

Reconstructing historical sea level anomalies from satellite altimetry and GPS-corrected tide gauges

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Vertical rates symposium

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Tide gauges: long records, sparse coverage

Satellite altimetry: (near) global coverage, short time span

Combine datasets to reconstruct historical sea level (anomalies)

apply GPS corrections to tide gauge measurements to adjust for land movement

Algorithm used: Optimal Interpolation (Kaplan 1997, Church 2004)

- extract main spatial patterns (Empirical Orthogonal Functions, EOFs) from satellite altimetry data
- derive their amplitude time series (PCs) by modified least squares fit to tide gauge measurements
- „tablecloth“ analogy

1. GPS Issues

- Land movement at tide gauges

- Causes and effects

- Co-location and distance

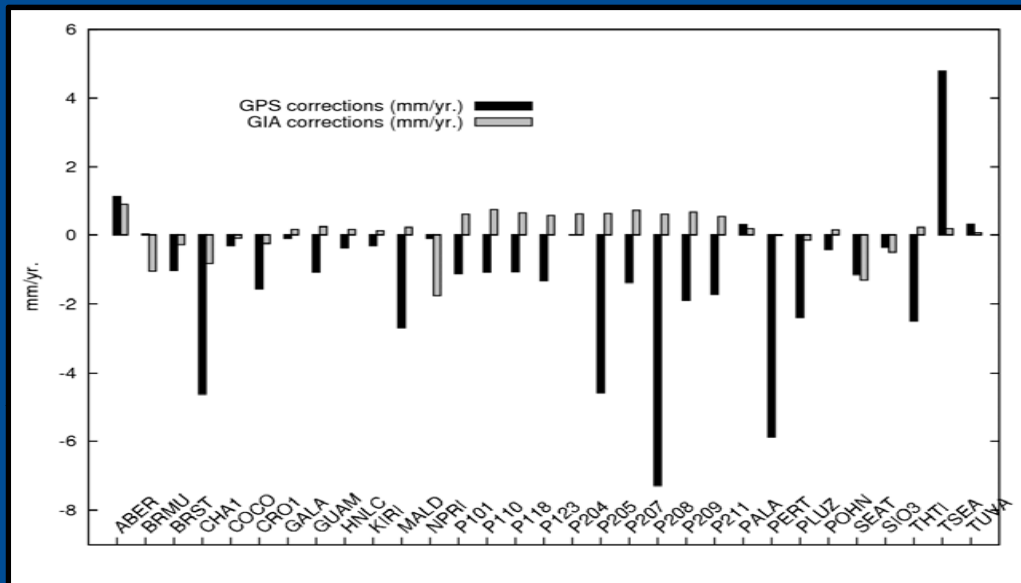
- Land movement duration

2. Reconstruction (OI) algorithm issues

- Choice of tide gauges

- Effect of missing tide gauges

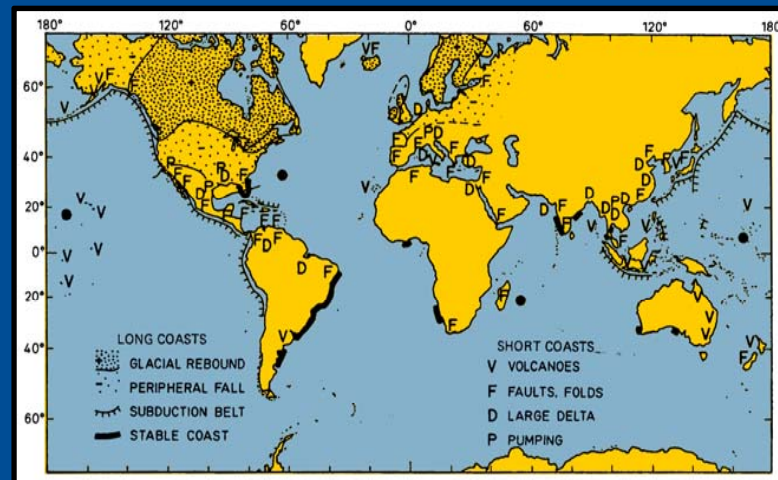
3. Results

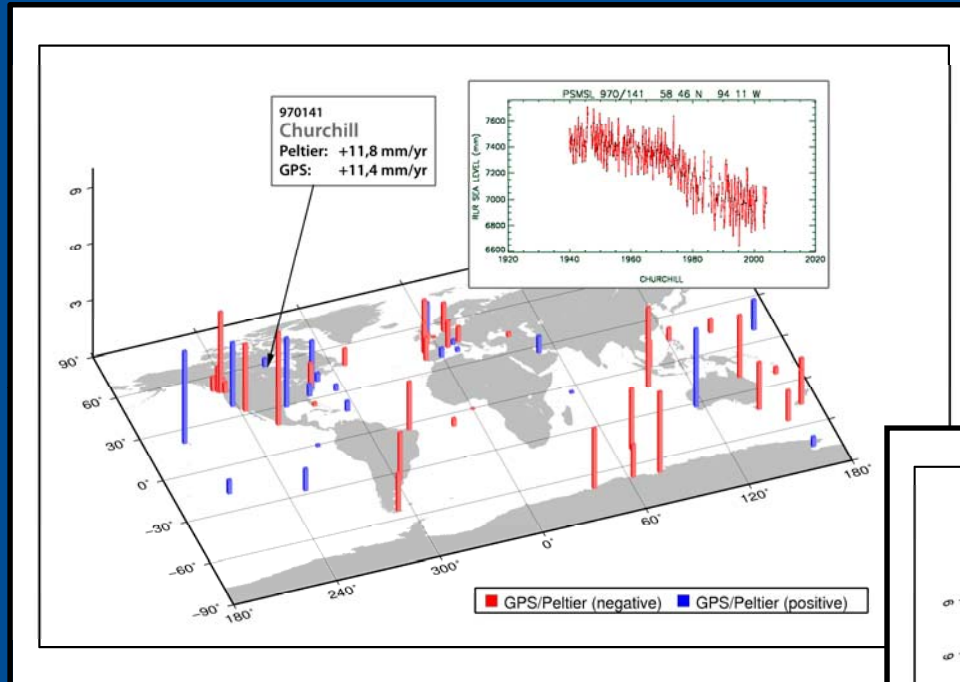


Glacial Isostatic adjustment (GIA) is the dominant land movement signal especially in Fennoscandia and Canada. Other areas may be subject to, e.g., earthquakes and subduction.

Anthropogenic factors (esp. groundwater and hydrocarbon extraction) play an increasing role in the 20th century.

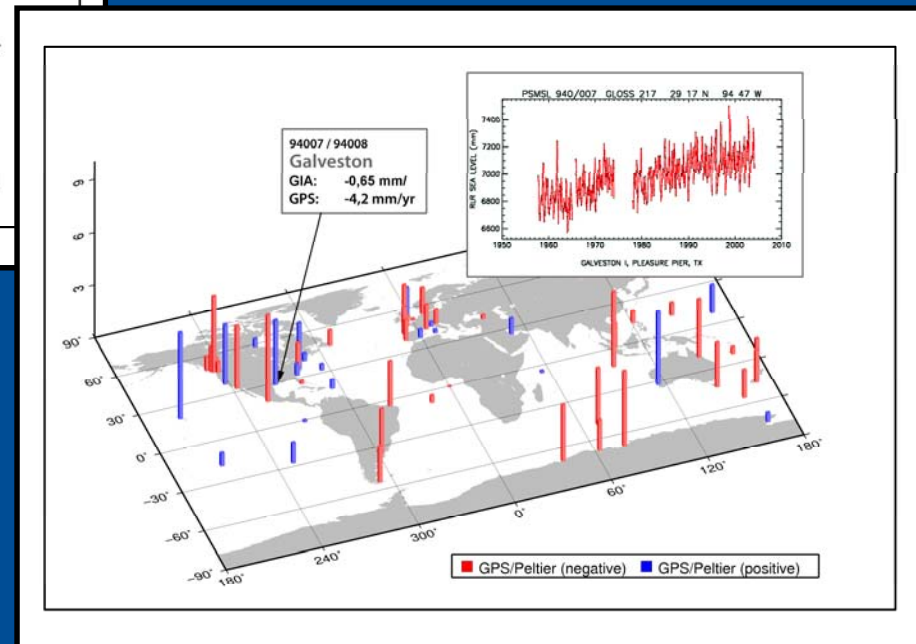
Right: A comparison of GPS and GIA model (Peltier VM2) vertical rates at selected tide gauges.





Good agreement in areas where GIA is dominant land movement signal (e.g. Churchill PSMSL 970/141).

Large discrepancies in areas where land movement cause is anthropogenic or related to other geological processes / events (e.g. Galveston PSMSL 940/007(8)).



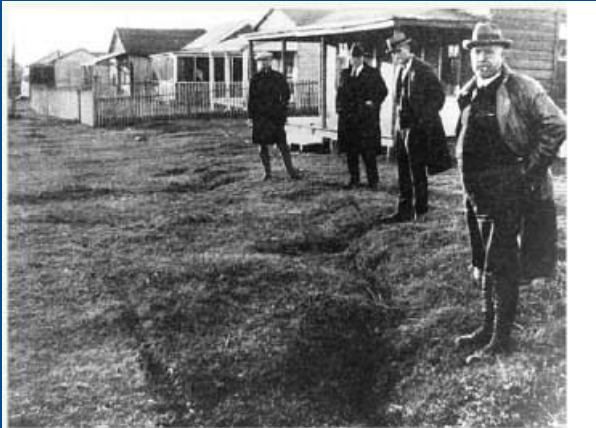


Figure 2. 1926 photograph of a new fault scarp 0.5 miles north of the Goose Creek oil field. Fault offset at the surface is approximately 16 inches. From Galloway et al, 1999.

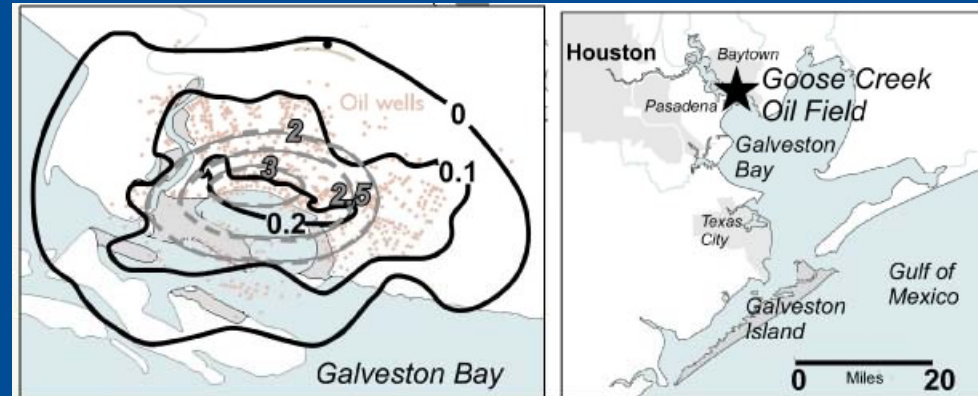
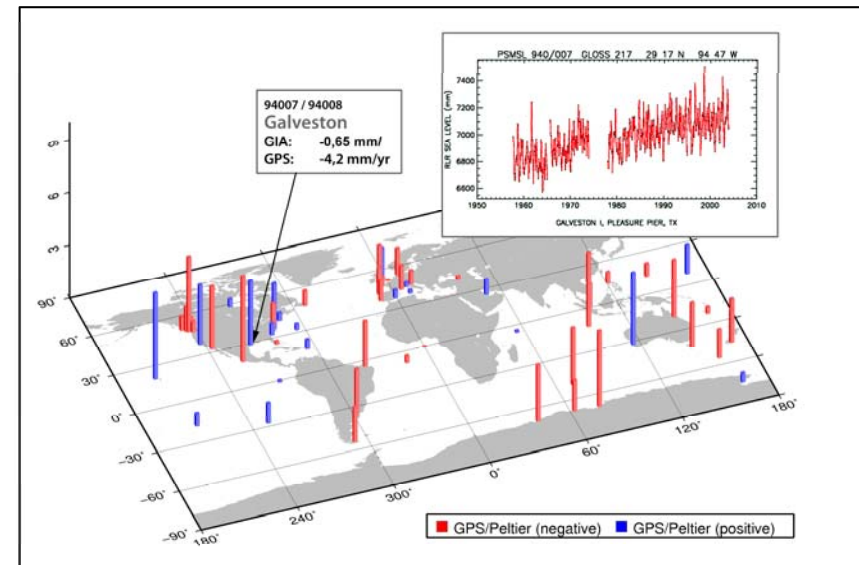
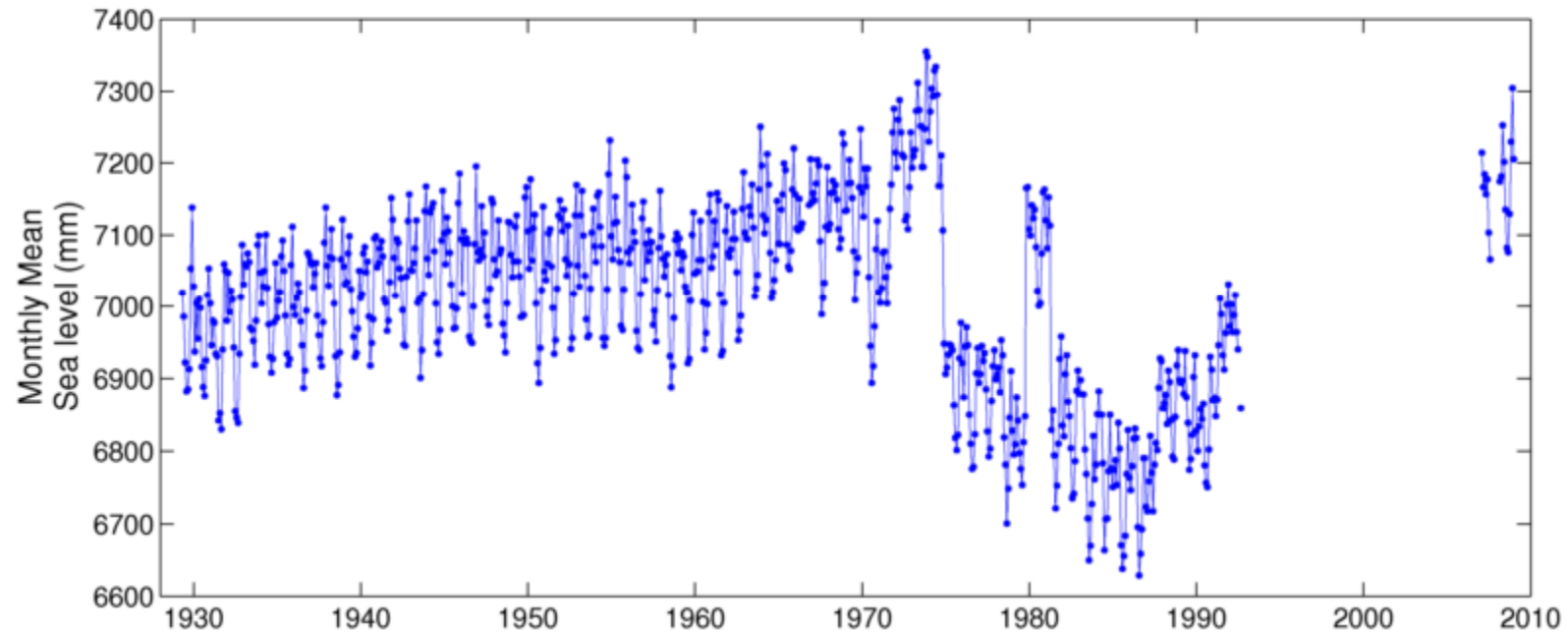


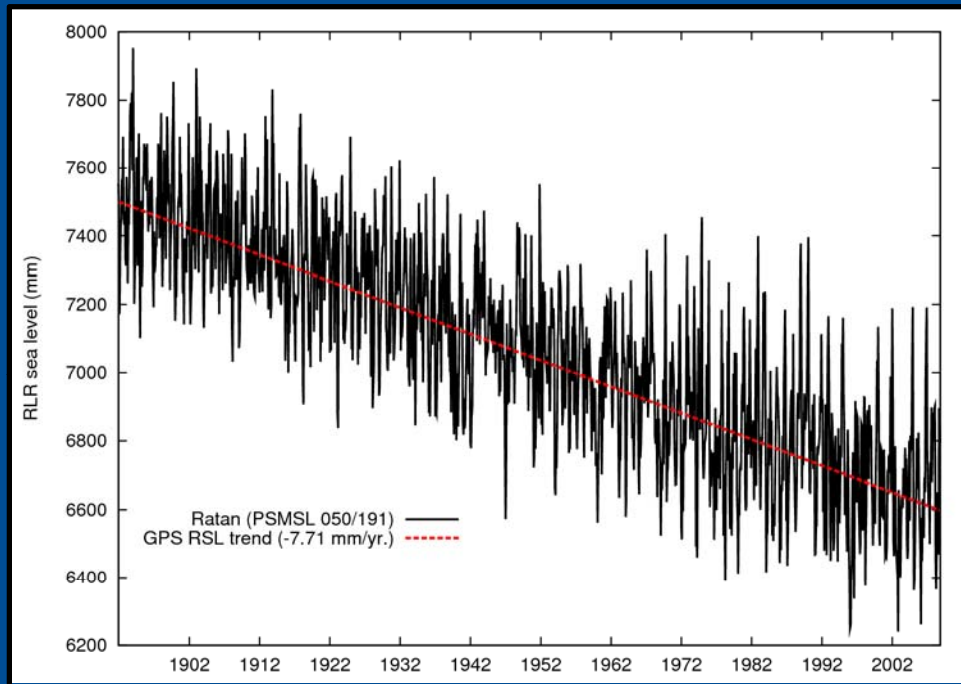
Figure 1. Measured subsidence between 1918 and 1926 around Goose Creek oilfield. Lines of equal subsidence (feet) for an 8-year period are shown in gray lines—for a 1-year period, in black lines. Modified from Galloway et al, 1999.

Subsidence at Galveston tide gauge caused by groundwater extraction related to oil drilling
(Source: Houston Geological Society)



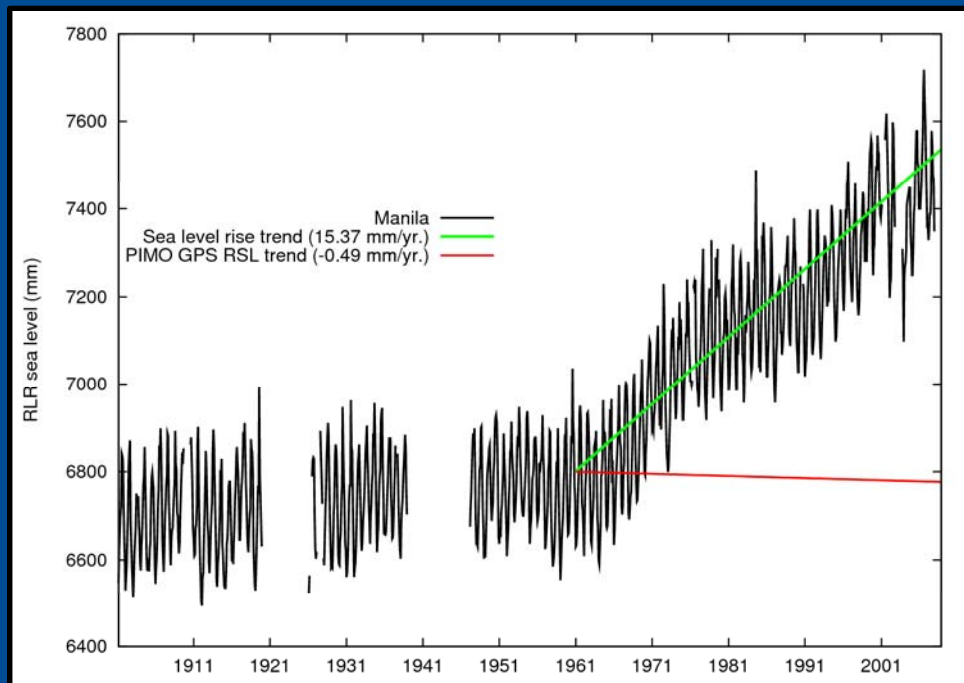


Subsidence at Takoradi (Gulf of Ghana) coincides with start of offshore drilling in the 1970s.



Glacial isostatic uplift at Ratan tide gauge is covered perfectly by MAR6 GPS station at 11 km distance.

Concerning the question of co-location (distance between TG and GPS station): It is not possible (nor advisable) to set a fixed distance between tide gauge and GPS station that defines “co-location” (within reason). Rather, it is important whether the land movement process affects both stations equally.

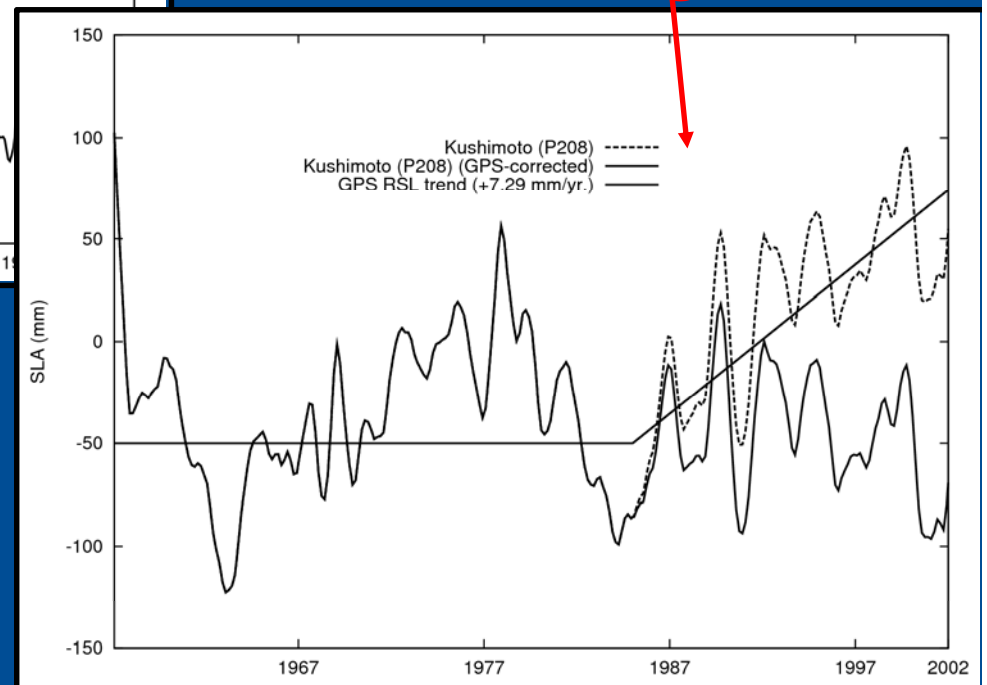
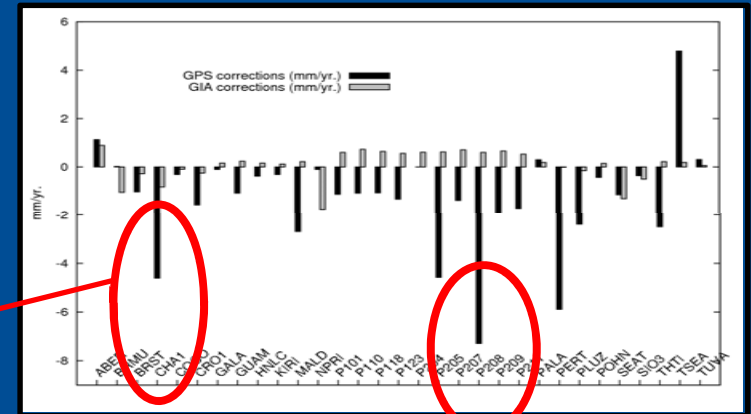
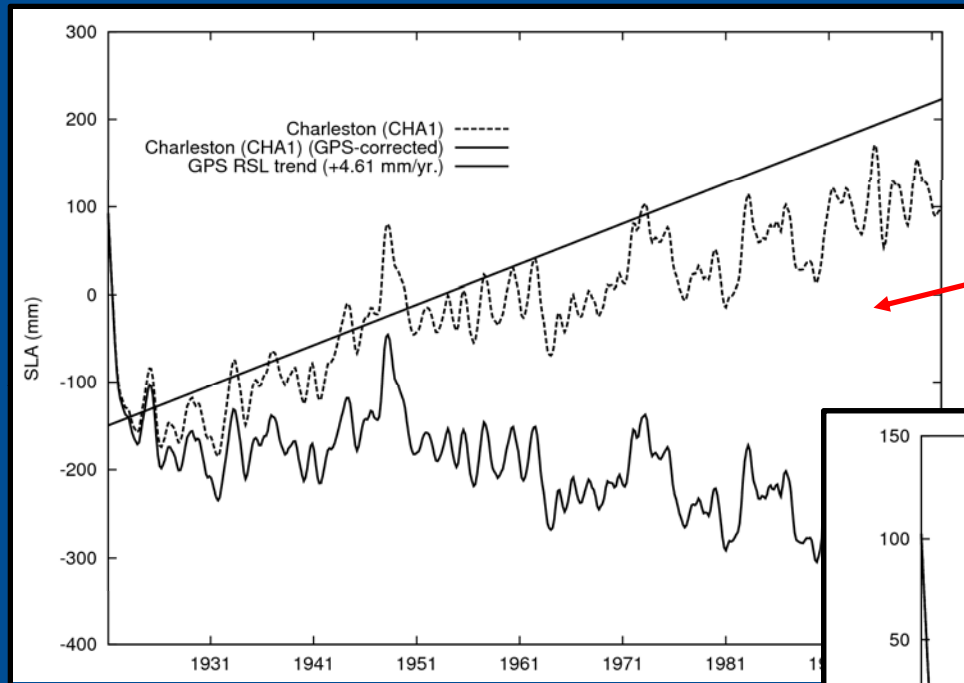


Sea level rise at Manila is *not* covered by the PIMO GPS station at 13 km distance.

Explanation:

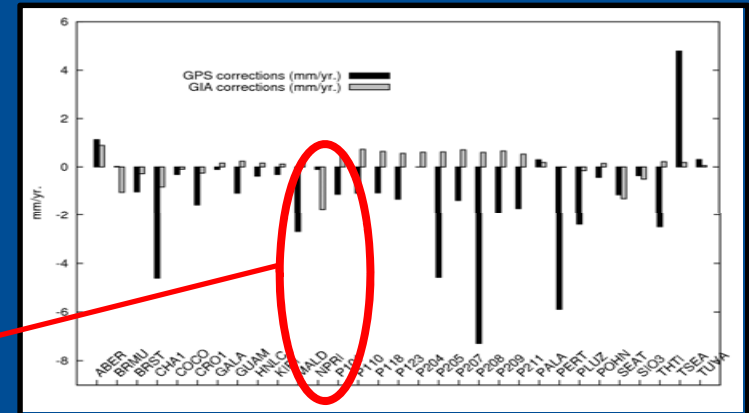
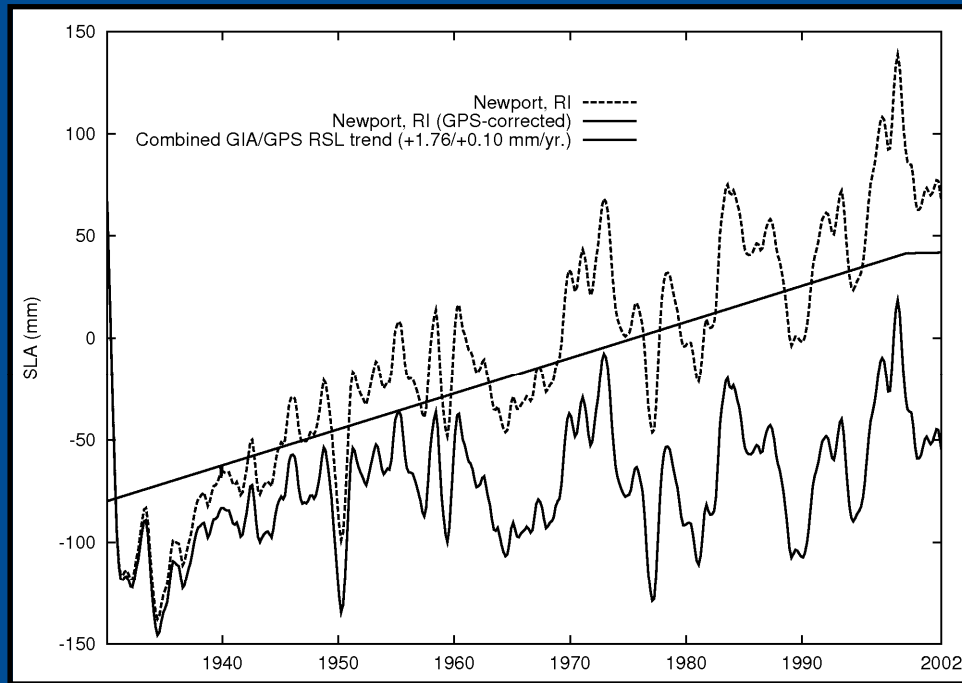
Sea level rise caused by sedimentation ?

Locations subject to different land movement processes ?



GPS trends are extracted from comparably short time series (< 10 yrs.)

When applying vertical rates to tide gauge measurements, careful assessment is necessary to determine when the land movement process started.



Newport (Rhode Island) has a strong GIA subsidence signal (-1.76 mm/yr.), but the GPS trend is low at -0.10 mm/yr.

Inspection of the time series indicates that the process has come to a halt in the mid-1990s.

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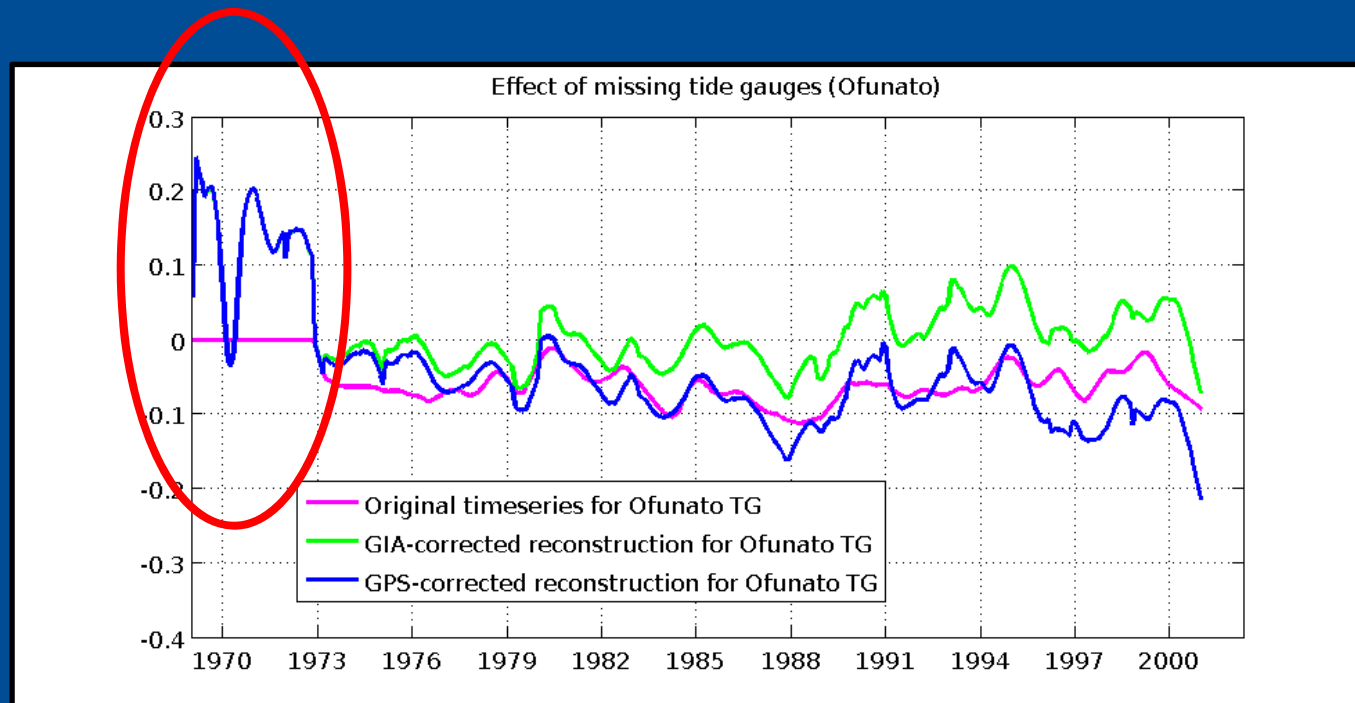
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Optimal Interpolation for sea level reconstructions (Church 2004)

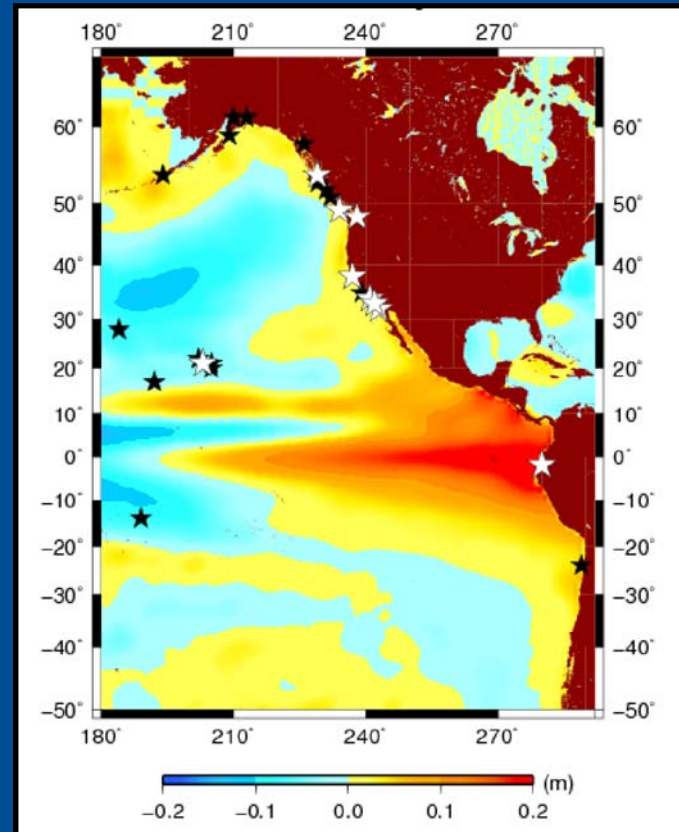
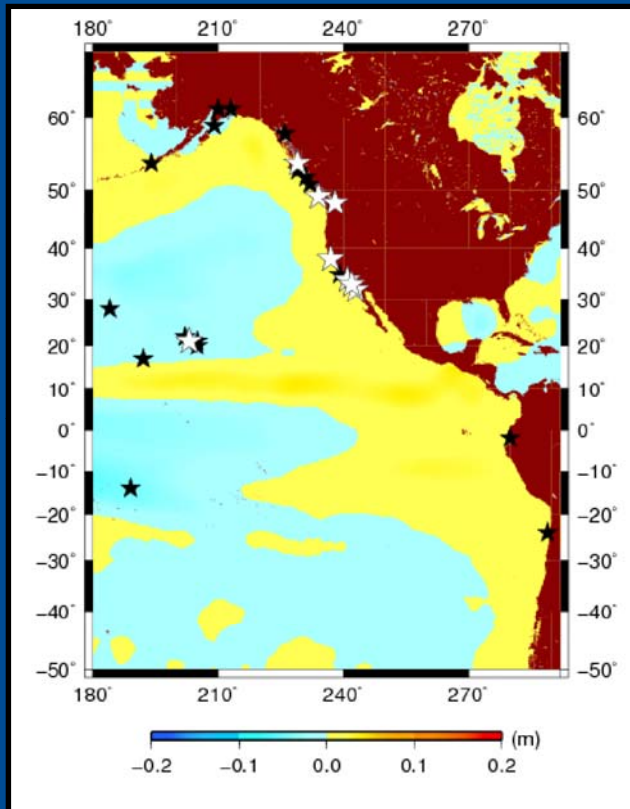
- use as many tide gauges as possible
- use also short timeseries
- jumps resulting from GIA corrections negligible

Problem:

- number of available TG records decreases when going back in time
- with fewer TGs, reconstruction becomes volatile due to nonlocal effects
- influence of TGs in areas with increased variance is higher
- GPS trends tend to be higher, lead to larger jumps in reconstruction, resulting in trend differences $\sim 1-2$ mm/yr.



Unconstrained time series will shift trend
avoid use of gappy and short TG time series !



Effect of the exclusion of a single tide gauge out of 9.
 Similar effects may occur when using badly correlated TGs and
 TG timeseries with strong coastal effects.

Recommendation:

- choose TGs following Douglas' recommendations (no bays, estuaries, good correlation with altimetry, no coastal effects)
- avoid gaps and short time series
- check for plausibility

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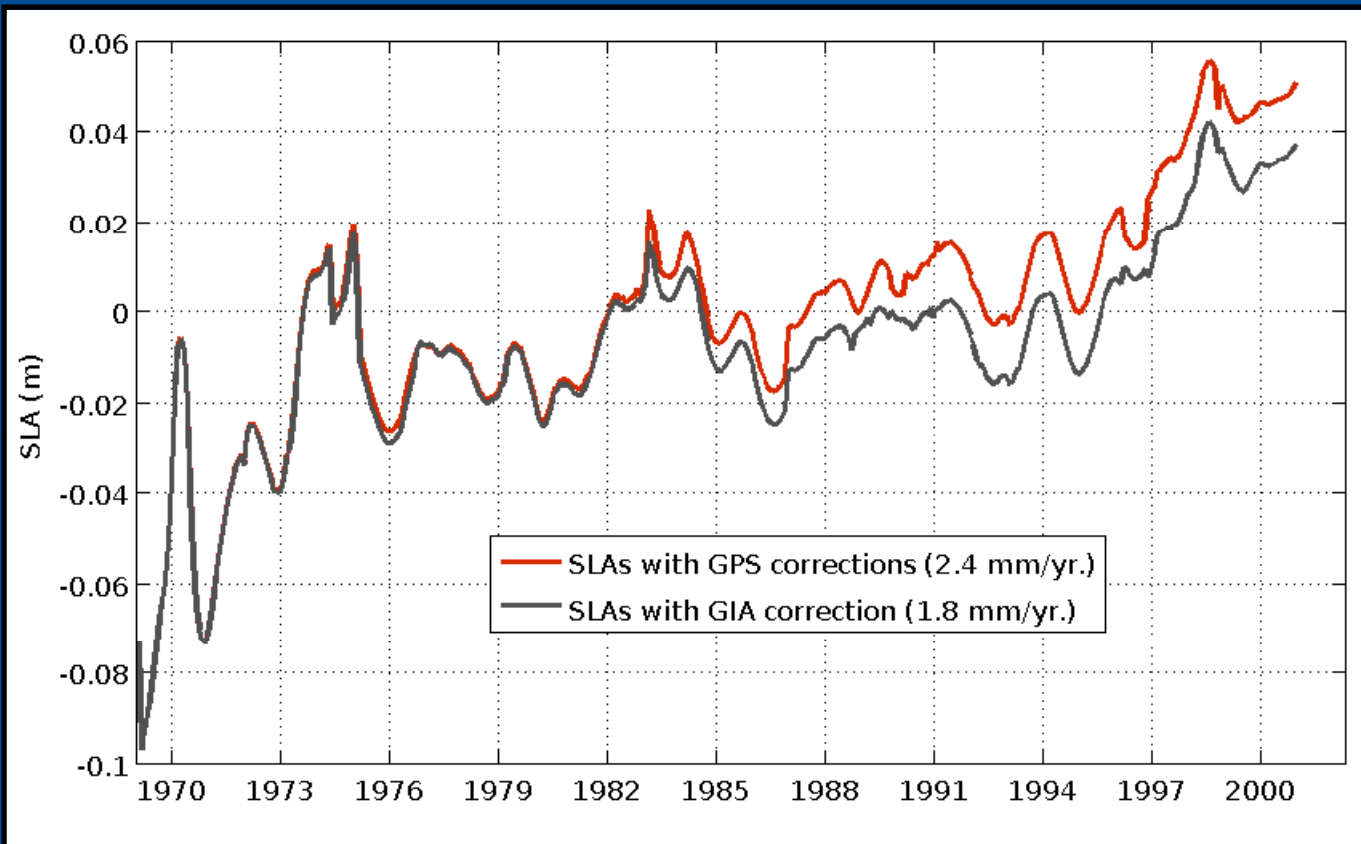
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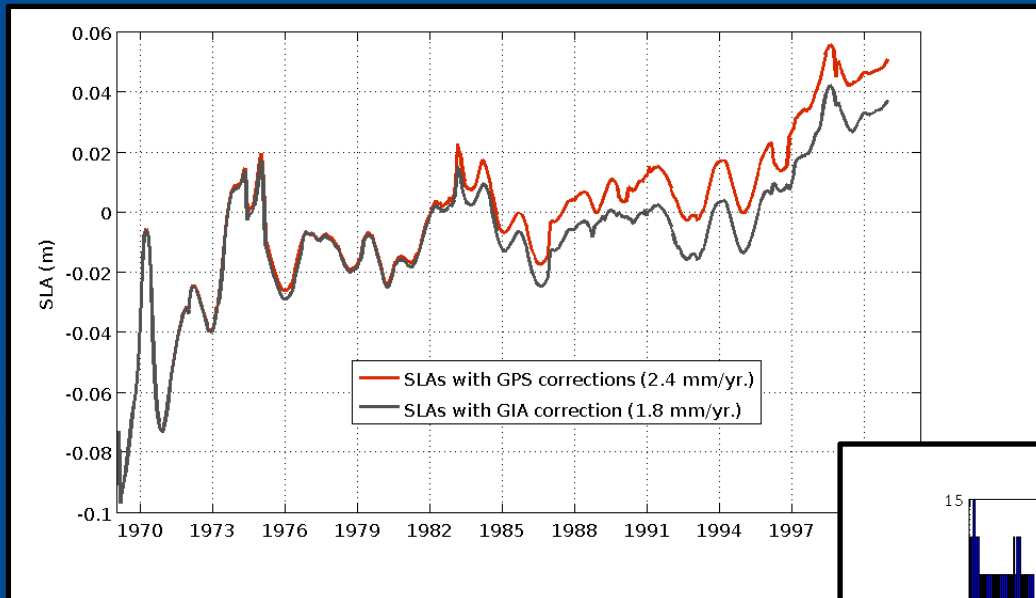
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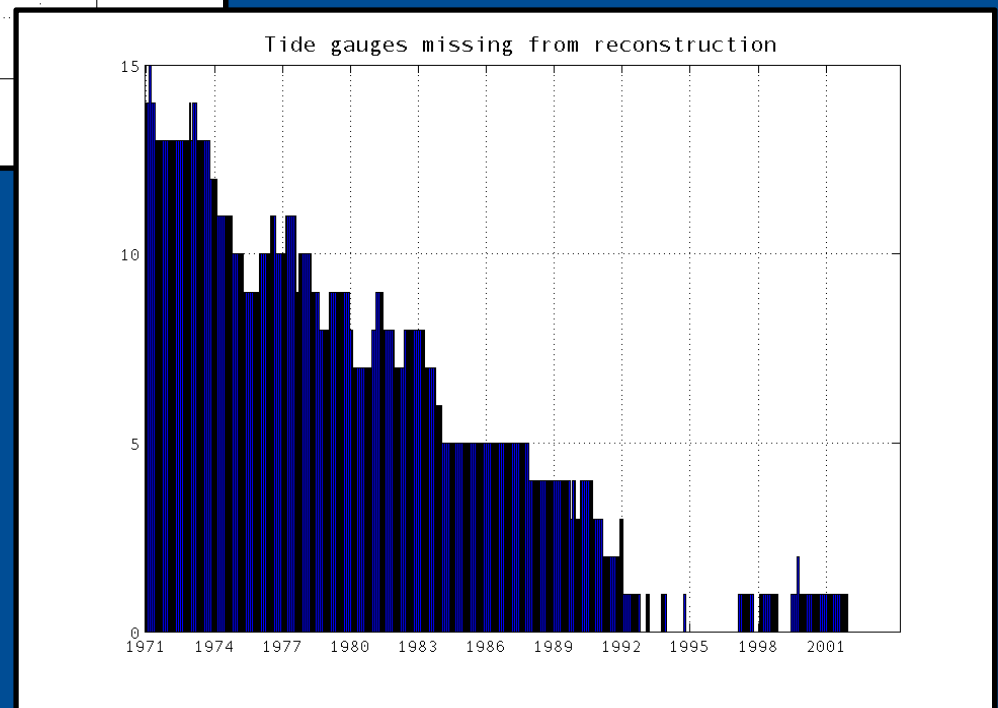
A comparison of reconstructed sea level anomalies for 1970-2001, compared with TOPEX altimetry.

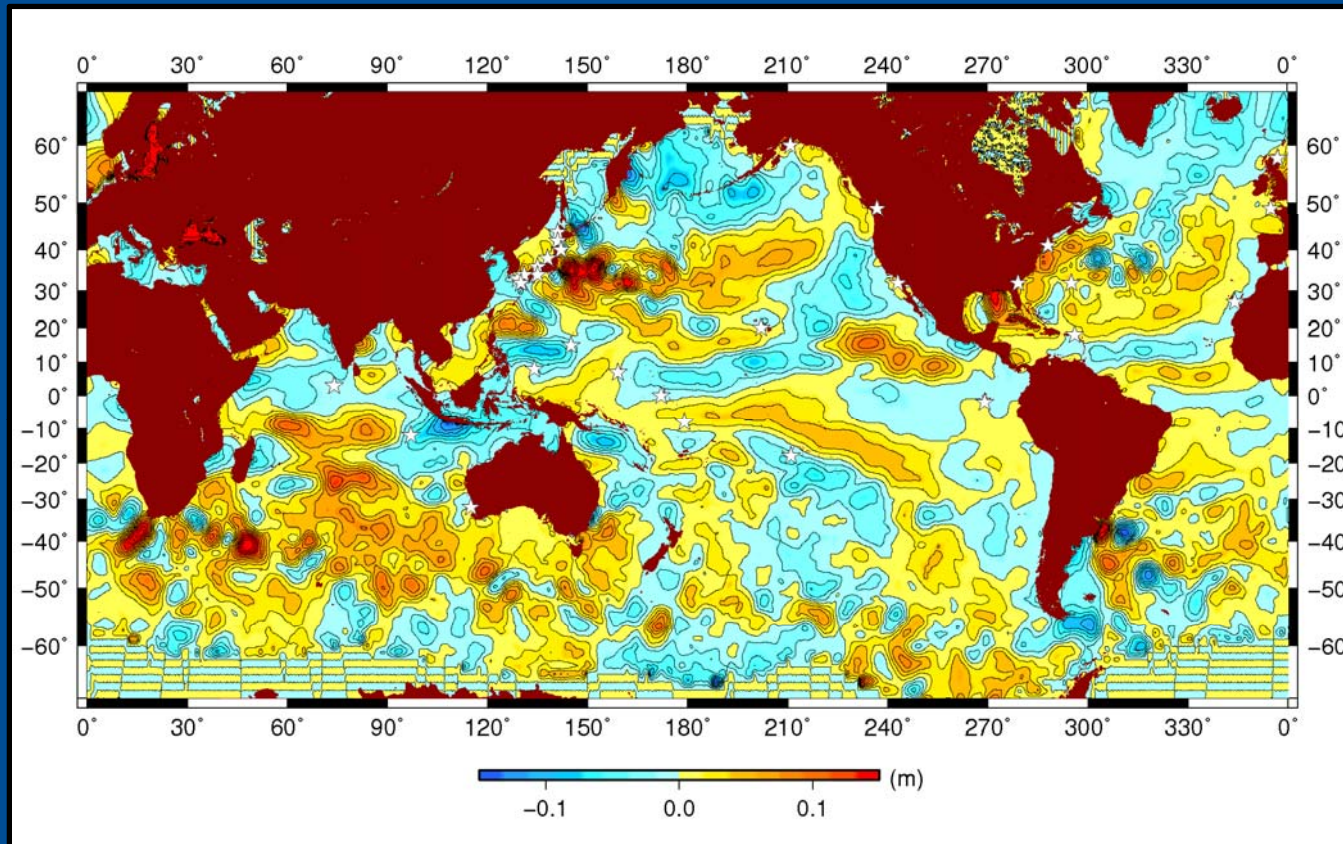
Both use GIA and GPS vertical corrections (30 tide gauges, OI algorithm (Kaplan 1997 / Church 2004)).

Use in sea level reconstructions



Caveat:
Influence of missing tide gauges:
overall trend may be lower

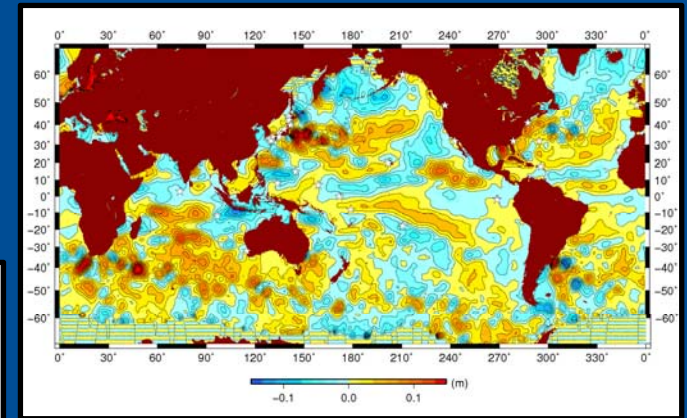
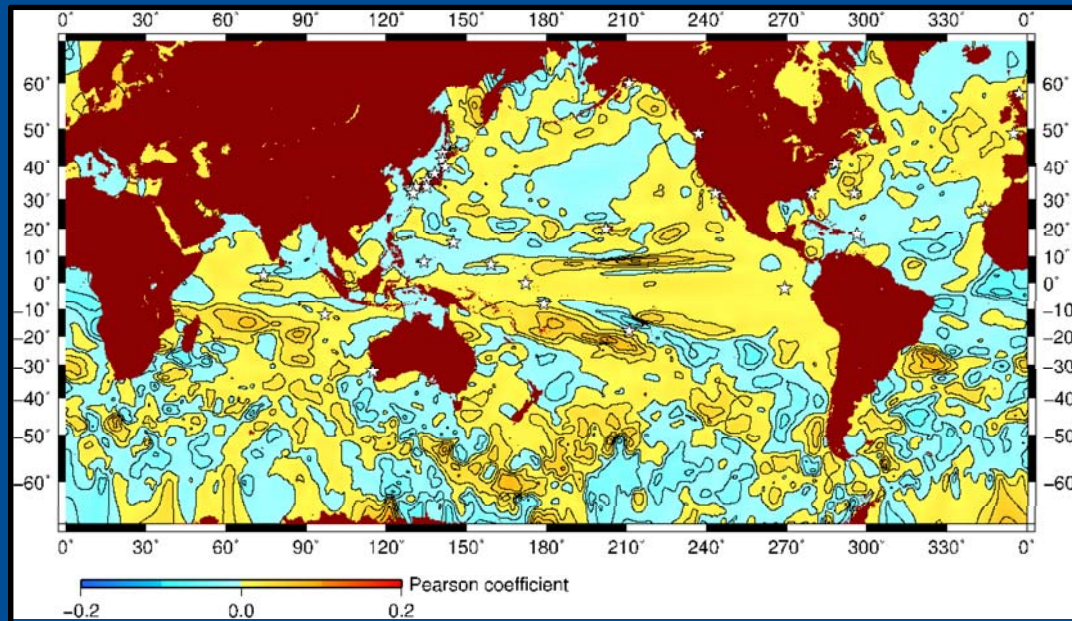




Regional distribution of trend differences between GPS- and GIA-corrected versions for the 1970-2001 period.

Note that differences occur also in areas where no TGs are present (nonlocal effects, suppression or enhancement of dominant patterns).

Double-check for TOPEX period:
Correlation is improved also for areas where
no TGs are present



Enhancement of patterns with strong
variability

GPS corrections can markedly improve historical SLA reconstructions

Reconstructed trend difference may explain differences in tide gauge and RA sea level rise estimates

GPS issues:

GPS corrections must not be applied blindly, determine start and stop of LM process

Attention: including tide gauges with short records or with gaps will lead to jumps in the reconstruction (especially if large trend corrections are applied)

Reconstruction issues:

nonlocal effects - split benefit (artefacts vs. physical processes)
including more tide gauges only beneficial if tide gauge is „good“
careful selection of tide gauges necessary (correlation, variance) especially when only few gauges are used

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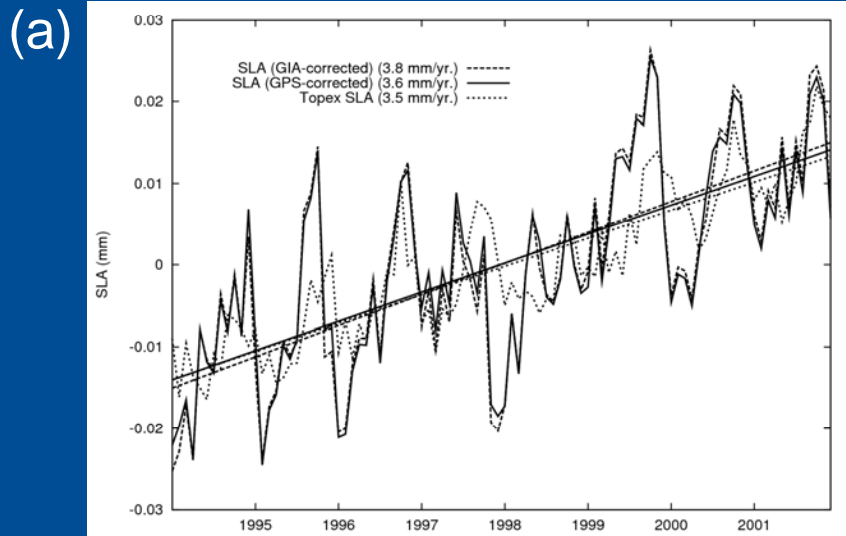
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Bo Christiansen (DMI Copenhagen)

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A comparison of reconstructed sea level anomalies for (a) 1994-2001, compared with TOPEX altimetry. (b) 1970-1990.

Both use GIA and GPS vertical corrections (30 tide gauges, Ol algorithm (Kaplan 1997 / Church 2004)).

The reduction of the trend in (a) compares well with the results from Wöppelmann (2007). In (b), the GPS-corrected version gives an increased trend of 1.4 mm/yr. vs. 1.2 mm/yr. Not that differences in the trend depend strongly on the set of tide gauges used for the reconstruction and start of the land movement processes.

