Université de **La Rochelle**

LIENSs
UMR 6250
LIttoral ENvironnement et Sociétés

Séminaire GRGS sur la géodésie millimétrique

Quelques éléments de réflexion sur les applications « niveau de la mer »

Guy Wöppelmann
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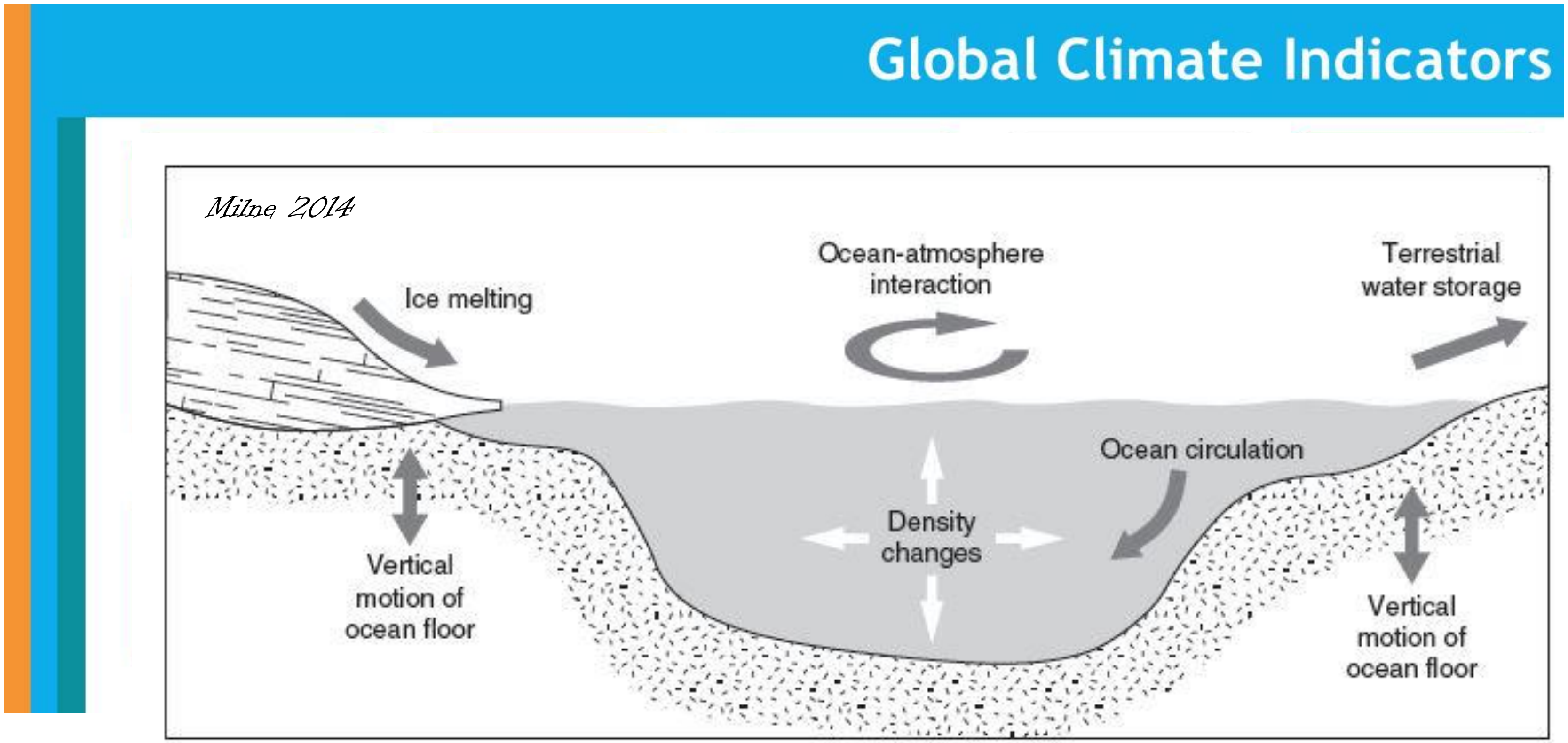
Essential Climate Variables (ECV)

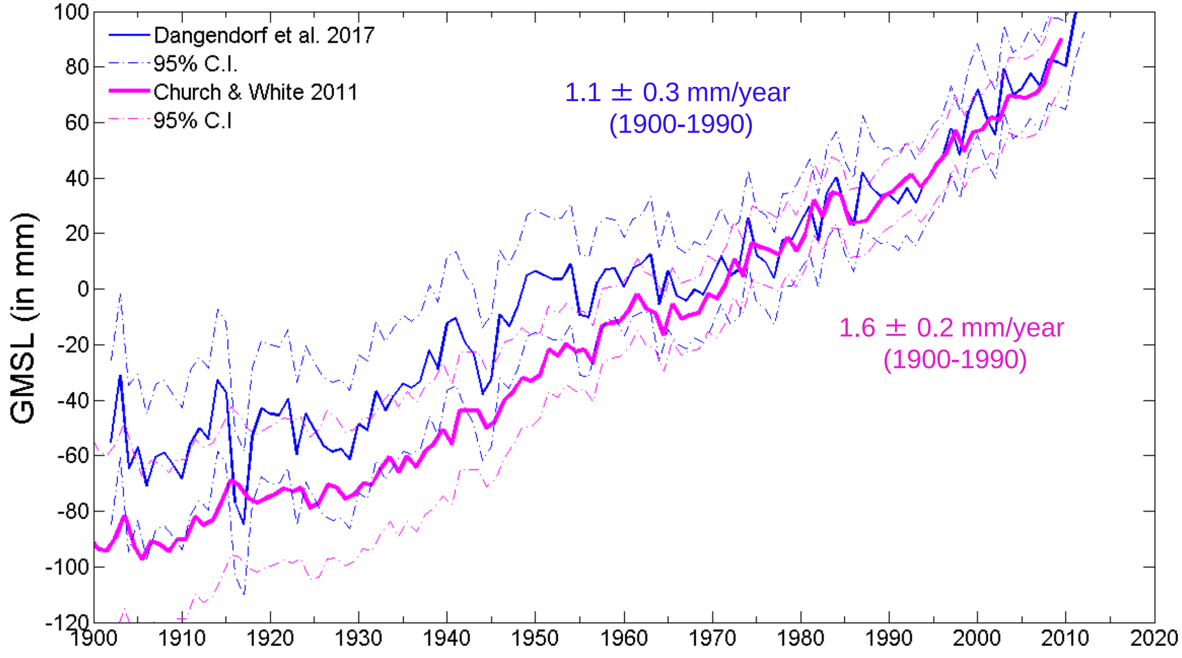
Bojinski et al. 2017



defined by GCOS (Global Climate Observing System)
and WMO (World Meteorological Organization)

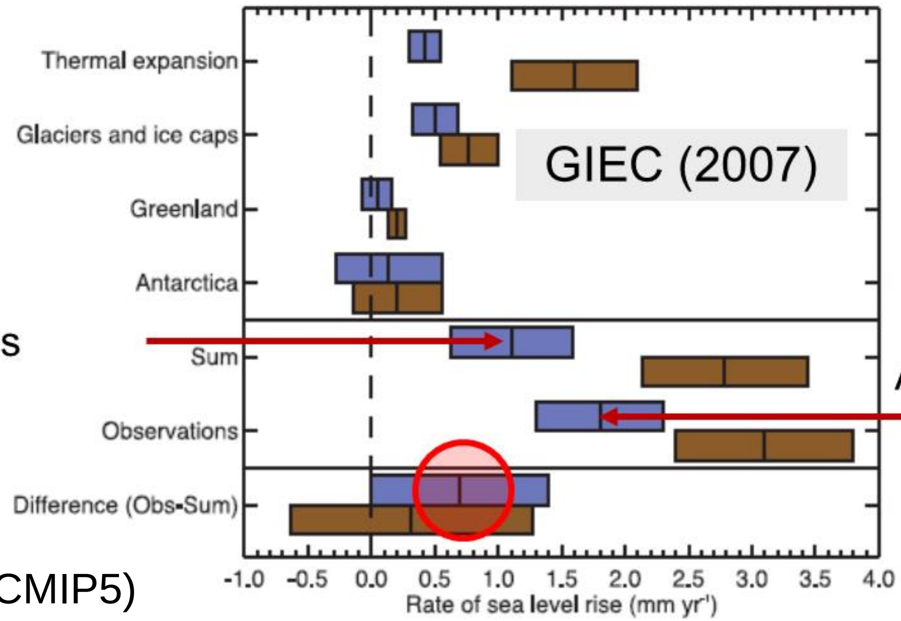
GCOS 2018 ; WMO 2018)

Assessing the 20th Century Global Mean Sea Level (GMSL) Rise



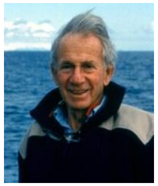
- An important (scientific & societal) need, because
  - Sea level is an Essential Climate Variable: ocean warming, ice melting
  - 0.5 mm/year difference in GMSL corresponds to ~180 Gt per year of melted water from land-ice

(1.6 mm/year) → Where does the difference wrt climate contributions come from???



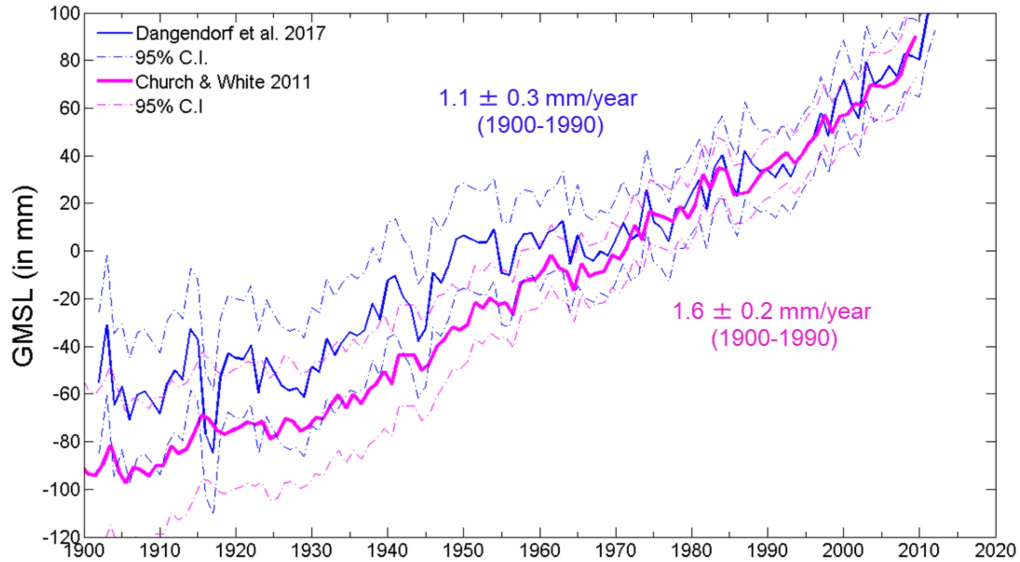
Σ des contributions
~1.1 mm/an

Analyses marégraphes
~1.8 mm/an

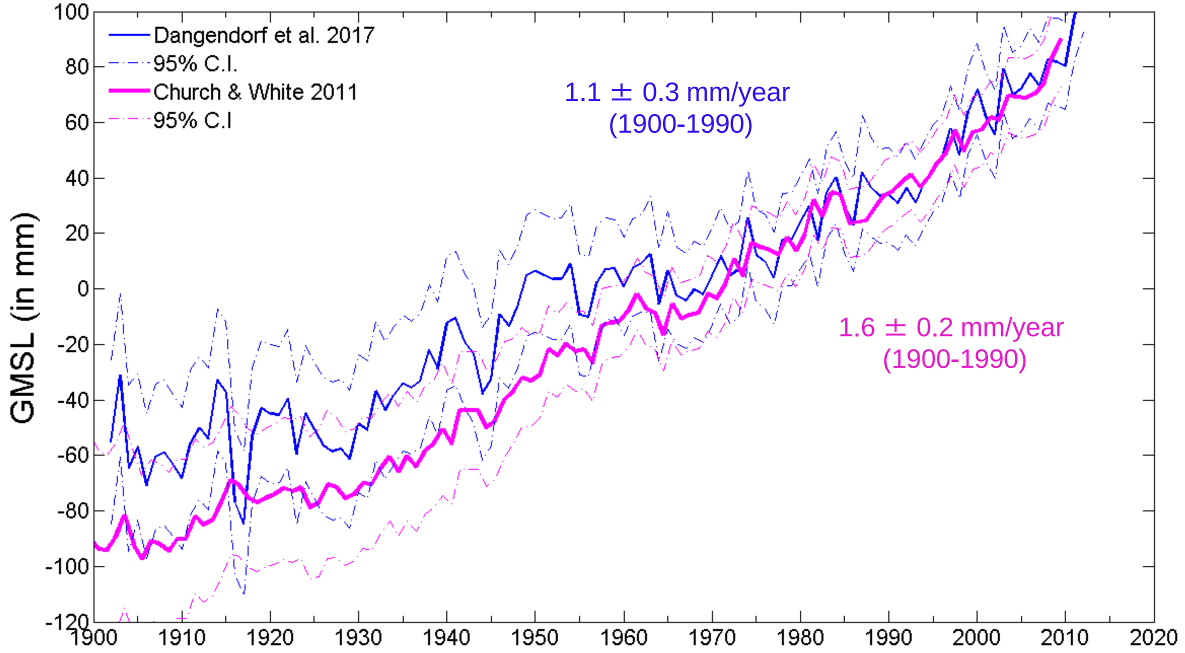



Scripps Institute, La Jolla, San Diego, California

Σ des contributions (CMIP5)
~1.0 $\pm$ 0.2 mm/an



Assessing the 20th Century Global Mean Sea Level (GMSL) Rise



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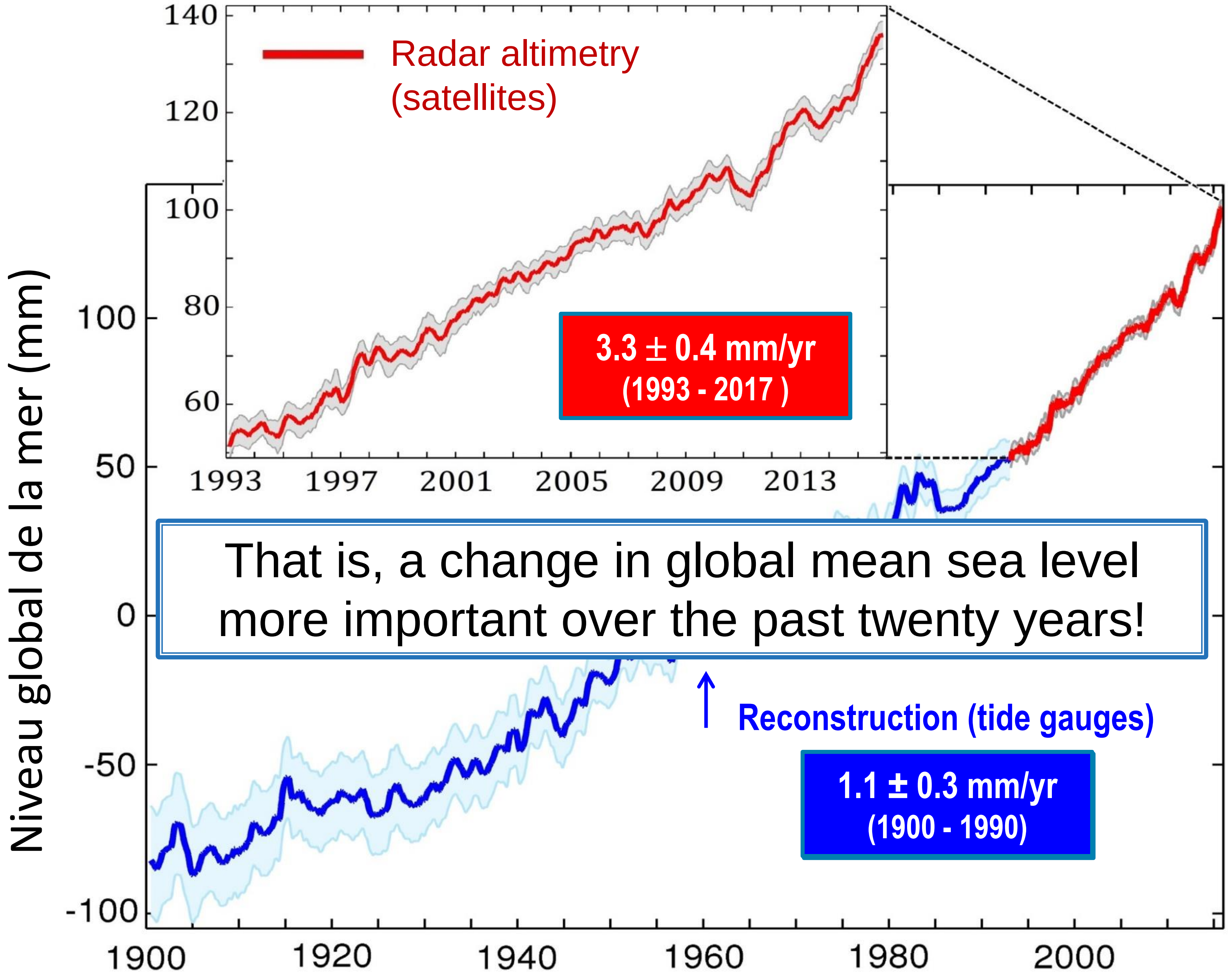
  - 0.5 mm/year difference in GMSL

    corresponds to ~180 Gt per year of melted water from land-ice

(1.6 mm/year) → Where does the difference wrt climate contributions come from???

(1.1 mm/year) → An increased (accelerated) sea level rise since 1990s (3.2 mm/year)!!!

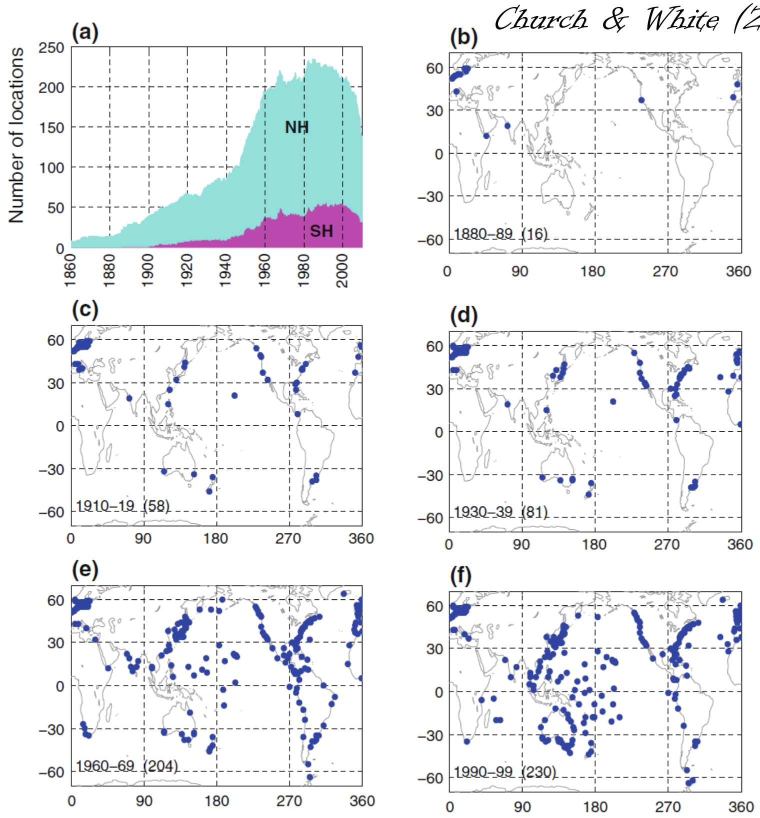


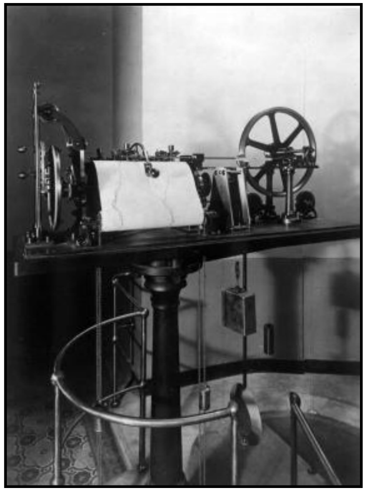
Niveau global de la mer (mm)
Radar altimetry
(satellites)
3.3 ± 0.4 mm/yr
(1993 - 2017)
That is, a change in global mean sea level
more important over the past twenty years!
Reconstruction (tide gauges)
1.1 ± 0.3 mm/yr
(1900 - 1990)
140
120
100
80
60
1993
1997
2001
2005
2009
2013
100
50
0
-50
-100
1900
1920
1940
1960
1980
2000

Reducing uncertainties in estimates of 20th Cy sea-level change: an important need & a challenge

- A challenge, because
  - Long instrumental records before 1990s are rare and heterogeneous (sampling, quality)
  - Located at the coast, recording either climate or/and solid earth processes

Church & White (2011)





Marseille (France)

Vairao (French Polynesia)

Reducing uncertainties in estimates of 20th Cy sea-level change: an important need & a challenge

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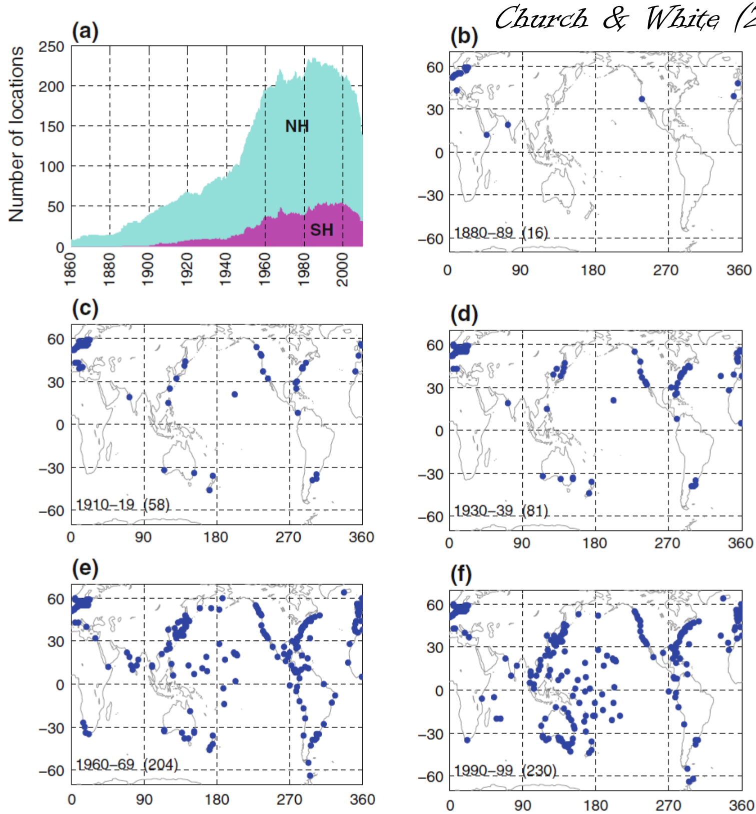
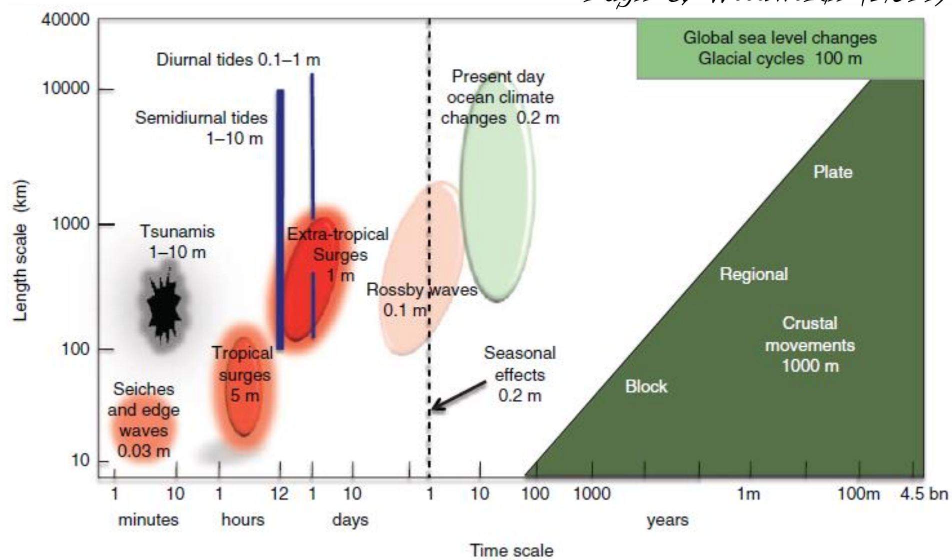


Pugh & Woodworth (2014)



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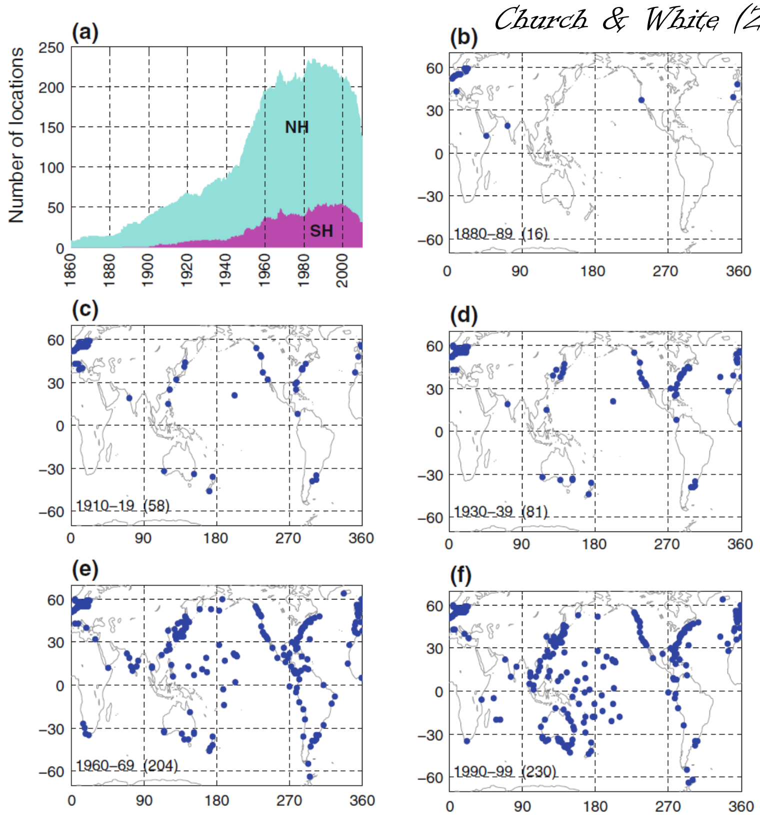
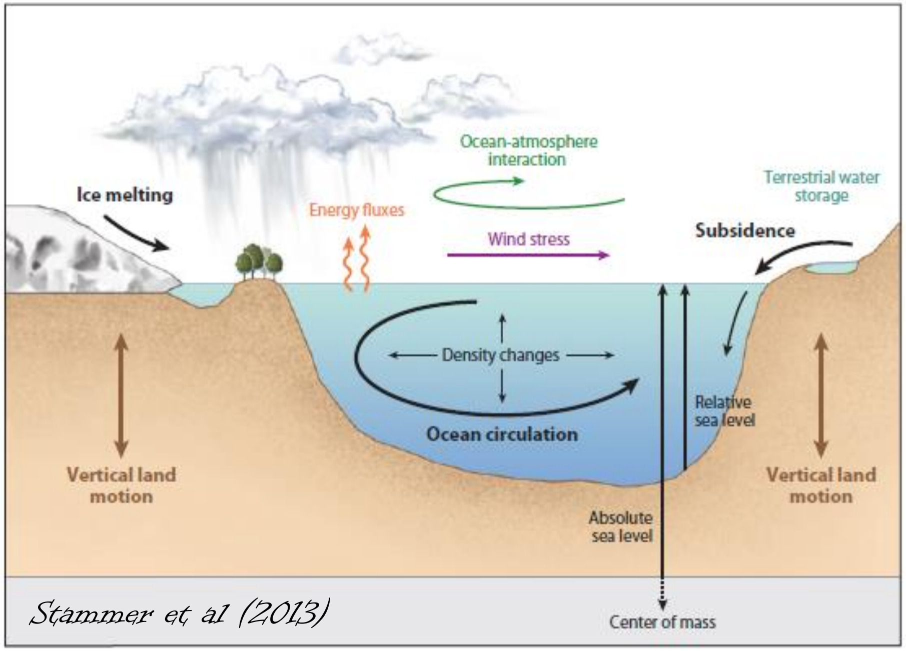
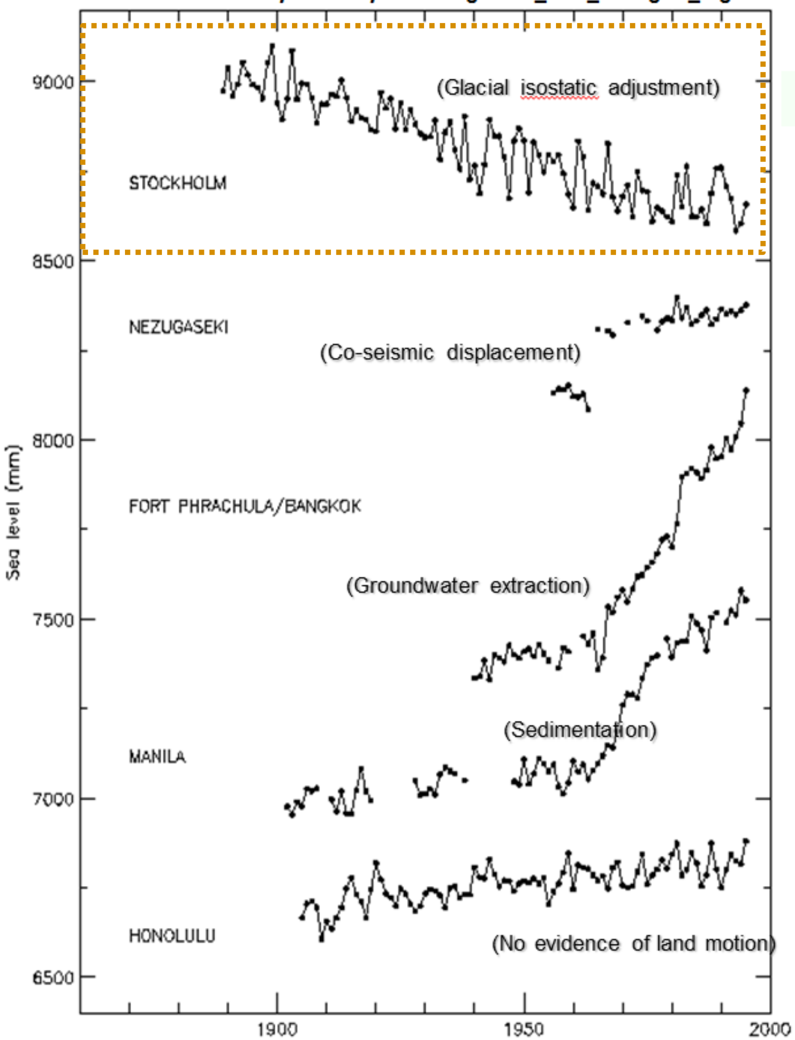




Stammer et al (2013)

Déplacements verticaux de la terre solide

Source PSMSL: http://www.psmsl.org/train_and_info/geo_signals/

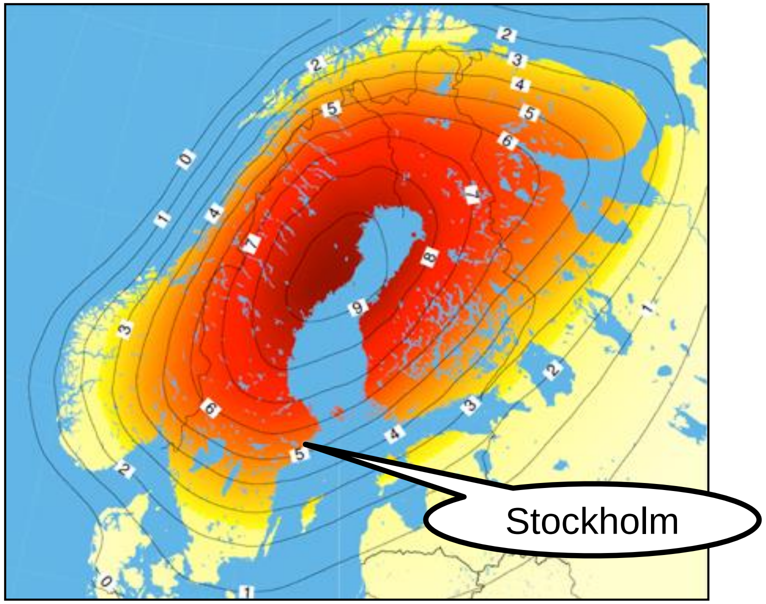


Tendance du marégraphe de Stockholm

-3.8 ± 0.2 mm/an (1889 – 2015)

+5.2 mm/an (GIA soulèvement crustal)

Prédiction du modèle de rebond postglaciaire
https://www.maanmittauslaitos.fi/en/research/interesting-topics/land-uplift



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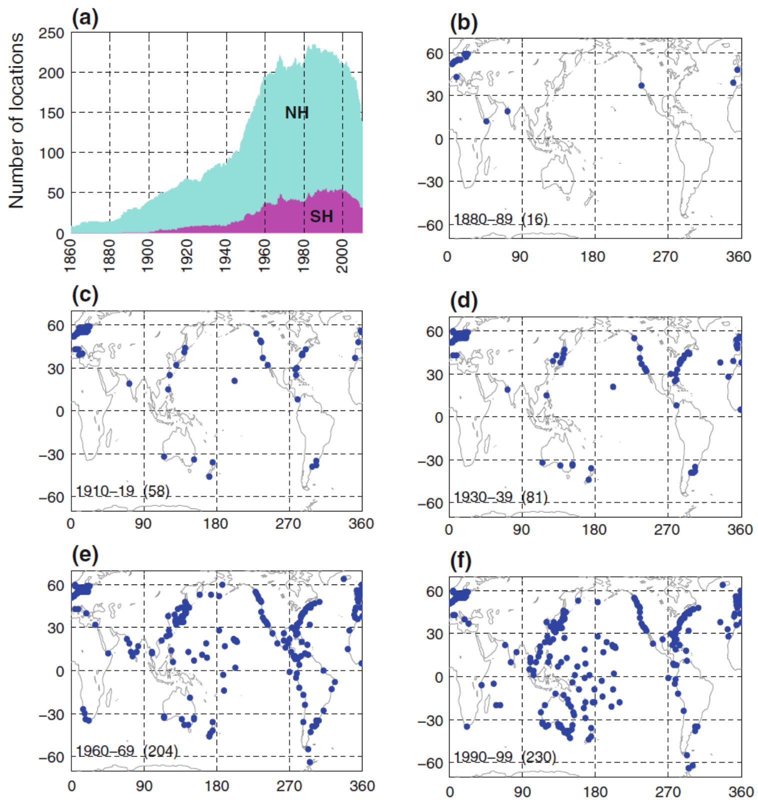
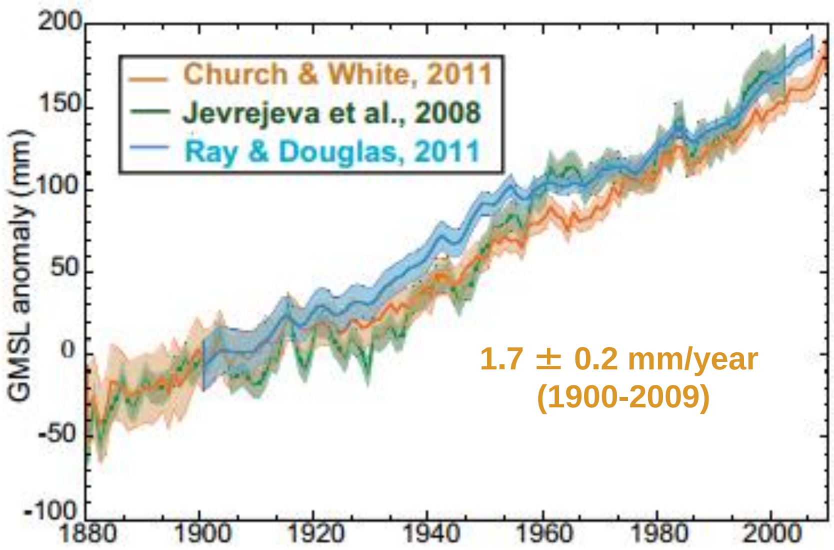




Vertical Land Motion (VLM): one of the dominant uncertainties in determining rates of sea-level change

PNAS PNAS PNAS PNAS PNAS

Reassessment of 20th century global mean sea level rise

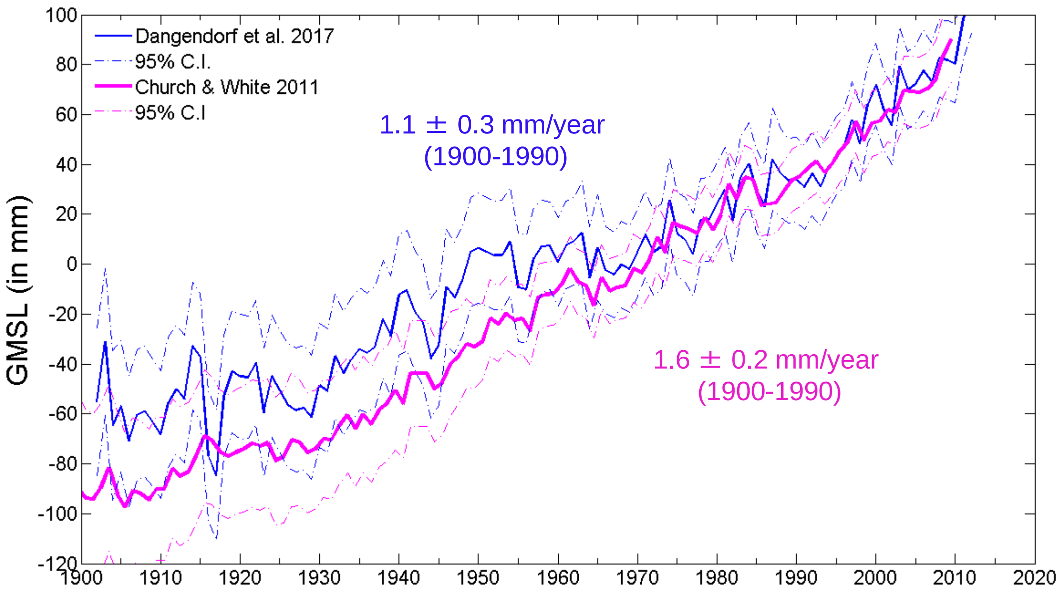
Sönke Dangendorf[a,1], Marta Marcos[b], Guy Wöppelmann[c], Clinton P. Conrad[d], Thomas Frederikse[e], and Riccardo Riva[e]

[a]Research Institute for Water and Environment, University of Siegen, 57076, Siegen, Germany; [b]Instituto Mediterráneo de Estudios Avanzados (IMEDEA) [Instituto mixto entre la Universidad de las Islas Baleares (UIB) y el Consejo Superior de Investigaciones Científicas (CSIC)], E-07190, Esporles, Spain; [c]Littoral Environnement et Sociétés (LIENSs), Universite de La Rochelle-CNRS, 17000, La Rochelle, France; [d]Centre for Earth Evolution and Dynamics, University of Oslo, NO-0315 Oslo, Norway; and [e]Department of Geoscience and Remote Sensing, Delft University of Technology, 2628CN, Delft, The Netherlands

Edited by Anny Cazenave, Centre National d'Etudes Spatiales, Toulouse Cedex 9, France, and approved April 17, 2017 (received for review September 28, 2016)

The rate at which global mean sea level (GMSL) rose during the 20th century is uncertain, with little consensus between various reconstructions that indicate rates of rise ranging from 1.3 to 2 mm·y^{-1}. Here we present a 20th-century GMSL reconstruction computed using an area-weighting technique for averaging tide gauge records that both incorporates up-to-date observations of vertical land motion (VLM) and corrections for local geoid changes resulting from ice melting and terrestrial freshwater storage and allows for the identification of possible differences compared with earlier attempts. Our reconstructed GMSL trend of 1.1 ± 0.3 mm·y^{-1} (1σ) before 1990 falls below previous estimates, whereas our estimate of 3.1 ± 1.4 mm·y^{-1} from 1993 to 2012 is consistent with independent estimates from satellite altimetry, leading to overall acceleration larger than previously suggested. This feature is geographically dominated by the Indian Ocean–Southern Pacific region, marking a transition from lower-than-average rates before 1990 toward unprecedented high rates in recent decades. We demonstrate that VLM corrections, area weighting, and our use of a common reference datum for tide gauges may explain the lower rates compared with earlier GMSL estimates in approximately equal proportion. The trends and multidecadal variability of our GMSL curve also compare well to the sum of individual contributions obtained from historical outputs of the Coupled Model Intercomparison Project Phase 5. This, in turn, increases our confidence in process-based projections presented in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

global mean sea level | tide gauges | vertical land motion | fingerprints | climate change



GMSL budget with estimates of the contribution of the ice sheets, using Coupled Model Intercomparison Project Phase 5 (CMIP5) historical runs as forcing. However, as discussed in ref. 13, the

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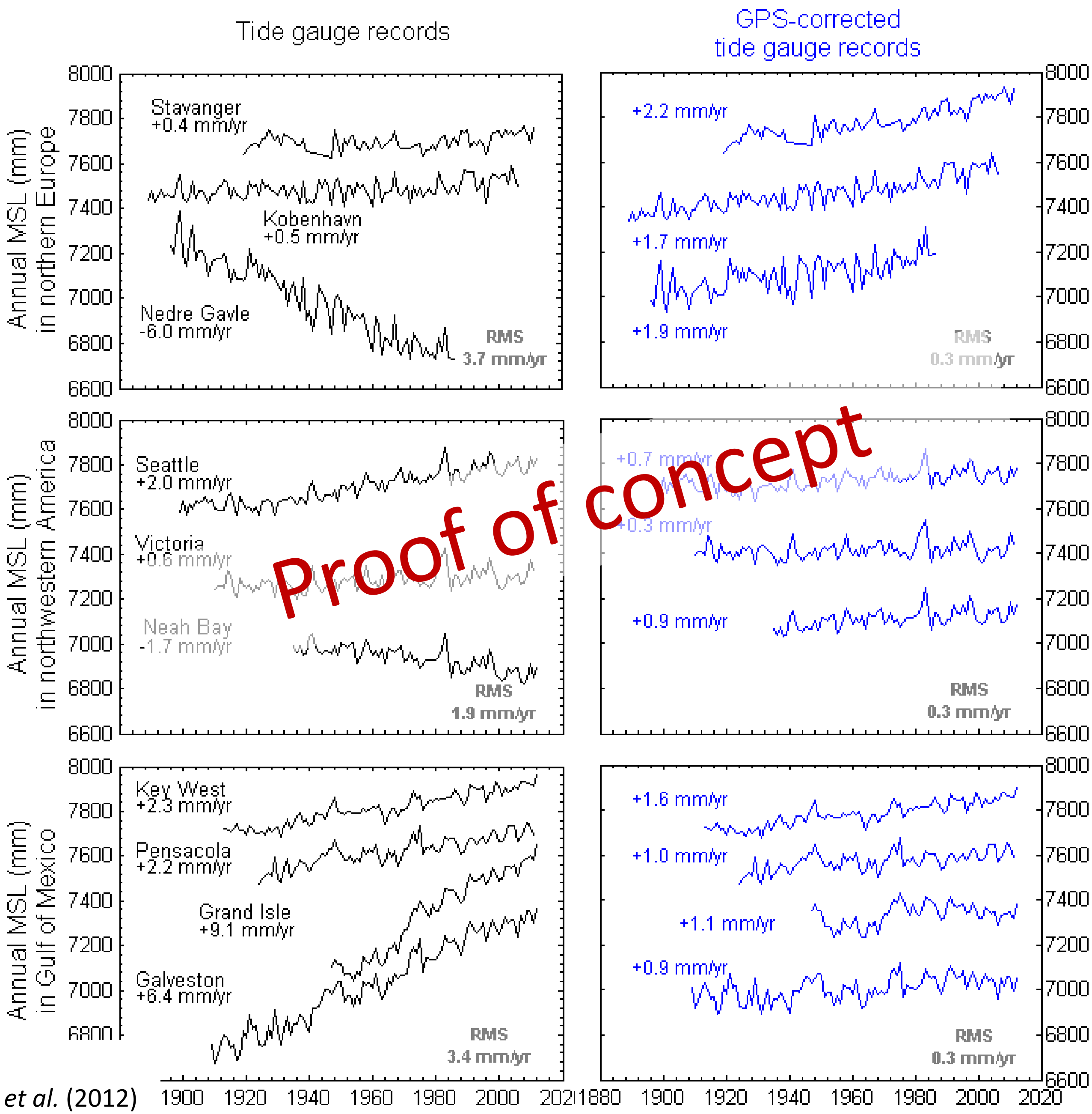
The GPS solution

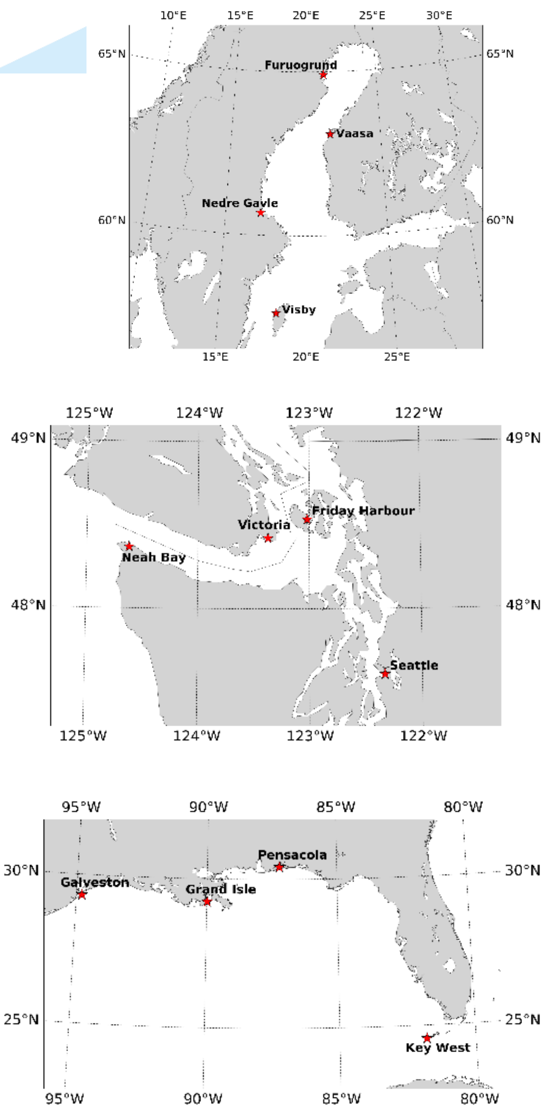
Progreso (GLOSS 213)

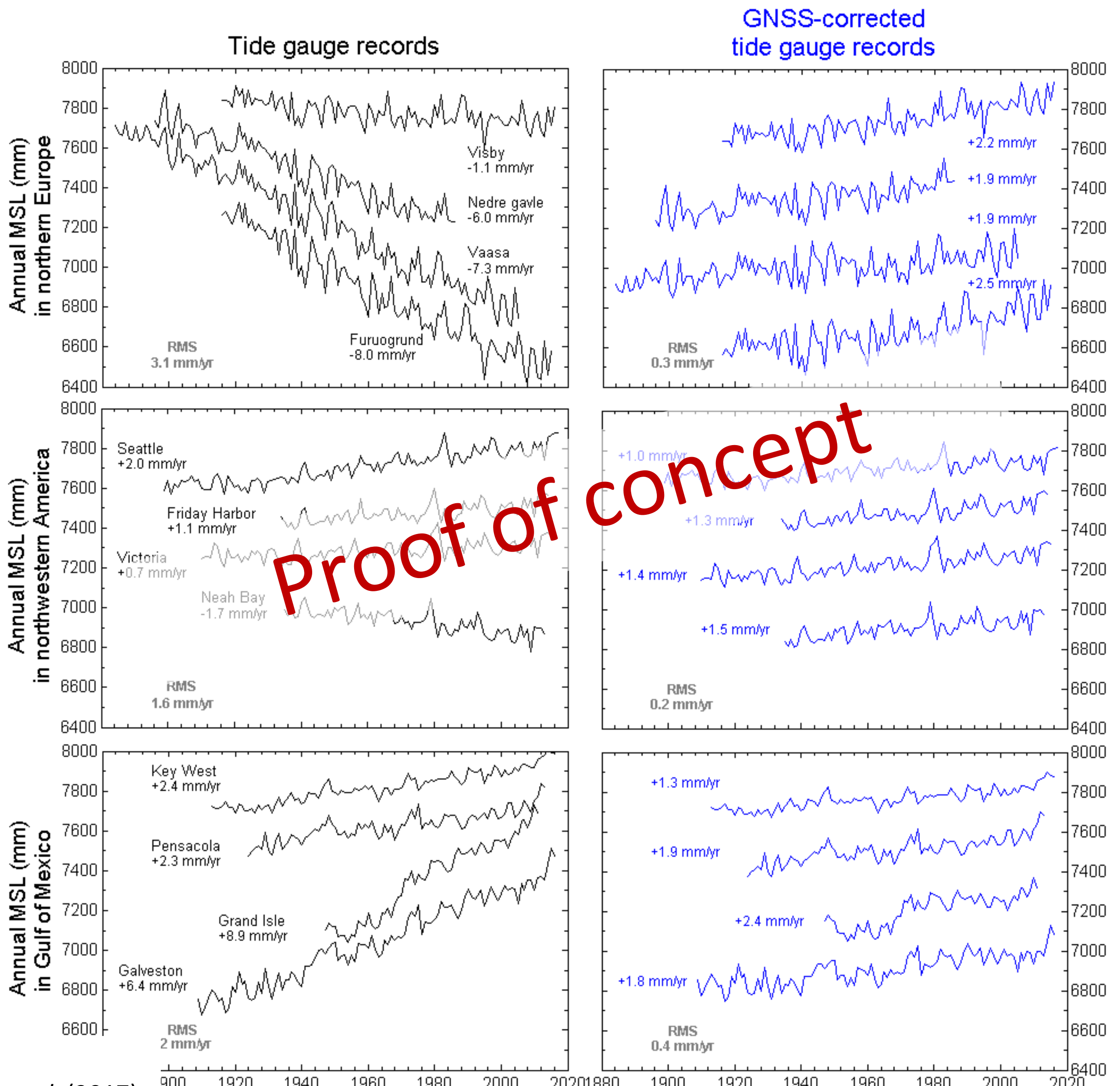
Male (GLOSS 28)



Updated from Wöppelmann *et al.* (2007)
using **ULR5** solution by Santamaria-Gomez *et al.* (2012)

The GPS solution





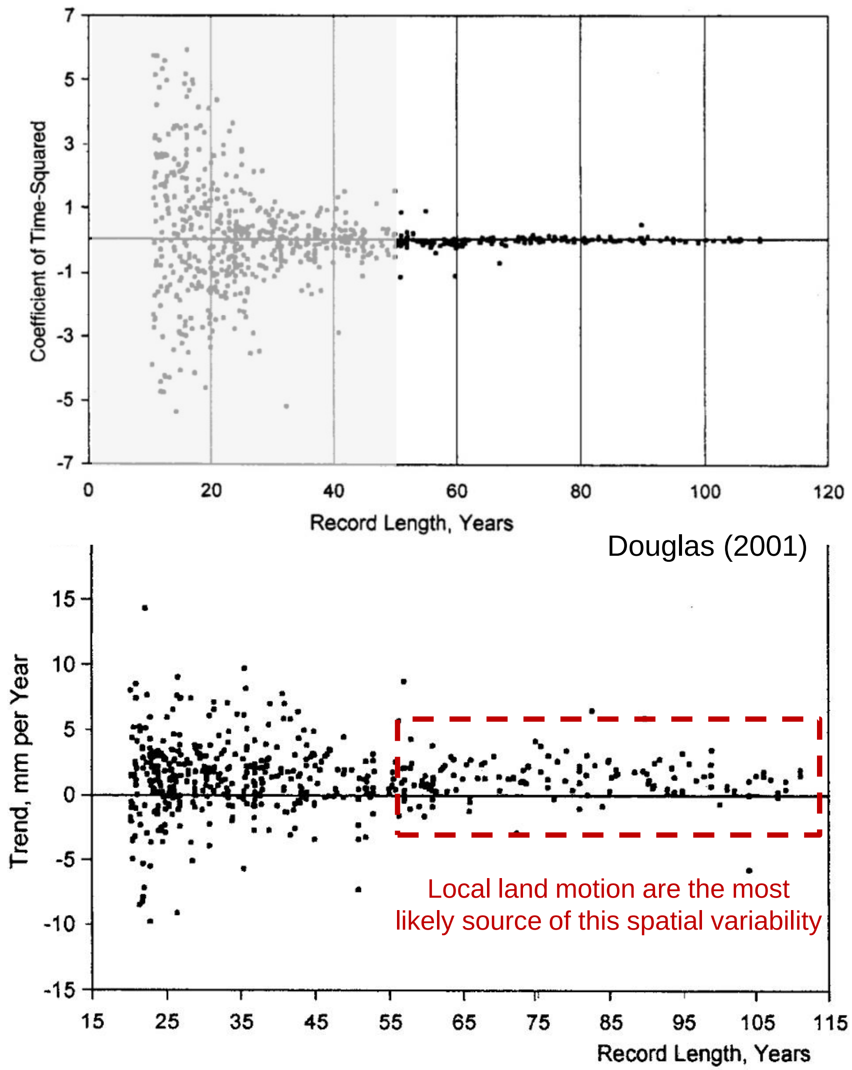
Updated from Wöppelmann *et al.* (2007)
using **ULR6** solution by Santamaria-Gomez *et al.* (2017)

Further investigating spatial variability in sea level trends

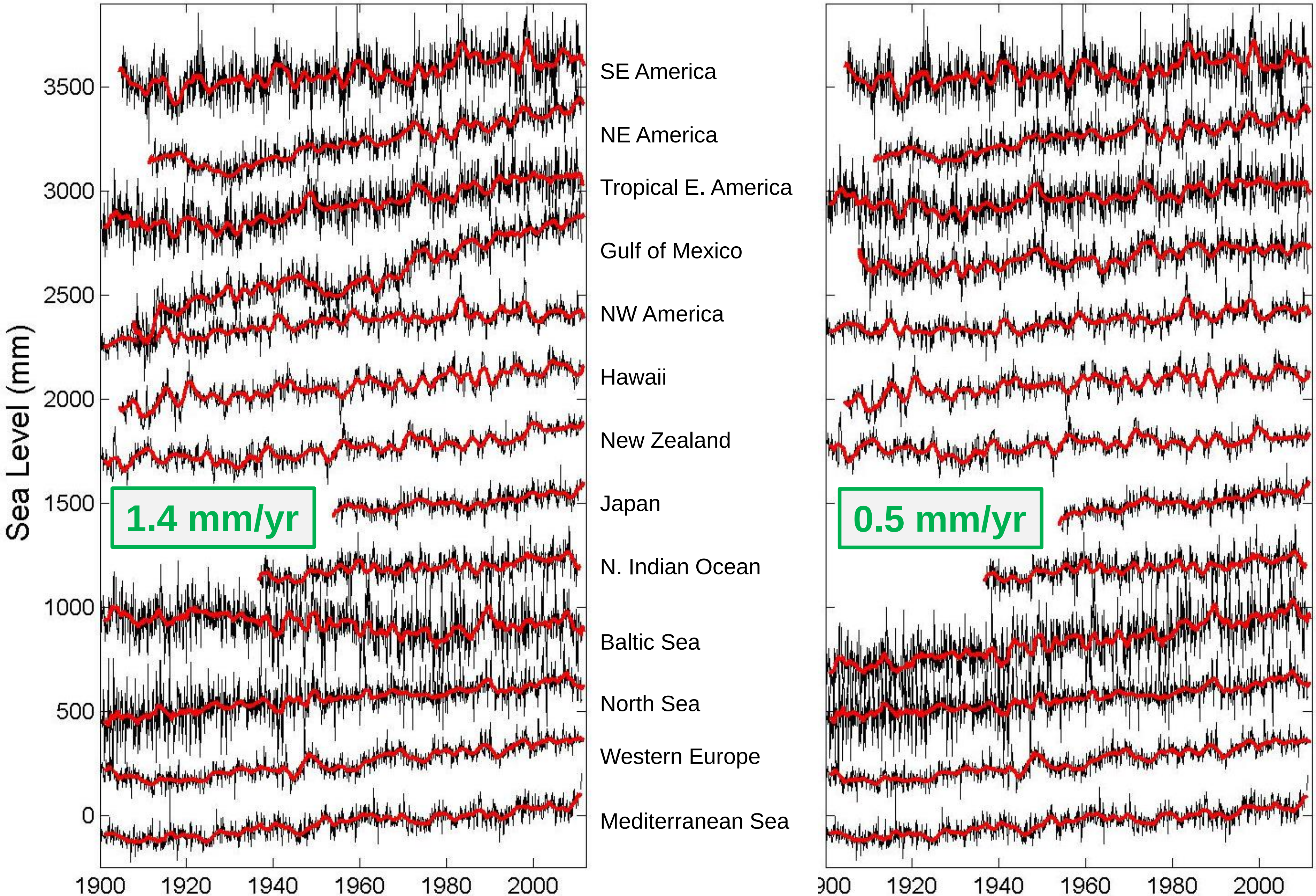
- Station selection criteria:
  - → Tide gauge records > 50yr from 1900
    - → 70% of valid data
  - → Regional grouping based on correlation coefficients
  - → Nearest robust GPS velocity estimate
    - → Same land (Islands)
    - → GIA gradient of TG-GPS stations < 0.4 mm/yr
    - → Active tectonic areas : co-location or redundant GPS data

76 records

grouped into 17 regions
following Jevrejeva *el al.* (2006)
for regional reconstructions



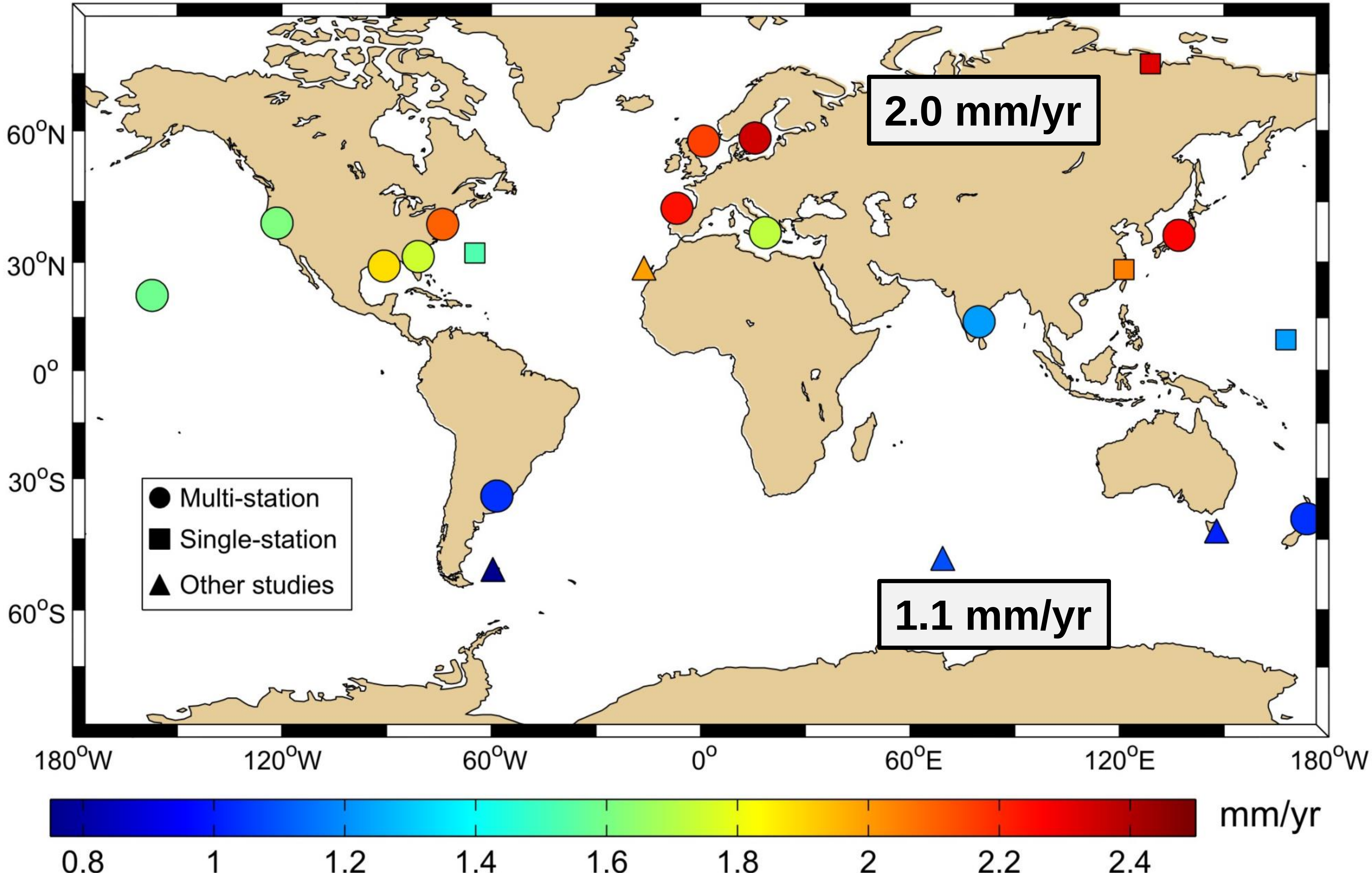
Wöppelmann et al (2014)



Sea Level (mm)
3500
3000
2500
2000
1500
1000
500
0
1900
1920
1940
1960
1980
2000
900
SE America
NE America
Tropical E. America
Gulf of Mexico
NW America
Hawaii
New Zealand
Japan
N. Indian Ocean
Baltic Sea
North Sea
Western Europe
Mediterranean Sea
1.4 mm/yr
0.5 mm/yr

Spatial patterns of sea level change

GPS-corrected trends



Wöppelmann et al (2014)

Spatial patterns of sea level change

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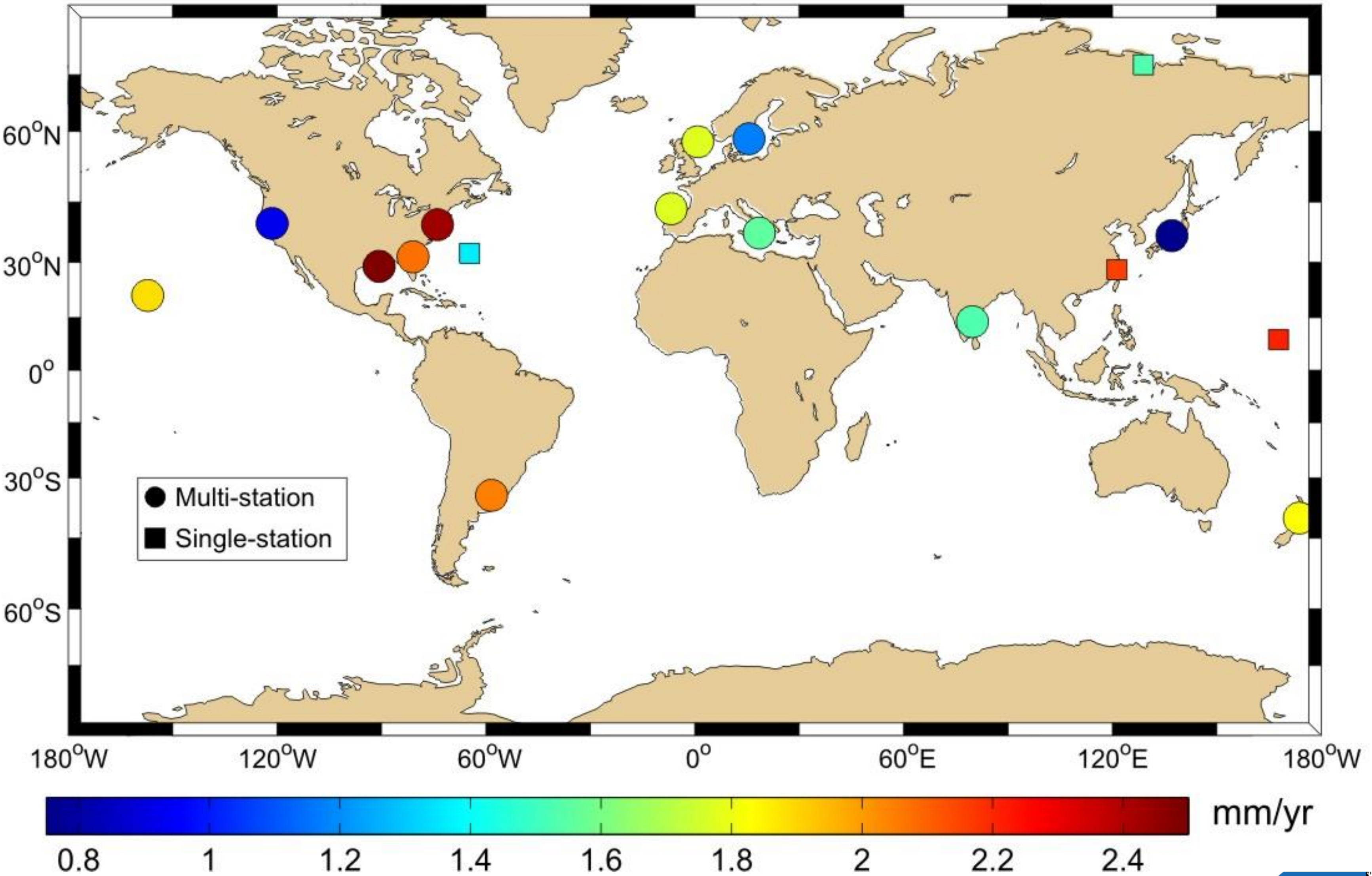
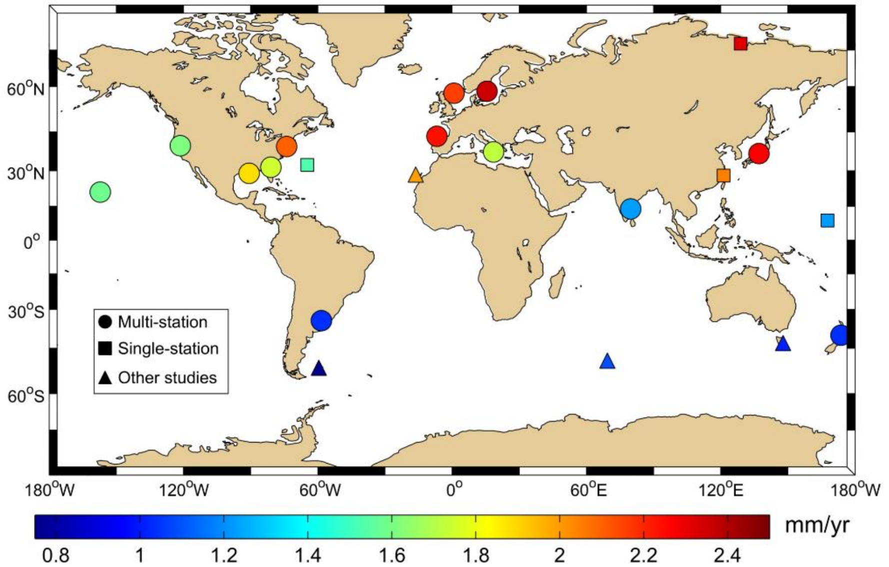
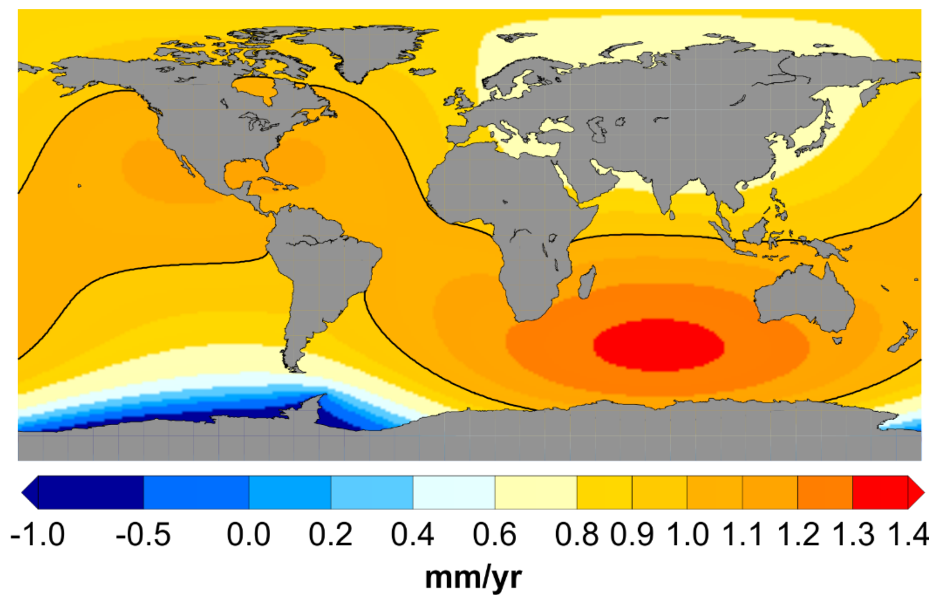


Wöppelmann et al (2014)

Origin of the "hemispheric" spatial pattern of sea level change?



Update from M. Tamisiea (NOC, Liverpool)



Bias in GPS velocities?	X
Tide gauge spatial distribution?	X
Thermo-steric effect (ocean temperature) ?	X
Fingerprints of land-ice melting?	X

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Errors in the Terrestrial Reference Frame
(Beyond GPS…)

- Impact on the vertical velocities
  (e.g. Collilieux & Wöppelmann, 2011)

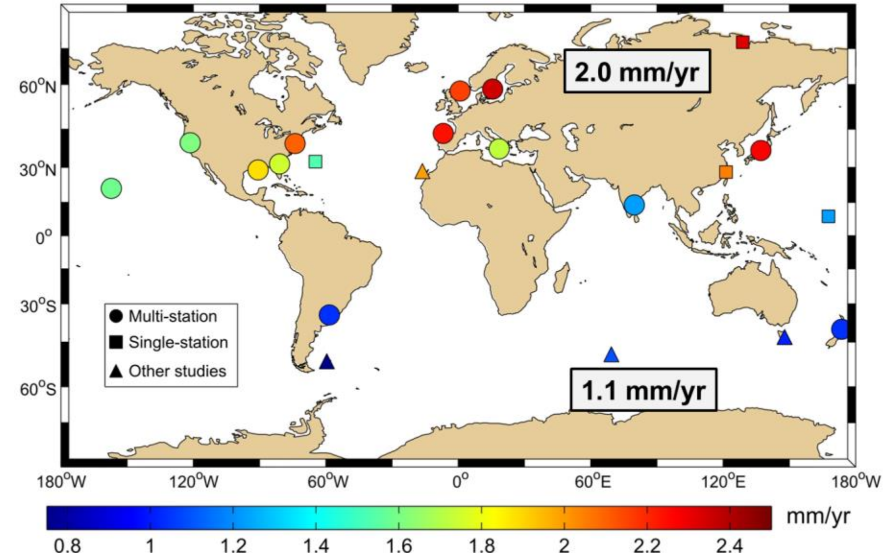
$$\Delta v^{up}_{i,j}(\Delta\dot{d},\,\Delta\dot{\mathbf{T}}) = \Delta\dot{d} + \mathbf{G}(\lambda_{ij},\phi_{ij})\cdot\Delta\dot{\mathbf{T}}$$

drift in scale   drift in origin

$$\mathbf{G}(\lambda_{ij},\phi_{ij}) = [\cos(\phi_{ij})\cos(\lambda_{ij}) \quad \cos(\phi_{ij})\sin(\lambda_{ij}) \quad \sin(\phi_{ij})]$$

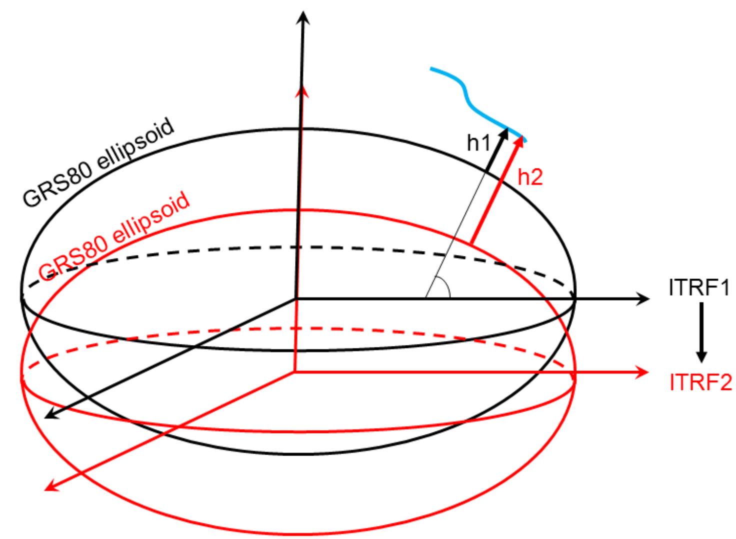
- Impact on the GMSL change

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



Collilieux *et al.* (2014)
Report of the IAG Sub-commission 1.2

Most likely: $\Delta Tz \cong 0.5$ mm/yr
$\Delta d \cong 0.3$ mm/yr
$\rightarrow$ **~ 0.5 mm/yr**



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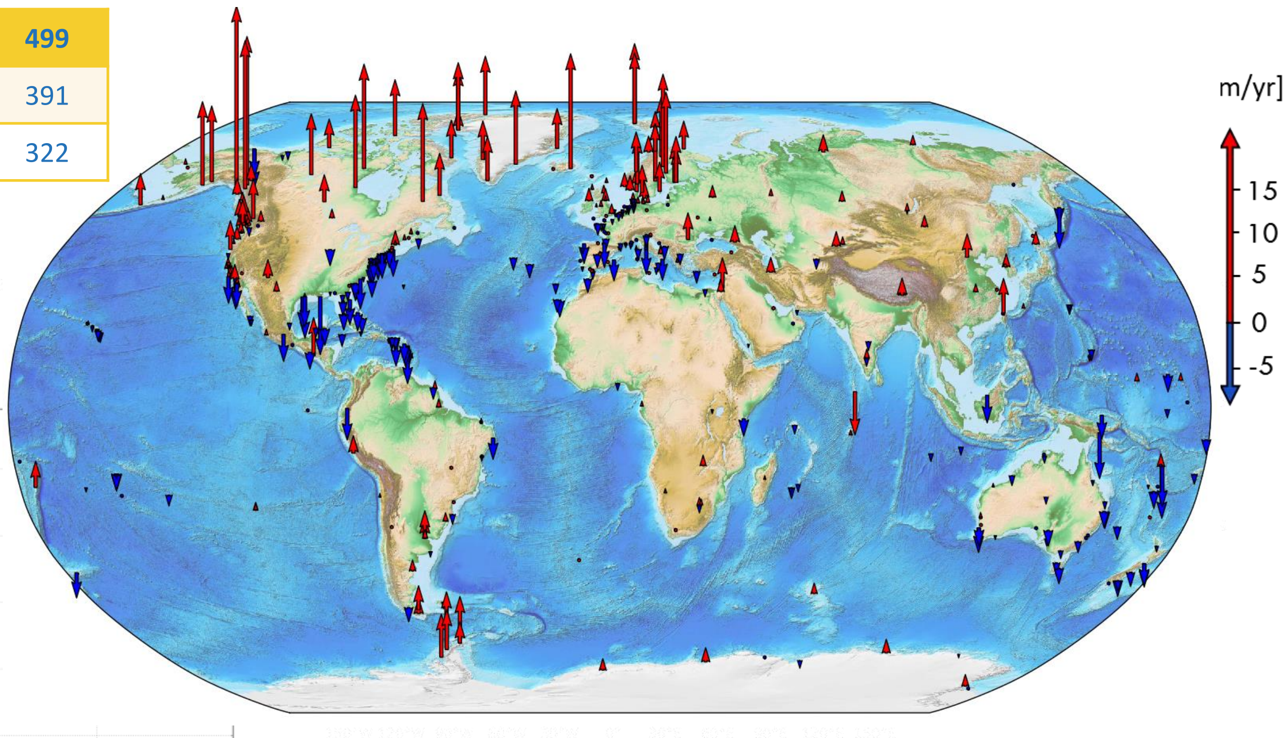
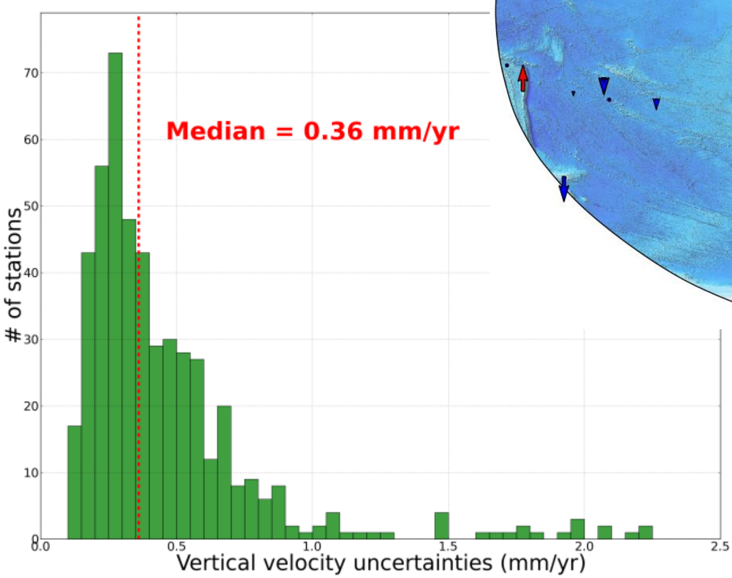
Latest GPS velocity field from University of La Rochelle (ULR) analysis centre

Total # of GPS velocities	499
Dedicated to sea level applications	391
Distance < 15 km from a TG	322





- GPS data over 1995-2014 period
- Minimum record length of 3 years without offset
- Participation into repro2 (IGS) – ITRF2014

IGS INTERNATIONAL GNSS SERVICE

Santamaria-Gomez et al (2017)

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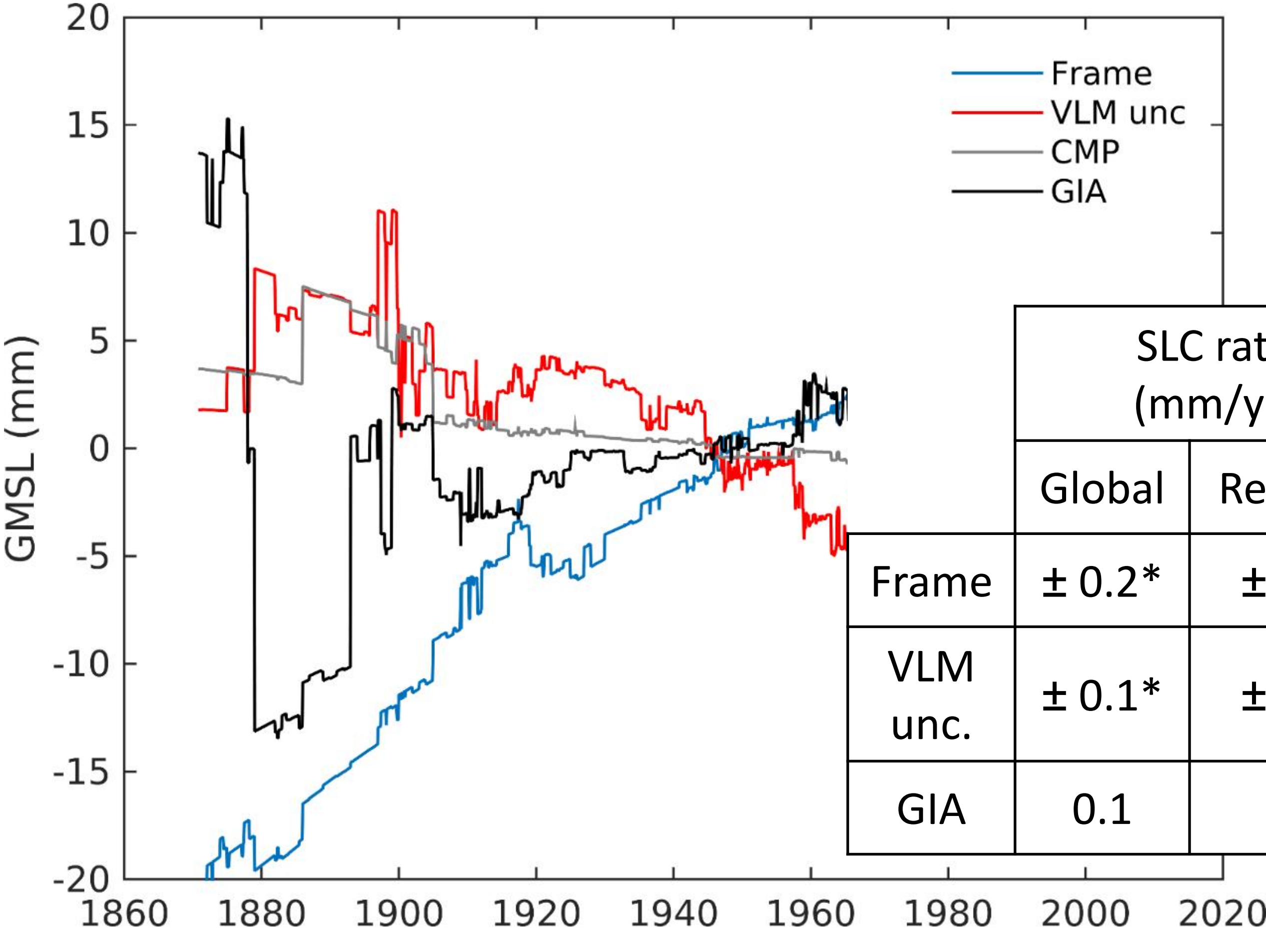
Propagation of VLM errors in global & regional sea level changes

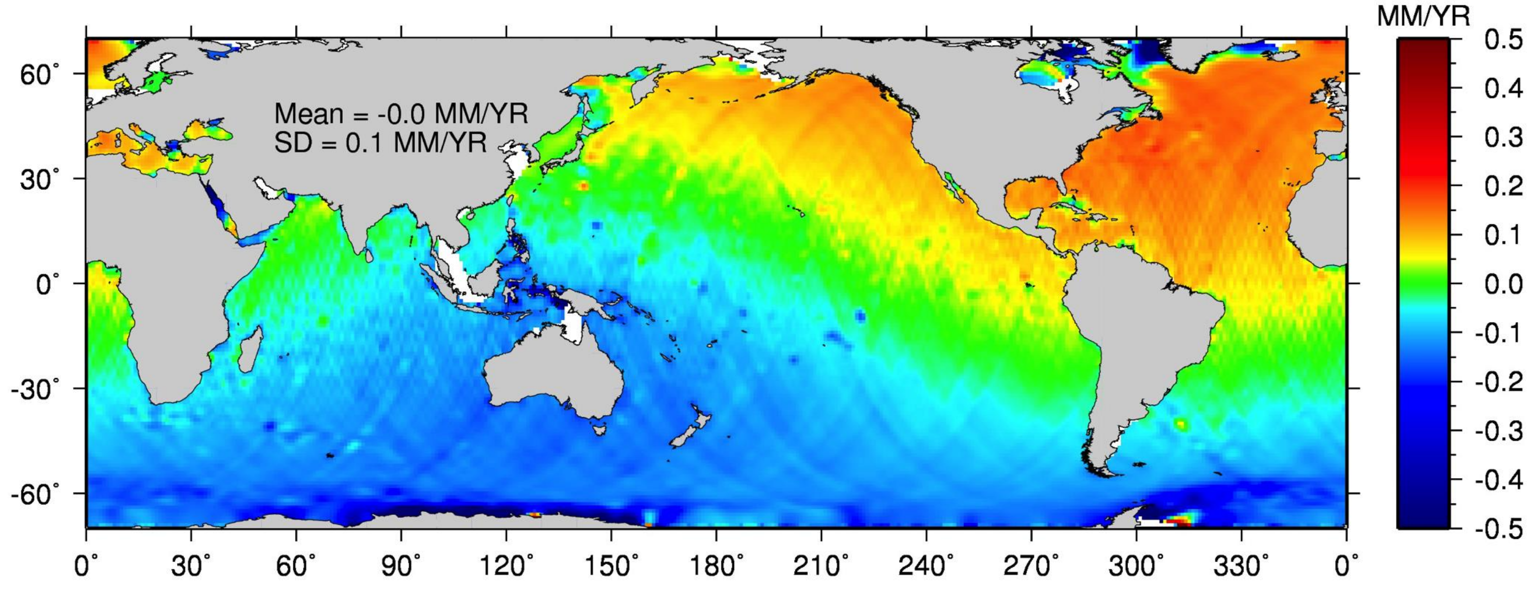


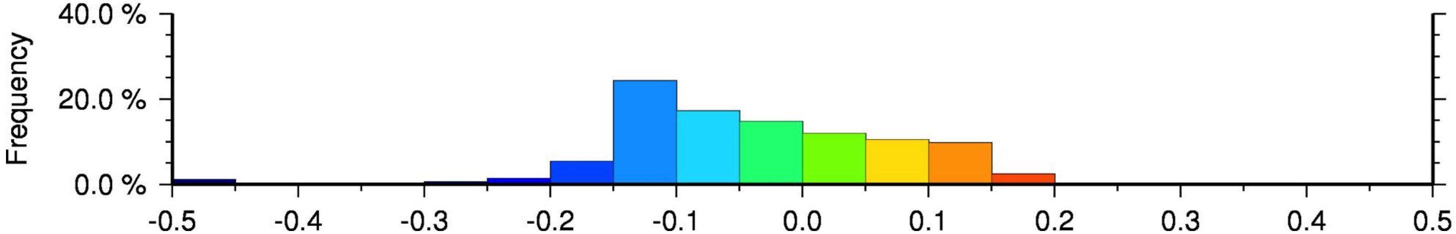
	SLC rate (mm/yr)		SLC accel ($x10^{-3}$ mm/yr^2)	
	Global	Regional	Global	Regional
Frame	± 0.2*	± 0.4*	± 2.6*	± 7.8*
VLM unc.	± 0.1*	± 0.4*	± 4.8*	± 13.4*
GIA	0.1	0.5	2.8	9.0

* 95% CI

Santamaria-Gomez et al (2017)

Transitioning from ITRF 2008 to ITRF 2014
Impact on regional sea level estimates

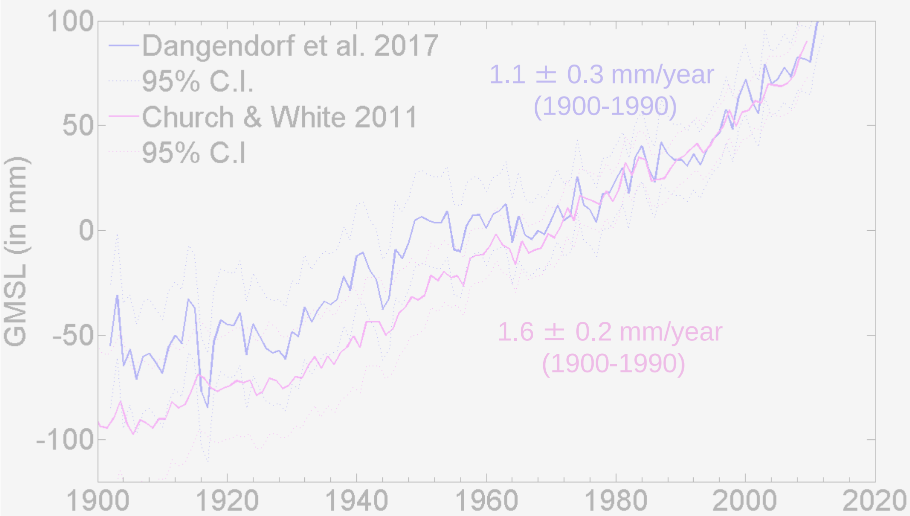




"For the objective of 0.3 mm/yr in global sea level accuracy to be met, the reference frame drift should ideally be kept below 1 mm/yr. A goal of 0.5 mm/yr stability seems appropriate." Cazenave et al (2009)

Beckley et al (OSTST 2016)

GLOBAL SCALE (CLIMATE)



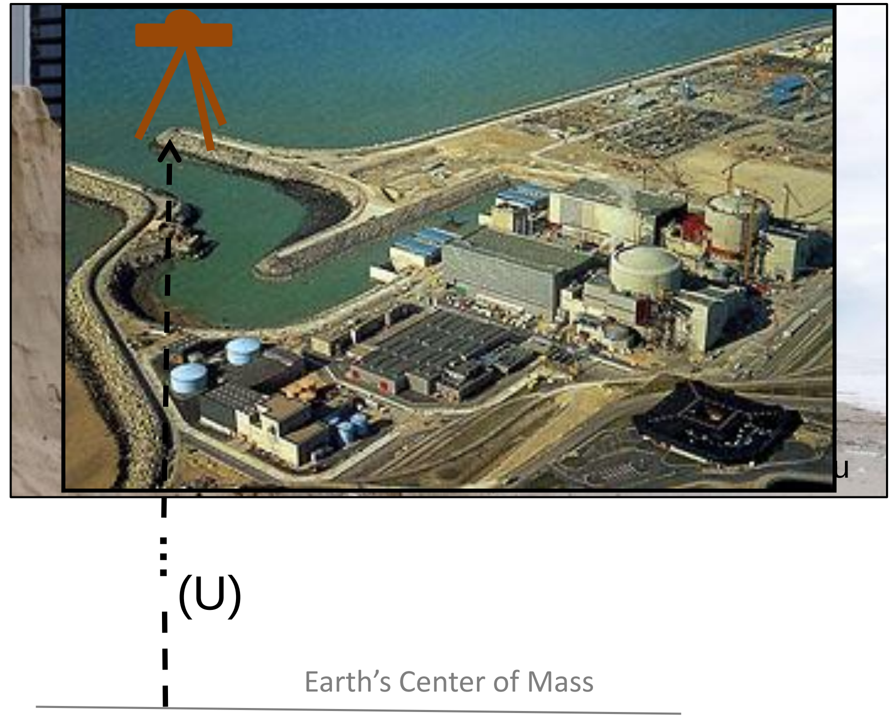
- *Douglas* (1997): 1.8 mm/yr using high-quality **23 TGs**
- *Spada & Galassi* (2012): 1.5 mm/yr using **22 TGs**

- To reach ±0.2 mm/yr (95% CI) in GMSL rates using 25 “perfect” stations (unbiased, representative)

$$\text{ME}= t \times \frac{SE}{\sqrt{N}} \rightarrow 0.2 = 2.06 \times \frac{SE}{\sqrt{25}}$$

→ individual standard errors of VLM estimates less than 0.5 mm/yr

LOCAL SCALE (COASTAL IMPACTS)



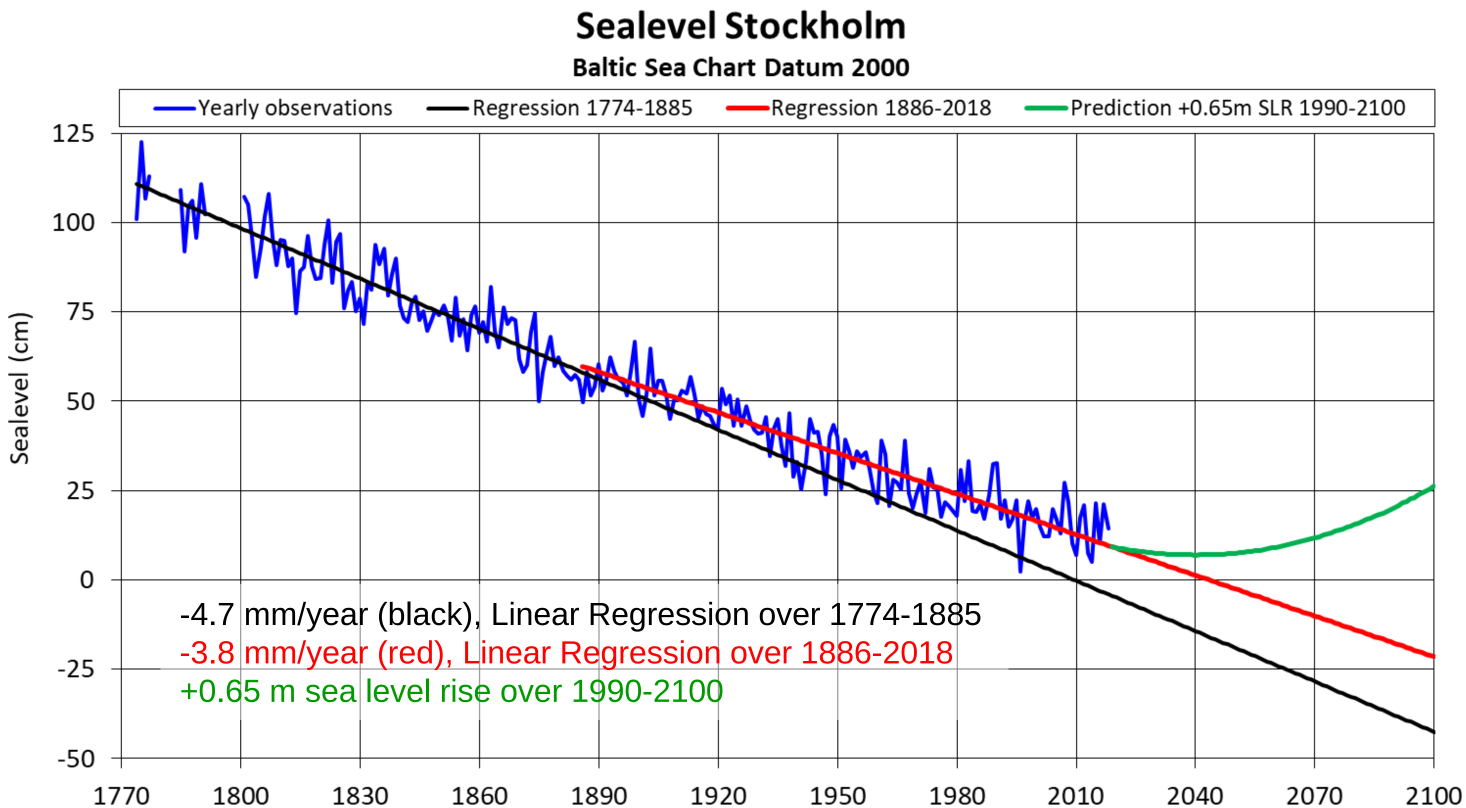
- Future sea and land levels, and coastal management
  - “Future”: ~50 years for coastal infrastructures
  - Changes: > 5 cm → start to be worried

$$\text{ME} = \frac{5\ cm}{50\ years} = 1 \text{ mm/yr}$$

$$\rightarrow \text{SE} \sim 0.5 \text{ mm/yr}$$

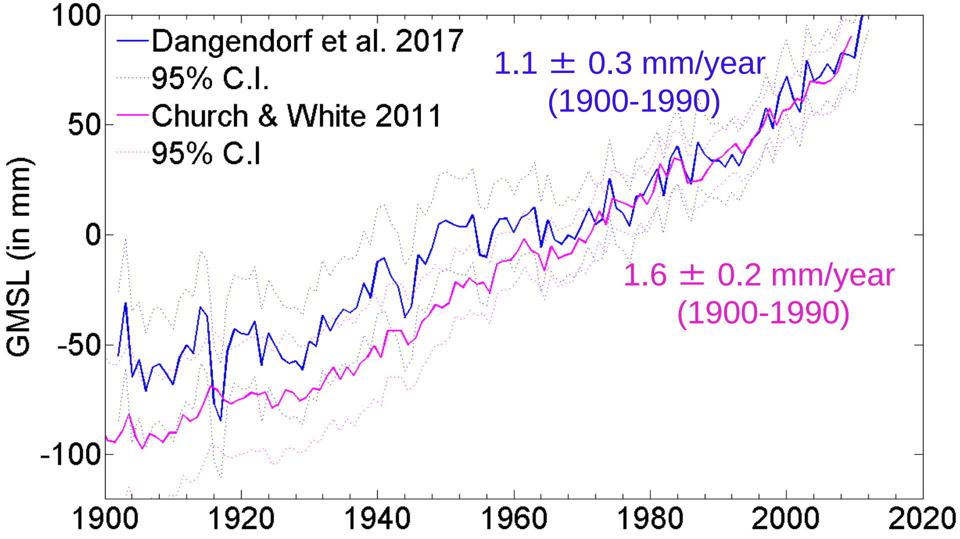
Wöppelmann & Marcos (2016)

Coastal impact studies: anticipating future sea levels



Hammarklint (2019)

GLOBAL SCALE (RECONSTRUCTIONS)

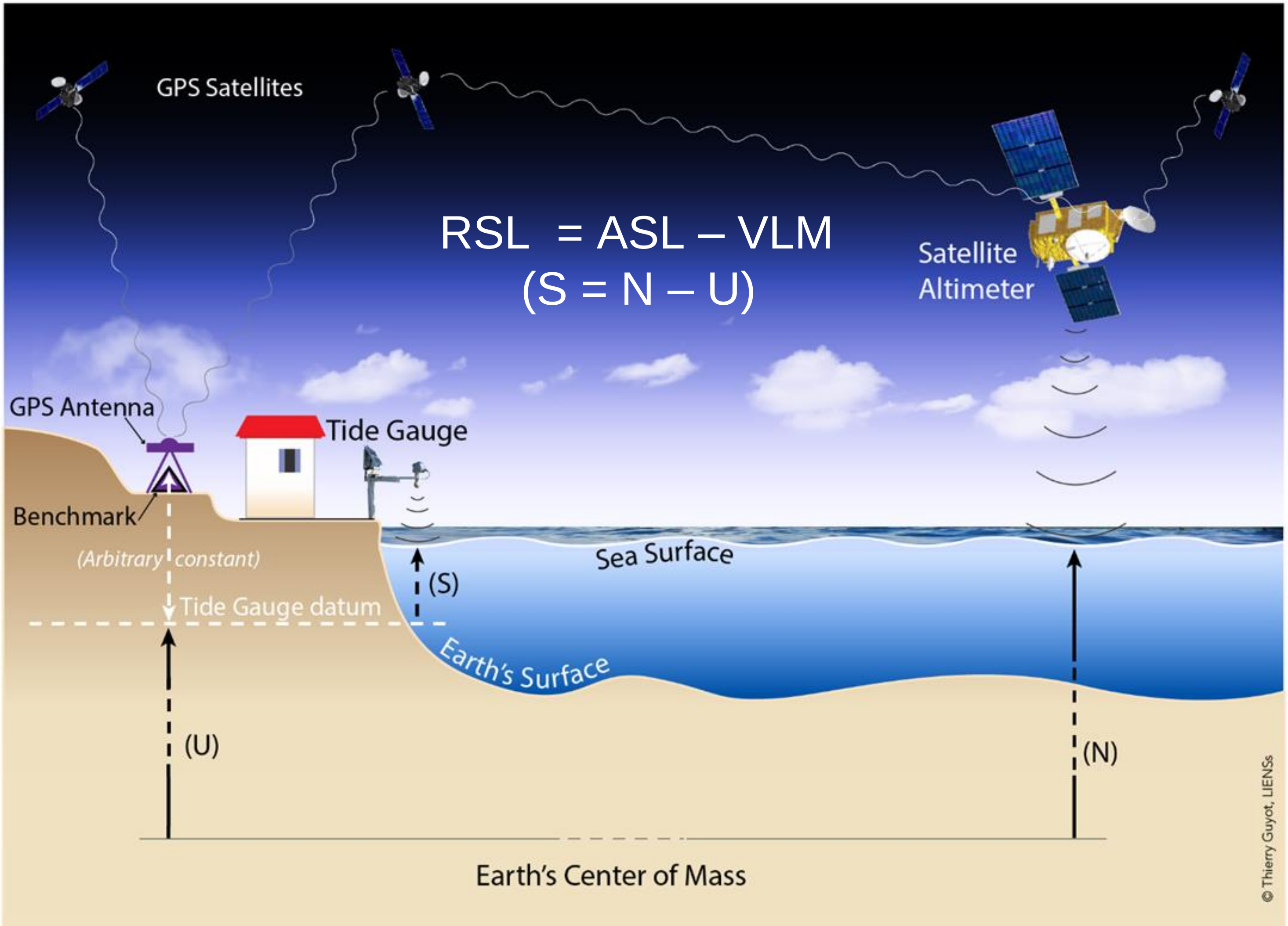


LOCAL SCALE (COASTAL IMPACTS)

- TG records contain climate & VLM signals
- VLM is missing in satellite altimetry data

- Accurately knowing VLM is crucial, either for
  - → using tide gauge records,
  - → or using satellite altimetry data
- Pros & Cons are application-depended
  - → Understanding sea level change and its spatial variability
  - → Understanding what are the dominant factors to best anticipate future changes in sea levels at the coast

RSL the quantity that matters for coastal management & society



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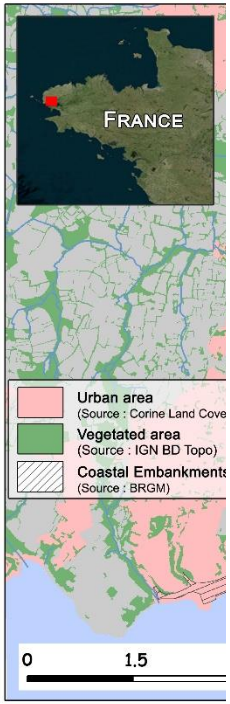
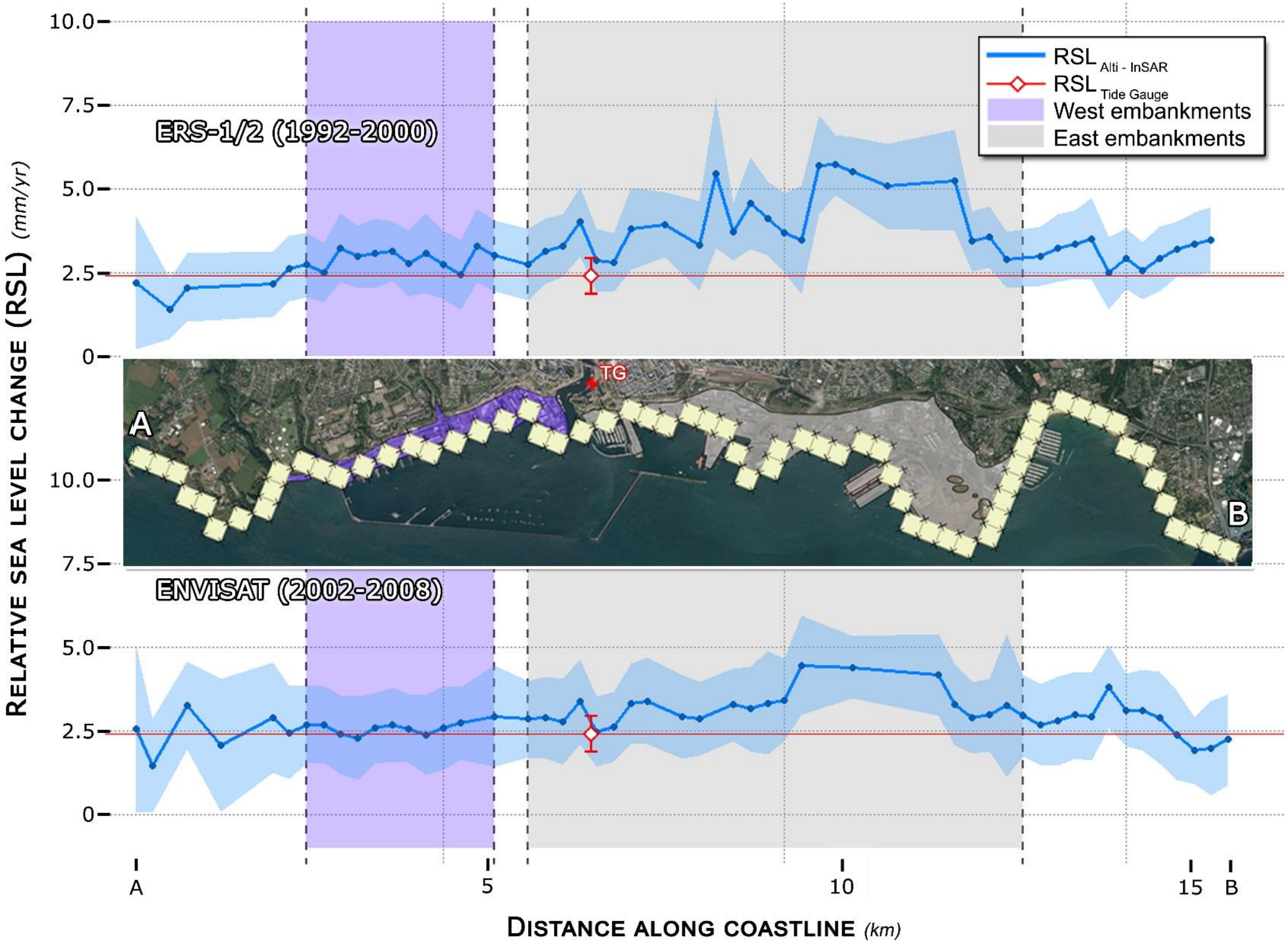
RSL the quantity that matters for coastal management & society



Poitevin et al (2019)



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Wrap-up
Need for precisely knowing VLM@TGs

- VLM plays a key role in understanding sea level change (global) and variability in spatial trends (regional, local, coastline)
  - Can bias GMSL trend estimates based on TGs
  - Can hamper predictions of future sea levels, and anticipation (management…)

- Uncertainty required in VLM determination to be useful in sea level change studies
  - Ideally, a small fraction of the climate signals, which are of ~2 mm/year
  - That is, at the sub-millimetre per year level (better than 0.5 mm/year)

- Geophysical model predictions *versus* Observation estimates
  - A large range of geophysical processes can cause VLM, but "few" models can predict these with the above accuracy (see Wouter van der Wal)
  - Some studies suggest that space geodesy can help (see Part 2)