Relativistic geodesy and ocean challenges
what is at stake in ocean sciences?

By Marie-Françoise Lequentrec-Lalancette , SHOM

IAG Joint Working Group 2.1 Relativitsic Geodesy

- Oceans = geologic layer with relief - liquid layer – atmospheric layer

- Relativistic geodesy where ?
  - Coastal areas
  - Deep areas

- What for? What are the challenges ?

For nautical chart and safety of navigation :

high accuracy in shallow depth and navigation areas

For new uses of coastal areas : marine renewable energy (current, tide, Wind..) , fich farm..

For exploration in deep oceans (the future) mine operations, ..

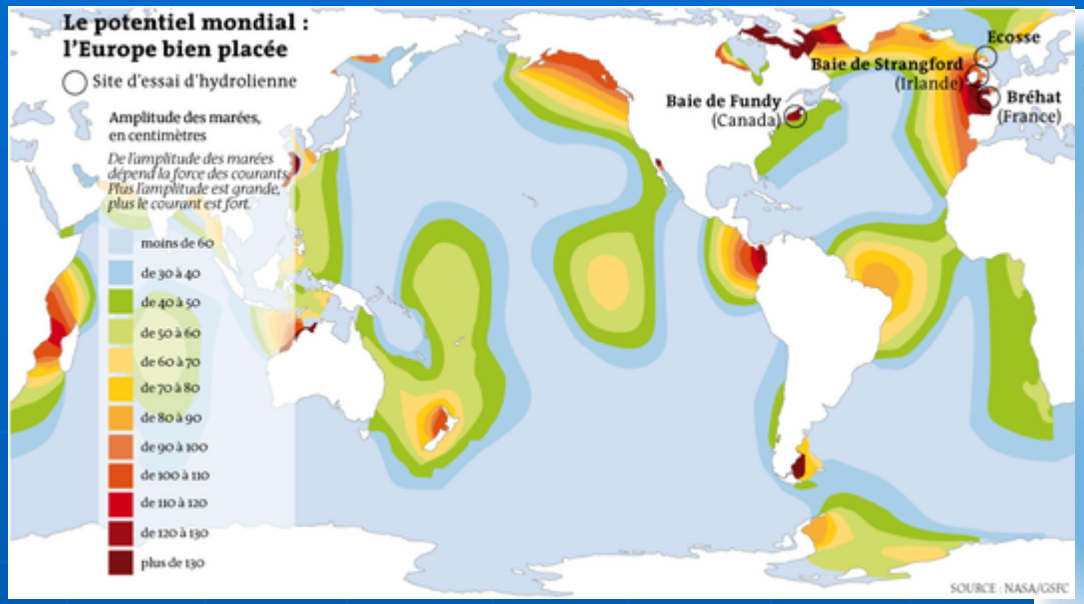
AND For the sustainable development objectives (SDG 14 UN) :
Conserve and sustainably use the oceans, seas and marine resources

Safety of navigation

Depth Z

➔ Mean sea level par rapport au niveau moyen

➔ Chart Datum (Low Astronomical Tides) (NPBMA)

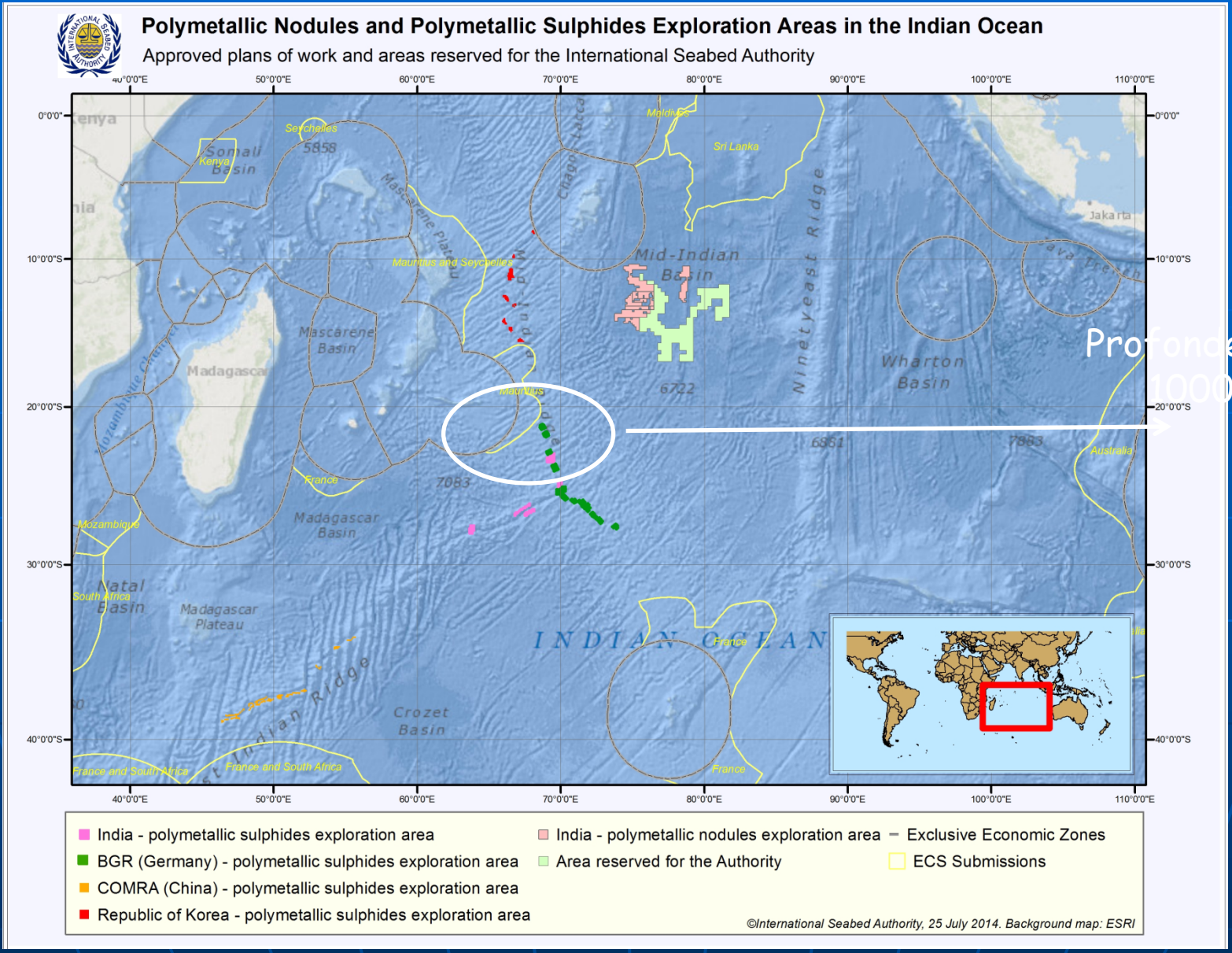

Le potentiel mondial :
l'Europe bien placée
Site d'essai d'hydrolienne
Amplitude des marées, en centimètres
De l'amplitude des marées dépend la force des courants. Plus l'amplitude est grande, plus le courant est fort.
moins de 60
de 30 à 40
de 40 à 50
de 50 à 60
de 60 à 70
de 70 à 80
de 80 à 90
de 90 à 100
de 100 à 110
de 110 à 120
de 120 à 130
plus de 130
Ecosse
Baie de Strangford (Irlande)
Bréhat (France)
Baie de Fundy (Canada)
SOURCE : NASA/GSFC


Lauréats du 1er appel d'offres éolien en mer
Éolien maritime France 498 MW
Éolien maritime France 450 MW
Ailes marines SAS 500 MW
480 MW Éolien maritime France
Dunkerque
PAS-DE-CALAIS
NORD
Fécamp
Courseulles-sur-Mer
Dieppe
SOMME
Le Havre
SEINE-MARITIME
Cherbourg
Saint-Brieuc
MANCHE
CALVADOS
EURE
Brest
FINISTÈRE
CÔTES-D'ARMOR
Saint-Malo
ILLE-ET-VILAINE
MORBIHAN
LOIRE-ATLANTIQUE
Saint-Nazaire
VENDÉE
CHARENTE-MARITIME
Bordeaux
GIRONDE
Lauréats
Zone d'installation des éoliennes du 1er appel d'offres

Hydrodynamic models ➔ coherent references for civil engineering or for risk prevention Currents, surges,

In this case the height ref is the mean sea level at the site

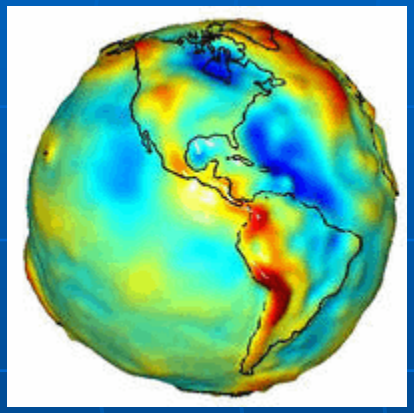
In deep oceans (minig but also IPCC challenges)

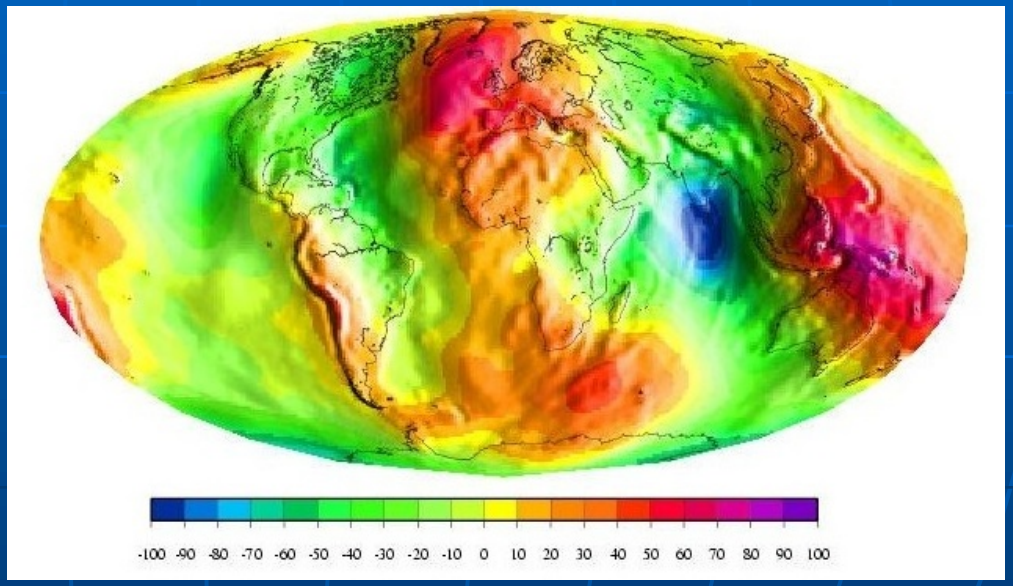


Profondeurs > 1000m

The knowledge of the geoid
(mean sea level is a proxy for equipotential surface of the gravity field that is W_0)

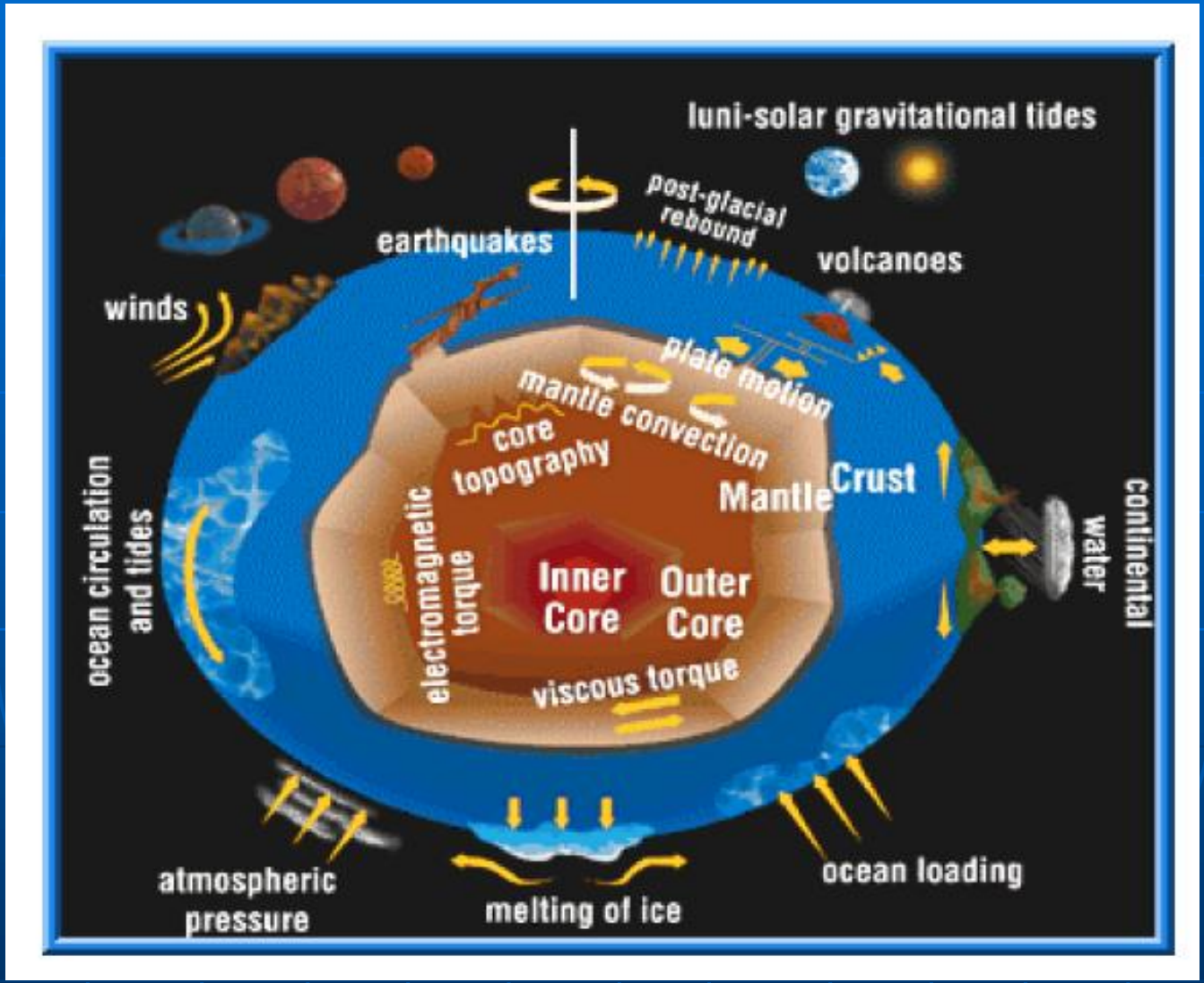
- To estimate geoid ➔ gravity field from GOCE Satellite or marine gravity data





Altitude reference frame to describe the shape of the Earth

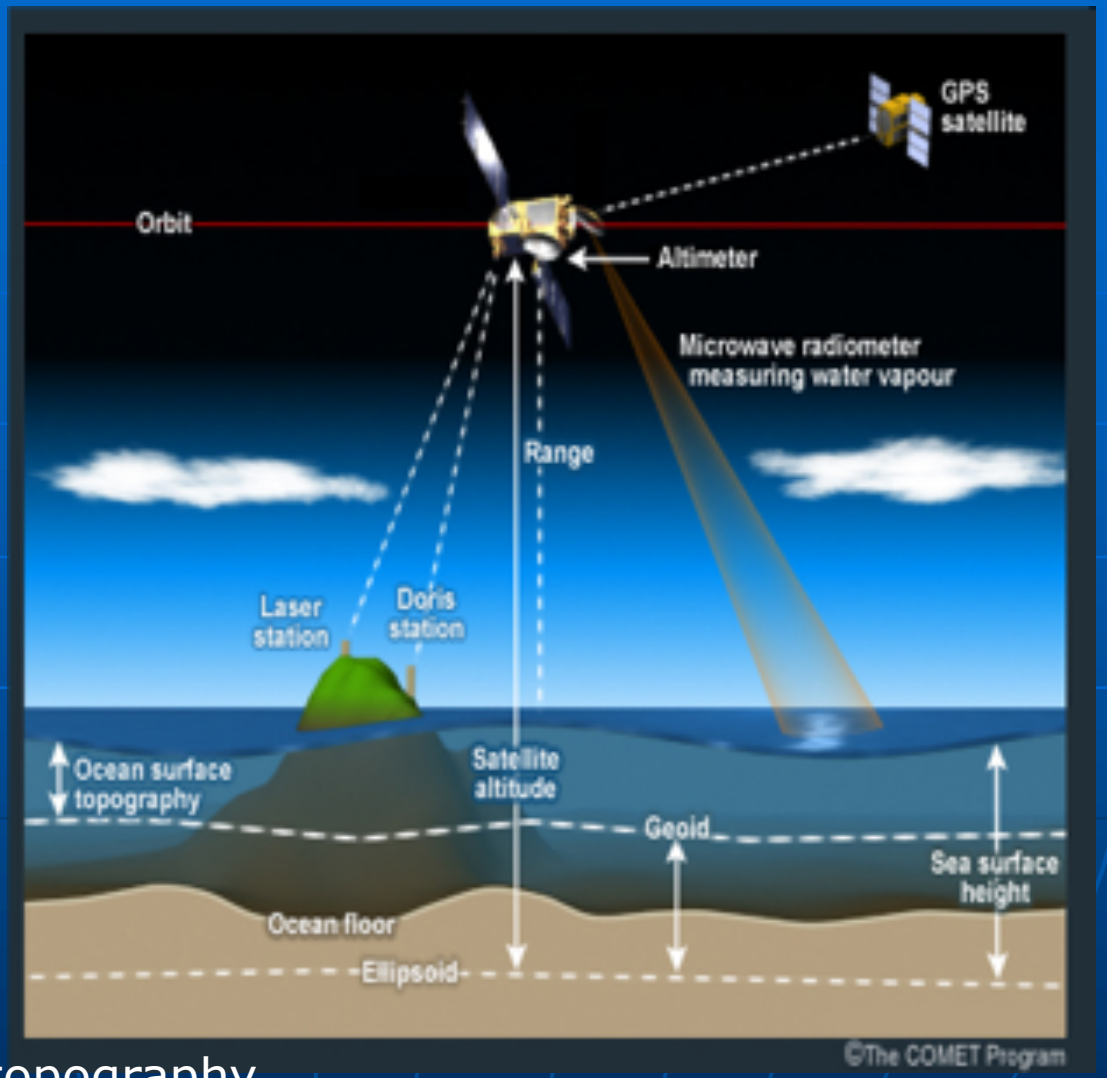
Forces affecting the shape of the earth: at sea what is not measured (temporal variations and beyond 10-6m/s2)



(From Chao (2000), modified by Andres, 2006)

To estimate mean sea level in deep oceans and up to prox 50 km from coasts

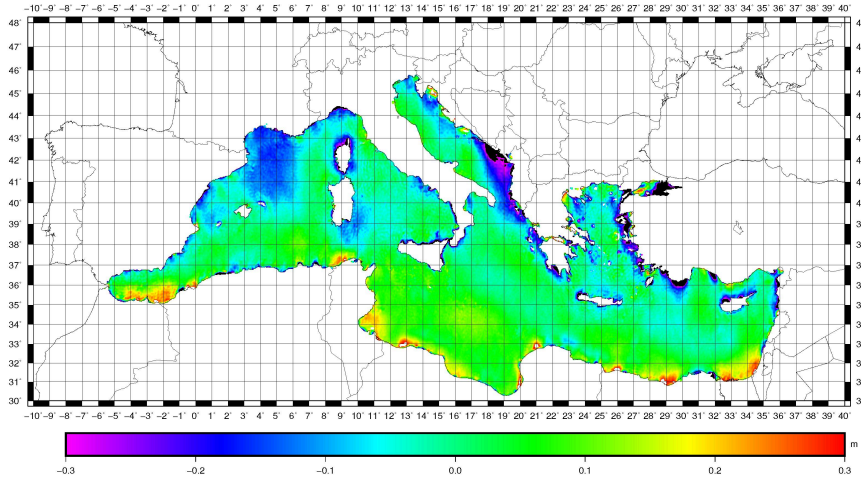
MSS = GeoidH + MDT



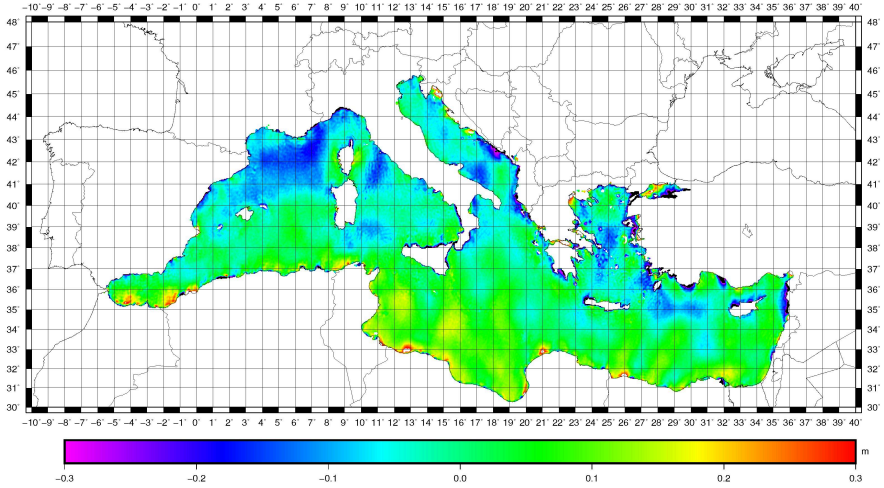
MDT= Mean Dynamic topography
MSS = Mean Sea level

The DTU15 MSS in the Mediterranean Sea vs geoid models (from Barzhagi et al., 2015)

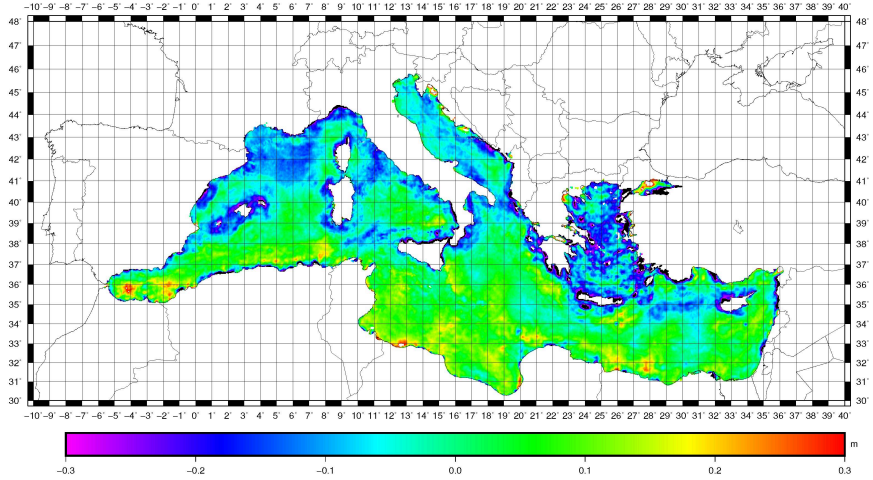
DTU15 – EGM2008



DTU15 – EIGEN_6C4



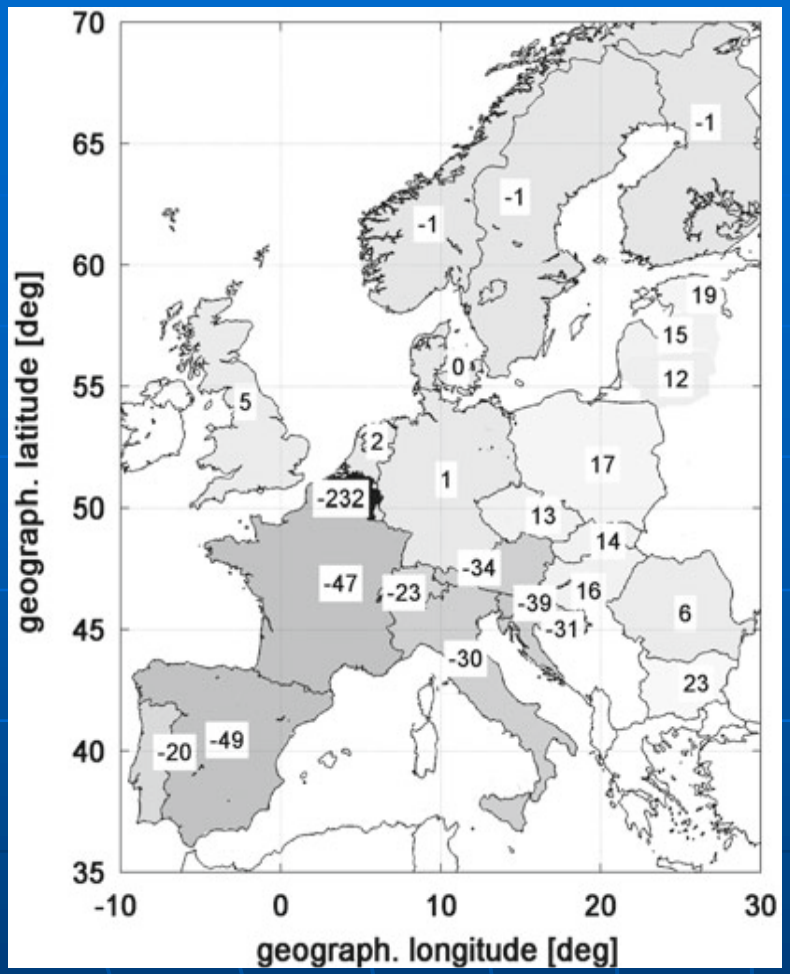
DTU15 – FFT_WG



	δ(EGM08)	δ(EIGEN)	δ(FFT-WG)
n	230682	230682	230682
E(m)	-0.001	0.000	-0.012
σ(m)	0.095	0.085	0.108
m(m)	-1.531	-1.354	-1.551
M(m)	0.835	0.934	1.047

Height reference disparities

sur les continents.



De Gerlach et Rummel, 2013)

Sur les océans le problème est le même

Recommandations de l'OHI: TWG (bathyelli)

Cartographie Terre-Mer

Airborne laser
reference vertical : ITRS

Bathymetry
reference➔ Chart datum

Terrestrial topography
référence vertical: IGN69

Need to merge all references
ITRS to IGN69 and ZH to IGN69
Legal framework

In shallow waters : Various levels needs

Mean Sea Surface tide gauges

Mean sea surface satellite altimetry

Height zero level

Quasi geoid

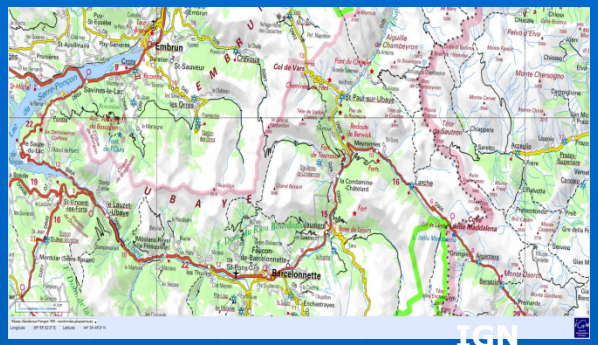
Geoid

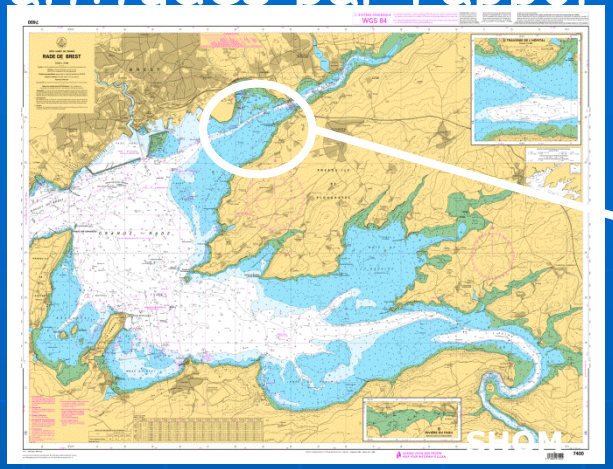
LAT: Low Astronomical Tides

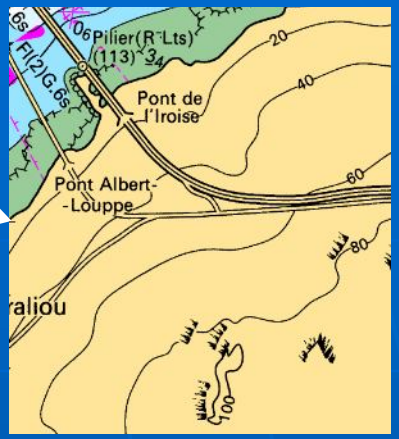
Hydrographic zero level

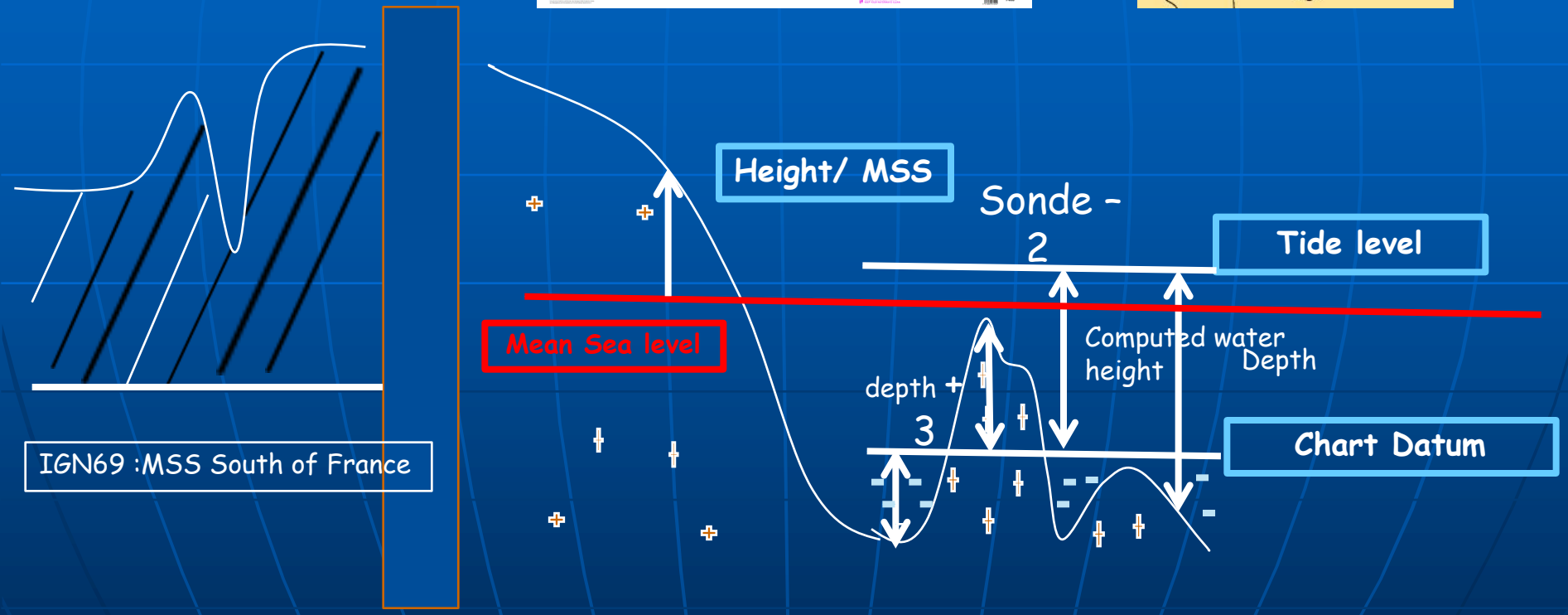
Ellipsoïde ITRS

Indications des altitudes par rapport au niveau moyen

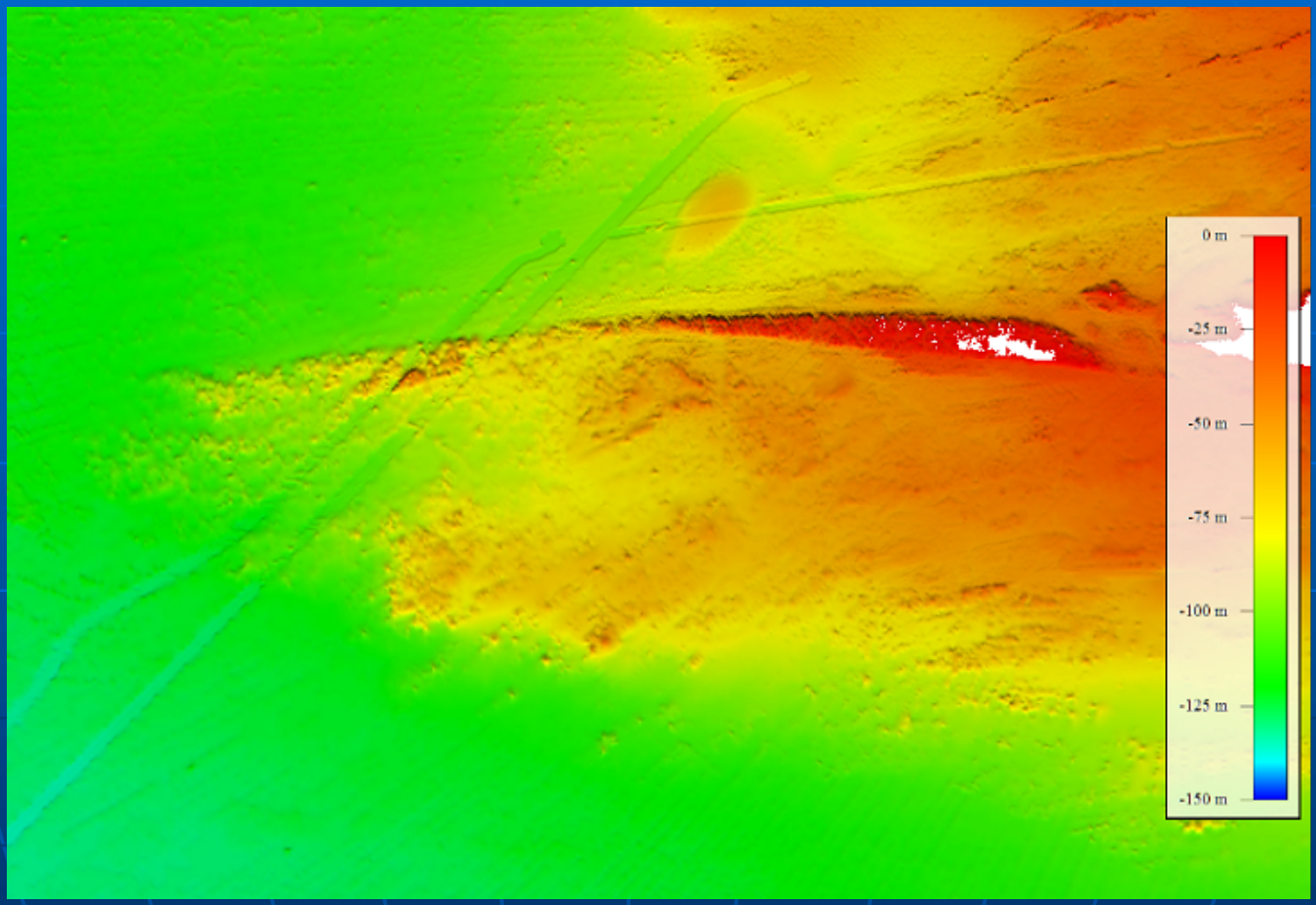


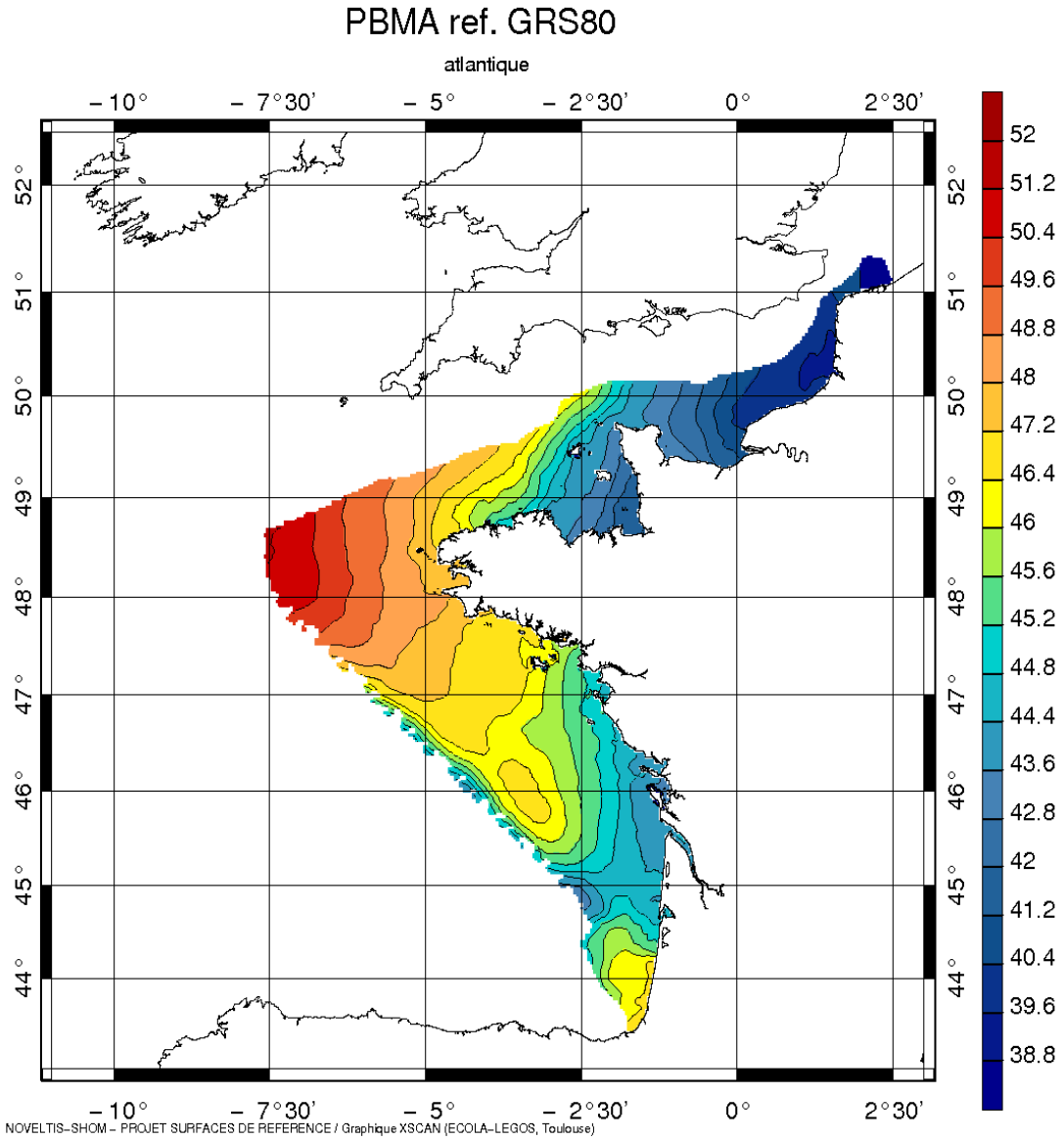






Map of geologic structure du to reference errors



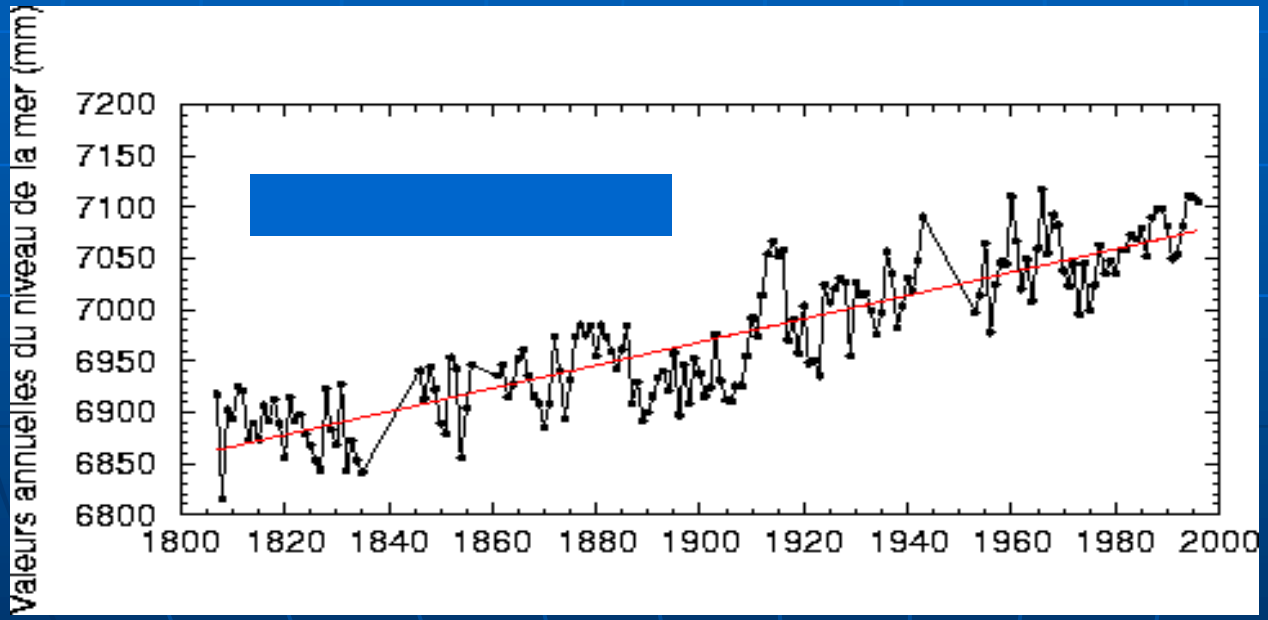


Goal for bathymetry:

LAT/ITRS ellipsoid
A continuous surface
(From Pineau et al., 2011)

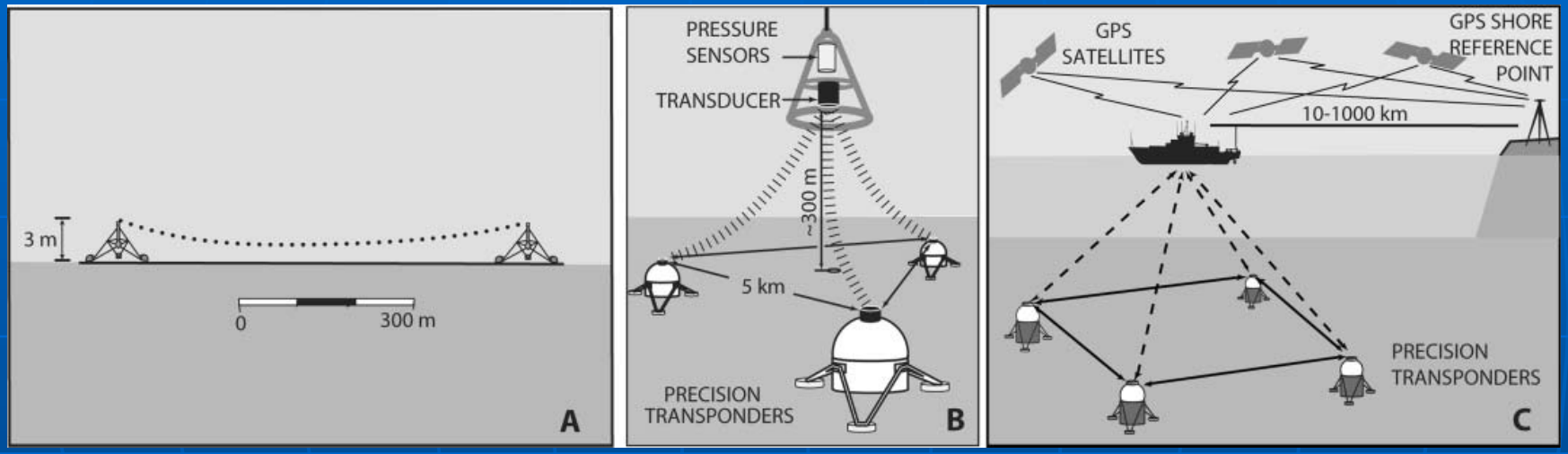
Absolute reference needed

The tide gauges record the elevation of the sea level



Examples of deep geodesy

positioning system on the sea bottom: geodynamic objective, tracking of devices (AUV, exploration submarines, etc.).

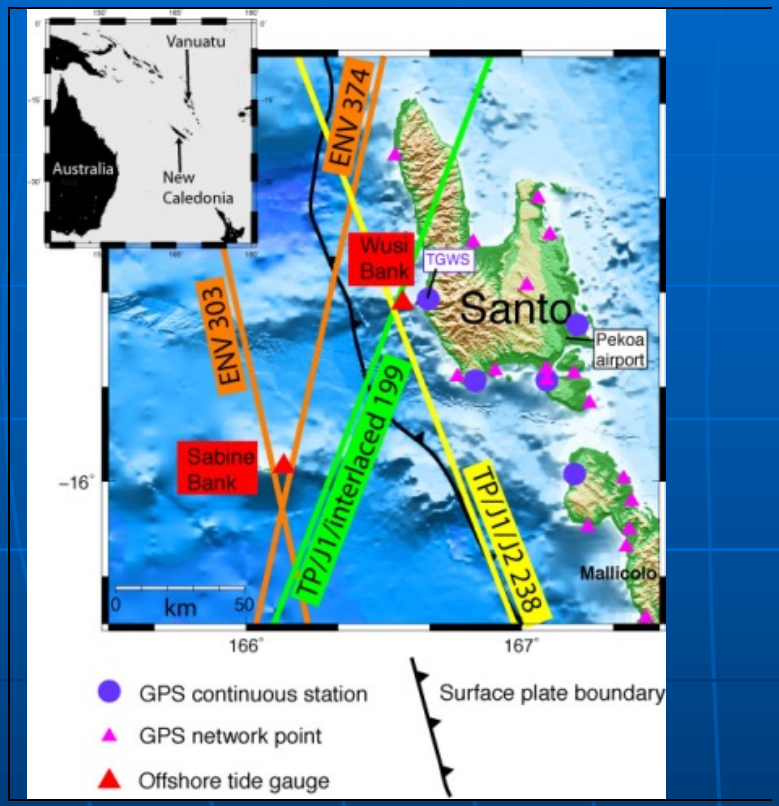


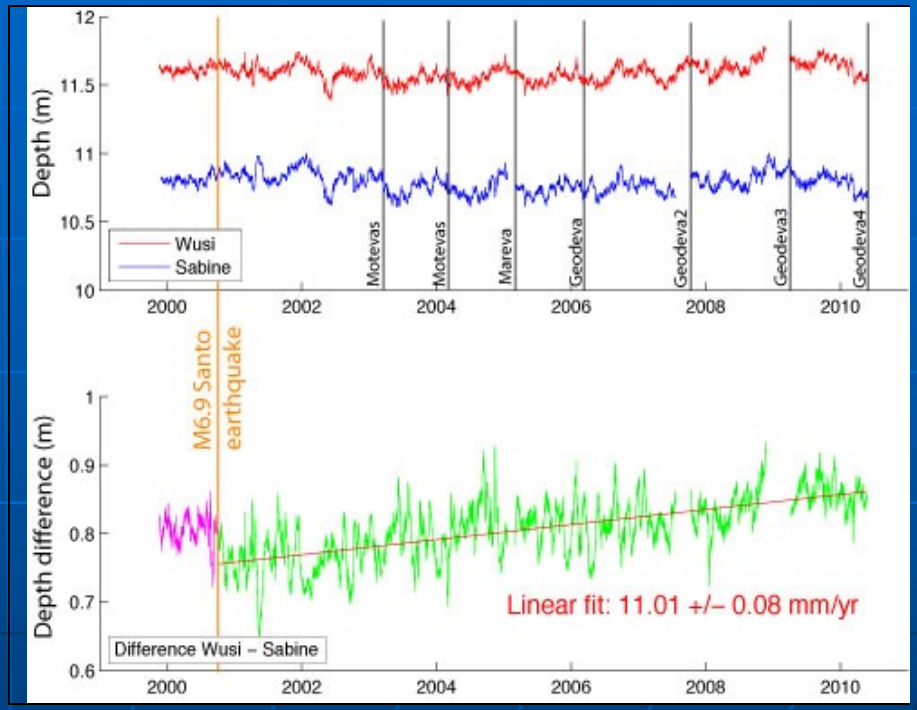
Principe

(Chadwell and sweeney, 2010)

Tectonic uses : plate movement

Ballu et al., 2010)





Geodesy has to be improve

- Relief of the oceans = bathymetry

- Nautical charts for navigation purposes locally accurate → international reference on going
- Coastal areas → known but references are often locally computed
- Deep areas and offshore → depending of the measurement effort

  hydrographic use→ 3000m +/- 100m

  Is it sufficient to achieve the future goals ??

In deep ocean for the geophysical outcomes

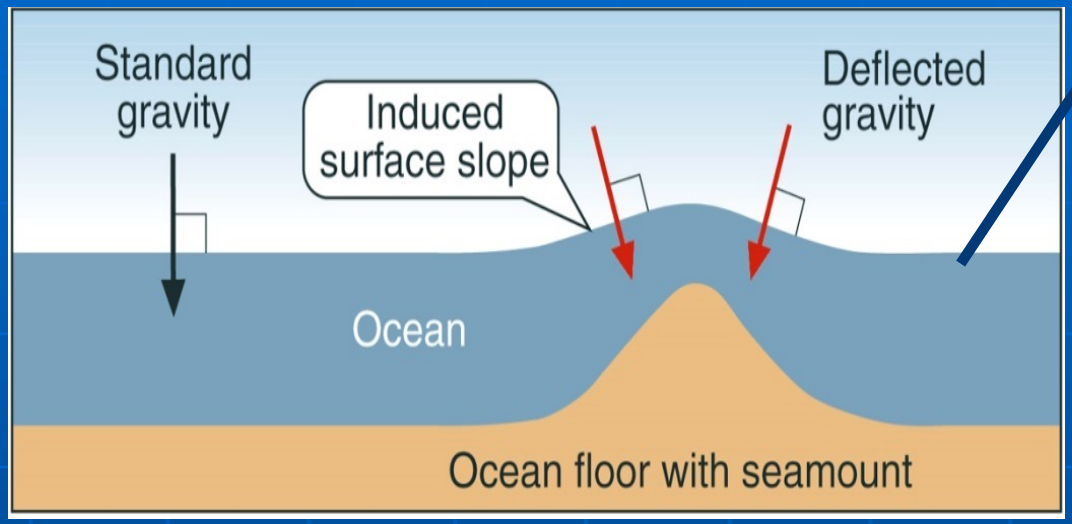


Figure : effects of a gravimetric anomaly

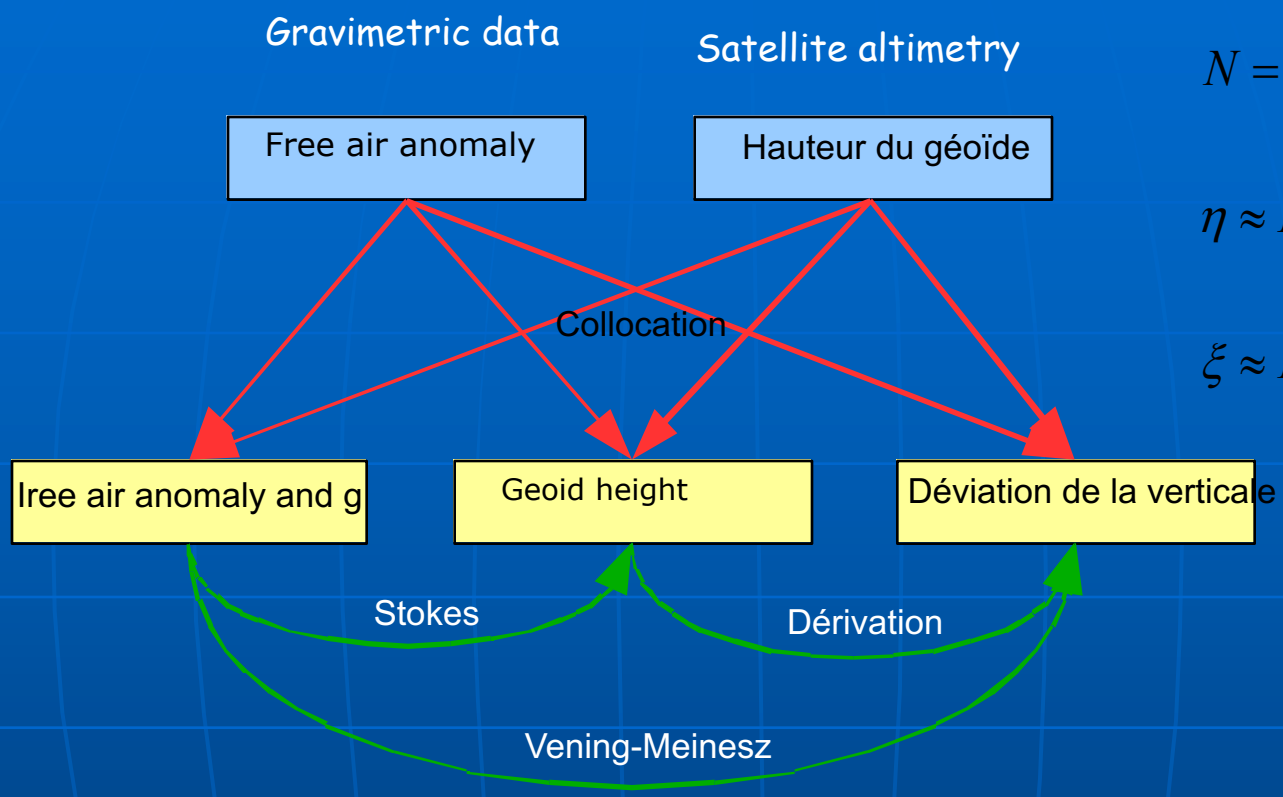
How to estimate g and geoid

$$\Delta g = L_{\Delta g}(T) = -\frac{\partial T}{\partial z} - 2\frac{T}{z}$$

$$N = L_N(T) = \frac{T}{\gamma}$$

$$\eta \approx L_\eta(T) = -\frac{1}{\gamma}.\frac{\partial T}{\partial x}$$

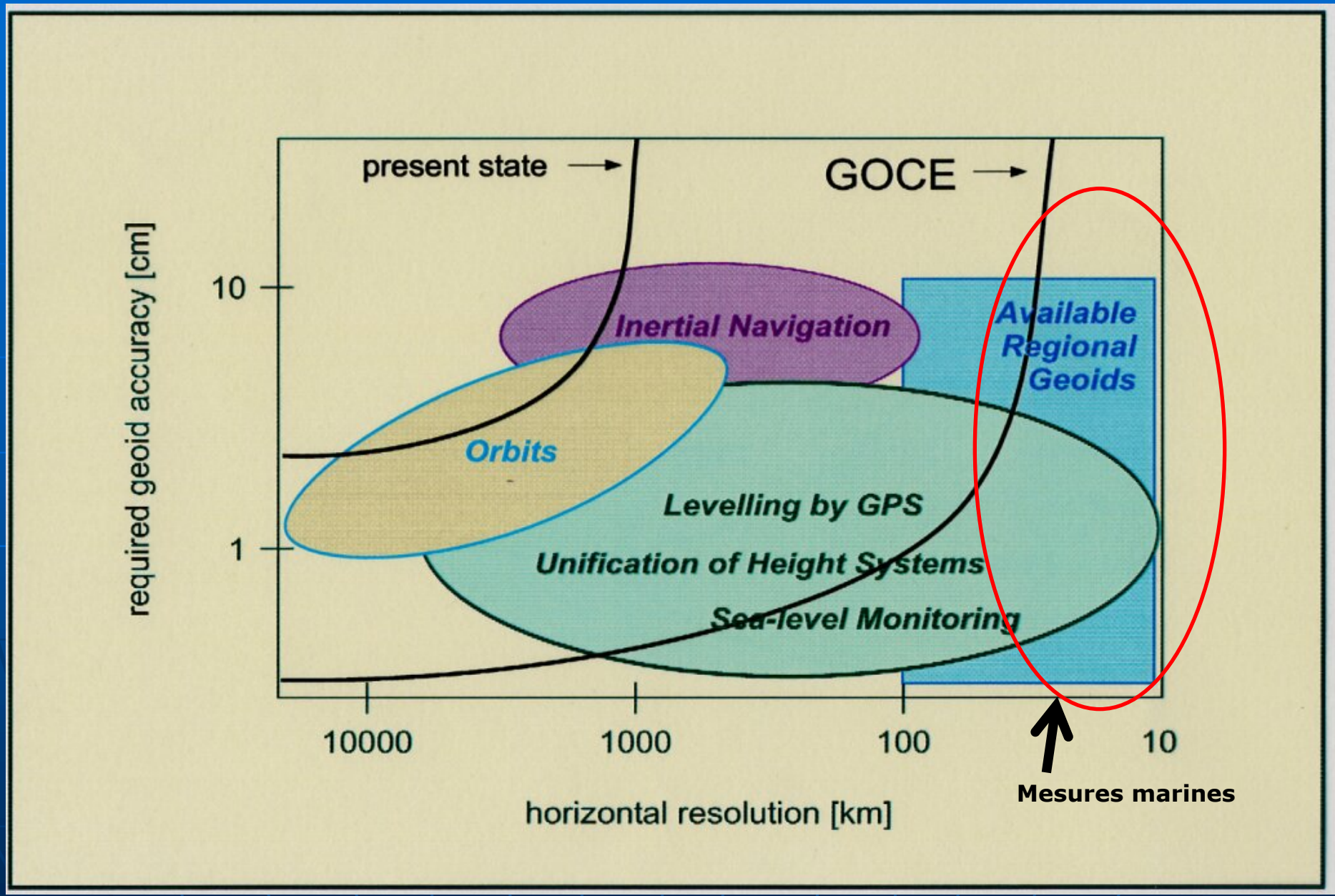
$$\xi \approx L_\xi(T) = -\frac{1}{\gamma}.\frac{\partial T}{\partial y}$$



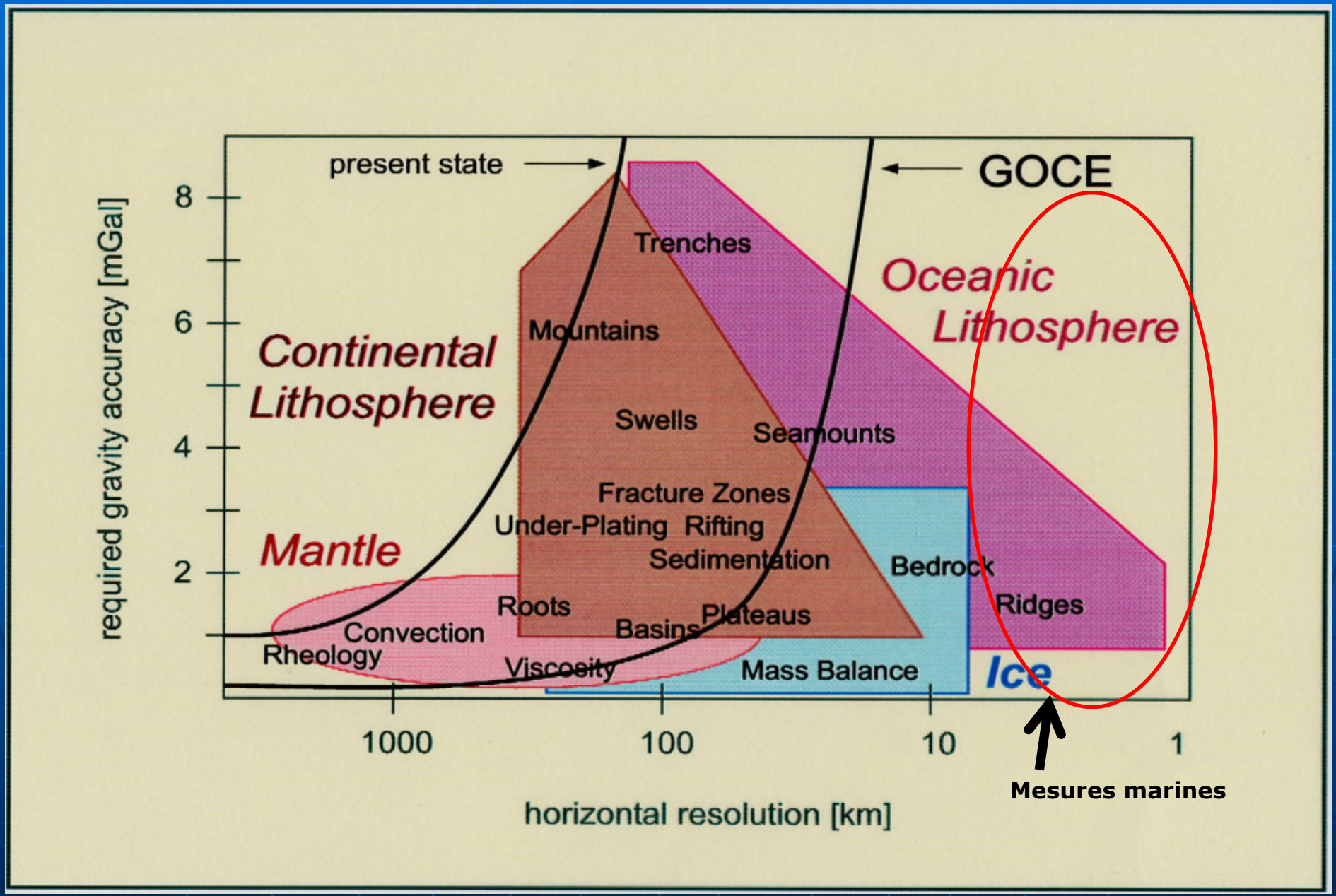
+ Techniques en Harmoniques Sphériques incluent les mesures d'orbitographie

En vert: méthodes intégrales ou dérivation
En rouge: Estimation statistique par collocation

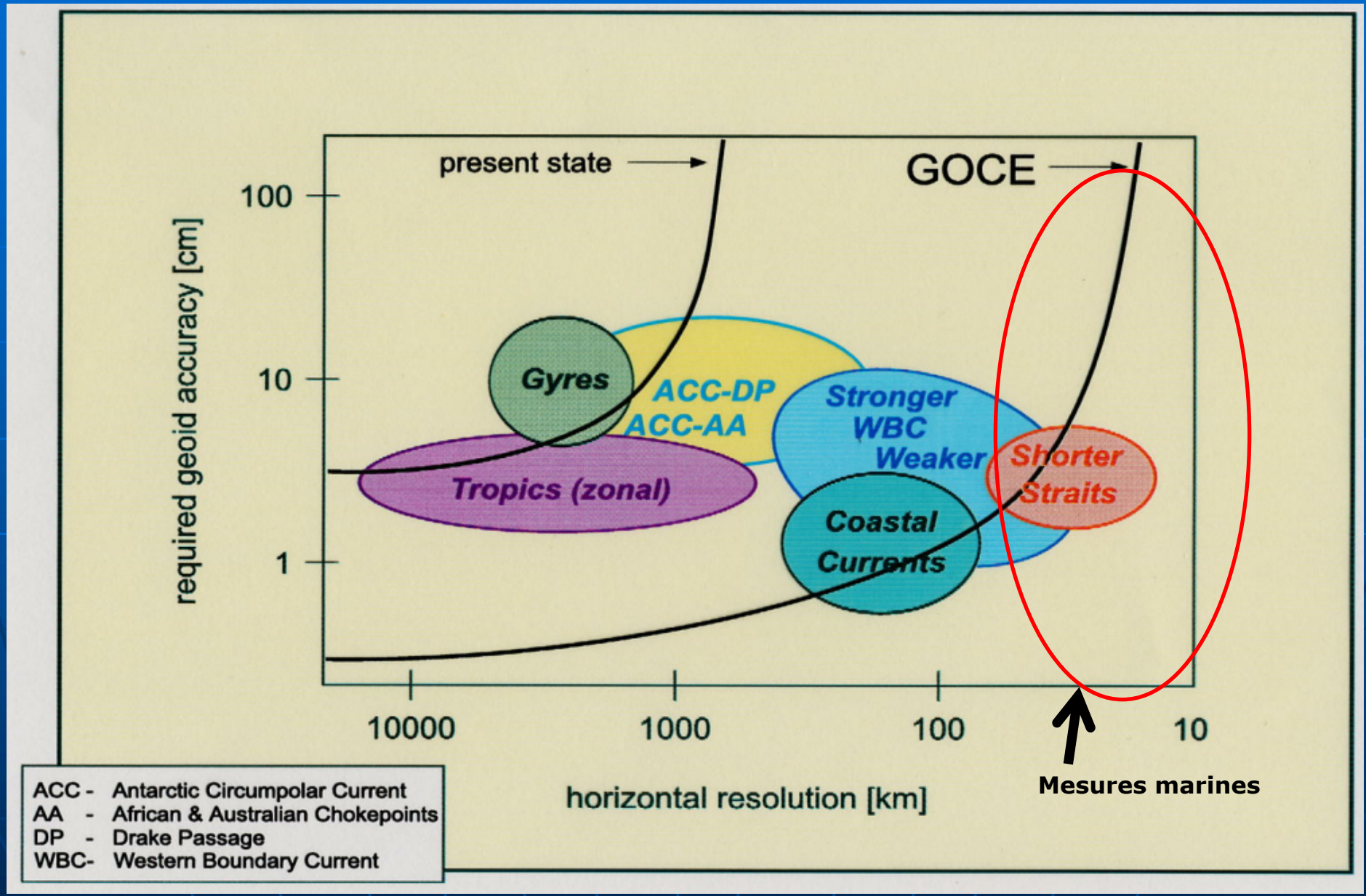
Geoid : Performances needed for geodesy



Gravité : Performances désirées en Géophysique vs. état actuel et vs. GOCE



Geoid : needed Performances in Oceanography



the oceans and seas ➔ 70% of the earth Surface
But no accurate global knowledge

- **knowledge of g :** gravity field by relative measurements or remote

- We are going to absolute g measurement by cold atom gravimeter On ship ==> 10^{-6} m/s2 (Bidel and al., Nat comm, 2017)

- On tide gauges ➔ absolute measurement of g 10 $^{-8}$ m/S^2

- **Knowledge of disturbing potential**

- Limitations of the accuracy by sensor support (ship, submarine, airborne)

- **Chronometric geodesy ➔** levelling tide gauges

- Is it time for submarine clocks, fibre links at under sea observatories (MAR)

- And why not levelling the depth of the oceans? in economical areas