Mesures et évolution récente du niveau de la mer

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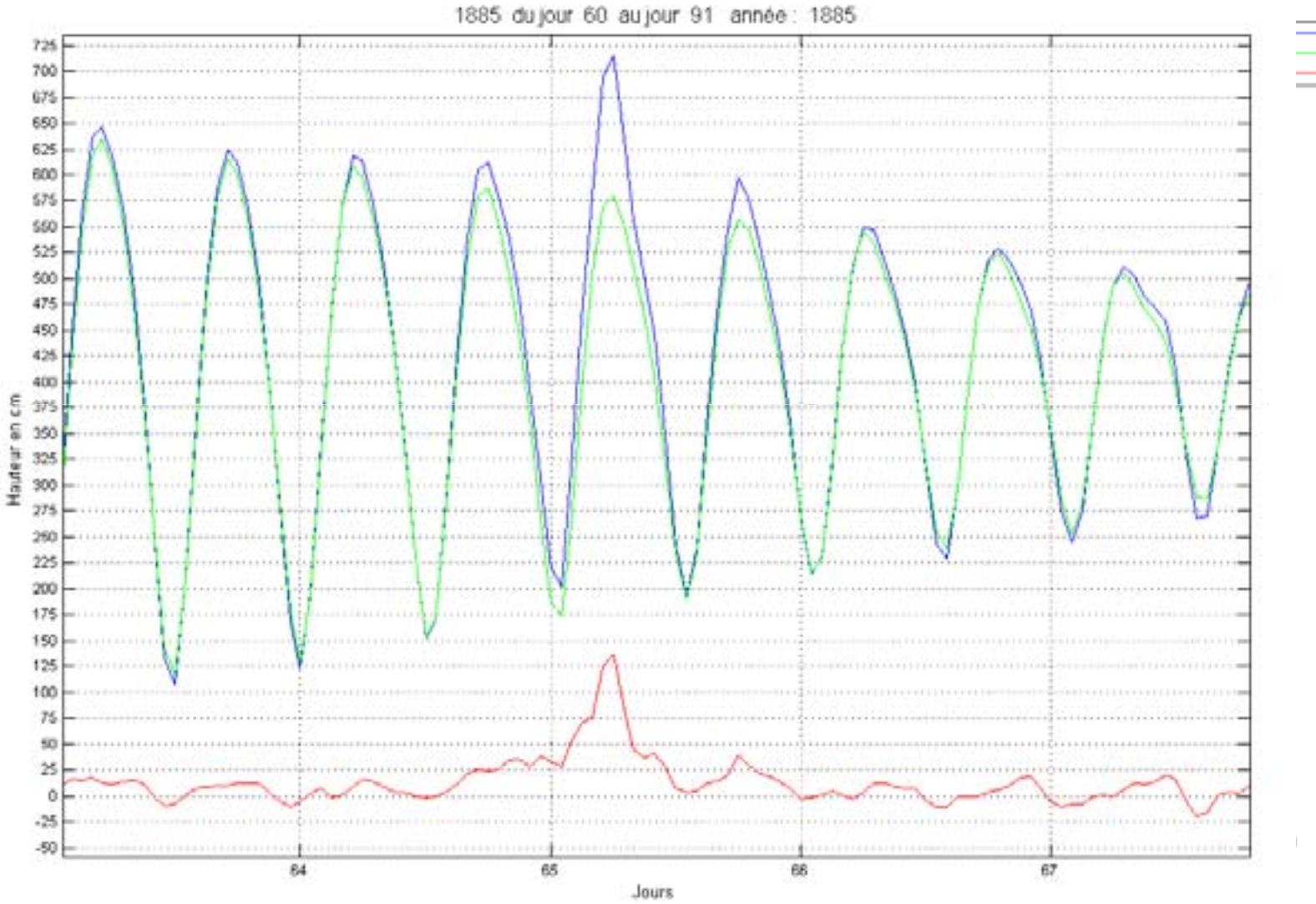
Plan:
1. Vers une définition de la problématique
2. Techniques et observations disponibles
3. Résultats, limites et incertitudes

Colloque « Les littoraux à l'heure du changement climatique »
18 Novembre 2010, Rochefort

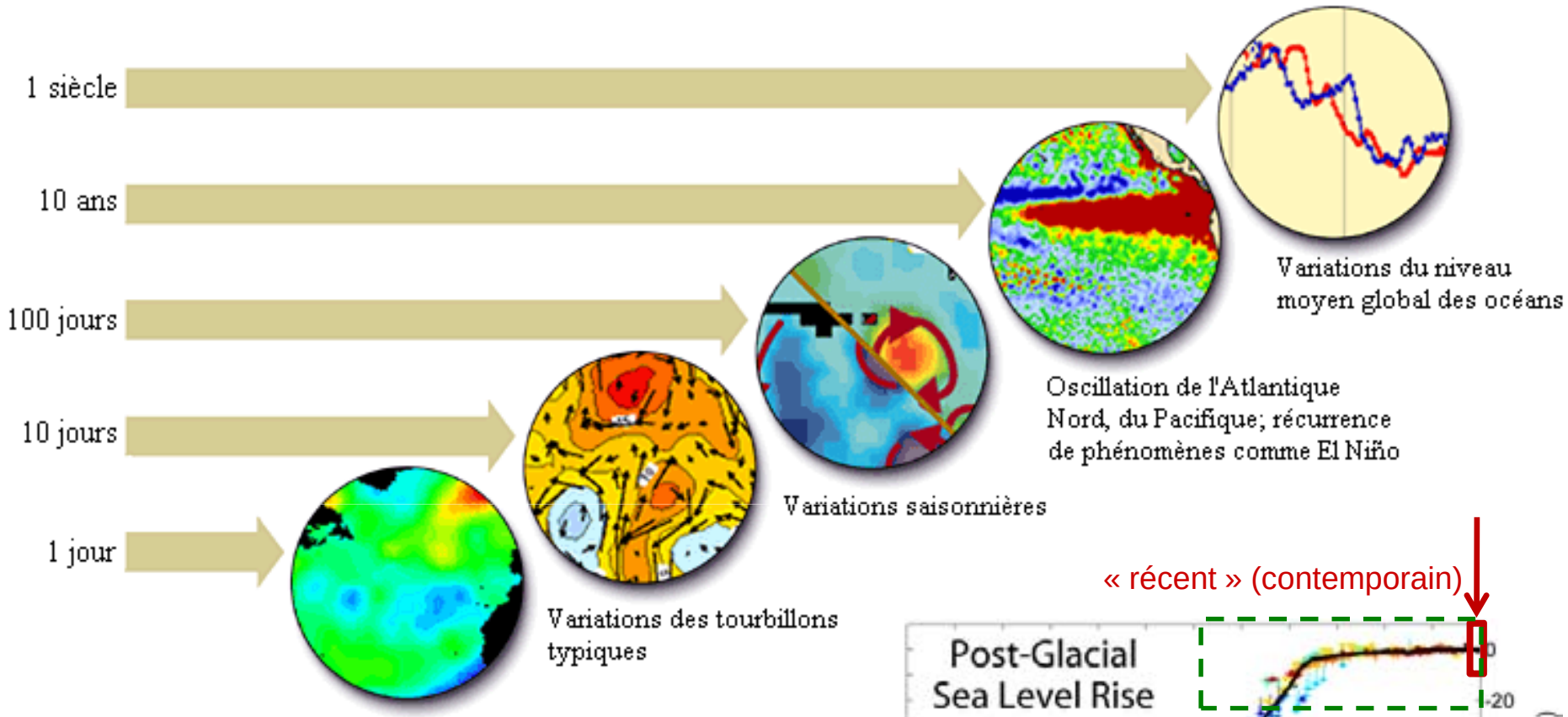
1. Vers une définition de la problématique

« Mais alors, elle monte ou pas ?... »

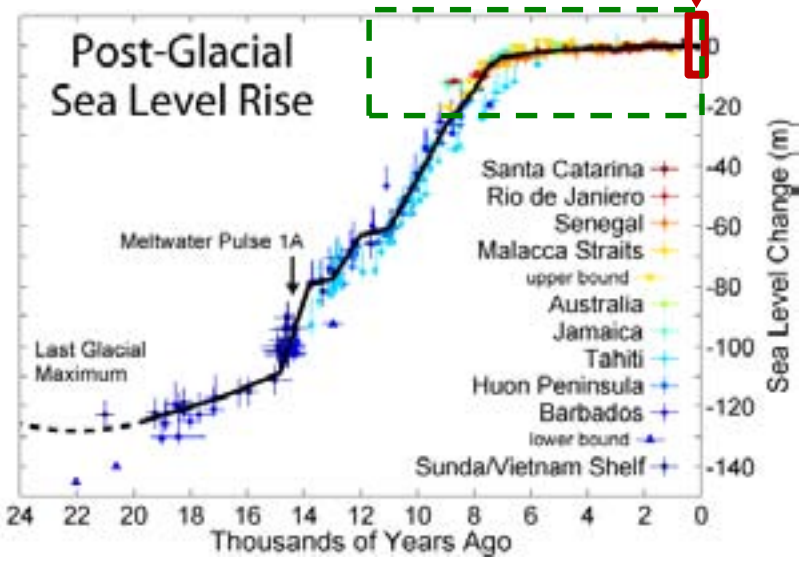
http://www.sonel.org/-Maregraphes-.html



Variabilité temporelle

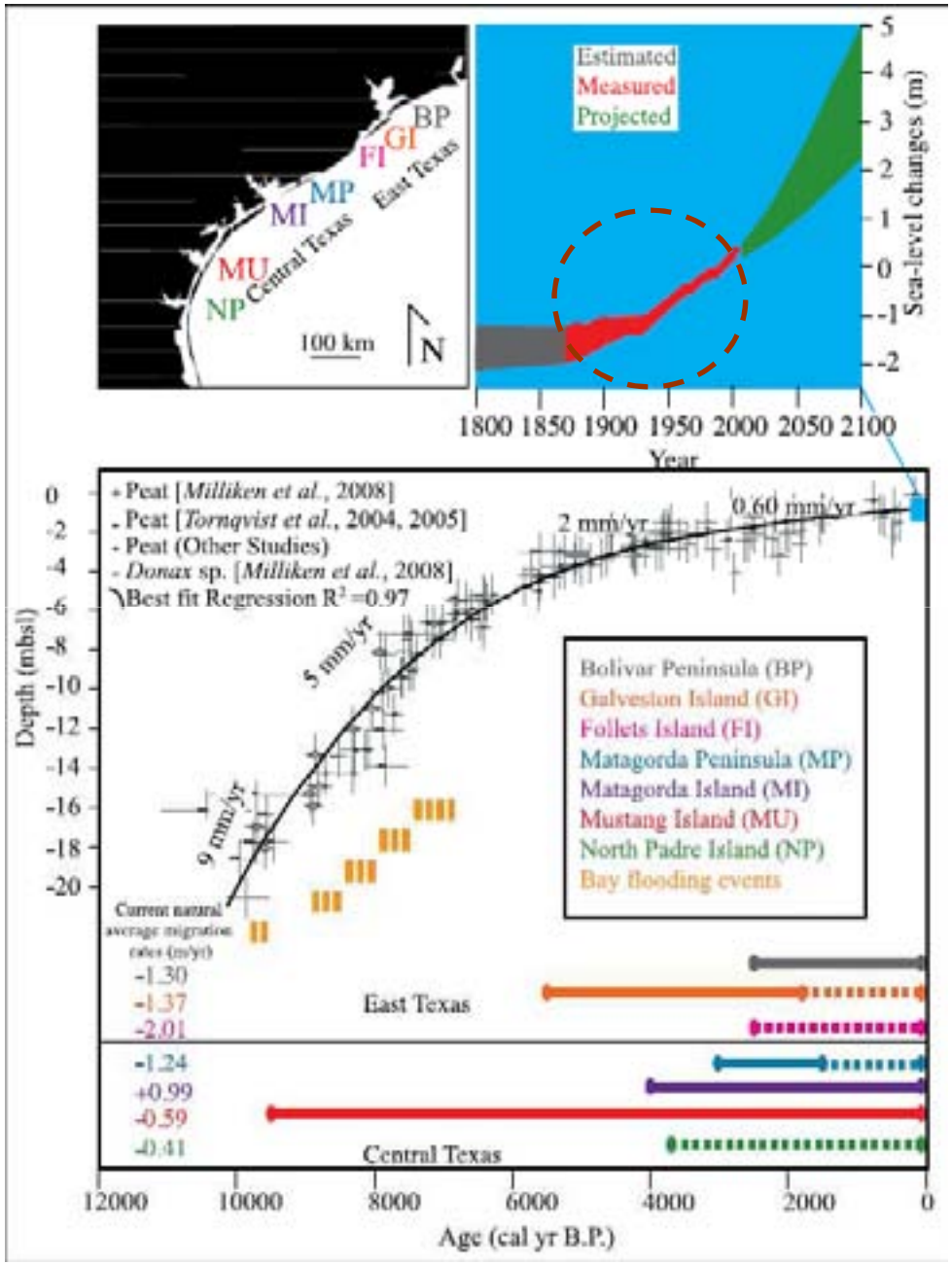


« récent » (contemporain)



Le passé plus lointain…

Ordres de grandeur…



Anderson et al. (2010)

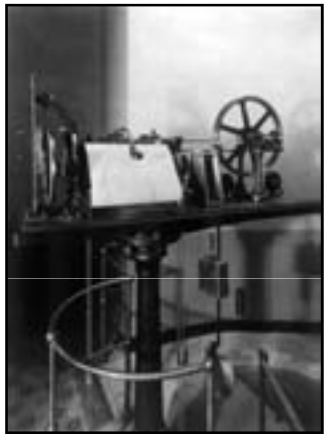
2. Comment observe-t-on?

1679 — 1830 — 1960 — 1992 — 2010

Niveau de la mer relatif

ECHELLE DE MAREE

$1cm < \sigma < 3cm$



MAREGRAPHE

$5mm < \sigma < 1cm$

PRESSION

$5mm < \sigma < 1cm$

RADAR

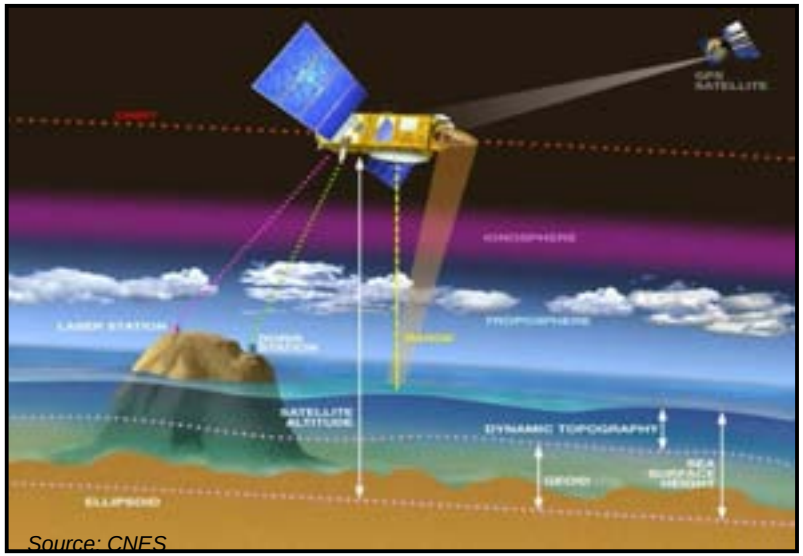
$1mm < \sigma < 5mm$

Bouée GPS

$? < \sigma < ?$

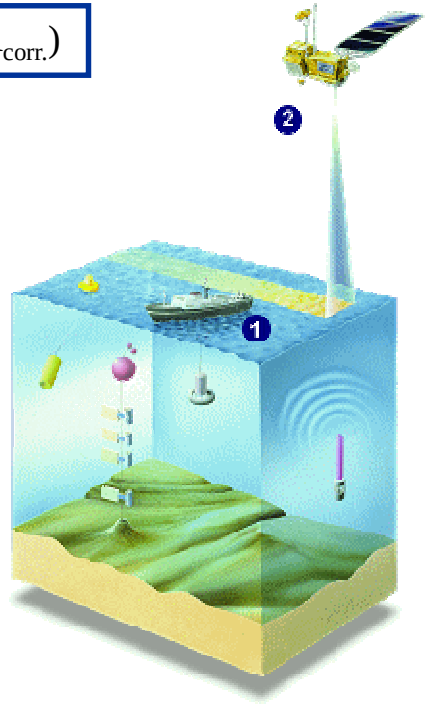
Martin Miguez et al. (2008)

Altimétrie radar embarquée sur satellite



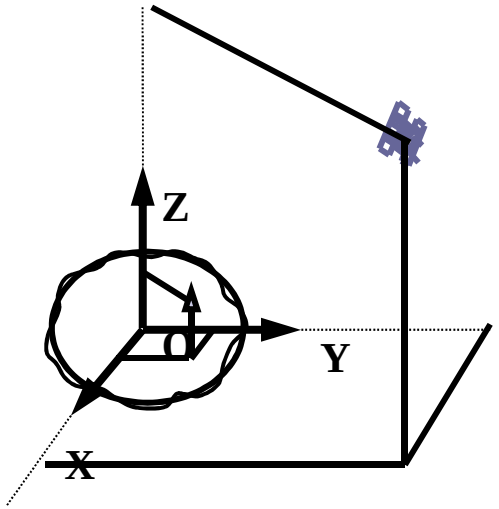
Source: CNES

$$h_{sea\text{-}level} = h_{sat.} - (R_{mes.} - \Delta R_{corr.})$$




Sputnik (4/10/1957)

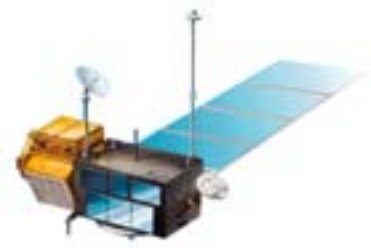
Satellites	Période
Skylab (navette)	1973
GEOS 3	1975 – 1978
SeaSat	1978 (3 mois)
GEOSAT	1985 – 1989
ERS-1	1991 – 1996
TOPEX-POSEIDON	1992 – 2005
ERS-2	1995 – 2003…
GFO	1998 – 2008
JASON-1	Déc. 2001 – …
ENVISAT	Mars 2002 – …
JASON-2	Juin 2008 – …



Bilan d'erreur des missions d'altimétrie spatiale

Centimètres

100
90
80
70
60
50
40
30
20
10
0



Erreur orbite
Erreur altimètre
Ionosphère
Troposphère
Biais EM

Signal océanique

GEOS 3
843 km
115°
Différents cycles de répétition

SEASAT
800 km
108°
3 jours

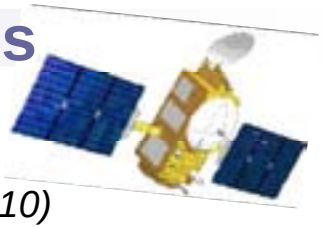
GEOSAT
800 km
108°
17 jours

ERS-1
780 km
98,5°
35 jours
(3/168)

T/P *(before launch)**(after launch)*
T/P
1336 km
66°
9,95 jours

Le Provost (2002)

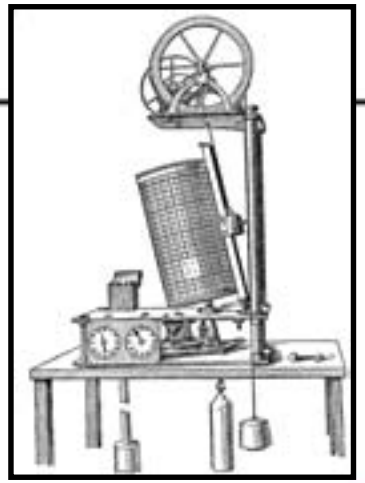
Évolution récente du niveau moyen des océans



Cazenave & Llovel (2010)

+3.4 ± 0.5 mm/an

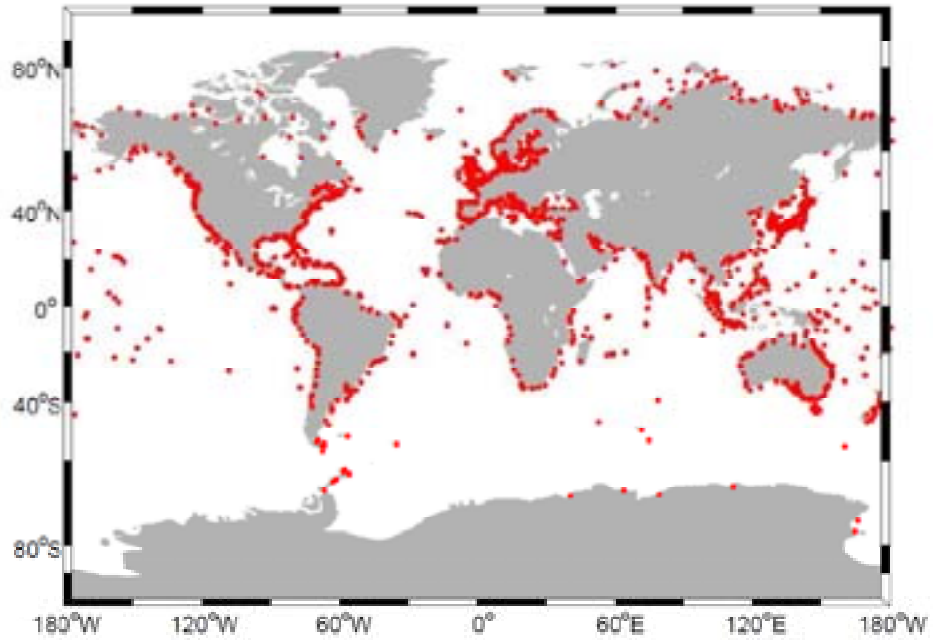
(1993-2009)



20^e s. ~17 cm soit +1.7 ± 0.3 mm/an

Church & White (2006)

Variabilité temporelle: une illustration



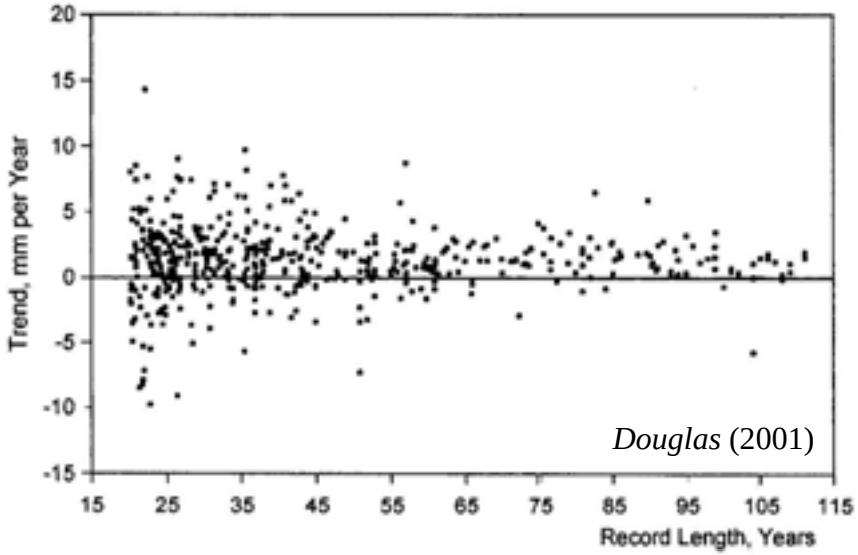
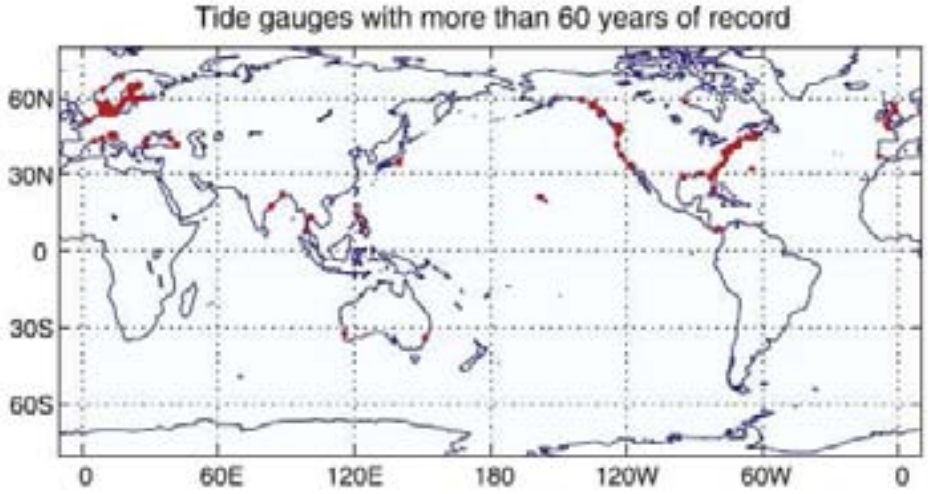


Figure 3.11 RLR-site sea level trends corrected for glacial isostatic adjustment.



- Geographical sampling of appropriate tide gauge records:
  - → Non uniform coverage of long-term tide gauge records
  - → **Northern hemisphere coastal sea-level change…**

Variabilité spatiale

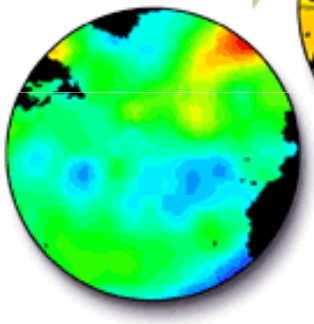
Global (40000 km) : Variations du niveau moyen

10000 km

1000 km

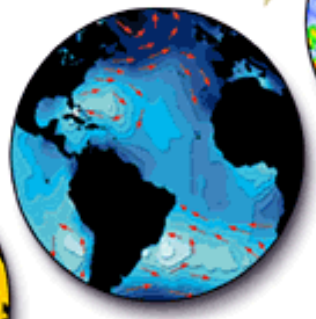
100 km

10 km

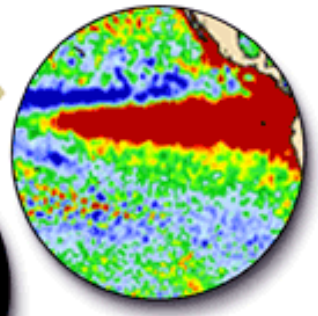


Vagues, cyclones, tempêtes.

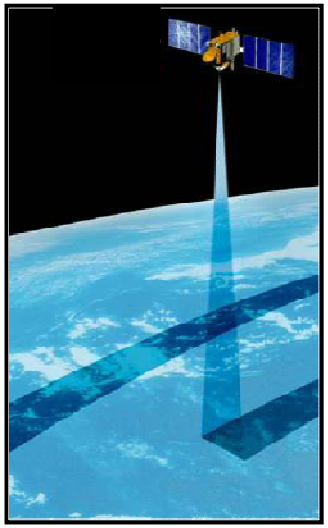
Tourbillons, marées

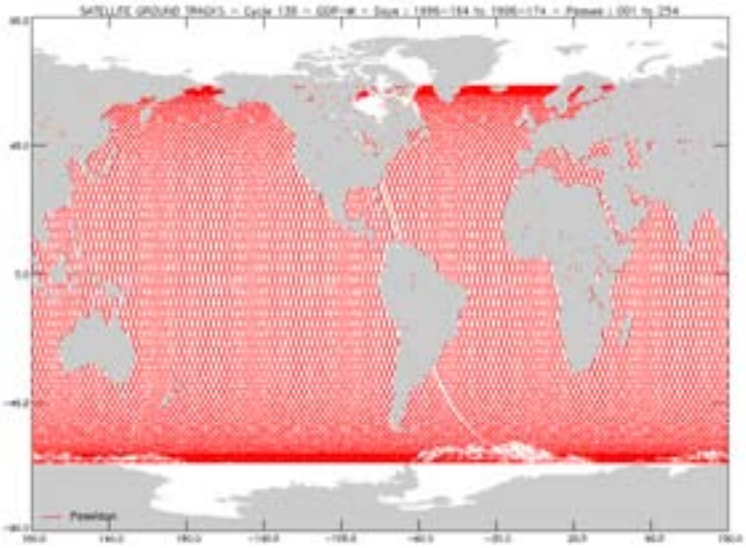


Grands courants
(Gulf Stream,...)

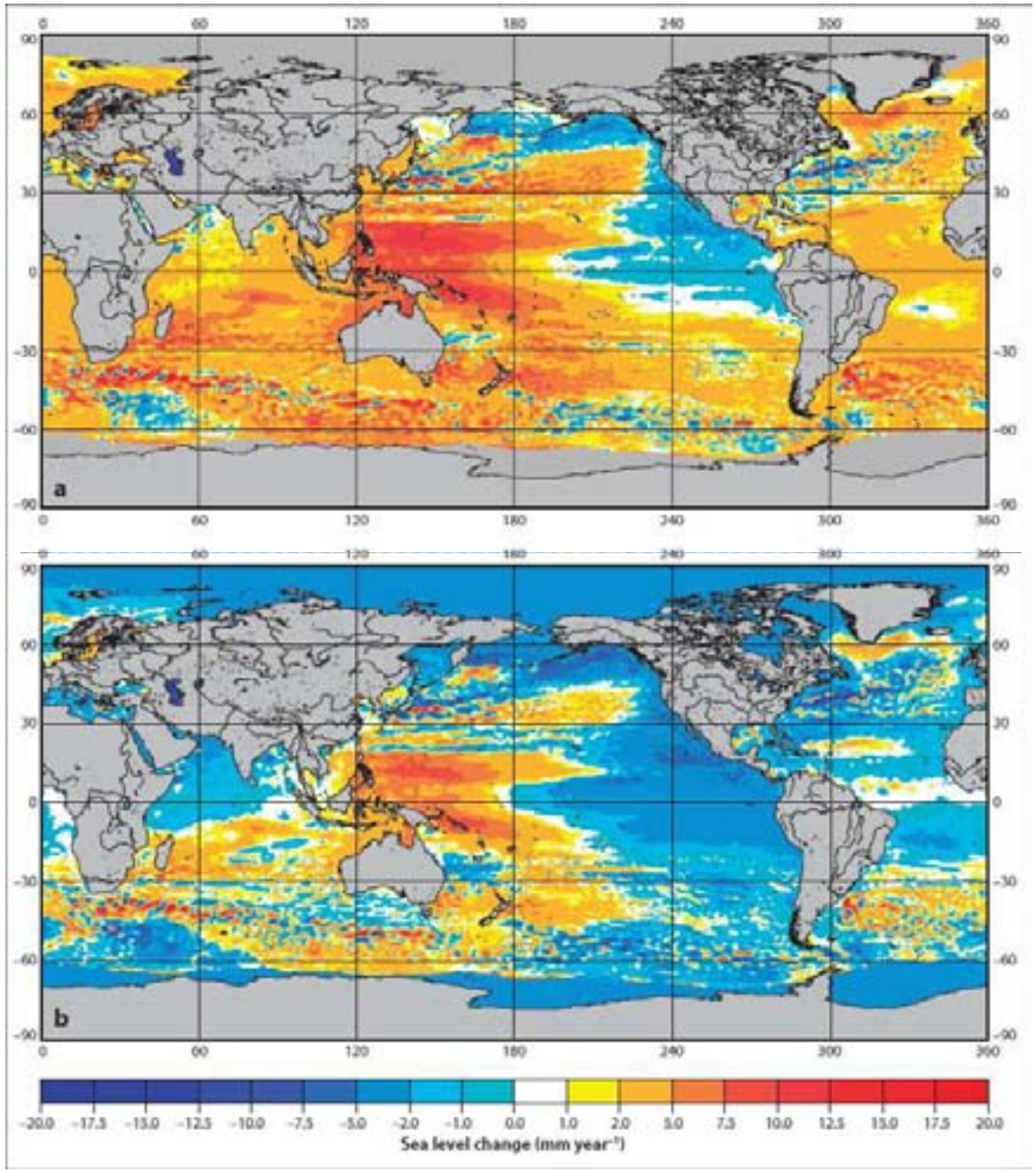


Oscillations des océans
(El Niño, oscillation décennale
du Pacifique, oscillation de
l'Atlantique Nord)





Distribution géographique des vitesses du niveau de la mer (1993-2008)

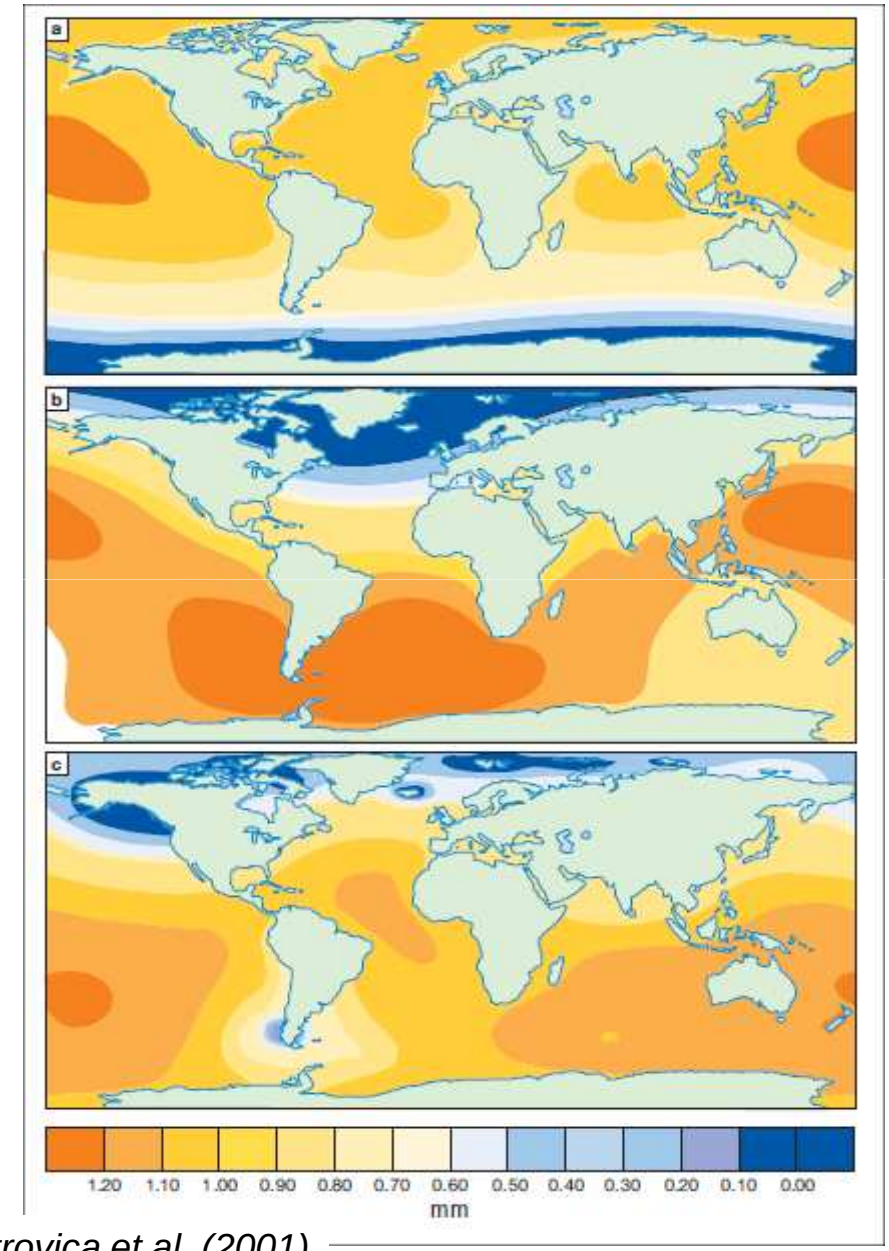


Idem que ci-dessus mais avec retrait d'une tendance globale et uniforme de 3.4 mm/an.

Cazenave & Llovel (2010)

Empreintes géographiques de la fonte des glaces

(The “fingerprint” issue)



Mitrovica et al. (2001)

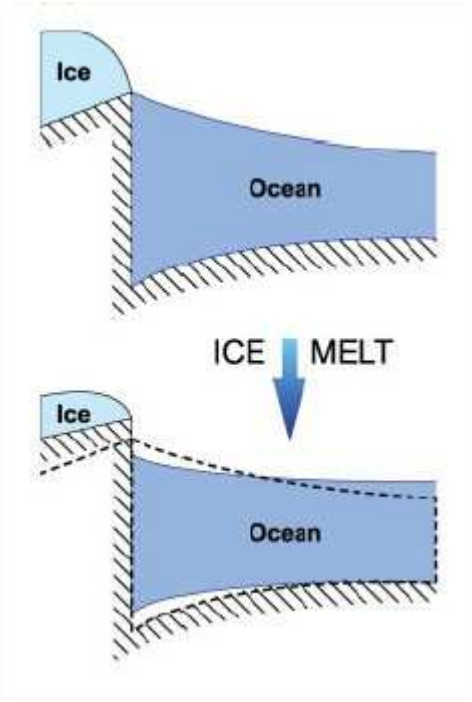


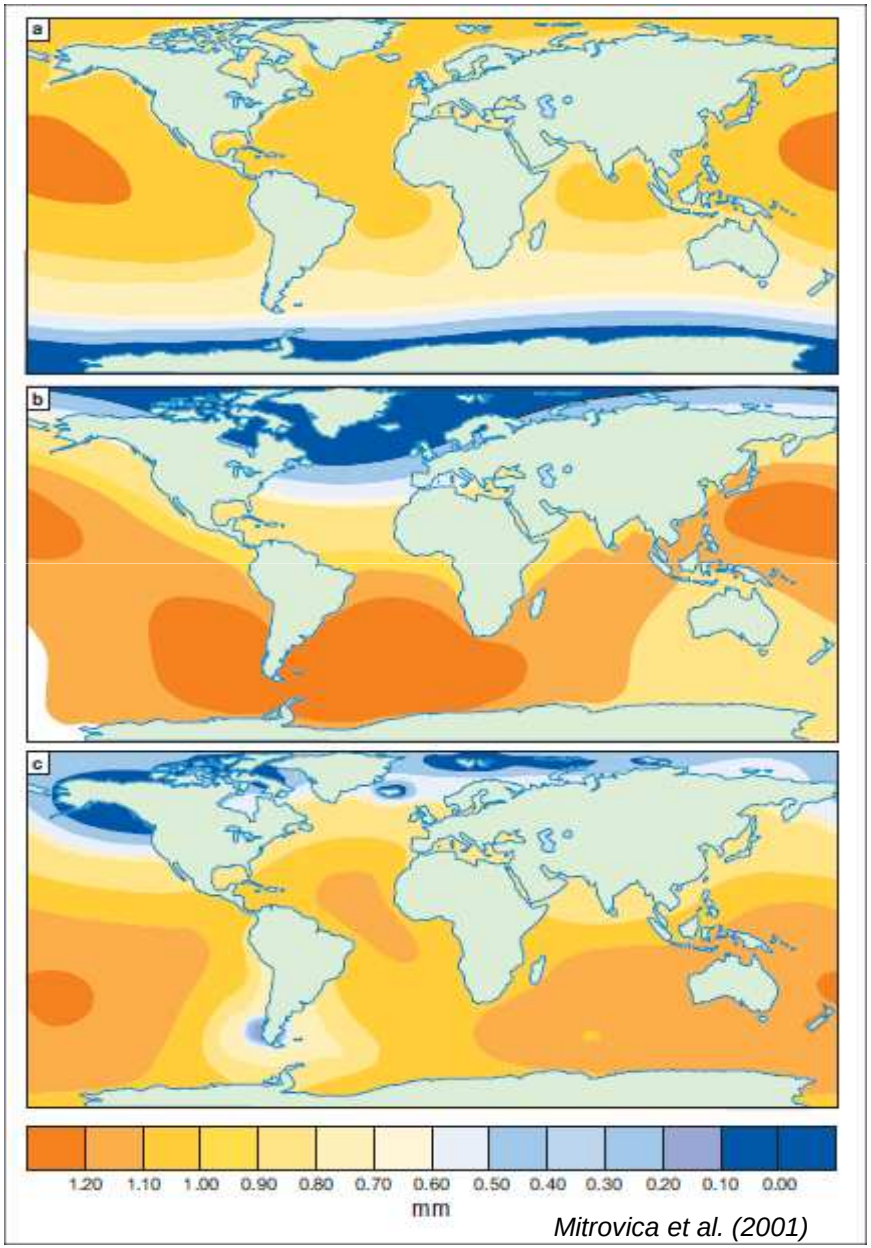
Illustration: fonte de l’équivalent de 1mm/an

a. Antarctique
b. Groenland
c. Glaciers de montagne

Projet CECILE (ANR)

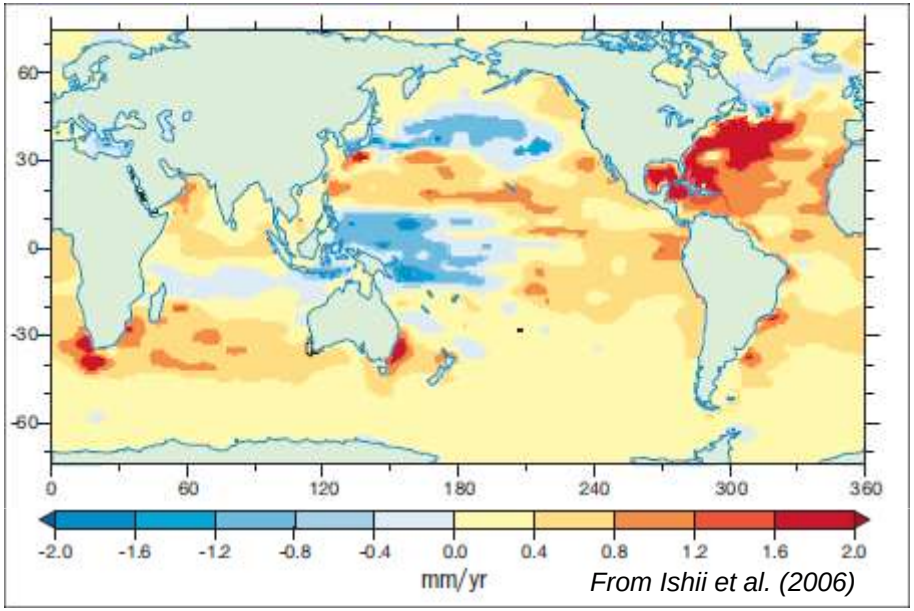
Évidences observationnelles des empreintes prédites par la théorie? (WP3)

Empreintes spatiales: évidence observationnelle?

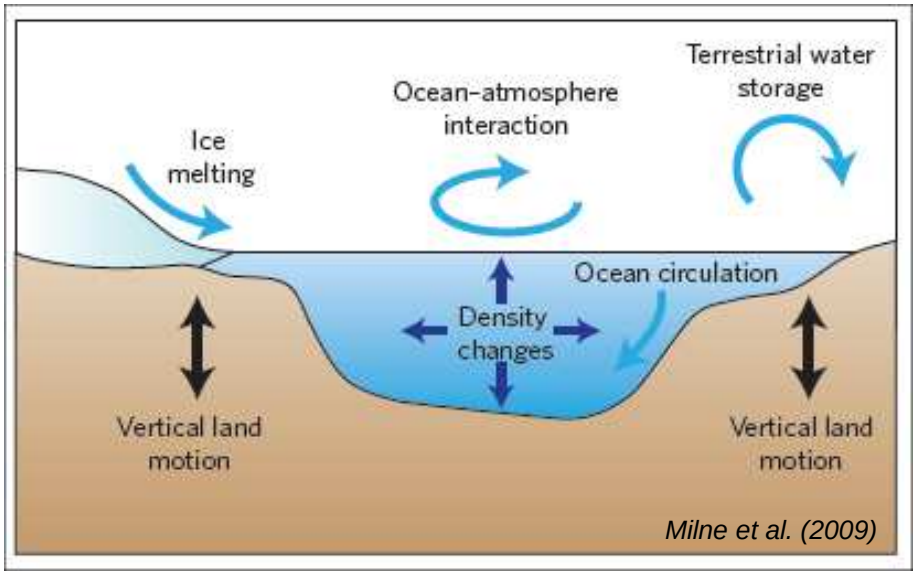


Mitrovica et al. (2001)

Une complexité accrue…

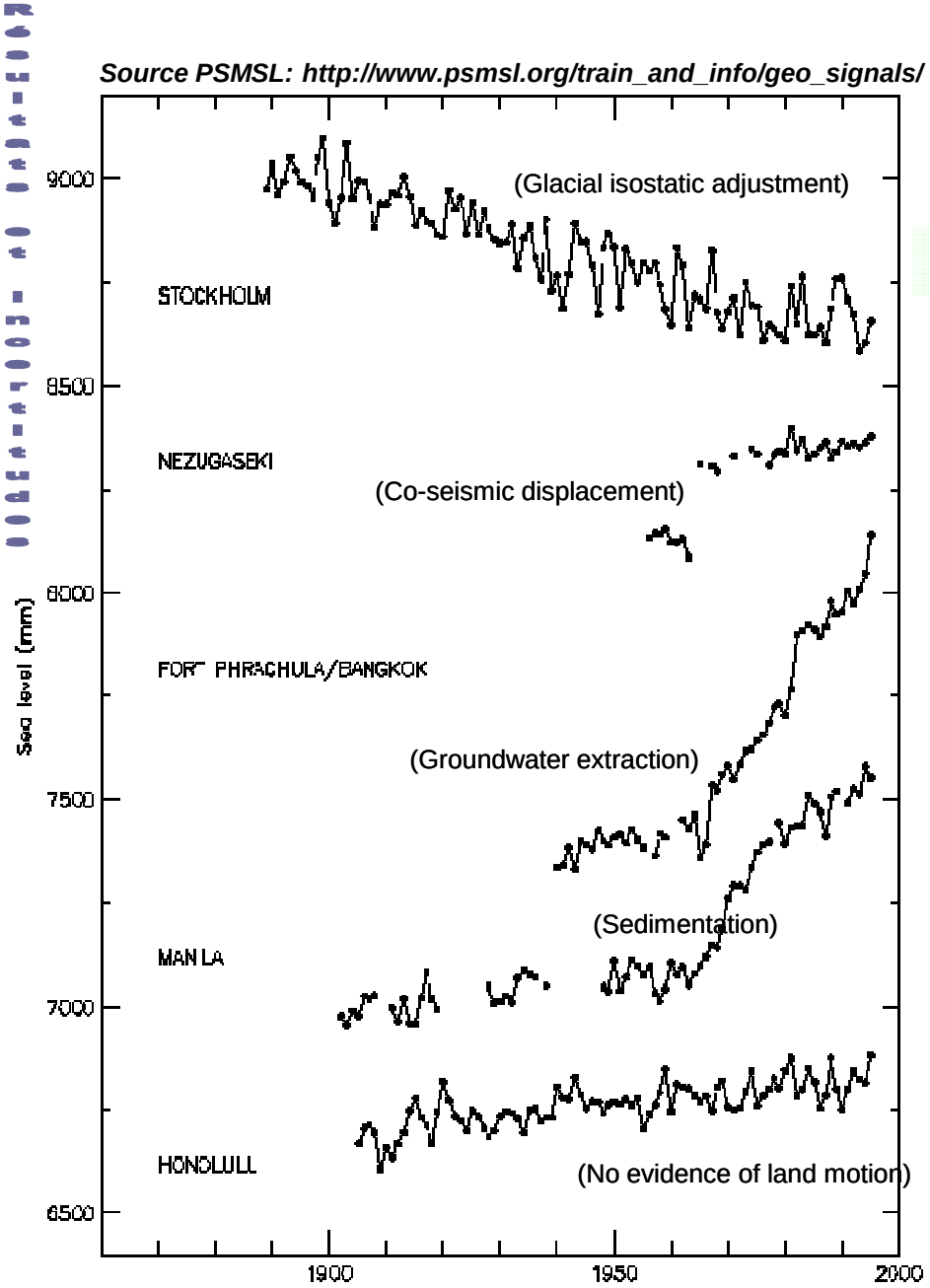


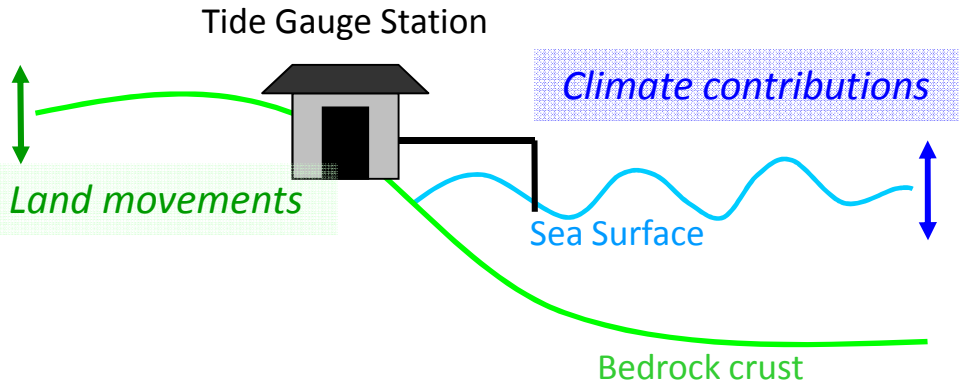
From Ishii et al. (2006)



Milne et al. (2009)

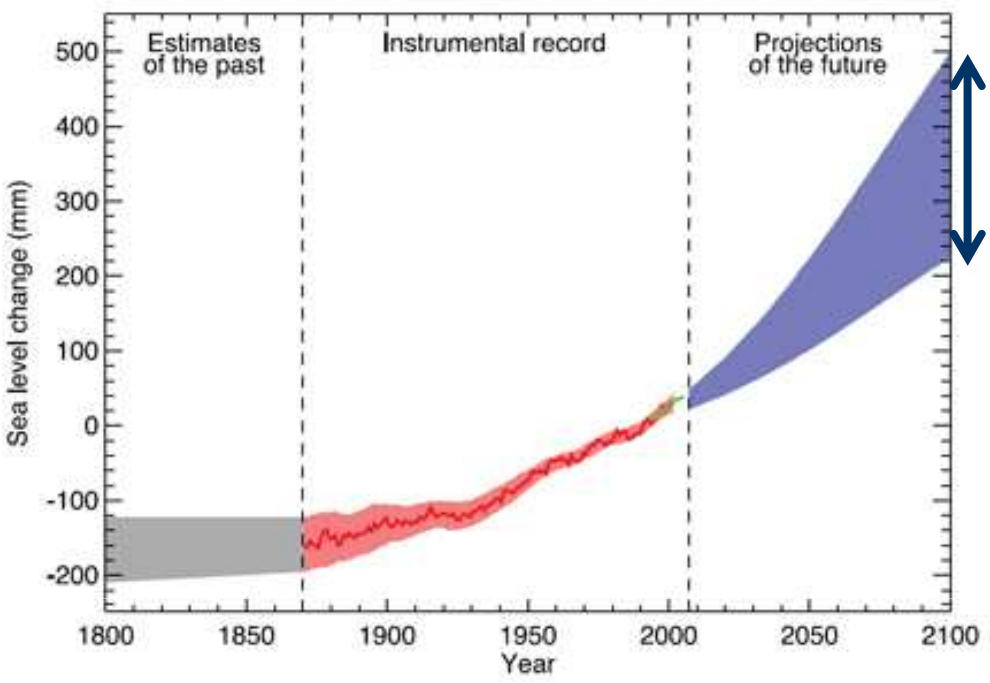
Empreintes spatiales: évidence observationnelle?





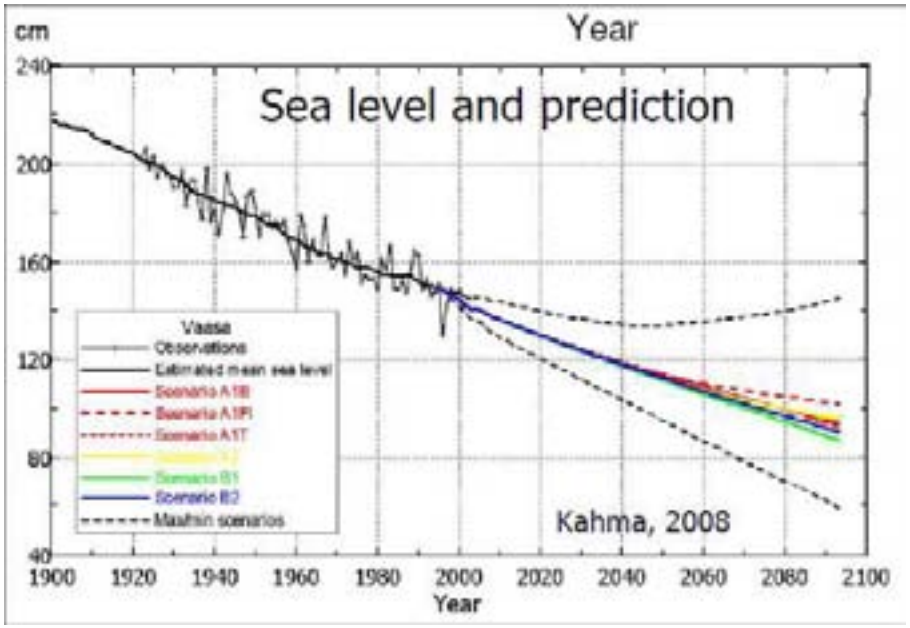
- Challenges
  - → Rates in sea-level change: ~1-2 mm/yr
  - → Standard errors several times smaller to be useful in those studies!
  - → Coastal management: climate sea level predictions + land movements

Prédictions (IPCC AR4, 2007)



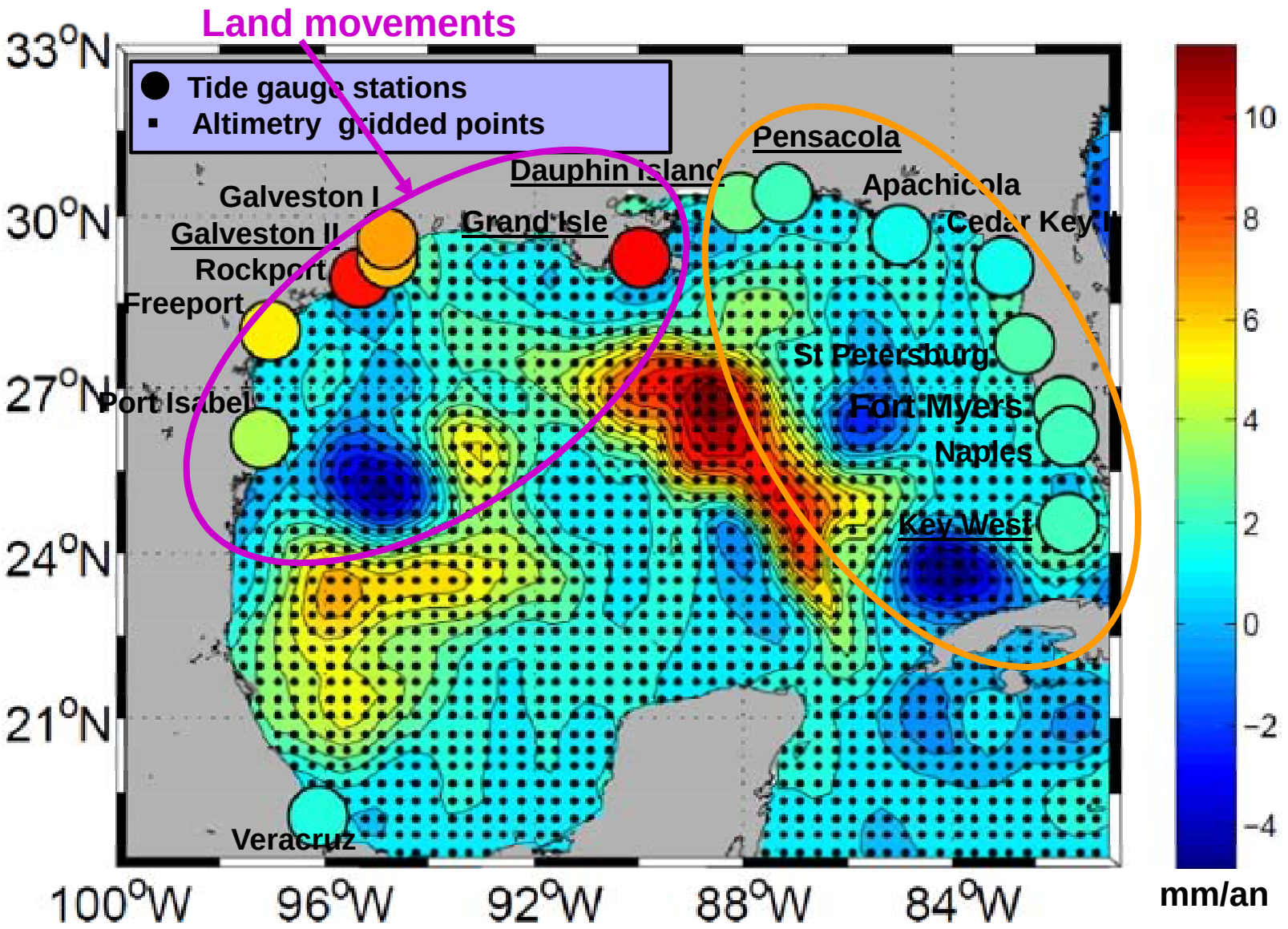
+20 – 50 cm

http://www.sonel.org/-GPS-.html



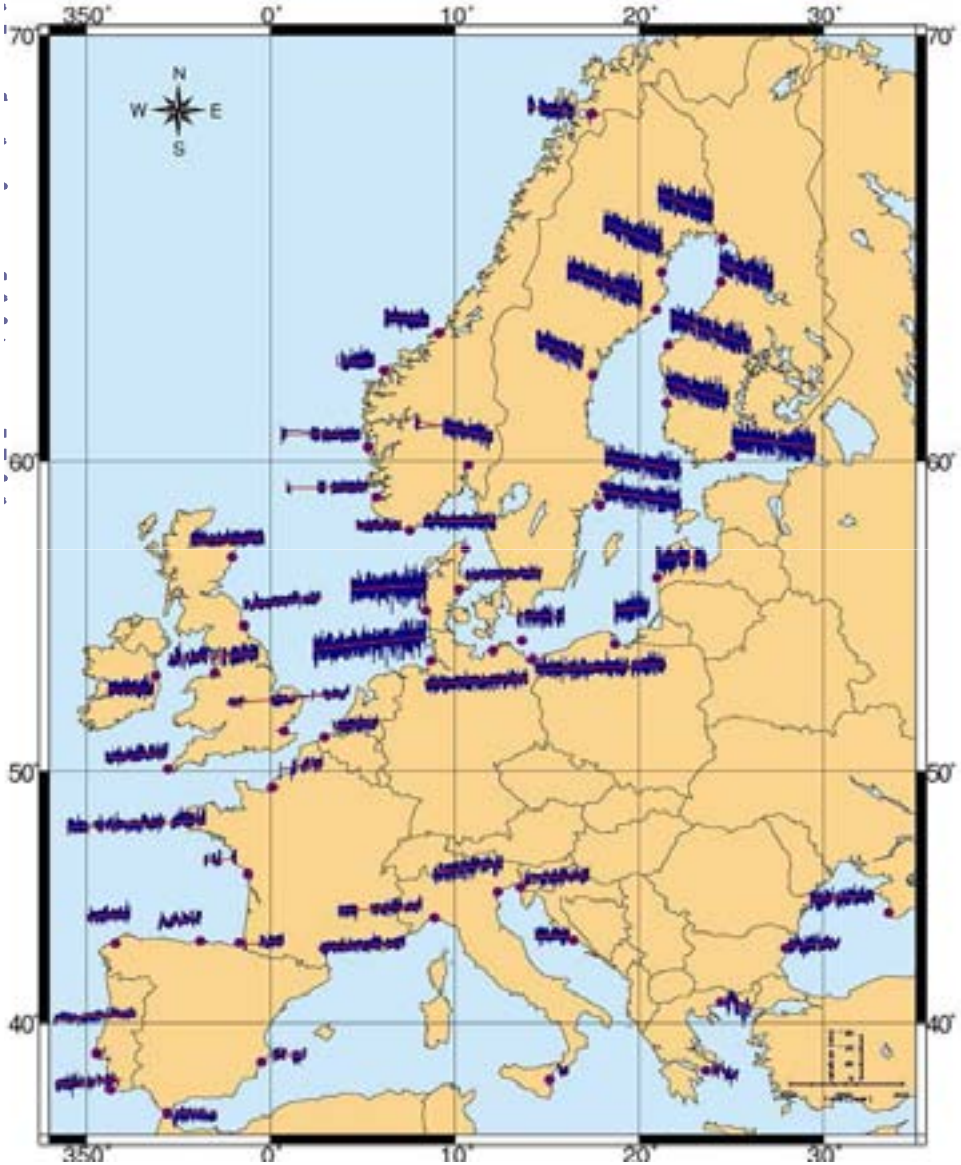
+8.6 ± 0.2 mm/yr (GPS ULR4)

Cas inverse: Grand Isle (+9.2 mm/an)

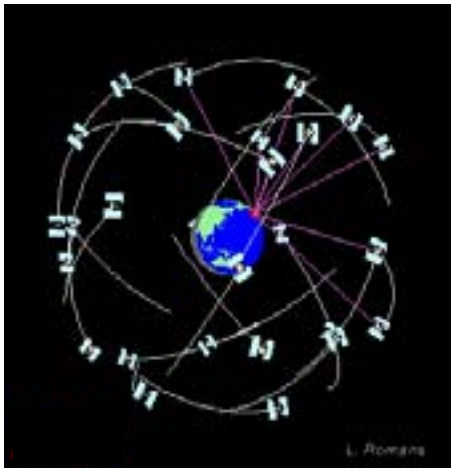


Letetrel et al. (2010)

Comment déterminer les mouvements verticaux?



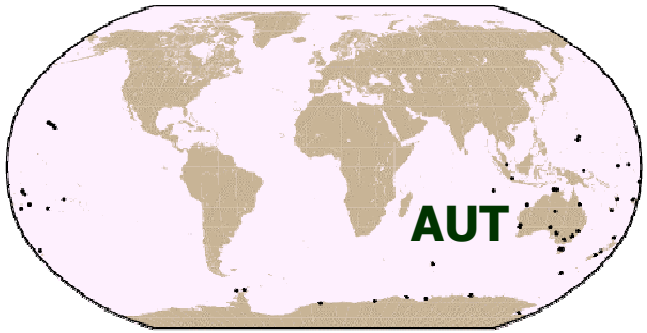
- Model predictions (GIA)
  - Uncertainties in the main geophysical parameters (lithospheric thickness, mantle viscosity…)
  - Imprecise knowledge of Earth's ice history
  - *What about other movements?*
- Measure (if one can…)
  - Introduction of GPS in continuous mode: CGPS@TG
  - Need for a stable and accurate reference frame

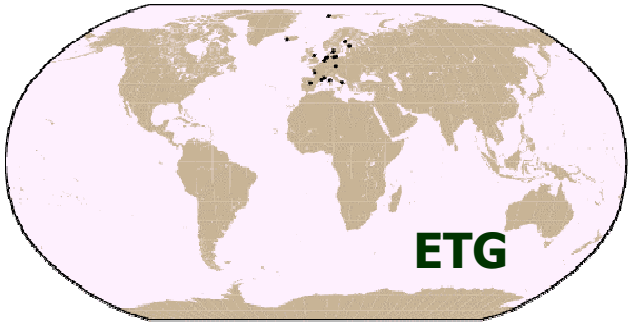


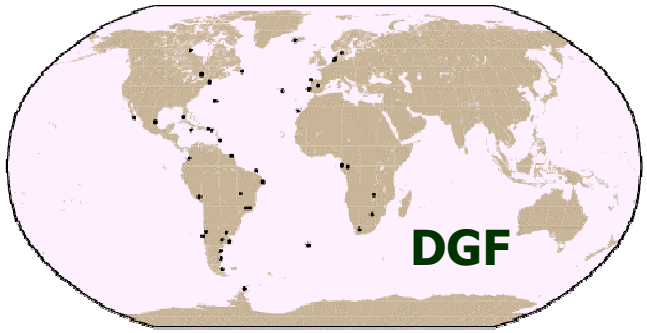
The TIGA pilot project (IGS)

(Initiated in 2001, on a best-effort basis)

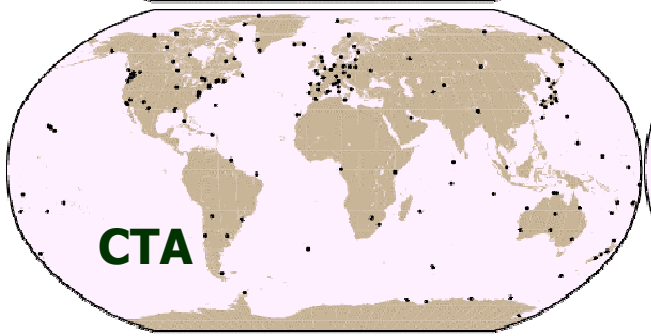
http://adsc.gfz-potsdam.de/tiga/index_TIGA.html

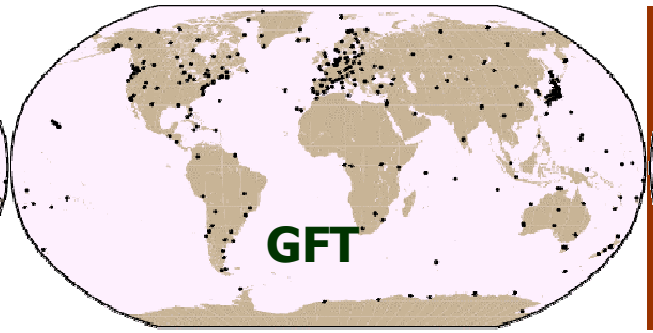


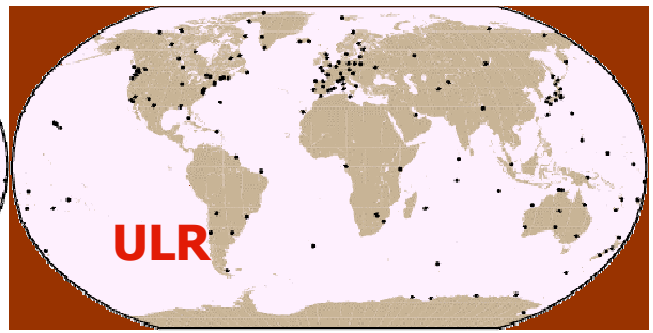




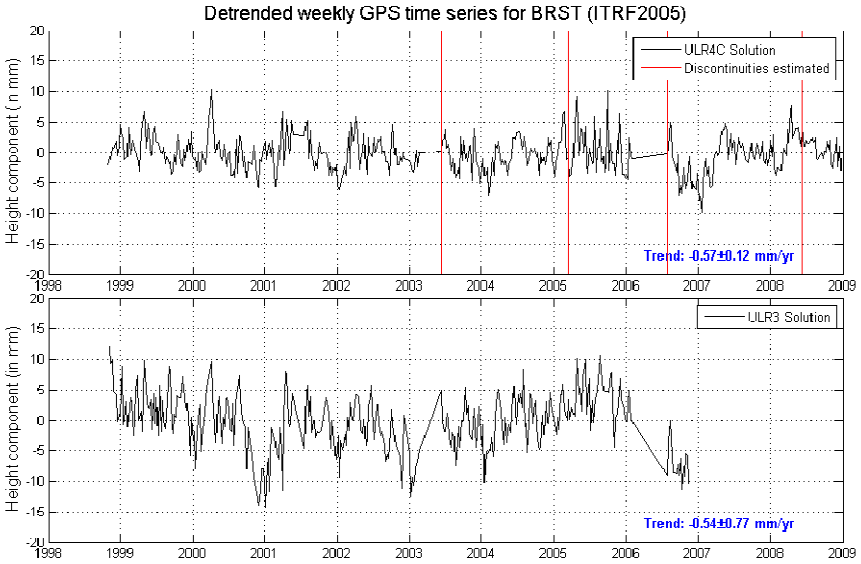
- "Tide Gauge Benchmark Monitoring"
  - 103 TOS, 2 TDC, 6 TAC, TAAC (?)
- Goals
  - Establish, maintain and expand a global cGPS@TG network
  - Compute precise station parameters for the cGPS@TG stations with a high latency
  - Reprocess all previously collected GPS data, if possible back to 1993
  - Promote the establishment of links to other geodetic sites (DORIS, SLR, VLBI,… AG)

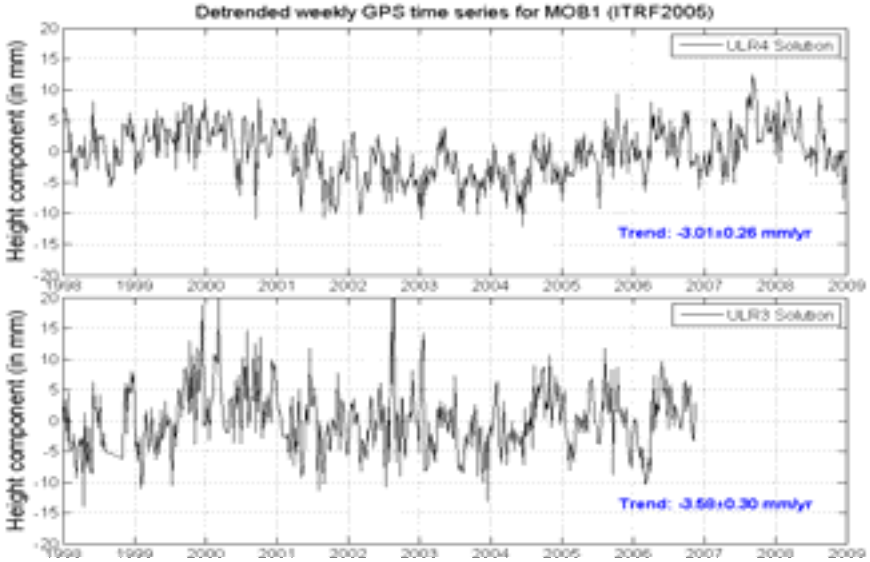


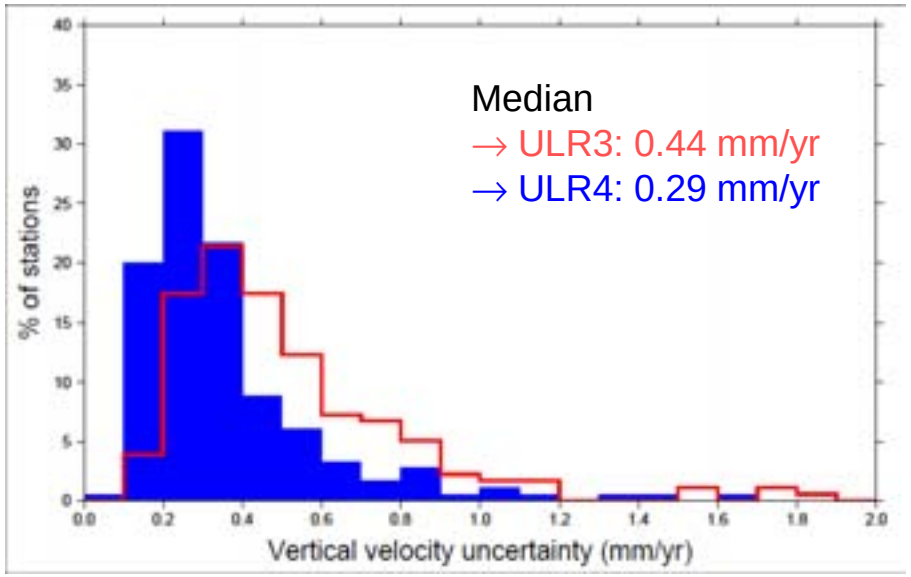


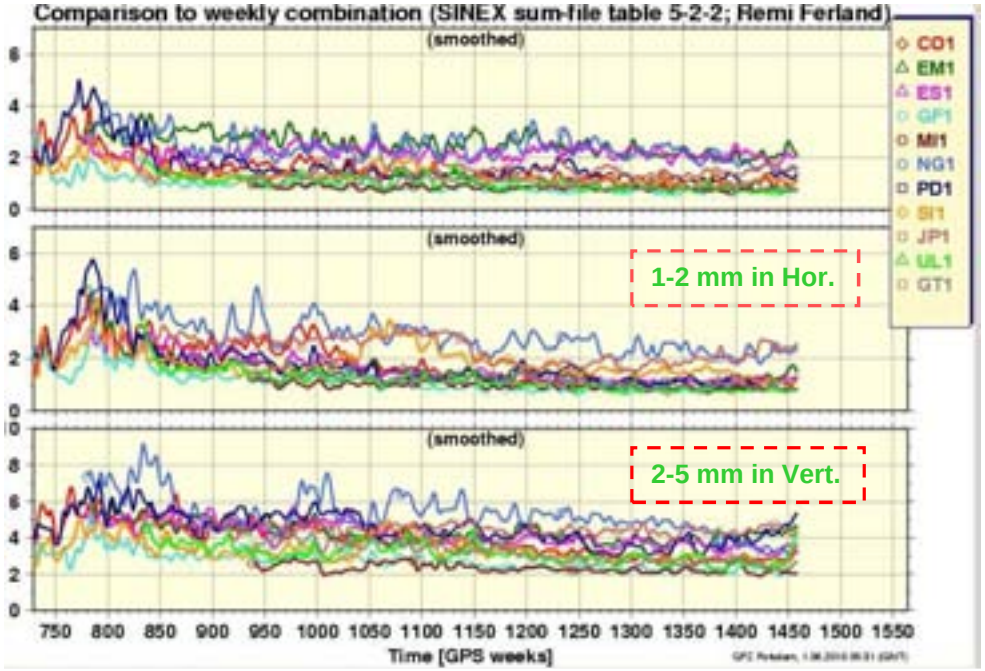


Latest ULR solution (Ph-D Santamaria-Gomez)



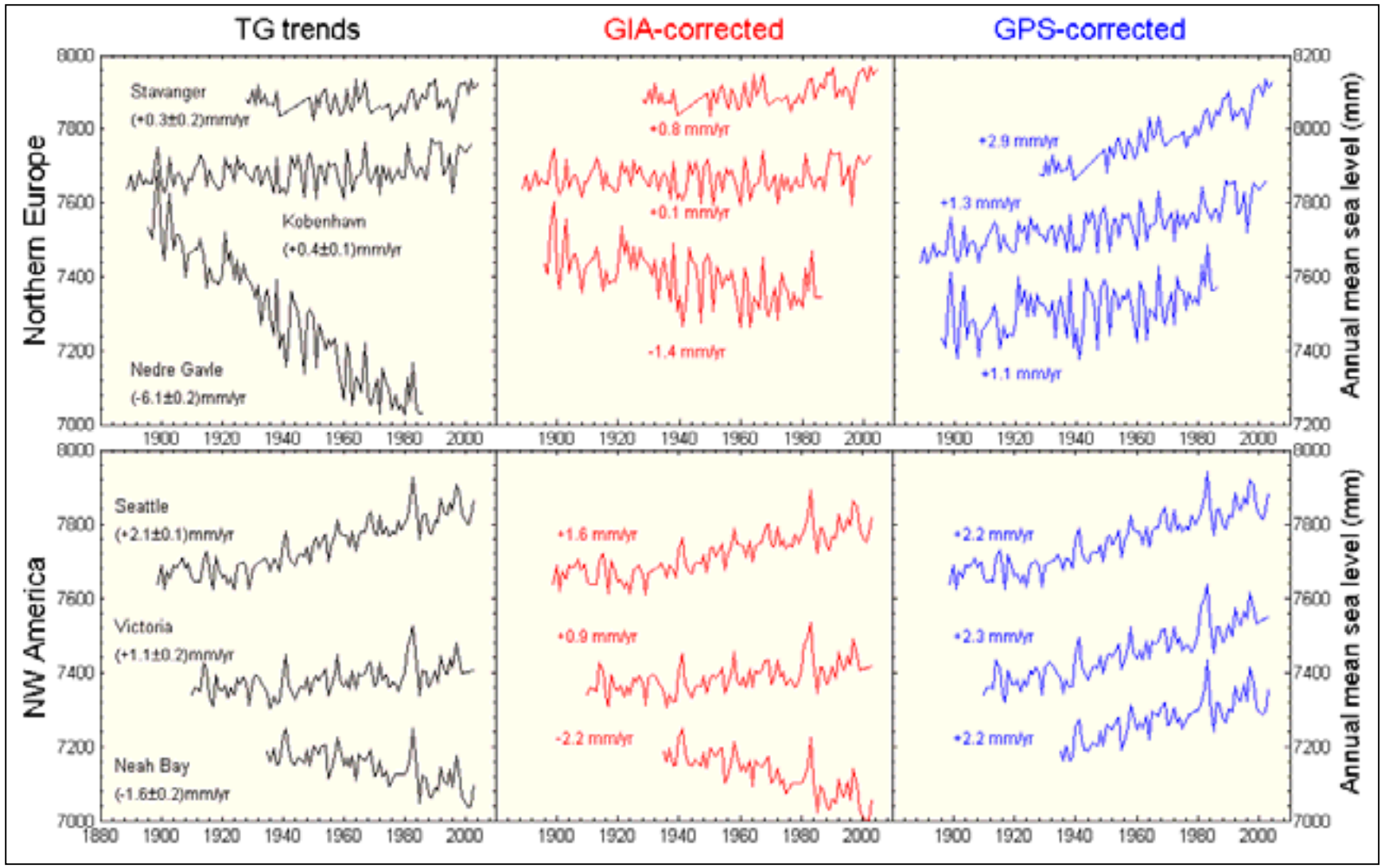






GPS velocities at TG... How well do they work?

ICE5Gv1.2 + VM4 models
(Peltier 2004)



For details: Wöppelmann et al. (2009) in *Geophys. Res. Lett.*
Rationale in *Global and Planetary Change* (2007)

Additional issues to do with cGPS@TG

- Working hypotheses
  1. Land movements are linear over the tide gauge records length
  2. GPS antenna vertical movement ↔ Tide gauge land movement
- Geological evidence
  - tectonically active zones…
- Indirect evidence (Douglas, 2001):

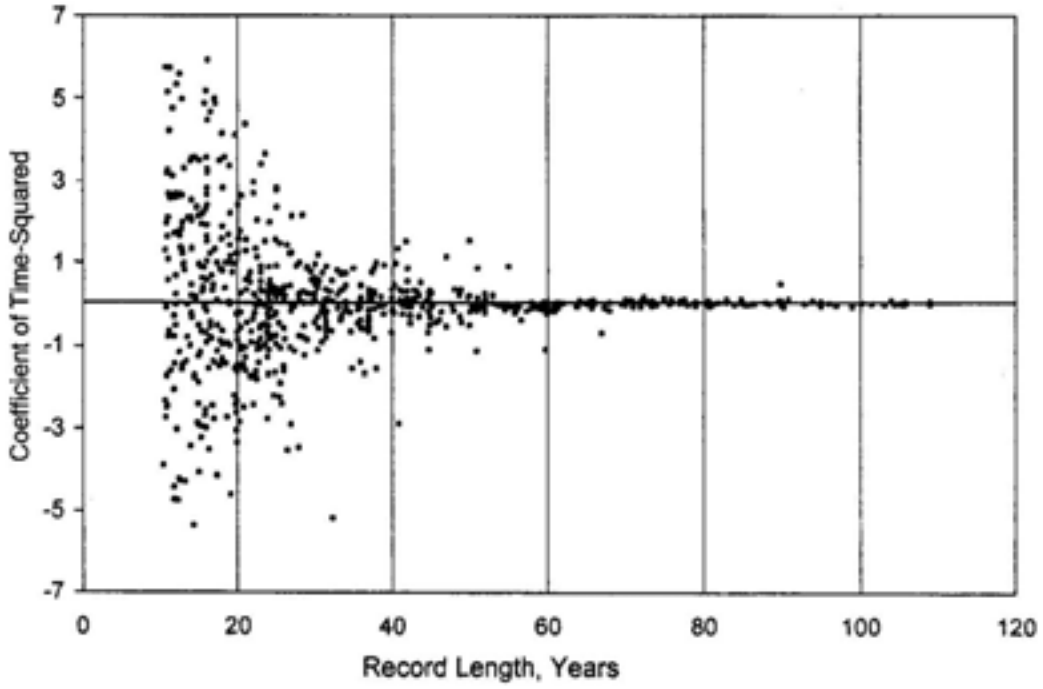


Figure 3.16 Acceleration component of relative sea levels.

Additional issues to do with cGPS@TG

- Working hypotheses
  1. Land movements are linear over the tide gauge records length
  2. GPS antenna vertical movement ↔ Tide gauge land movement
- Some examples…




- Local land motion monitoring (stability)
  - geodetic link between GPS antenna and TGBM
  - ancillary local information (equipment changes, topography…)

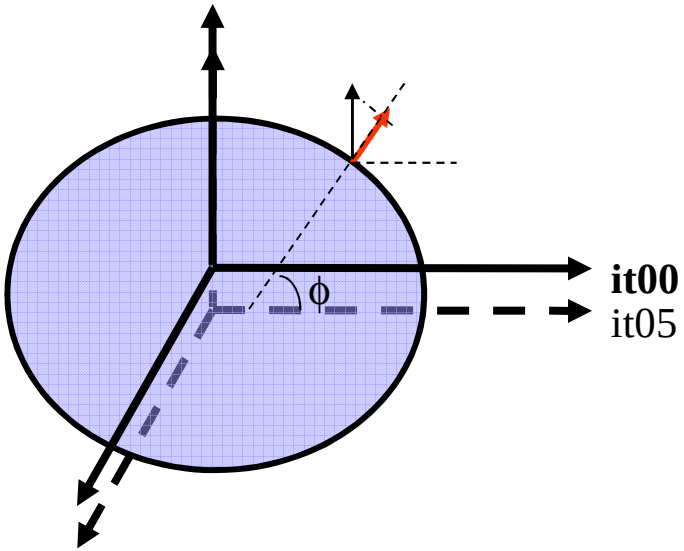
specially, if the GPS was not installed for sea level studies!

↳ For the rest: Douglas (2001) criteria…

Synthèse des résultats et nouvelles questions

	TG+GPS (mm/an)			**TG-GIA**
Solution	ULR1 ITRF2000 1999.0-2005.7	ULR2 ITRF2000 1997.0-2006.9	ULR3 ITRF2005 1997.0-2006.9	
Sea level trends scatter (indiv.)	1.32	1.23	1.15	1.49
Sea level trends scatter (region.)	0.93	0.87	0.62	0.98
Global Sea level trend	1.31±0.30	1.38±0.28	1.61±0.19	1.83±0.21

Douglas & Peltier (2001): 1.84±0.35mm/an

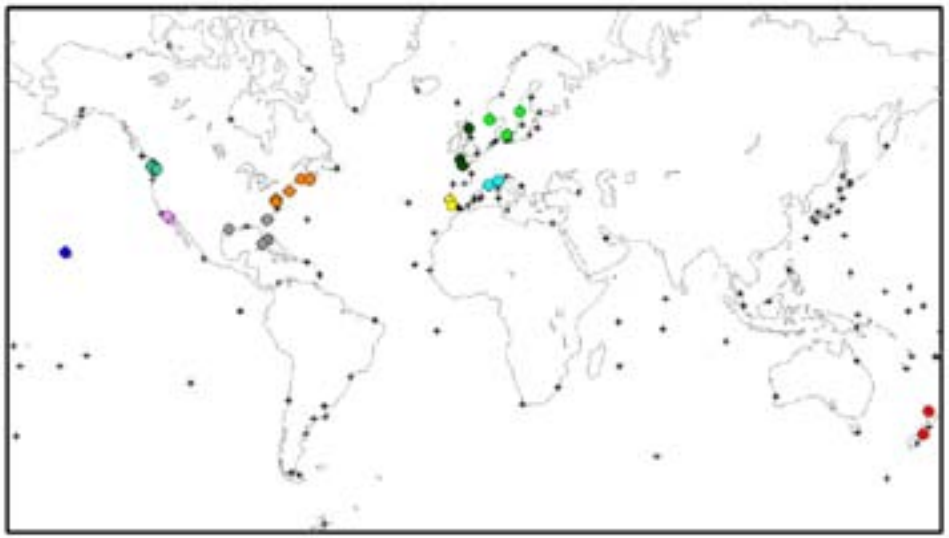


ITRF2000 versus ITRF2005
Impact on the vertical velocities…

$$\rightarrow \dot{h}_{it05} = \dot{h}_{it00} + 1.8 \times \sin(\phi)$$

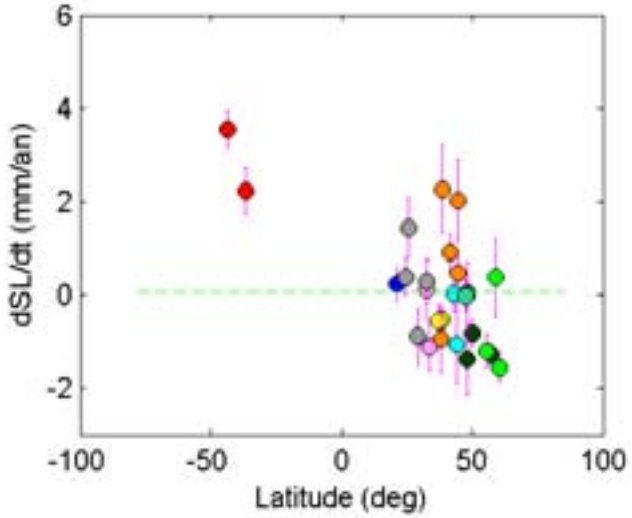
Which reference frame?

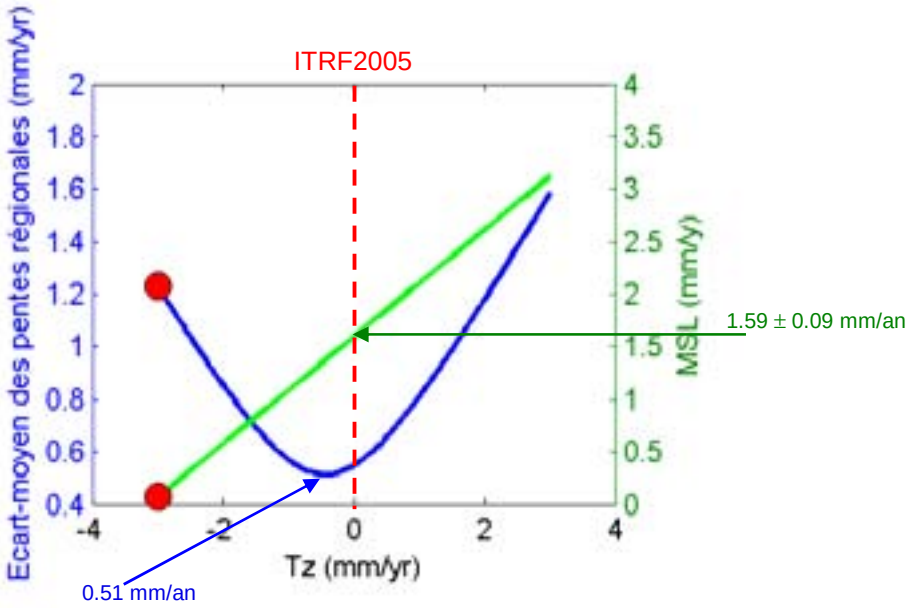
Quel repère ? (Collilieux & Wöppelmann, in press)



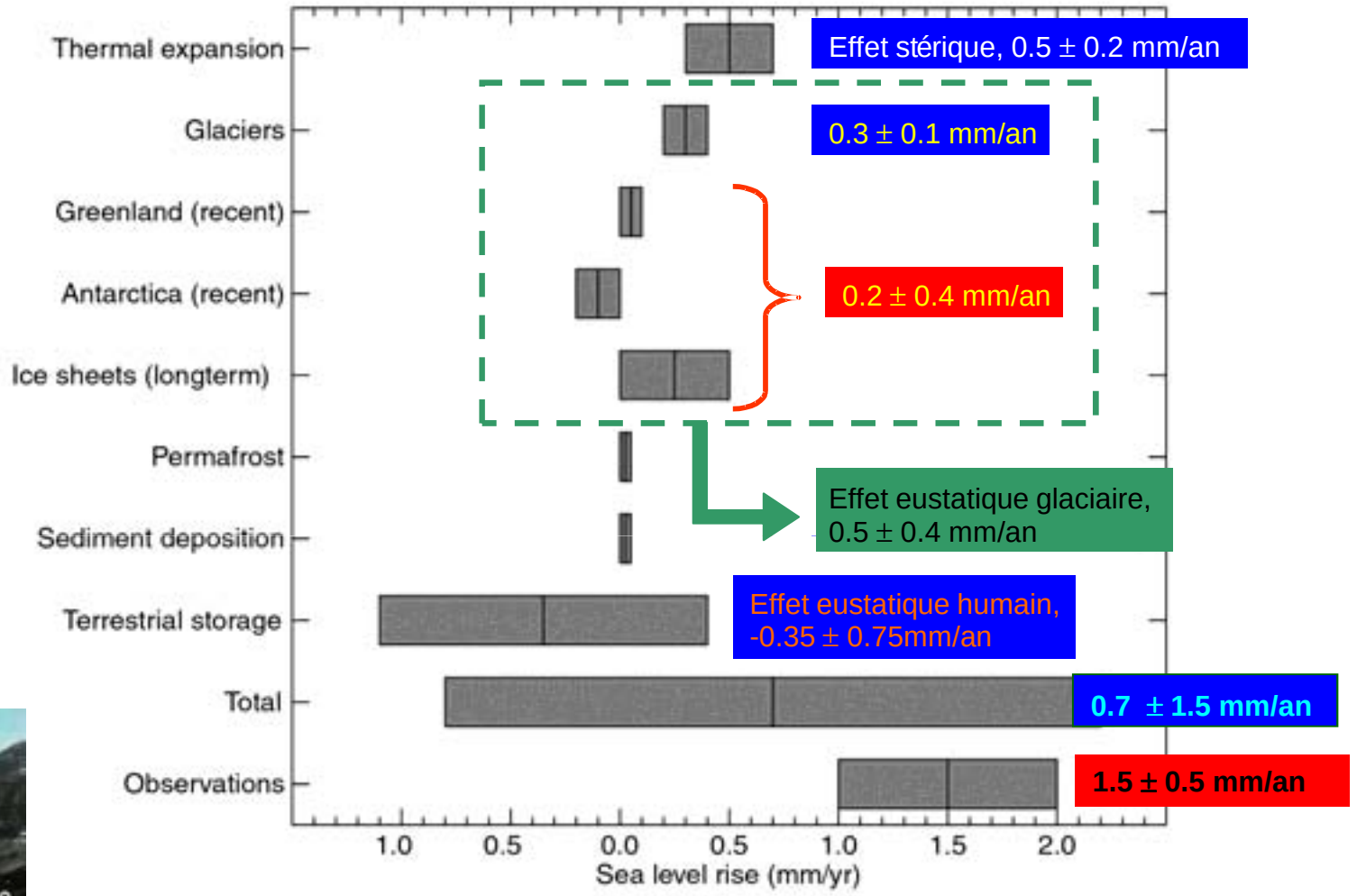
Critères de Douglas (2001)
- Séries marégraphiques > 60 ans
- 85% de données valides
- Groupement régionaux
- Prédictions GIA (Peltier 2001)

Wöppelmann et al. (2009)
- Marégraphes (80 ± 17 ans)
- Corrections GPS (8 ± 2 ans)
- 27 stations dans 10 régions
  (idem pour Douglas, 2001)





Observations et causes



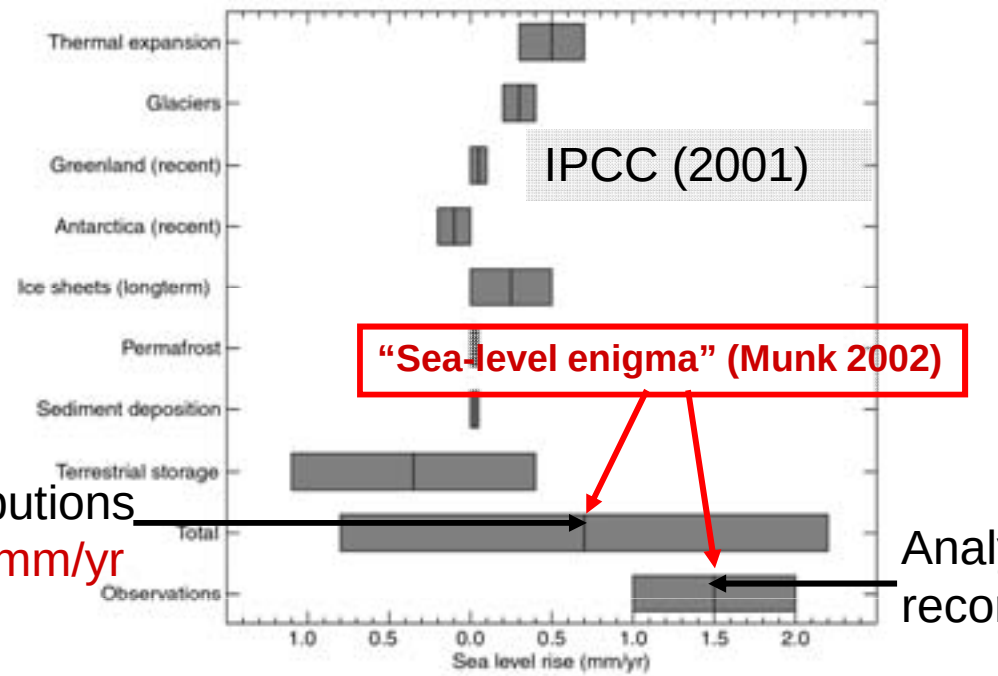
Glacier Pasterze, Autriche

“Sea level enigma” (Munk 2002)

→ D’où viendrait l’élévation observée manquante?

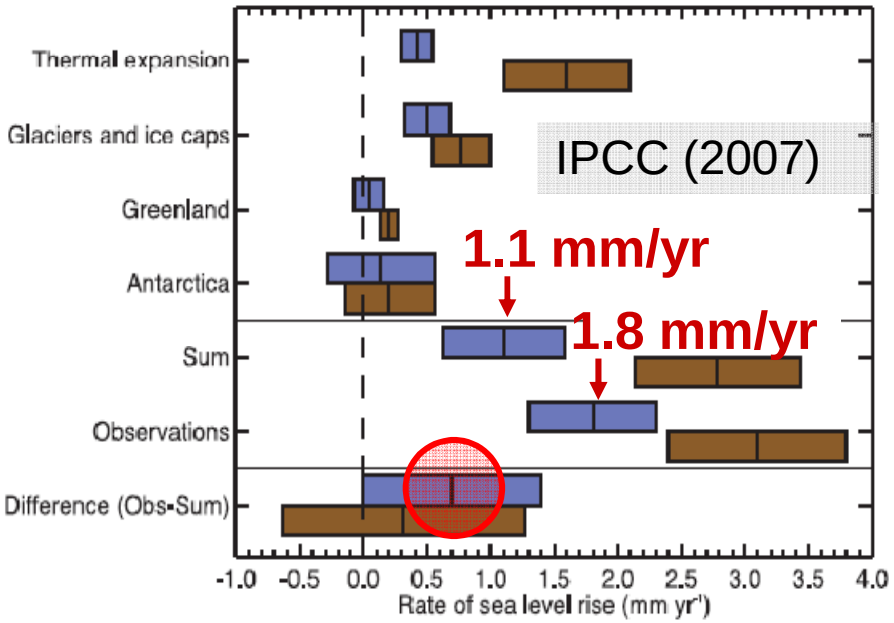
→ Comment prédire le futur si l’on n’explique pas le passé récent?

"Sea level enigma" (Munk 2002)

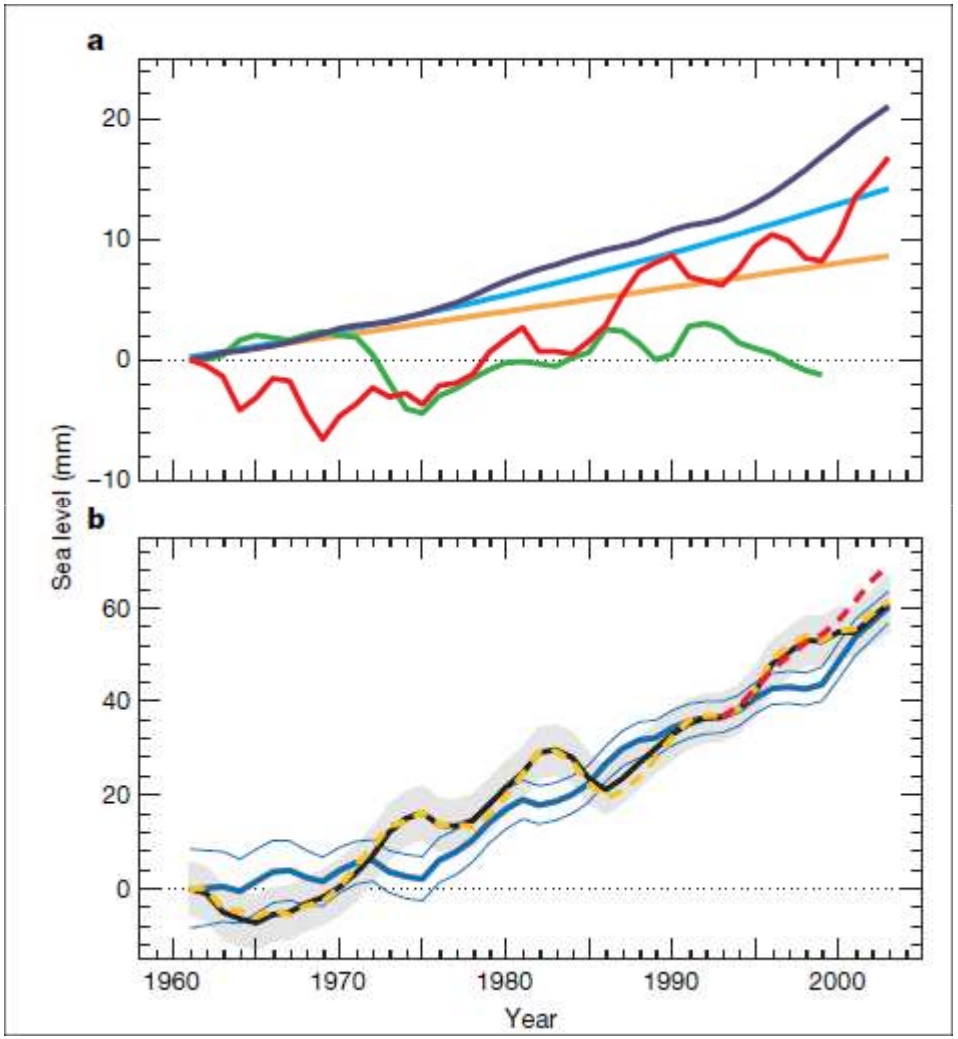


Sum of climatic contributions to sea level rise: ~0.7mm/yr

Analyses of tide gauge records ~1.5mm/yr



Budget 1961 – 2003 par Domingues et al. (2008)



→ Contributions:

- Groenland et Antarctique
- Autres calottes et glaciers alpins
- Dilatation thermique de 0-700m
- Dilatation océan profond
- Réservoirs d'eau terrestre

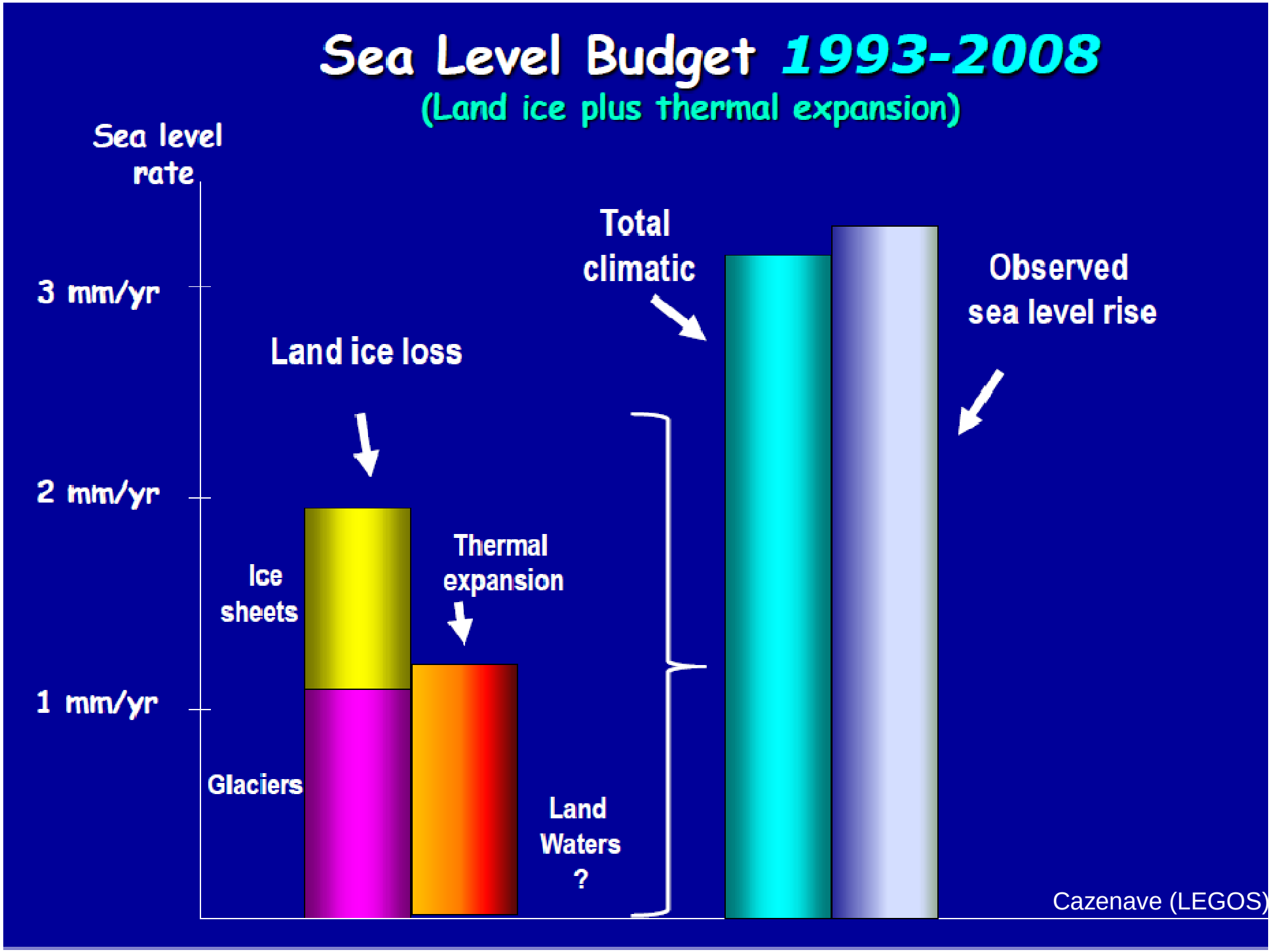
→ Somme des composantes vs Observations:

- Somme des composantes en a)
- Jevrejeva et al. (2006)
- Altimétrie radar embarquée sur satellite
- Cette étude (Domingues et al. 2008)

Soit,

1.5 ± 0.4 mm/yr (Somme des contributions)
1.6 ± 0.2 mm/yr (Observations)

Domingues et al. (2008)


Sea Level Budget 1993-2008
(Land ice plus thermal expansion)
Sea level rate
3 mm/yr
2 mm/yr
1 mm/yr
Land ice loss
Ice sheets
Glaciers
Thermal expansion
Land Waters ?
Total climatic
Observed sea level rise
Cazenave (LEGOS)

Quelques conclusions

- Une grandeur fondamentale au carrefour des disciplines
  - des enjeux scientifiques (changement climatique, tempêtes,…)
  - et des impacts économiques et sociétaux considérables!

- Des résultats impossibles sans une observation pérenne, continue, de qualité revue et confrontée régulièrement (transitions technologiques), archivée et accessible (supports, métadonnées)

- Un bilan global clôt sur la période satellitale (1992-…)
  Contributions climatiques *versus* observations directes

- Empreintes géographiques: global ≠ local
  - les prédictions climatiques ne sont pas suffisantes
  - importance des mouvements verticaux à la côte

- La France, très regardée au niveau international (GLOSS)
  - place conquise grâce à Topex/Poseidon,… (CNES)
  - des territoires un peu partout dans le globe (cf.sites GLOSS)