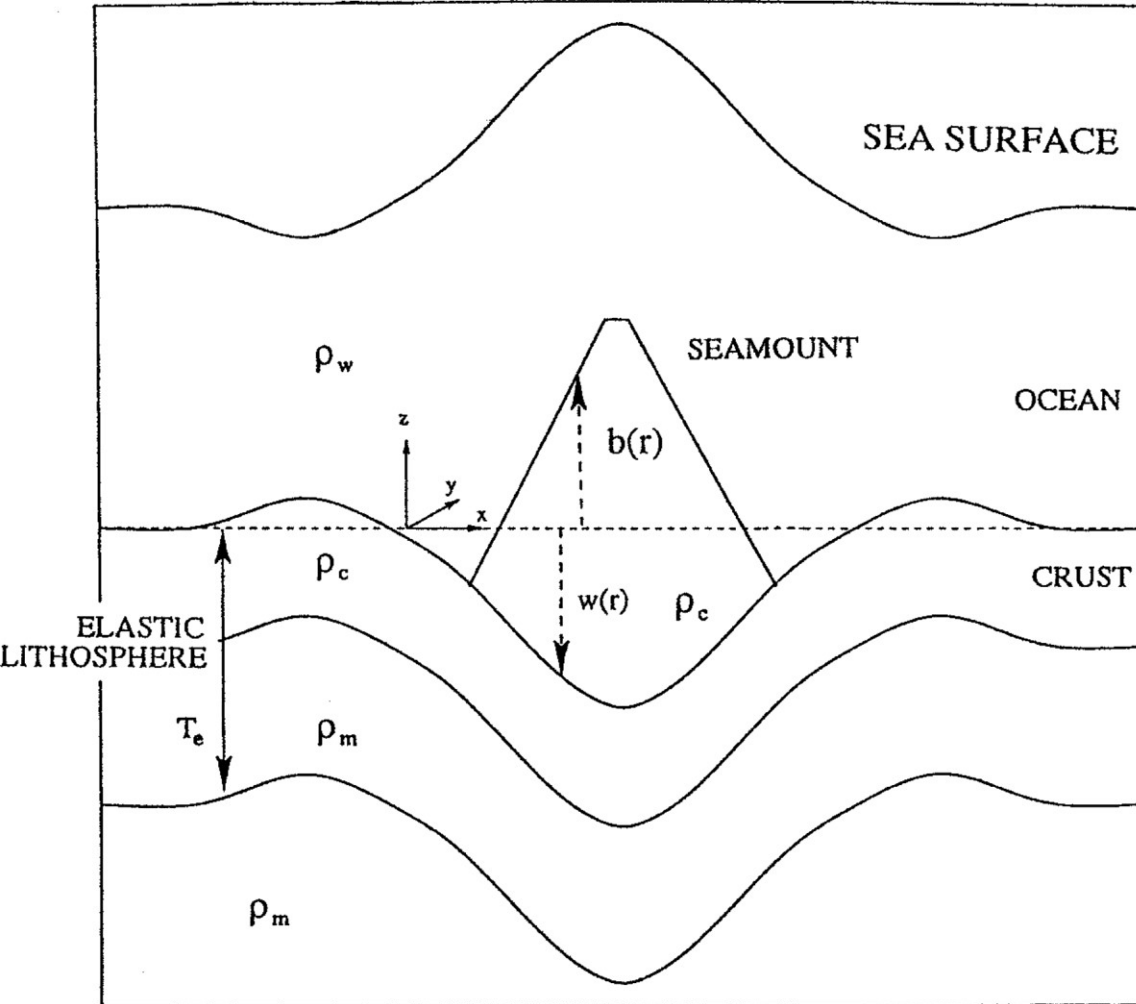
- ✓ If the observation point is situated at > 200 km (satellite observation case) the approach of Ramillien 2017 based on Legendre functions is used in order to reduce the number of inversion parameters

PRINCIPLE OF KALMAN FILTERING (KF)



DENSITY INTERFACE MODEL

A three-layer model is computed in our algorithm to take into account the compensated case.



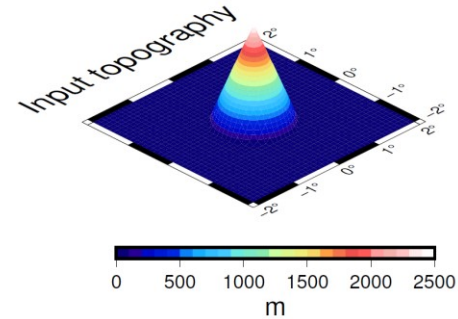
Constant	Symbol	Numerical value
Gravitational constant	$G \pm \sigma$	6.67×10^{-11} (SI)
Mean gravity	γ	9.81 m s^{-2}
Mean Earth radius	R	6371 km
Young's modulus	E	10^{12} N m^{-2}
Poisson's ratio	ν	0.25
Sea-water density	ρ_w	1000 kg m^{-3}
Crustal density	ρ_c	2700 kg m^{-3} (*)
Mantle density	ρ_m	3350 kg m^{-3}
Elastic thickness	T_e	10 000 m (*)

In this presentation, for preliminary tests non-compensated structures are considered .

APPLICATION TO SIMULATED DATA AND RECOVERY TESTS FOR VERTICAL GRAVITY GRADIENT

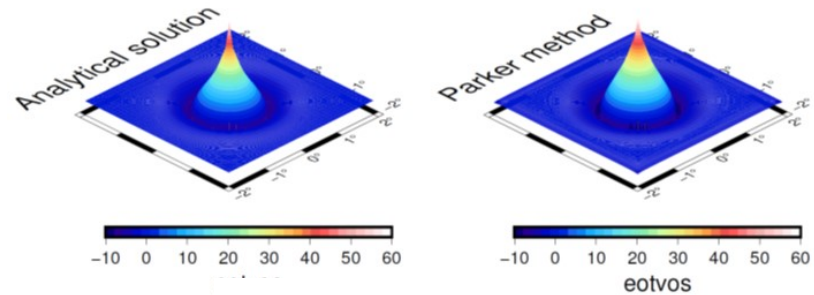
Generate synthetic
topography

Simulated conic seamount

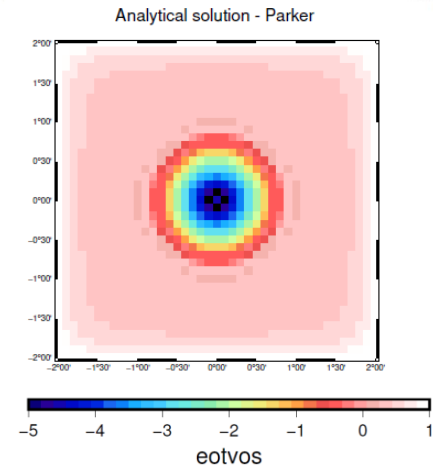


Forward problem:
Simulate observations

Comparison of different VGG computations



Inversed problem:
Estimate topography



INVERSION PARAMETERS (σ_d , σ_m)

σ_d is the standard deviation of observations errors

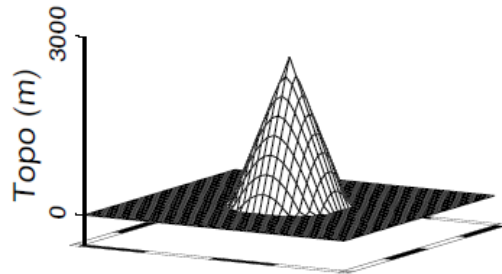
σ_m is the a priori standard deviation of topographic heights

Cold start is performed to show the ability of our methodology to reconstruct bathymetry without constraints.

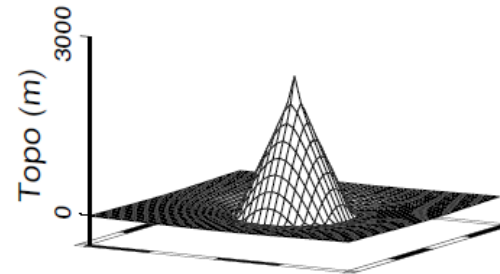
CONVERGENCE OF THE SOLUTION – RESIDUALS FROM TRUE SOLUTION

Solutions derived from vertical gravity gradients using $\sigma_d=1$ Eotvos and $\sigma_m=1000$ meters

INPUT BATHYMETRY



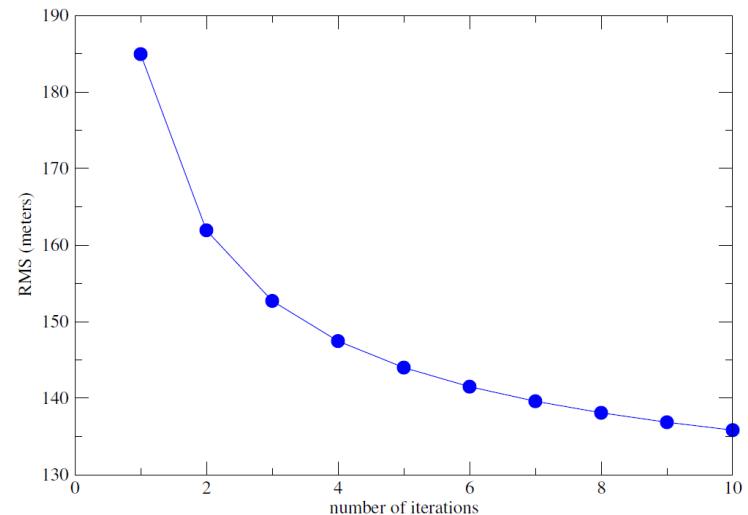
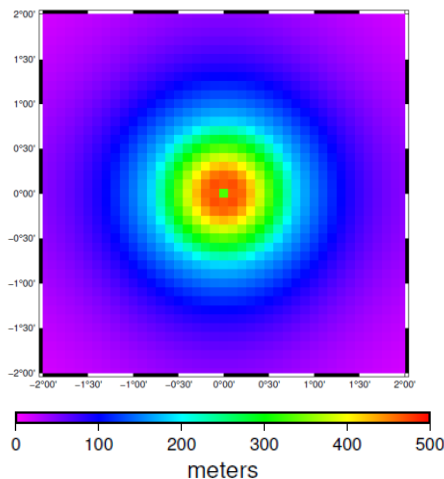
INVERSED BATHYMETRY



Convergence

DIFFERENCES

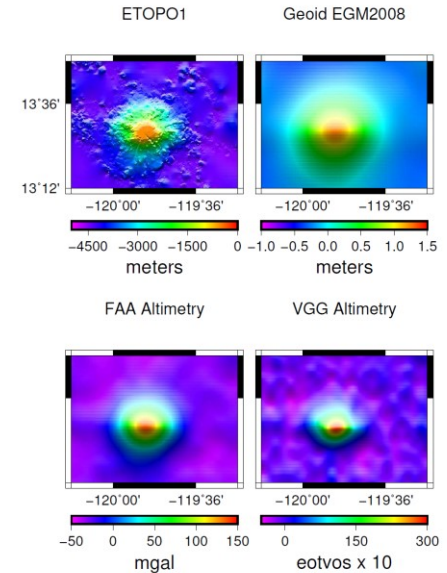
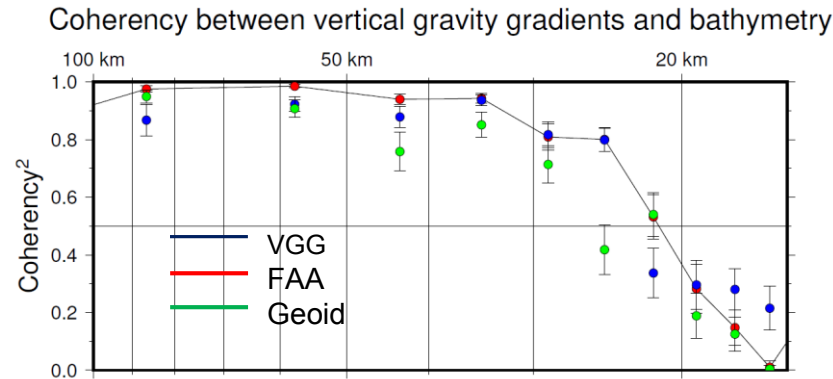
Simulated topography - Inversion



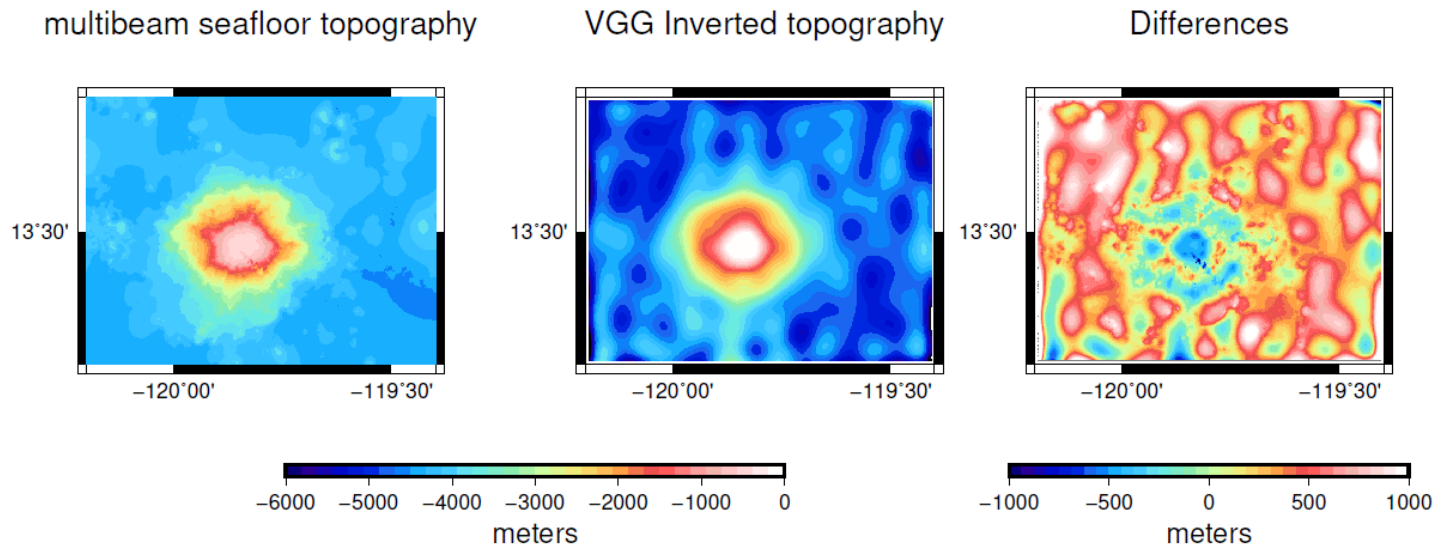
INVERSION RESULTS: ACAPULCO SEAMOUNTS TOPOGRAPHY

Coherence analysis: A seamount situated in the Acapulco area is used as a check case.

There is a very good coverage of multibeam observations



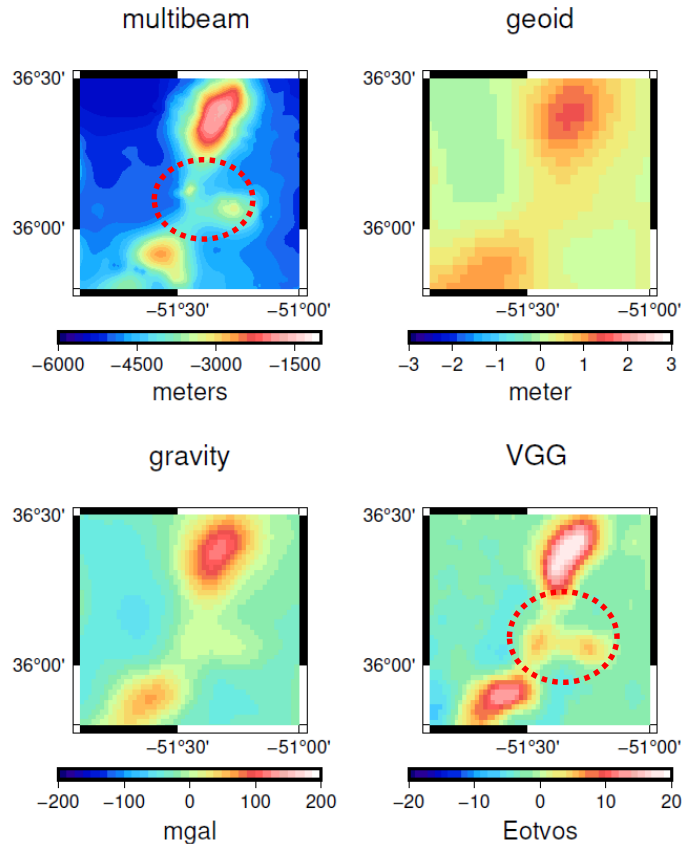
Inversion results: Noise is located on the seafloor and artefacts are generated. However, the seamount structure is well defined.



INVERSION RESULTS: NEW ENGLAND SEAMOUNTS TOPOGRAPHY

VGG is more sensitive to high spatial frequencies

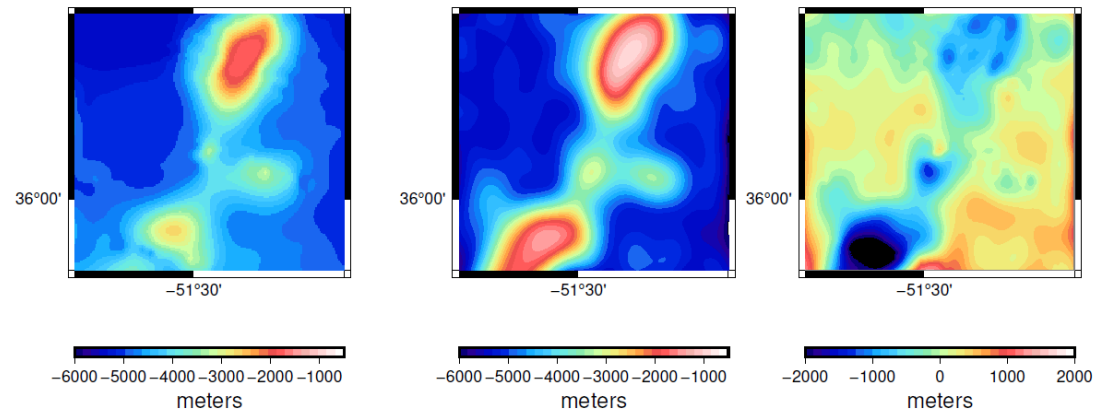
Inverted seafloor topography compared to multibeam observations



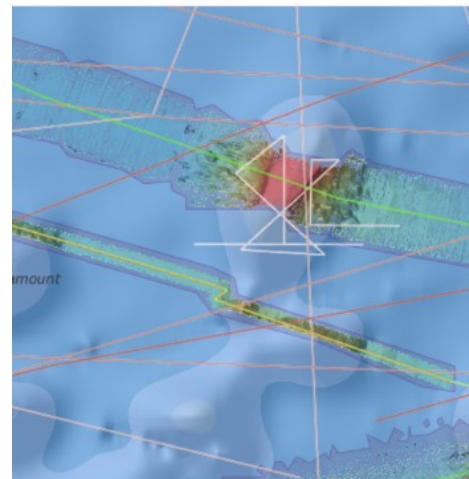
multibeam seafloor topography

VGG Inverted topography

Differences

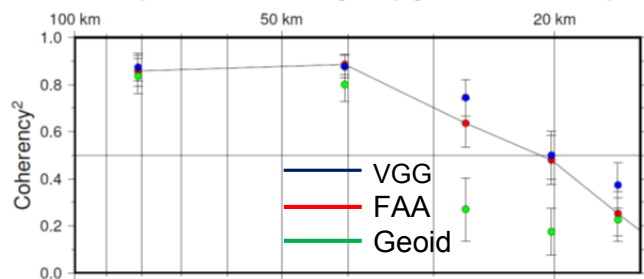


Multibeam and single beam coverage (ngdc, 2021)



Large differences are due to :
lack of multibeam observations,
but also edge effects in the
inversion process

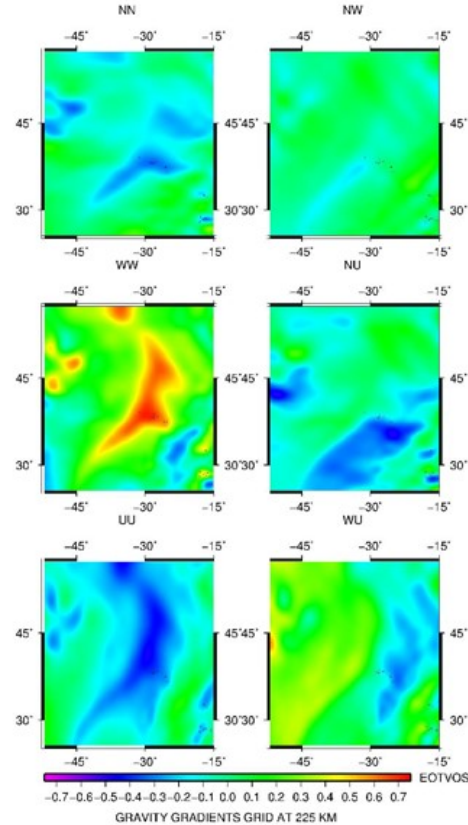
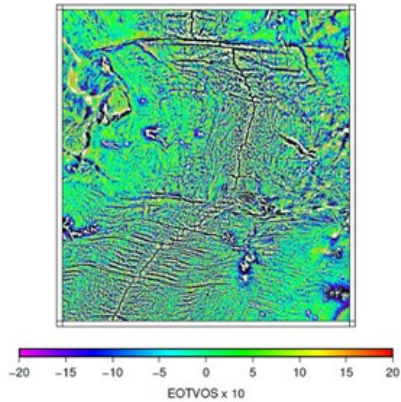
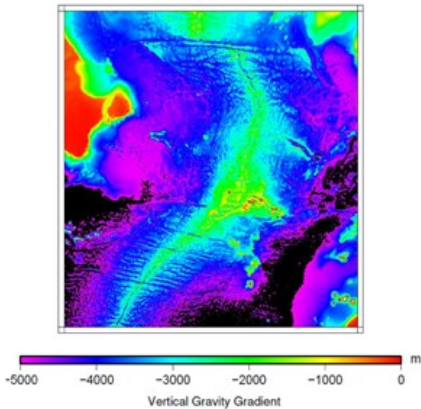
Coherency between vertical gravity gradients and bathymetry



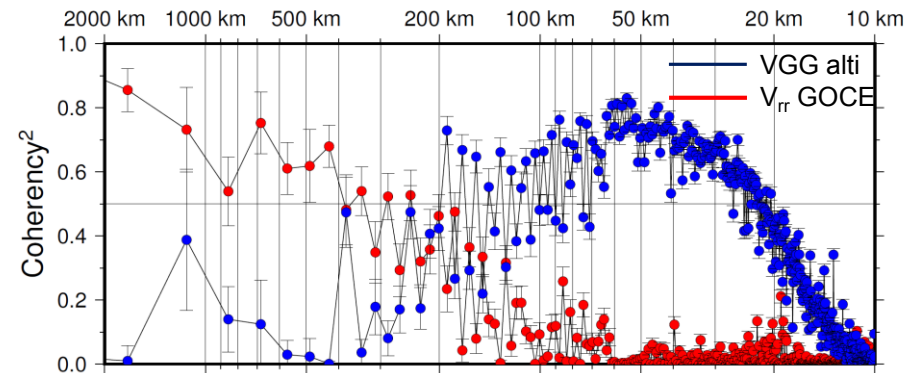
GOCE GRAVITY GRADIENTS

We will check GOCE gradients contribution to the knowledge of lithospheric parameters. We concentrate on the North Atlantic region.

ETOPO1



Coherency between gradients and bathymetry



As well know VGG leads a good coherence with respect to seafloor topography at high wavelengths (until 200km). GOCE observations give complementary information at large scales.

HIGHLIGHTS & PERSPECTIVES

- Vertical gravity gradient inversion has been successfully made.
- Inversions of simulated and real observations are made to show the performance of the method. The non-compensated cases are considered.
- Each input dataset that is integrated iteratively in the KF has the possibility to complement - or not, depending upon the data uncertainties - the current regional topography solution.

Next improvements:

Due to the large dimensions of the matrices related to topographic heights, the numerical computation still needs to be optimized, in particular to extend our KF recovery to very large oceanic regions.

The contribution of GOCE observations at large scales must be further studied.