La montée du niveau des océans : estimations et variabilité régionale

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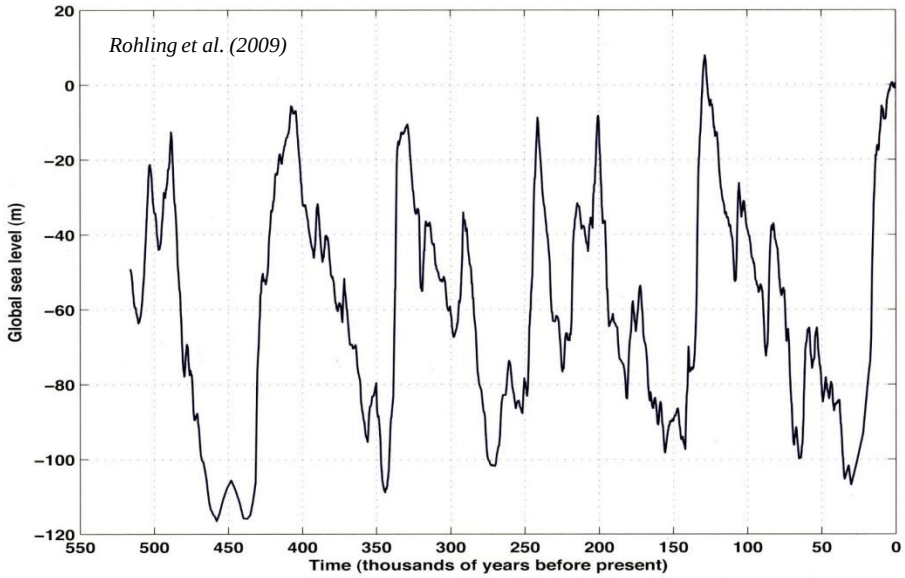
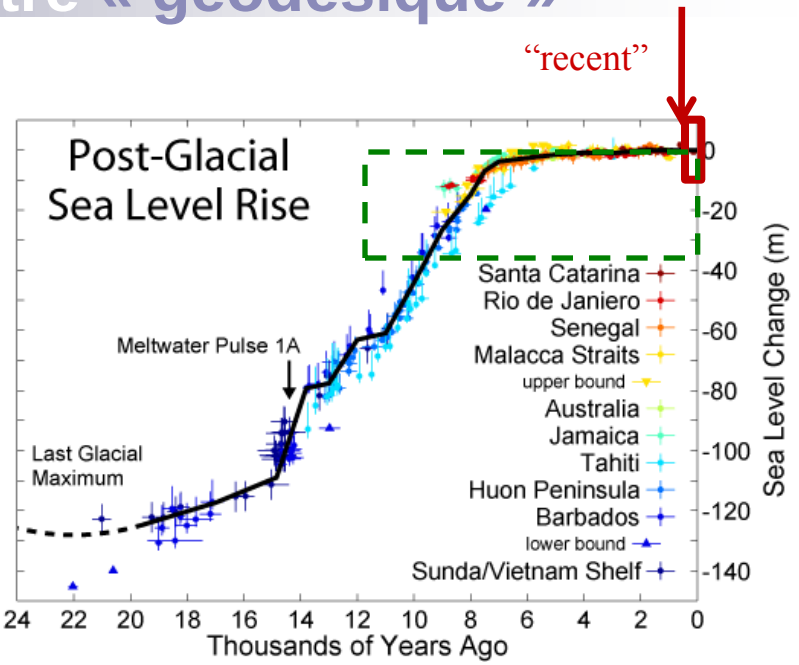
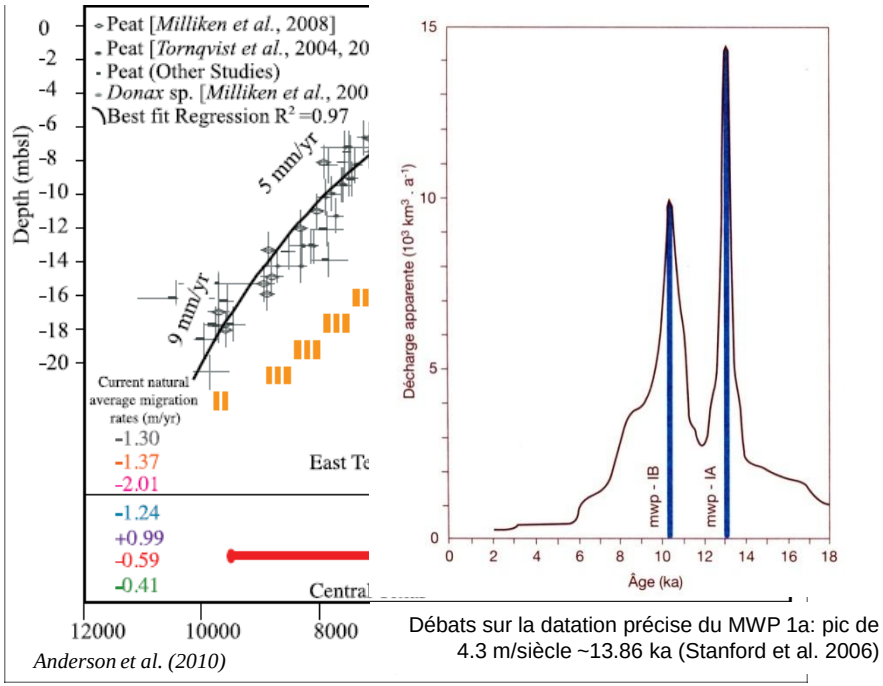
Plan:
1. Contexte et observations disponibles
2. Définition de la problématique
3. Résultats et incertitudes

Journée de la Société Météorologique de France
« Les multiples facettes du changement climatique »
23 mars 2011, ENS, Paris

1. Ordres de grandeur & périmètre « géodésique »

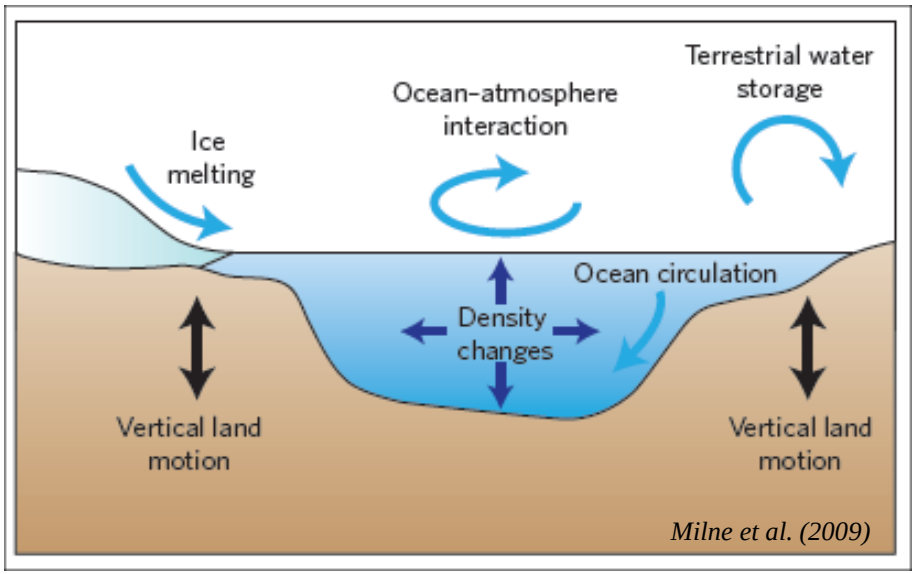






Anderson et al. (2010)

Débats sur la datation précise du MWP 1a: pic de 4.3 m/siècle ~13.86 ka (Stanford et al. 2006)



1. Observations disponibles

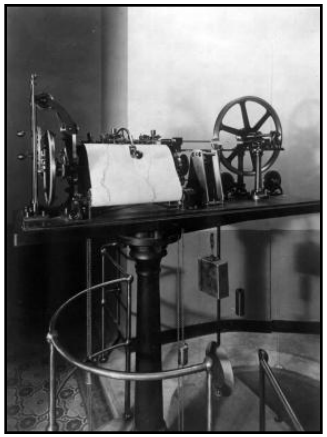
1679 — 1831 — 1960 — **1992** — 2010

Niveau de la mer relatif


P. de La Hire (1640-1718) J. Picard (1620-1682)

ECHELLE DE MAREE

$1\text{cm} < \sigma < 3\text{cm}$



MAREGRAPHE

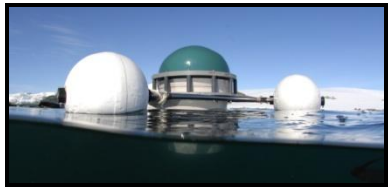
$5mm < \sigma < 1cm$

PRESSION

$5mm < \sigma < 1cm$

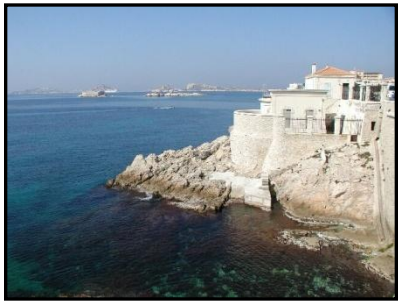
RADAR

$1mm < \sigma < 5mm$



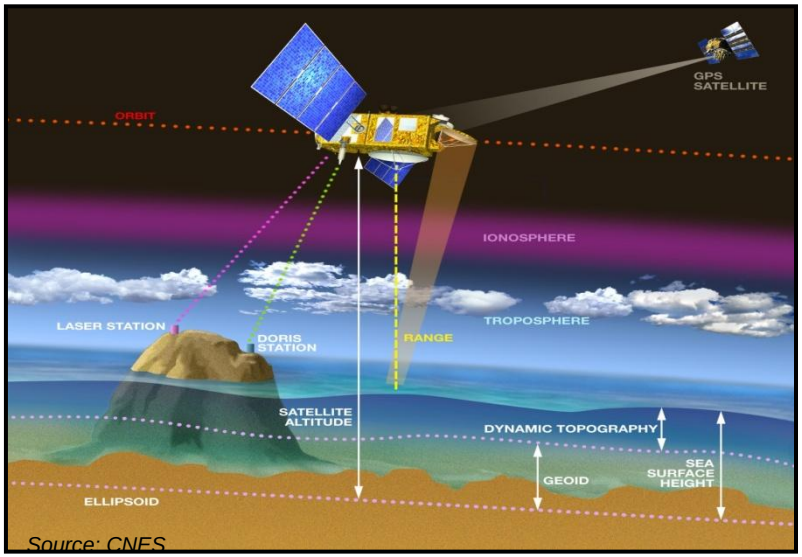
Bouée GPS

$? < \sigma < ?$

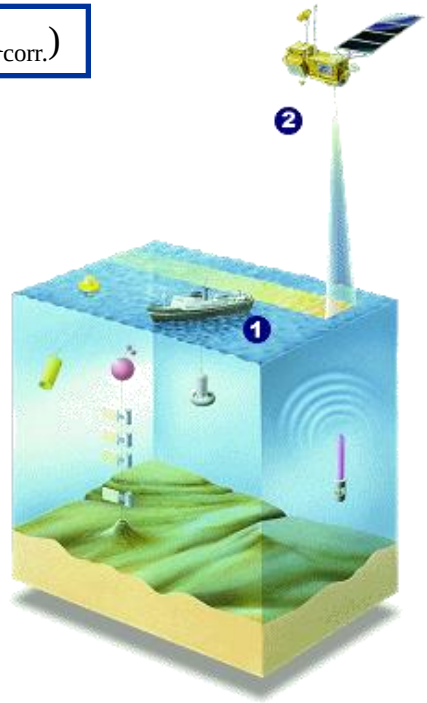


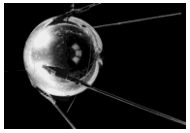
Martin Miguez et al. (2008)

1. Altimétrie radar embarquée sur satellite



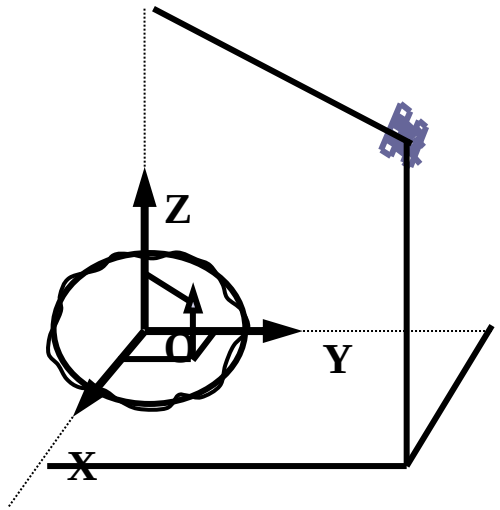
$$h_{sea\text{-}level} = h_{sat.} - (R_{mes.} - \Delta R_{corr.})$$



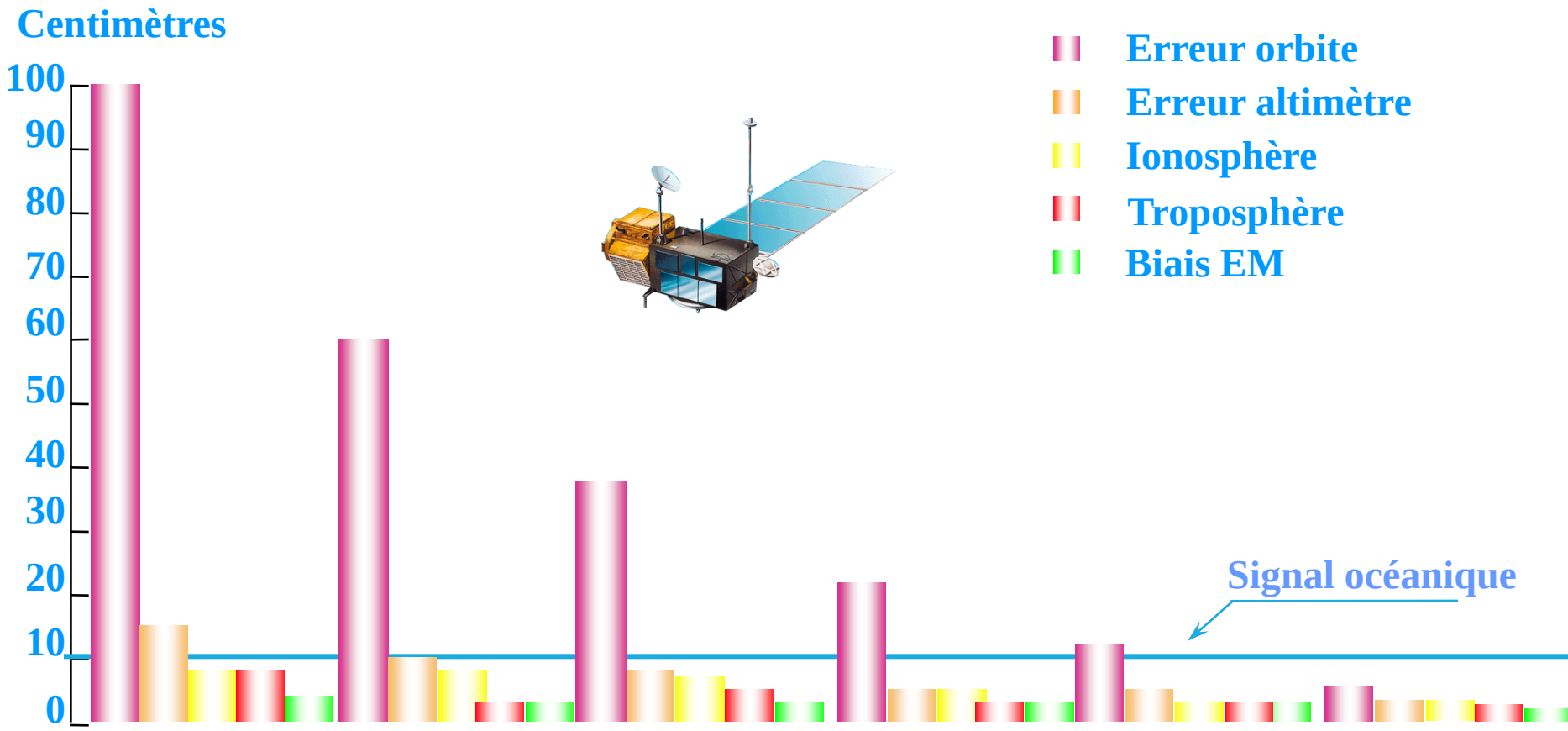


Sputnik (4/10/1957)

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 – …



1. Bilan d'erreur des missions d'altimétrie spatiale



GEOS 3
843 km
115°
Différents cycles de répétition

SEASAT
800 km
108°
3 jours

GEOSAT
800 km
108°
17 jours

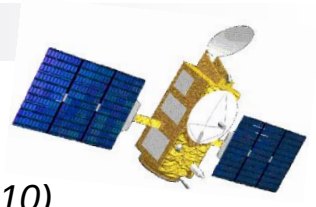
ERS-1
780 km
98,5°
35 jours
(3/168)

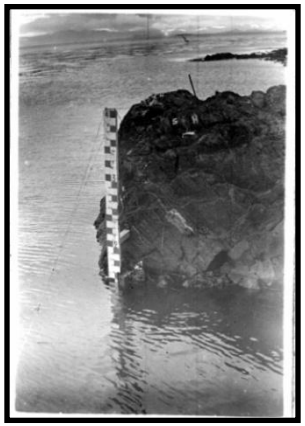
T/P
(before launch)
1336 km
66°
9,95 jours

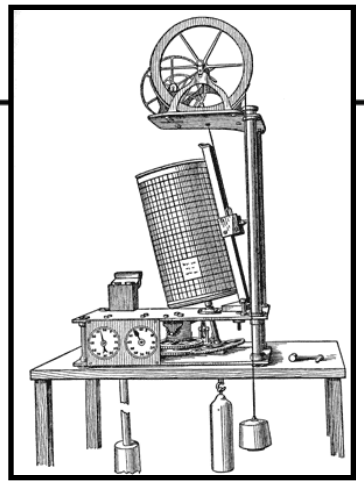
T/P
(after launch)

Le Provost (2002)

2. Évolution récente du niveau des océans







Cazenave & Llovel (2010)

+3.4 ± 0.5 mm/an

(1993-2009)

Holgate & Woodworth (2004)

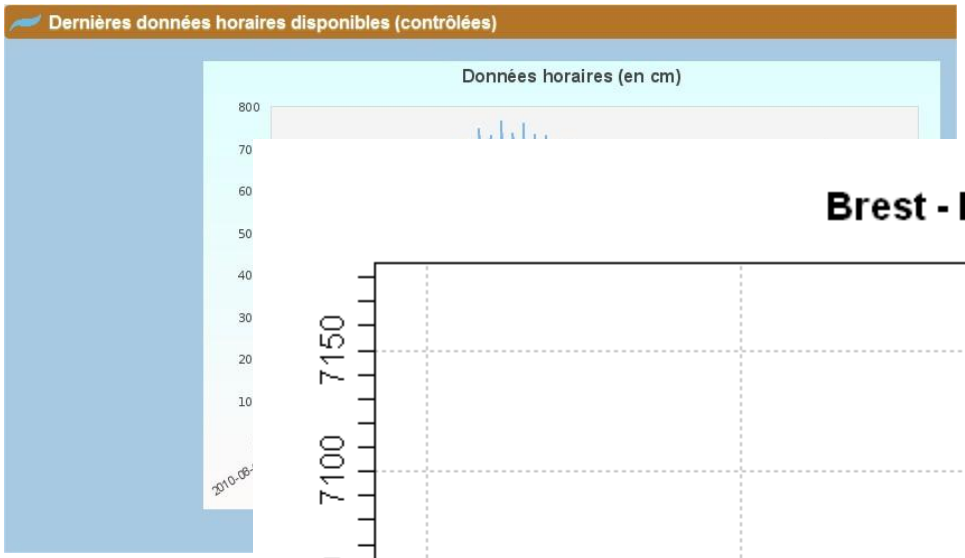
20e s. ~17 cm soit +1.7 ± 0.3 mm/an

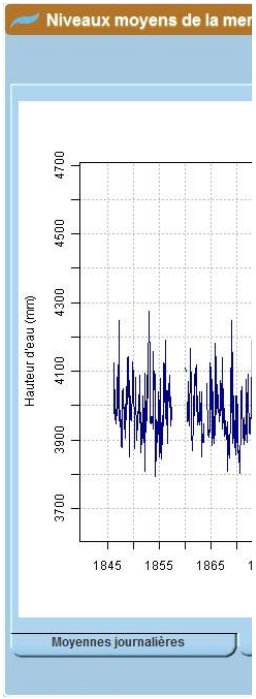
Church & White (2006)

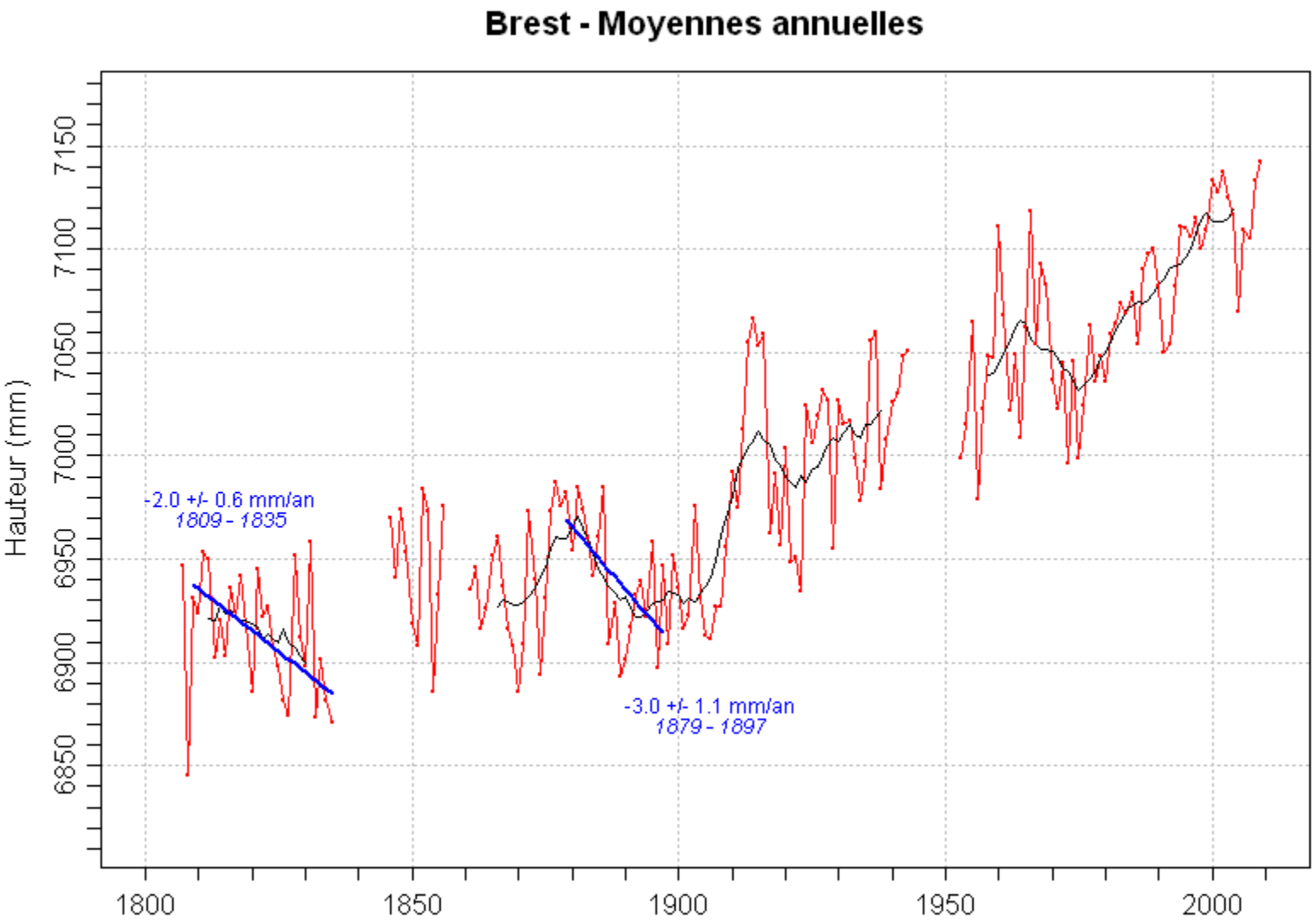
2. Définition de la problématique

SONEL

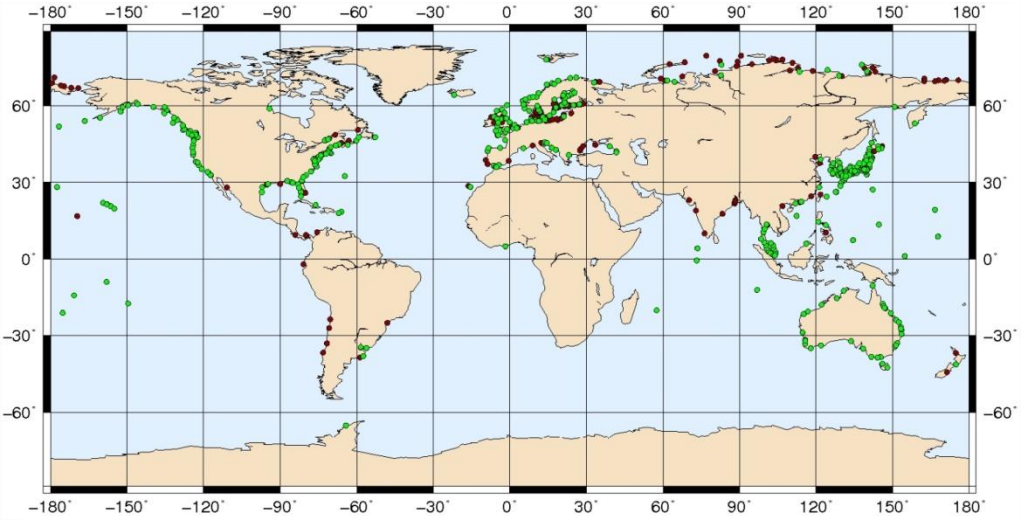
http://www.sonel.org/-Maregraphes-.html







2. Variabilité temporelle : Contraintes & Limites



Marégraphes avec plus de 20 ans de données (PSMSL)

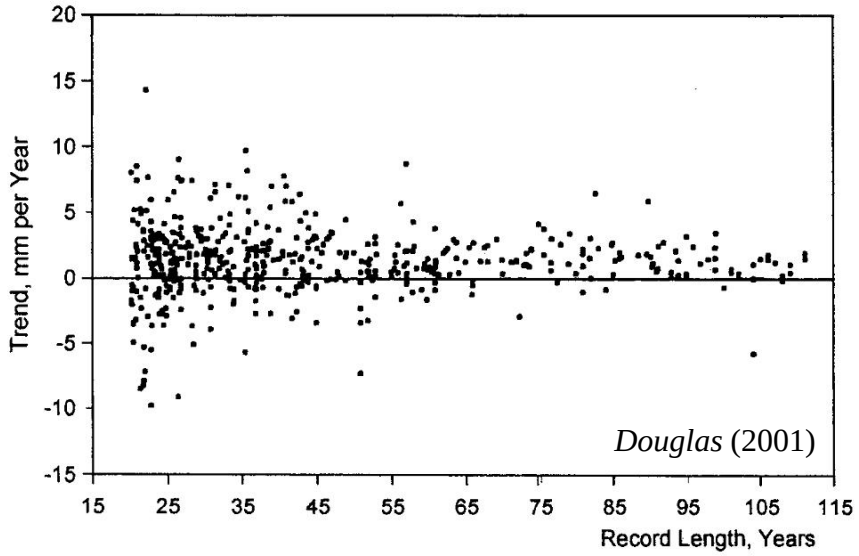
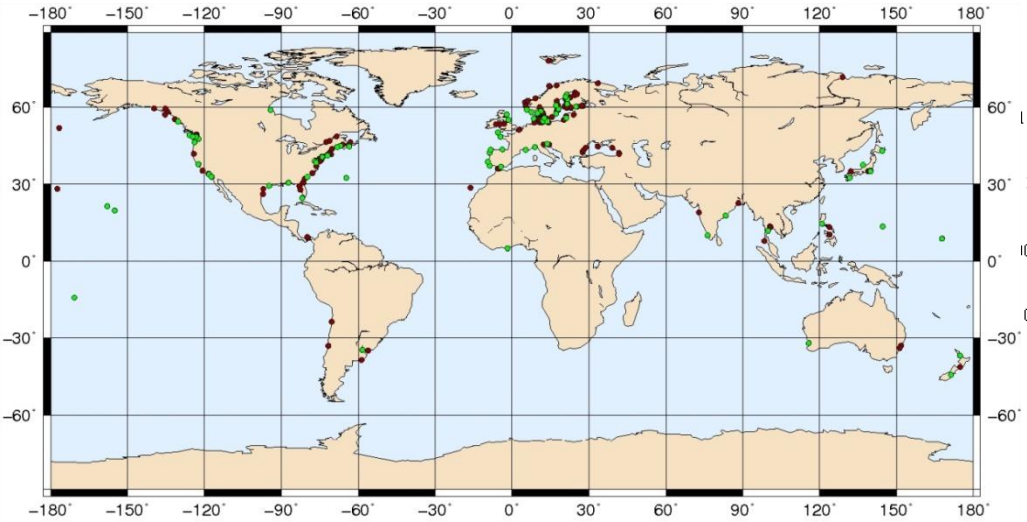
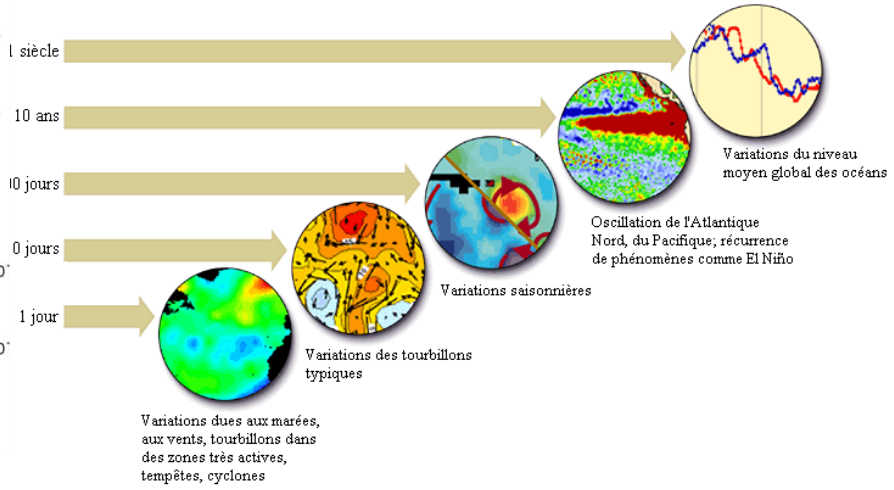


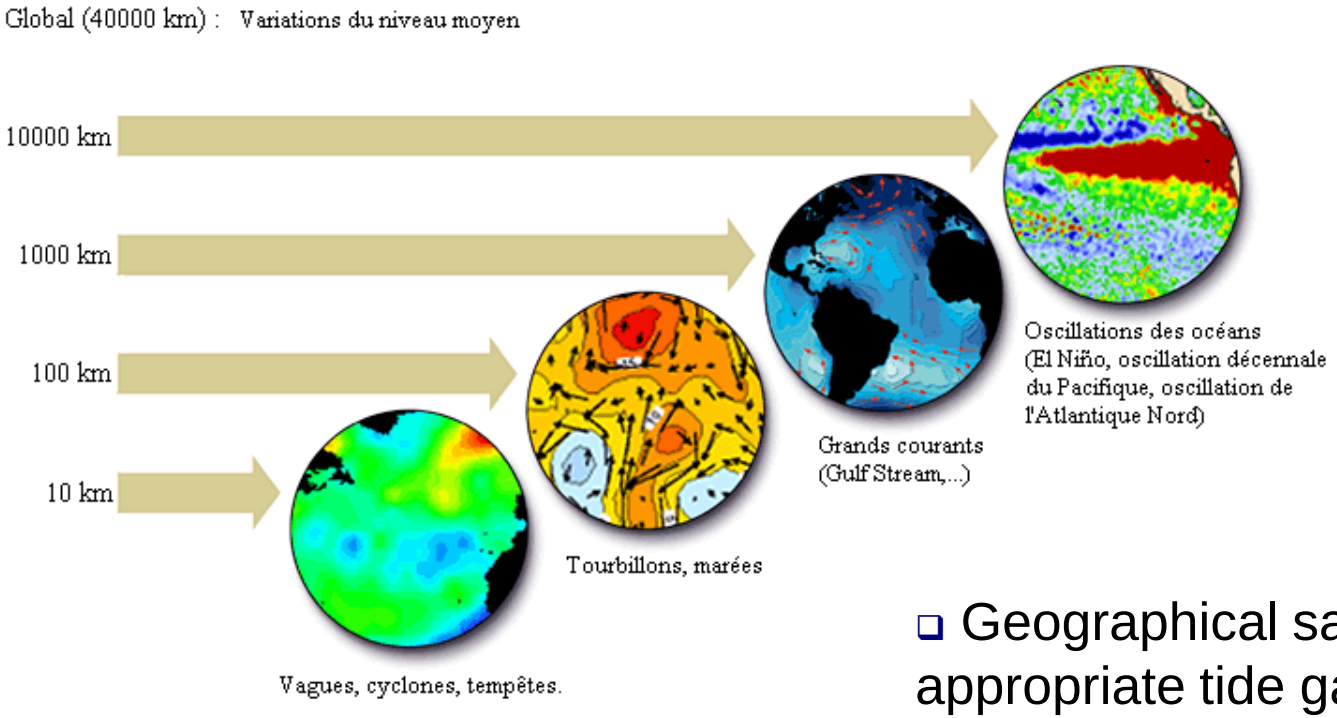
Figure 3.11 RLR-site sea level trends corrected for glacial isostatic adjustment.



Marégraphes avec plus de 60 ans de données (PSMSL)



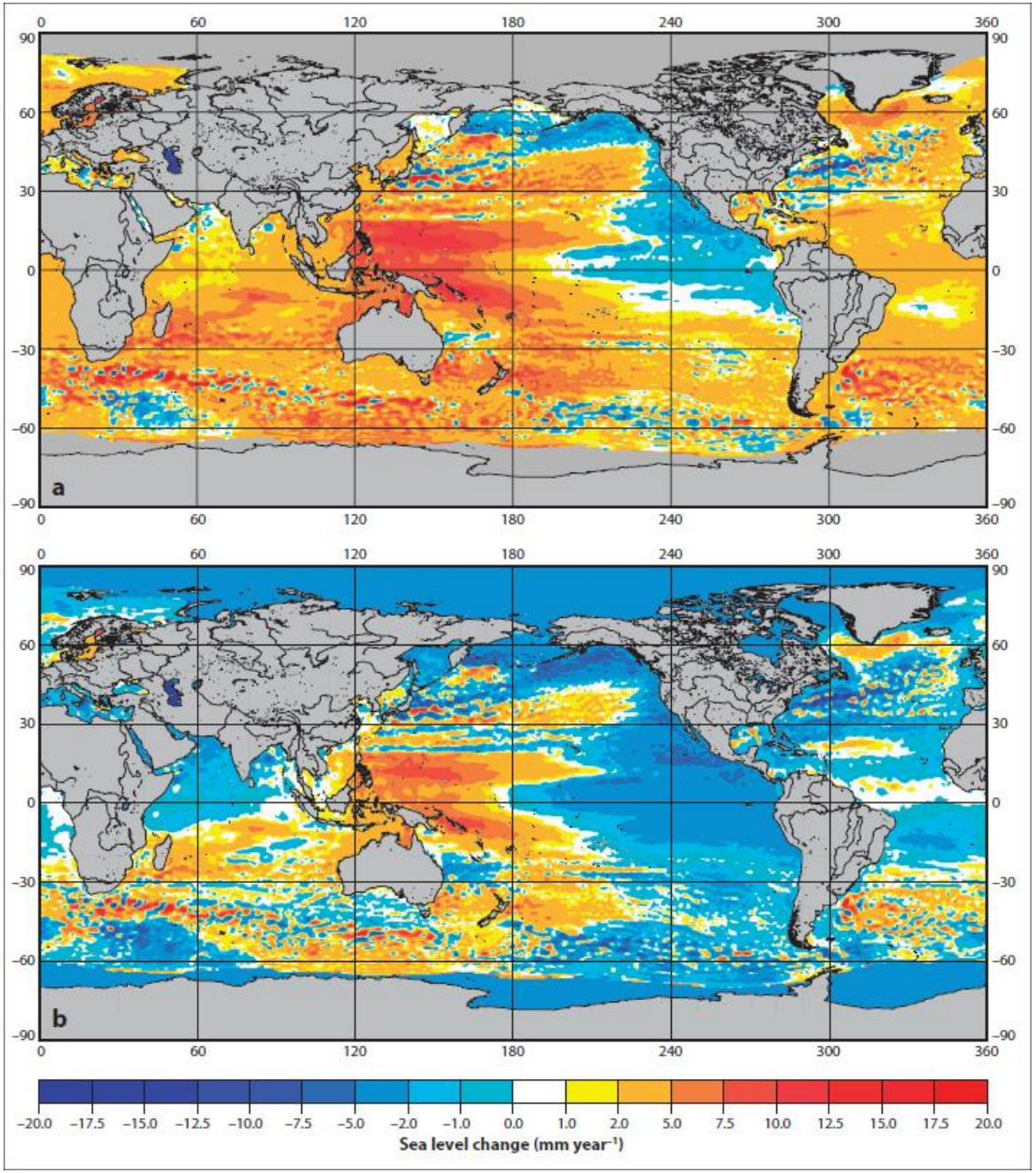
2. Variabilité spatiale…

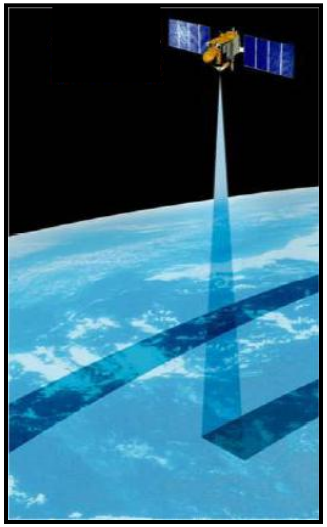


- Douglas (2001) criteria:
  - → Tide gauge records longer than 60yr
  - → 85% of valide data
  - → Regional grouping
  - → GIA corrections (Peltier 2001)
  - → **1.84 ± 0.35 mm/an** (~ Douglas, 1991)

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

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



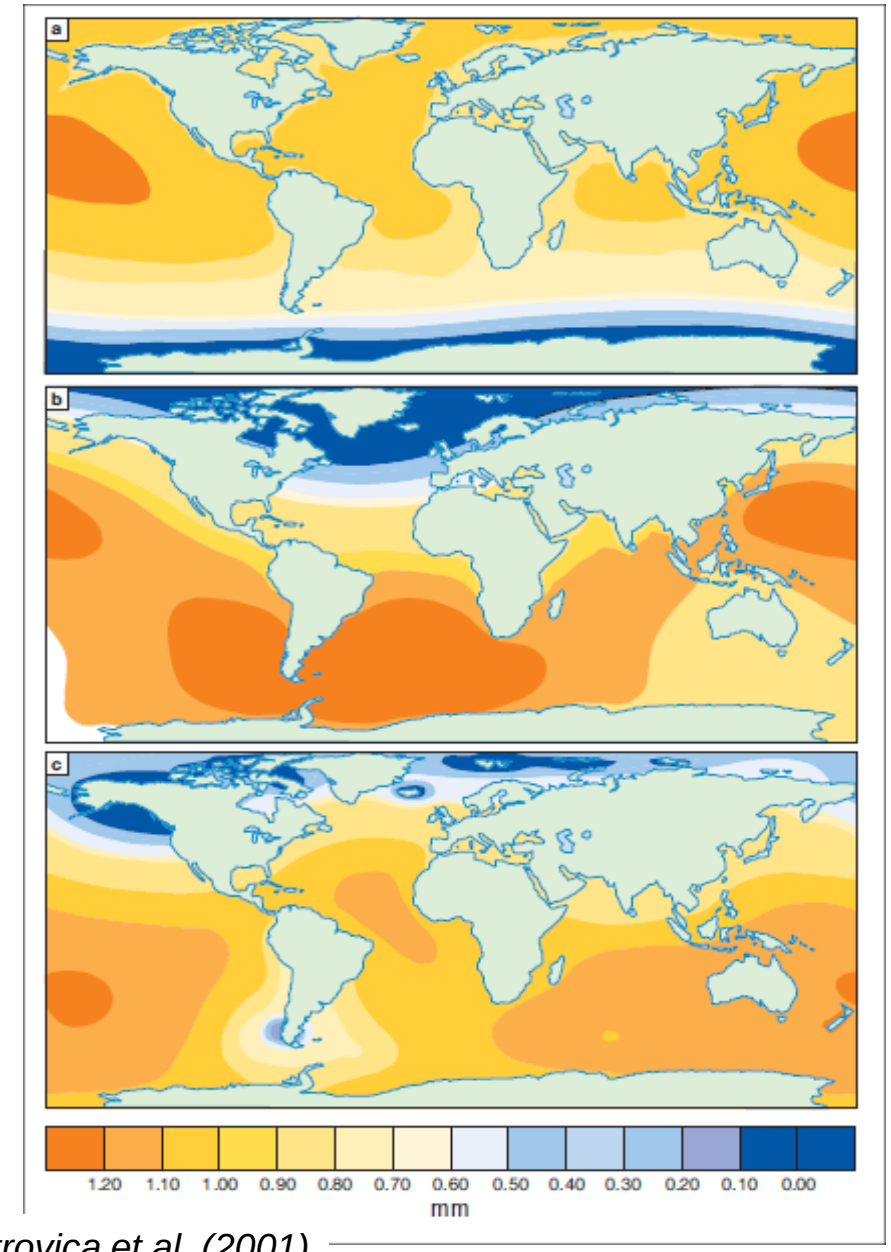


Idem que ci-dessus mais avec retrait d'une tendance globale et uniforme de 3.4 mm/an.

Cazenave & Llovel (2010)

2. Empreintes géographiques de la fonte des glaces

(The “fingerprint” issue)



Mitrovica et al. (2001)

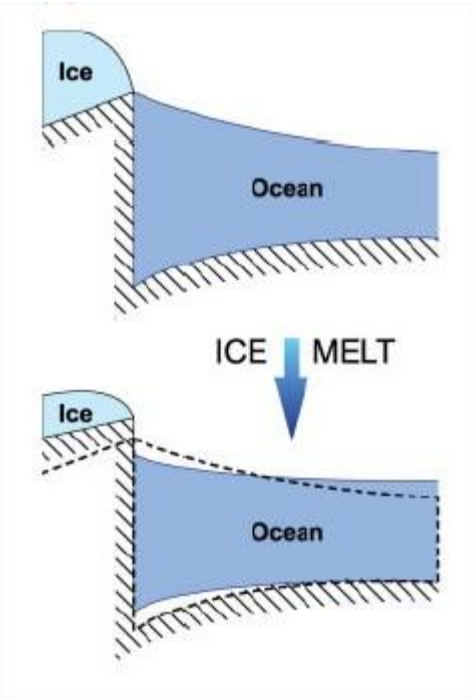


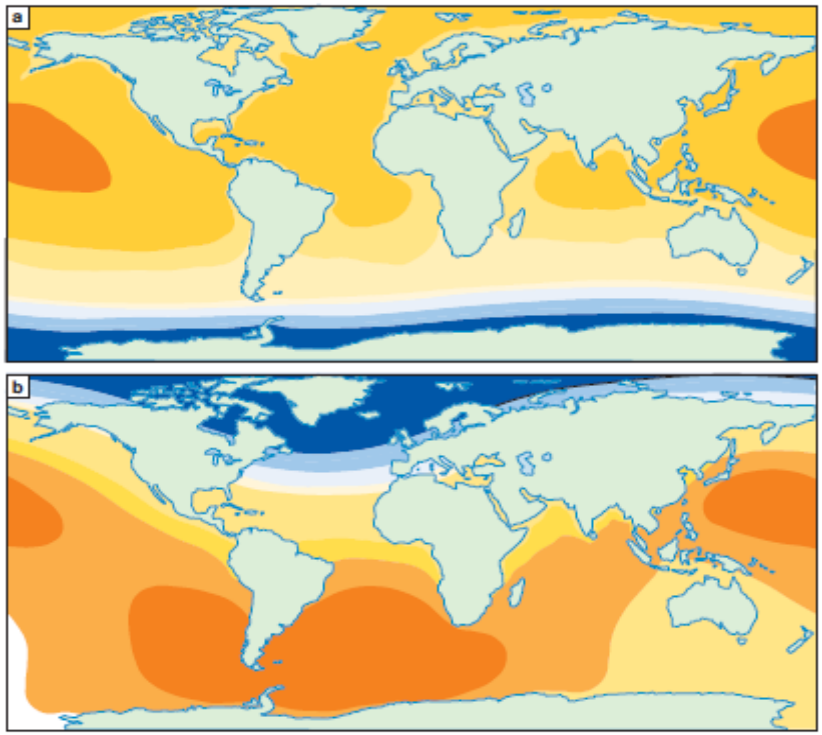
Illustration: fonte de l’équivalent de 1mm/an

a. Antarctique
b. Groenland
c. Glaciers de montagne

Projet CECILE (ANR)

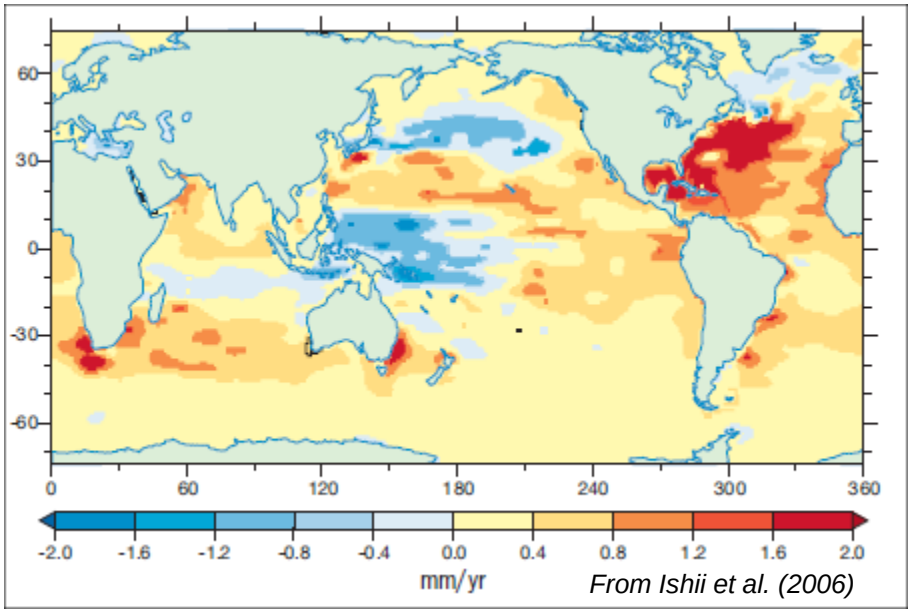
Évidences observationnelles des empreintes prédites par la théorie? (WP3)

2. Empreintes spatiales: évidence observationnelle?

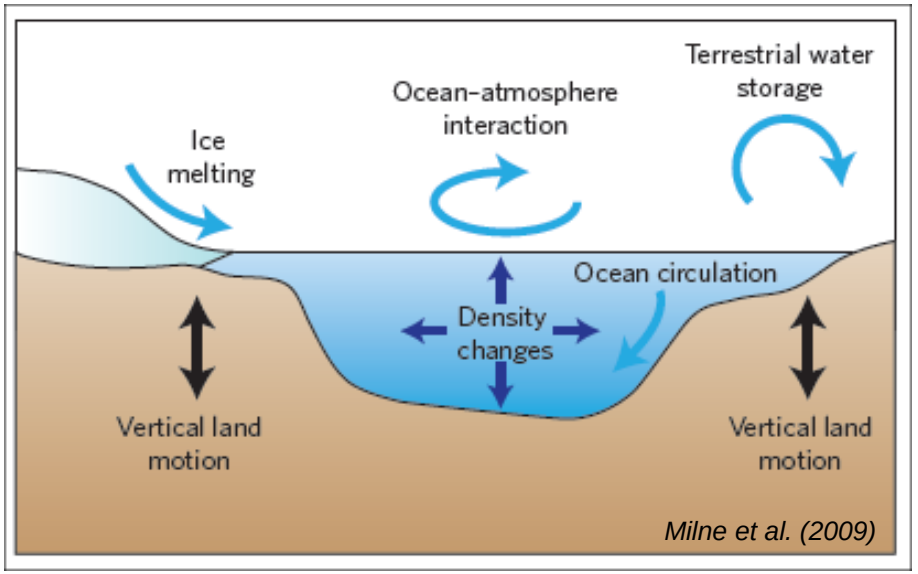


Mitrovica et al. (2001)

Une complexité accrue…

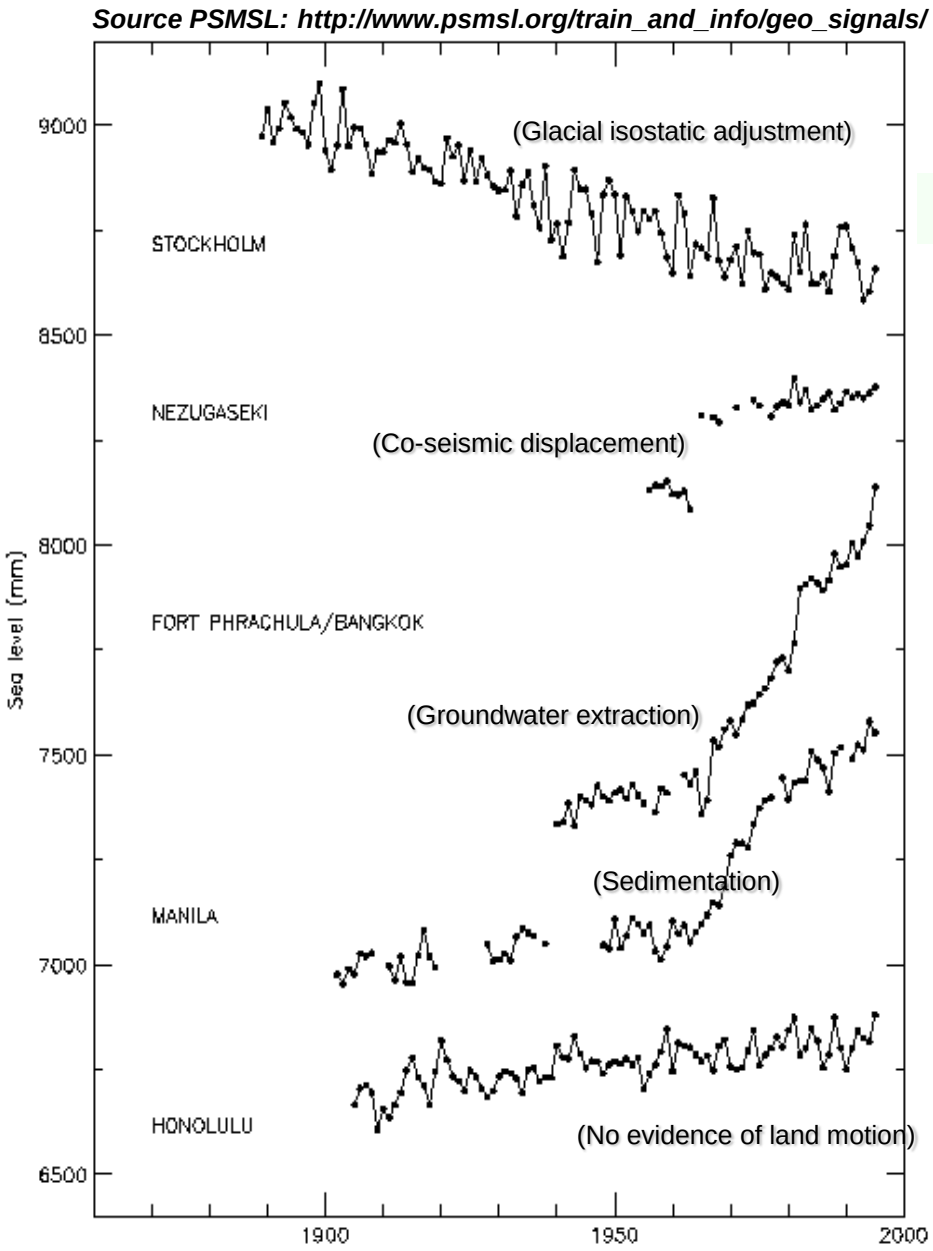


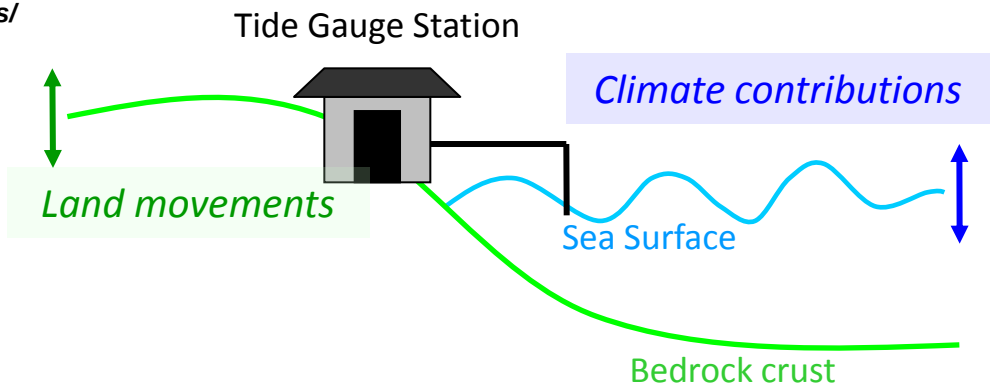
From Ishii et al. (2006)



Milne et al. (2009)

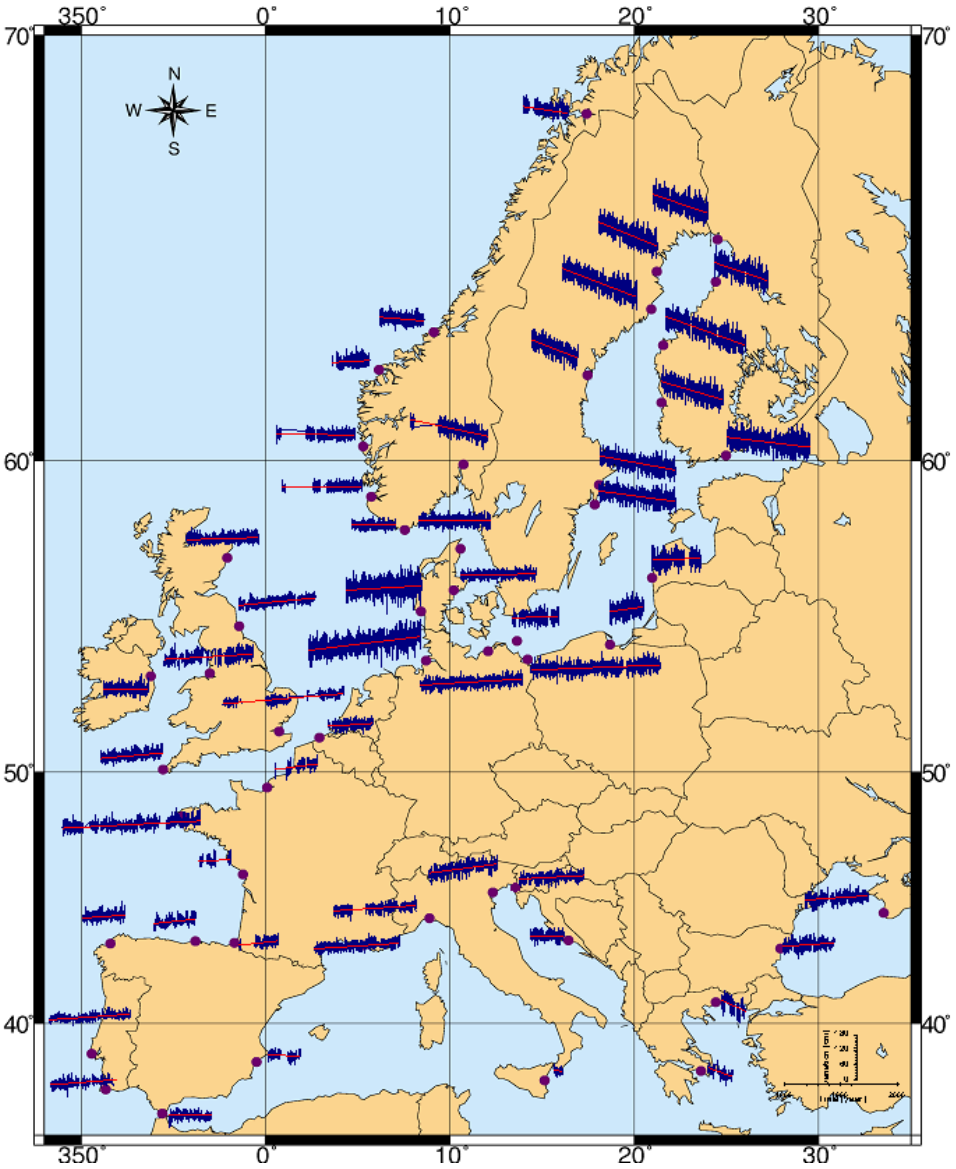
2. Empreintes spatiales: évidence observationnelle?



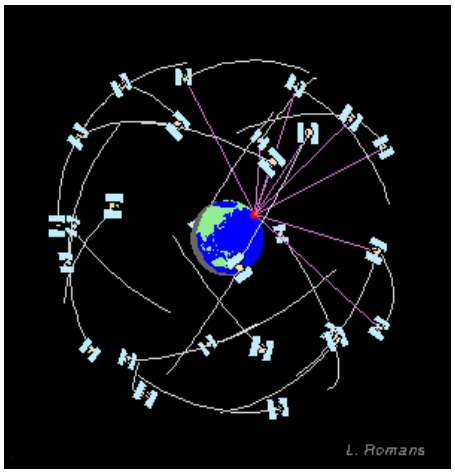


- Challenges
  - → Rates in sea-level change: ~1-2 mm/yr
  - → Standard errors several times smaller to be useful in those studies!
  - → Coastal management: climate sea level predictions + land movements

Comment déterminer les mouvements verticaux?



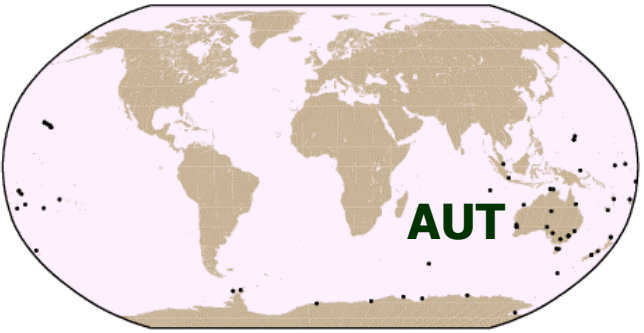
- Model predictions (GIA)
  - Uncertainties in the main geophysical parameters (lithospheric thickness, mantle viscosity…)
  - Imprecise knowledge of Earth's ice history
  - *What about other movements?*
- Measure (if one can…)
  - Introduction of GPS in continuous mode: CGPS@TG
  - Need for a stable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

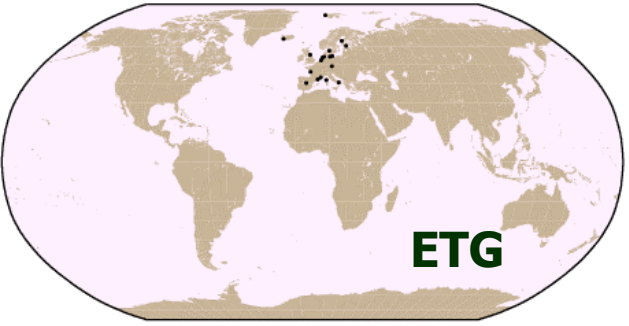


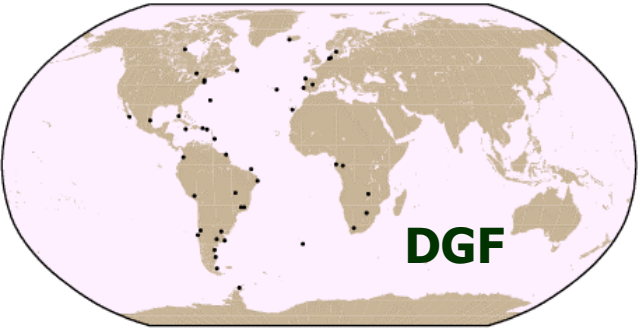
3. TIGA pilot project (IGS)

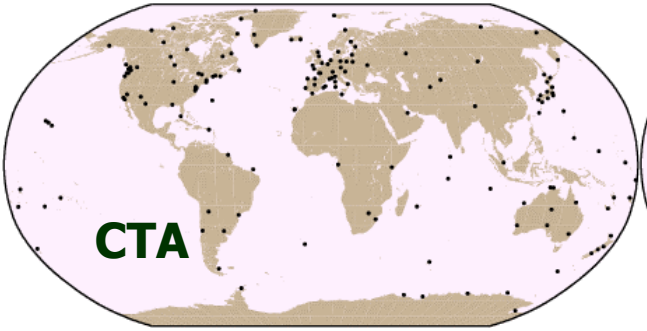
(Initiated in 2001, on a best-effort basis)

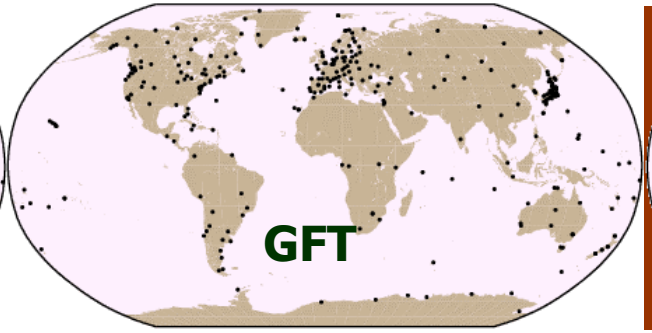
http://adsc.gfz-potsdam.de/tiga/index_TIGA.html

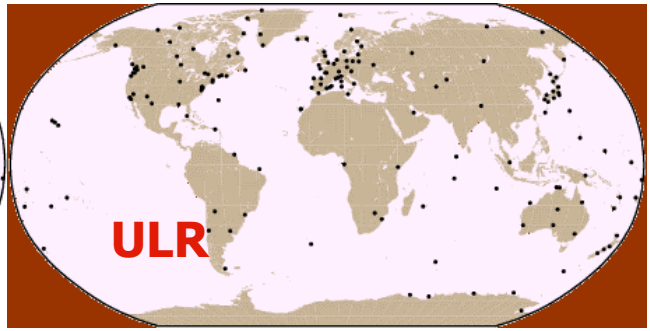








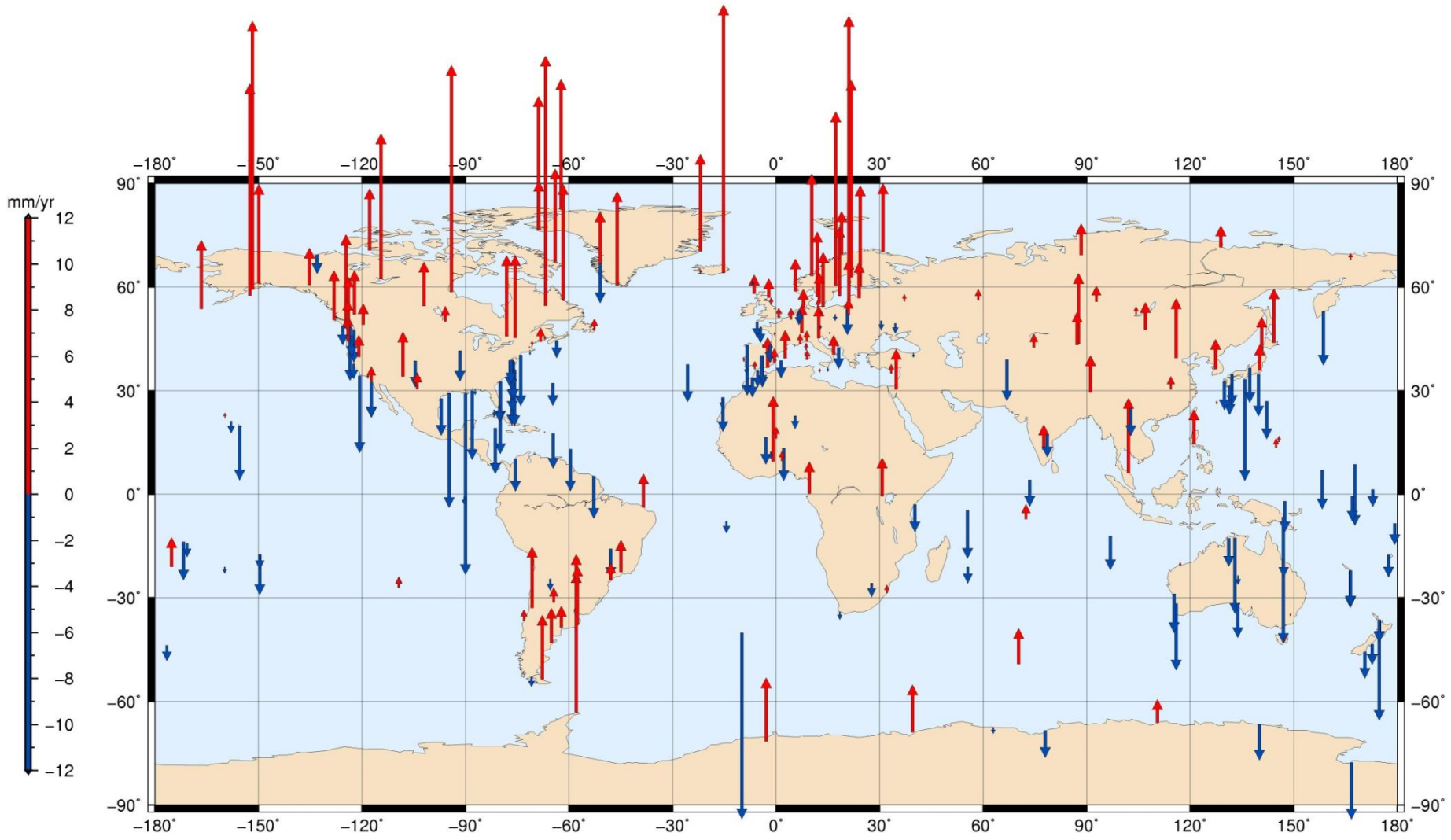




- "Tide Gauge Benchmark Monitoring"
  - 103 TOS, 2 TDC, 6 TAC, TAAC (?)
- Goals
  - Establish, maintain and expand a global cGPS@TG network
  - Compute precise station parameters for the cGPS@TG stations with a high latency
  - Reprocess all previously collected GPS data, if possible back to 1993
  -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

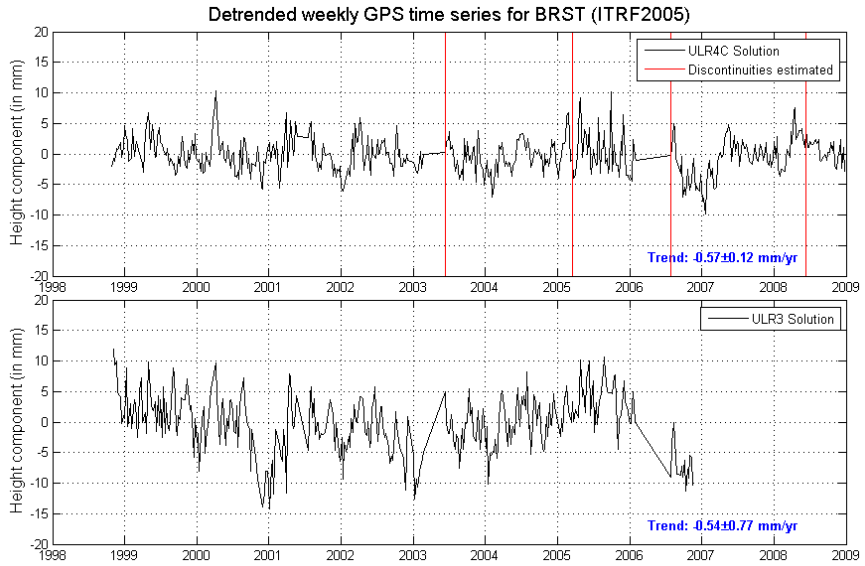
3. Dernière solution ULR (Ph-D. Santamaria-Gomez)

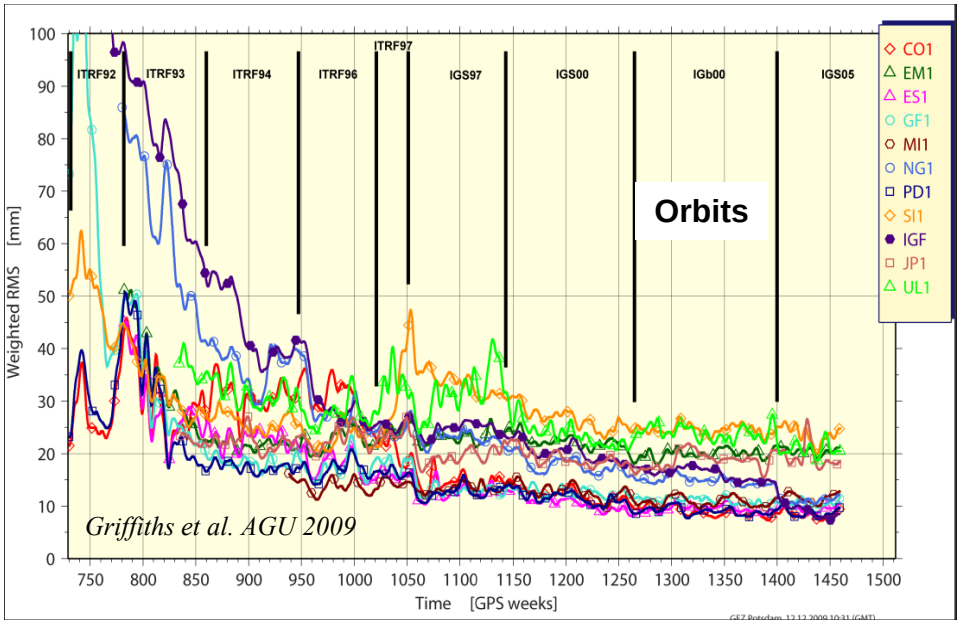
Santamaria-Gomez et al. (2011, *JGR)*

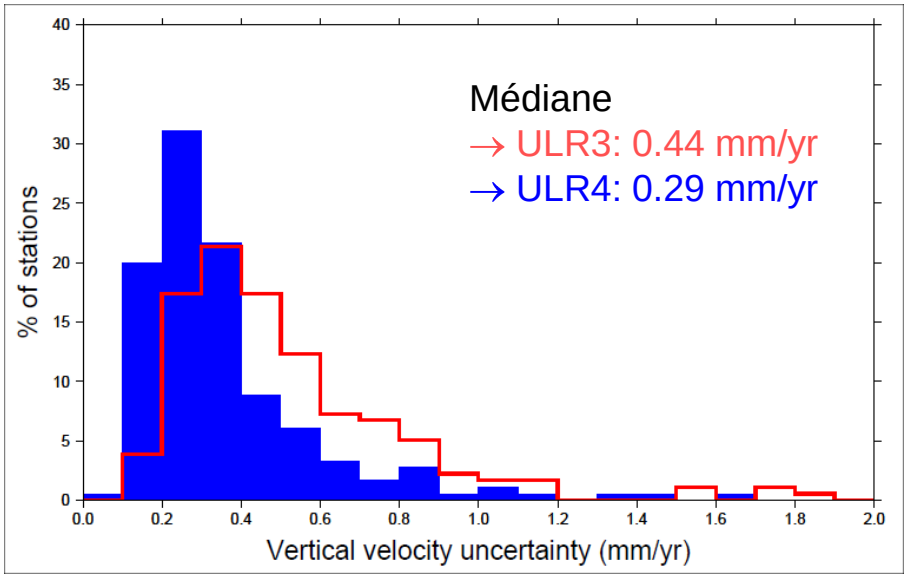


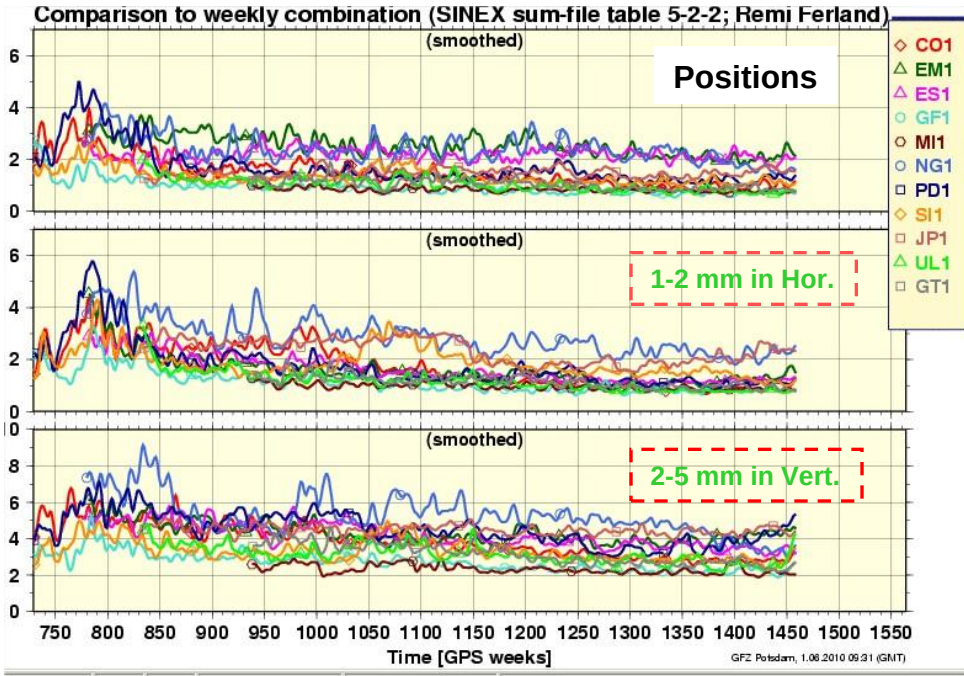
http://www.sonel.o rg/-Solutions-.html

3. Dernière solution ULR (Ph-D. Santamaria-Gomez)

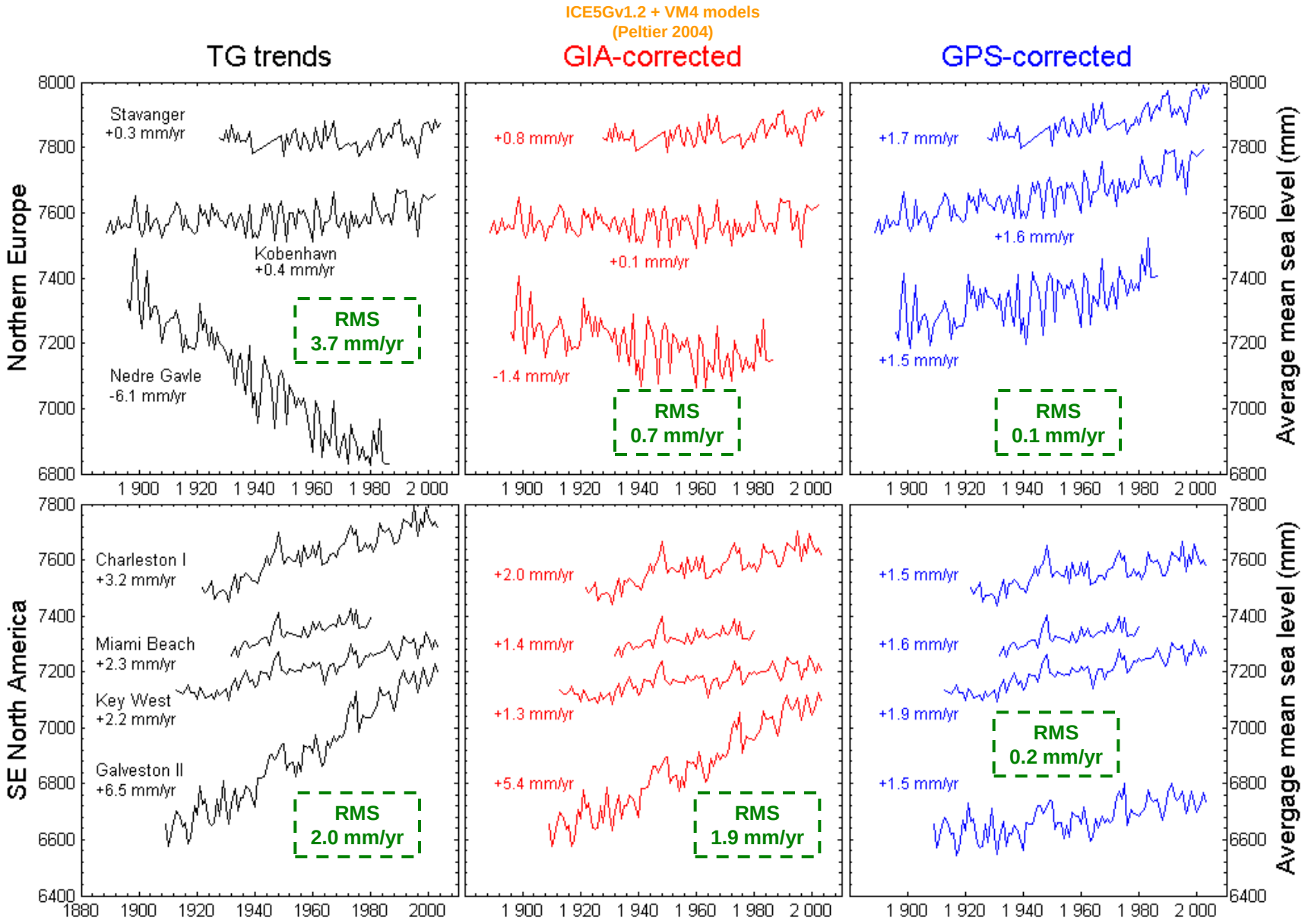








3. GPS velocities at TG... How well do they work?



For details: Wöppelmann et al. (2009) in *Geophys. Res. Lett.*

Rationale in *Global and Planetary Change* (Wöppelmann et al. 2007)

Limits: Working hypotheses

- 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):

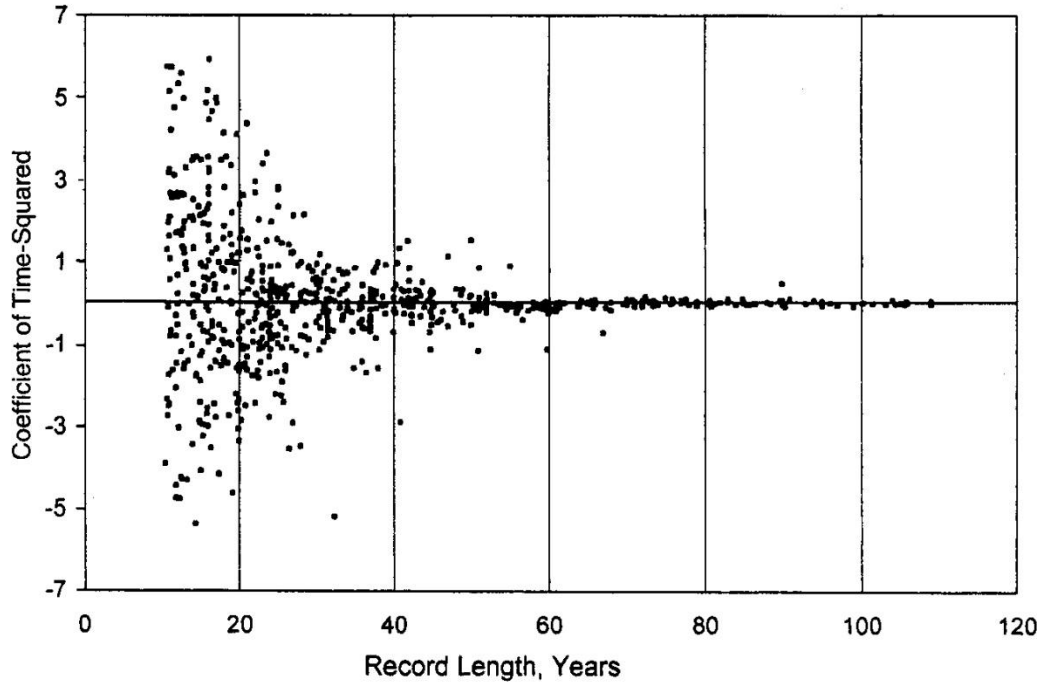


Figure 3.16 Acceleration component of relative sea levels.

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

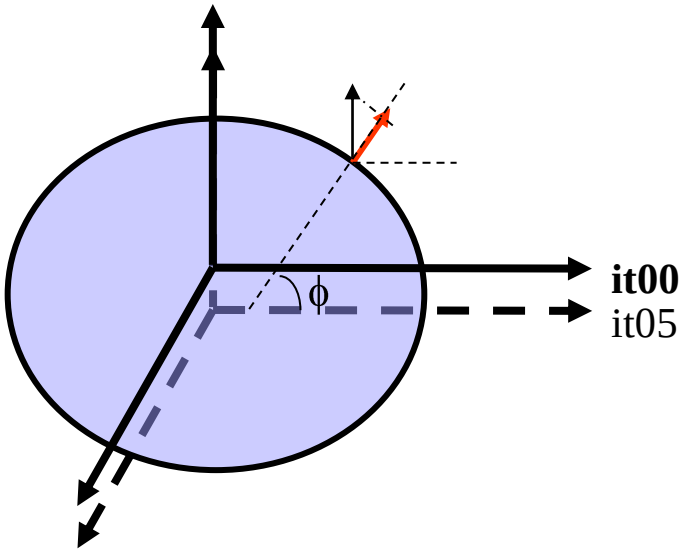
	TG	TG-GIA	TG+GPS (mm/yr)			
Solution	-	Peltier (2004) ICE-5G VM4	ULR1 ITRF2000 1999.0-2005.7	ULR2 ITRF2000 1997.0-2006.9	ULR3 ITRF2005 1997.0-2006.9	ULR4 ITRF2005 1996.0-2009.0
Sea level trends scatter (indiv.)	2.05	1.49	1.15	1.06	0.98	0.59
Sea level trends scatter (region.)	1.37	0.98	0.91	0.83	0.60	0.55
GSL trend		1.83 ± 0.21	1.31 ± 0.30	1.38 ± 0.28	1.61 ± 0.19	1.34 ± 0.12
			Wöppelmann et al. (2007) in *GPC*		Wöppelmann et al. (2009) in *GRL*	Santamaria-Gomez et al. (2011) in *JGR*

- Douglas (2001) criteria:
  - → Tide gauge records longer than 60yr
  - → 85% of valid data
  - → Regional grouping

  → 27 records grouped into 10 regions
  - → GIA corrections (Peltier 2001)
  - → **1.84 ± 0.35 mm/an**

3. Reference frame impact on GSLR estimates?

	TG	TG-GIA	TG+GPS (mm/yr)			
Solution	-	Peltier (2004) ICE-5G VM4	ULR1 ITRF2000 1999.0-2005.7	ULR2 ITRF2000 1997.0-2006.9	ULR3 ITRF2005 1997.0-2006.9	ULR4 ITRF2005 1996.0-2009.0
Sea level trends scatter (indiv.)	2.05	1.49	1.15	1.06	0.98	0.59
Sea level trends scatter (region.)	1.37	0.98	0.91	0.83	0.60	0.55
GSL trend		1.83 ± 0.21	1.31 ± 0.30	1.38 ± 0.28	1.61 ± 0.19	1.34 ± 0.12



Impact on the vertical velocities…

$$\Delta\frac{dS}{dt}(\Delta\dot{\mathbf{T}},\Delta\dot{d}) = \Delta\dot{d} + \left[\frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{n_i} p_{i,j}\mathbf{G}(\lambda_{ij},\phi_{ij})\right]\cdot\Delta\dot{\mathbf{T}}$$

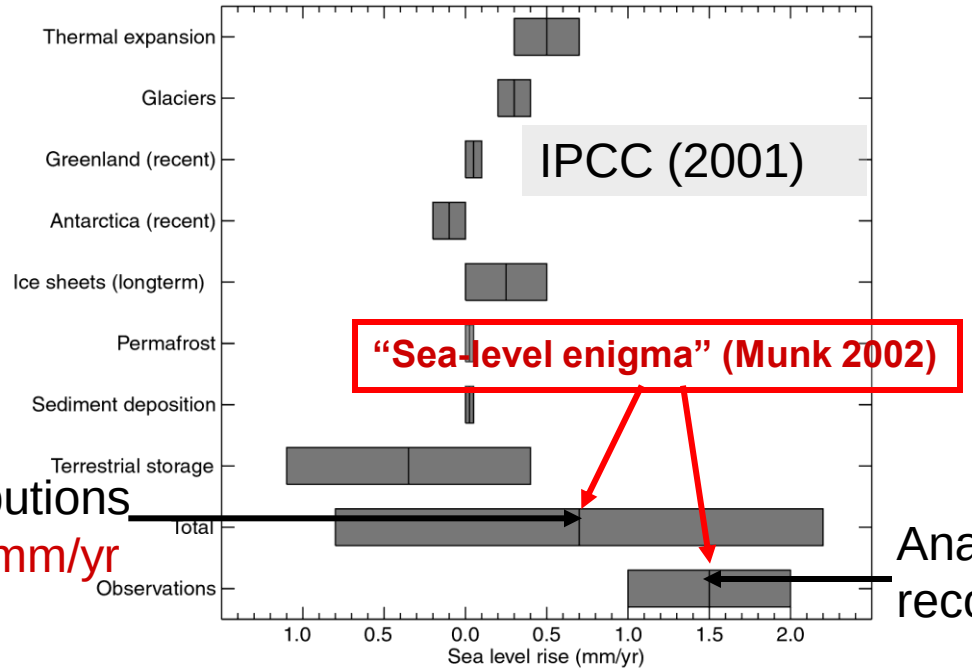
(Collilieux & Wöppelmann, 2011)

using: $\Delta Tz \cong 0.5\text{-}1.0$ mm/yr

$\Delta d = 0.5$ mm/yr

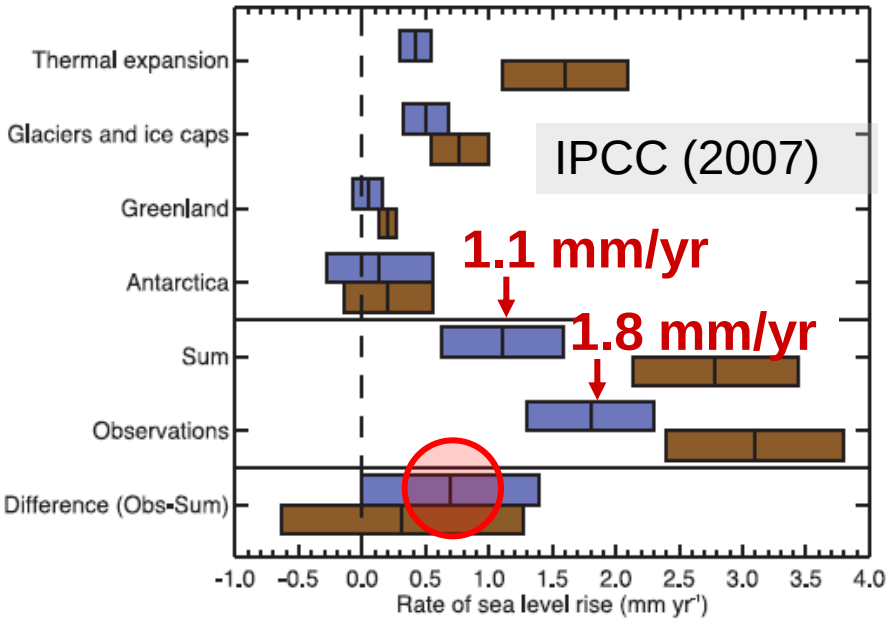
→ 1.6 ± 0.7 mm/yr

3. “Sea level enigma” (Munk 2002)

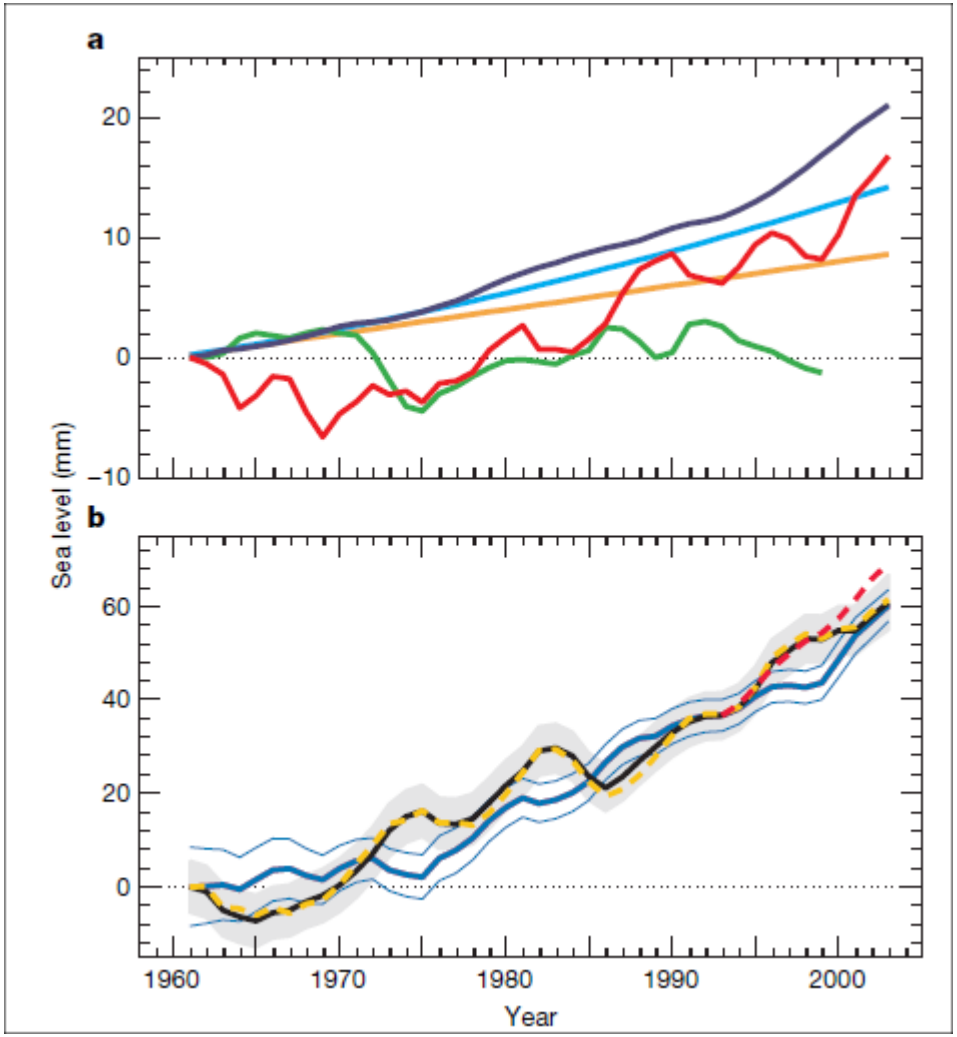


Sum of climatic contributions to sea level rise: ~0.7mm/yr

Analyses of tide gauge records ~1.5mm/yr



3. 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:

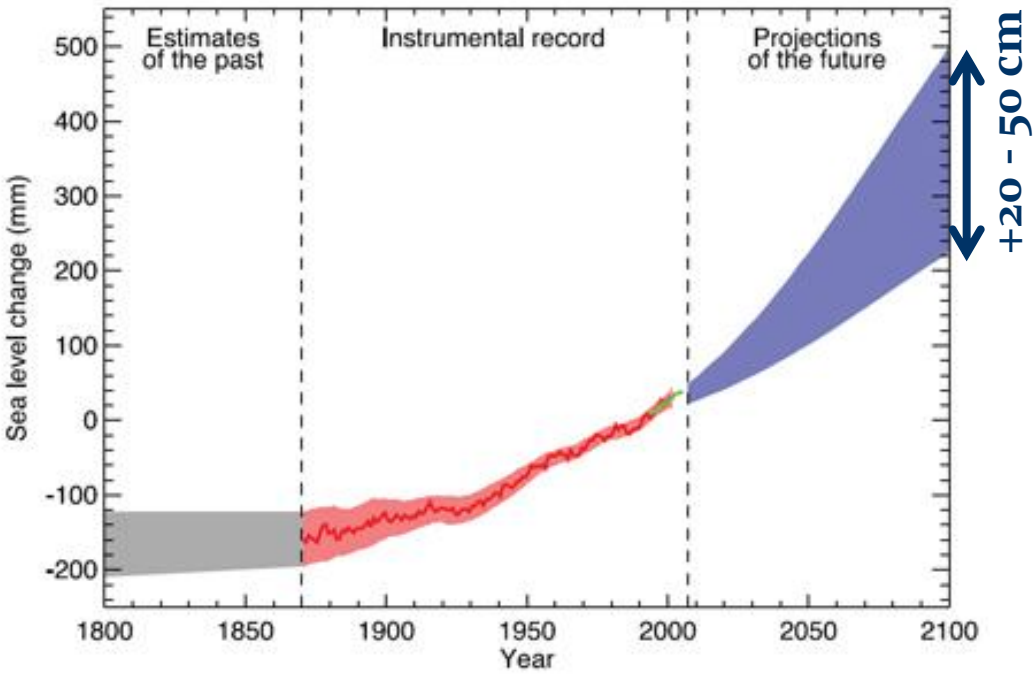
- ♦ Somme des composantes en a)
- ♦ Jevrejeva et al. (2006)
- ♦ Altimétrie radar embarquée sur satellite
- ♦ Cette étude (Domingues et al. 2008)

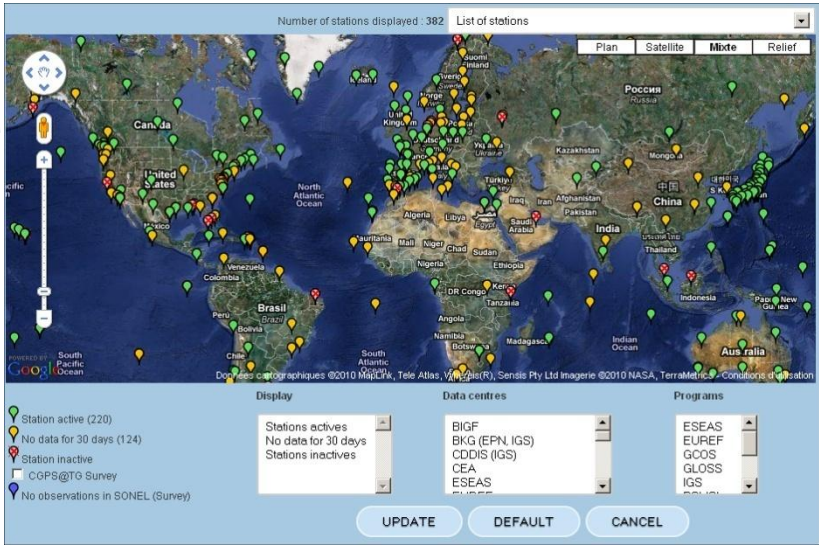
Soit,

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

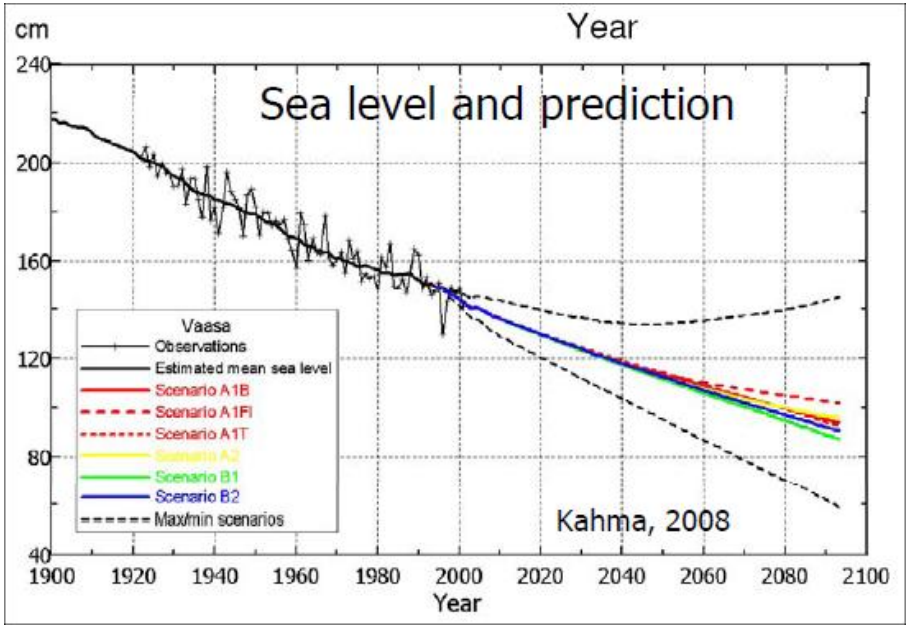
Domingues et al. (2008)

De l'importance des mouvements à la côte



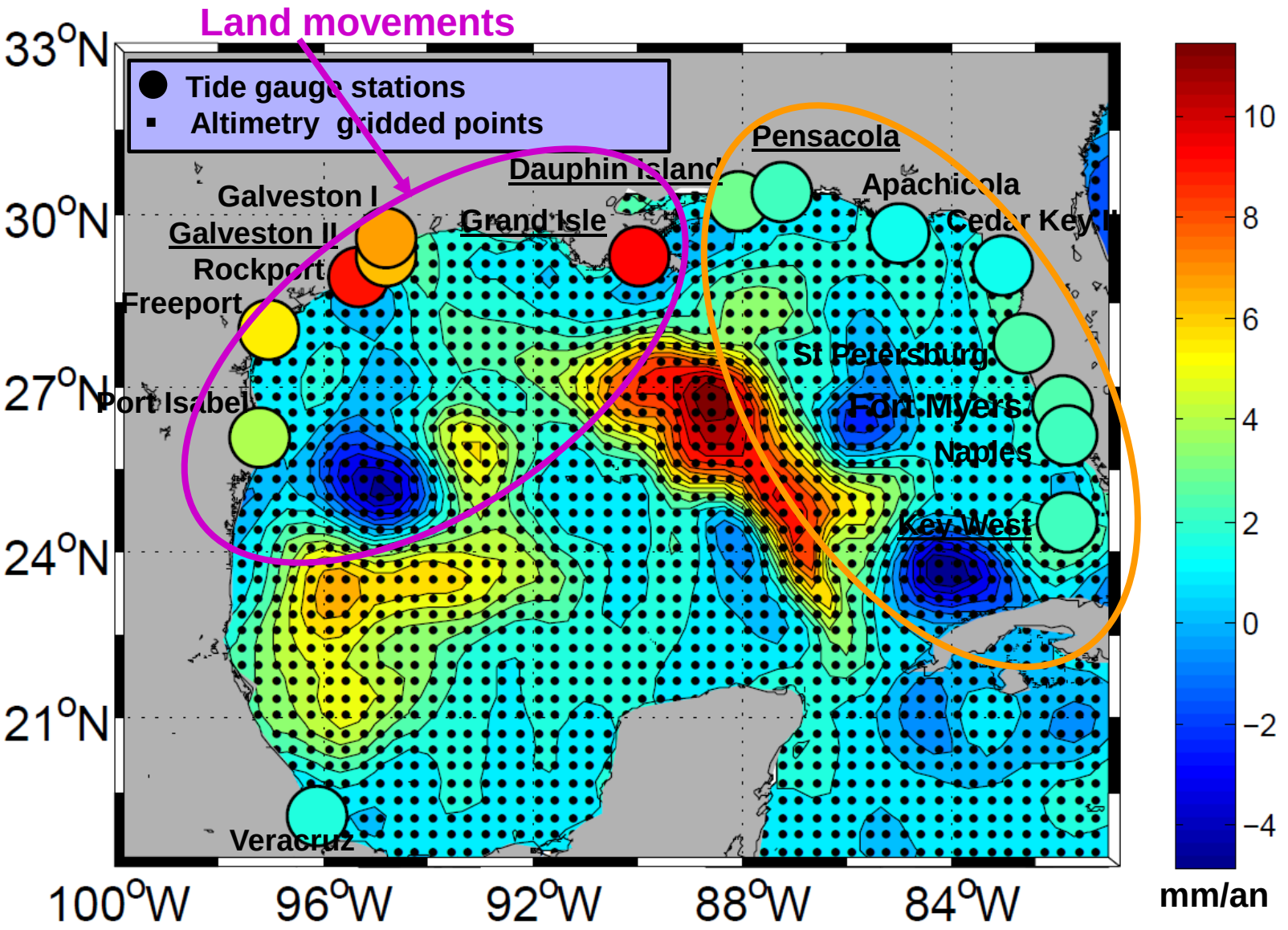


http://www.sonel.org/-GPS-.html



+8.6 ± 0.2 mm/yr (GPS ULR4)

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



Letetrel et al. (2010)

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)

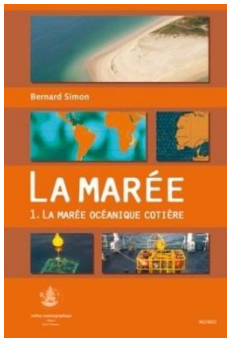
- Un bilan global clôt sur la période satellitale (1992-…)
  Contributions climatiques *versus* observations directes

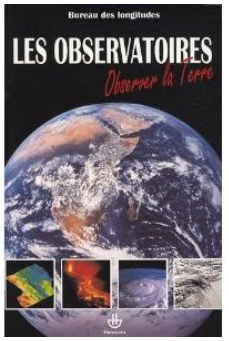
- Empreintes géographiques: global ≠ local
  - les prédictions climatiques ne sont pas suffisantes
  - importance des mouvements verticaux à la côte

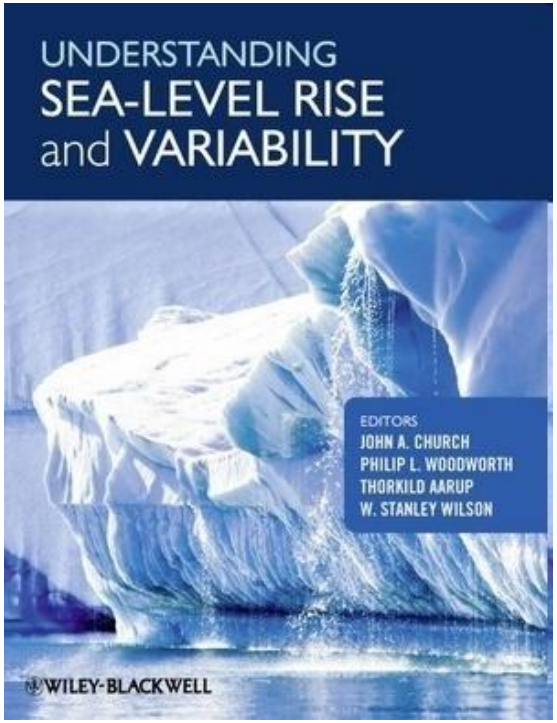
- La France, très regardée au niveau international (GLOSS)
  - place conquise grâce à Topex/Poseidon,… (CNES)
  - des territoires un peu partout dans le globe (cf.sites GLOSS)

Pour en savoir plus…

- Published papers in scientific journals
  - Santamaria-Gomez *et al.* (2011) in *Journal of Geophysical Research*
  - Collilieux & Wöppelmann (2011) in *Journal of Geodesy*
  - Bouin & Wöppelmann (2010) in *Geophysical Journal International*
  - Wöppelmann *et al.* (2009) in *Geopysical Research Letters*
  - Wöppelmann *et al.* (2007) in *Global & Planetary Change*
  - Wöppelmann *et al.* (2006) in *C.R. Geoscience*
- Others…
  - Cazenave & Llovel (2010) in *Annu. Rev. Marine Sci., pp.145-173.*
  - Domingues *et al.* (2008) in *Nature, pp.1090-1093.*
  - Milne *et al.* (2009) in *Nature Geoscience, pp.471-478*.
  - Woodworth (2006) in *Phil. Trans. R. Soc. A, pp.787-803.*
  - …







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Chap 2. Impacts of and Responses to Sea-Level Rise
Chap 3. A First-Order Assessment of the Impact of Long-Term Trends in Extreme Sea Levels on Offshore Structures and Coastal Refineries
Chap 4. Paleoenvironmental Records, Geophysical Modeling, and Reconstruction of Sea-Level Trends and Variability on Centennial and Longer Timescales
Chap 5. Modern Sea-Level-Change Estimates
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