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Yearly Mean Distribution of Sea Levels in the North Sea Since 1900

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Introduction

The coastal area of the North Sea is densely populated and prone to inundation due to storm surges. The patterns of sea level change in the North Sea have shown different behaviour as global ones during the last Decades.

Here, the yearly mean distribution of sea level in the North Sea is reconstructed from tide gauge and satellite altimeter data starting in 1900. Empirical orthogonal functions (EOF) estimated from Topex, Jason-1 and Jason-2 altimeter data from 1993 to 2012 were combined with historical data from 28 tide gauges from around the North Sea obtained from the Permanent Service for Mean Sea Level (PSMSL).

Altimetry

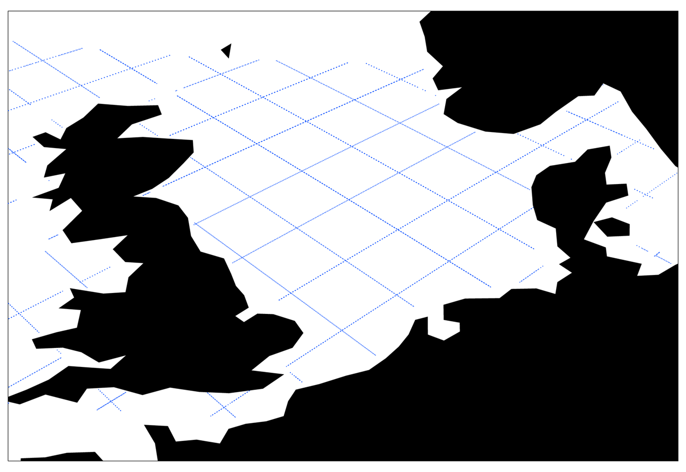


Fig. 1: Ground tracks of the satellite altimeters used

- Topex, Jason-1 and Jason-2 GDR-data, processed at GFZ
- EOT11a ocean tidal model
- No inverse barometric correction
- Yearly means 1993-2012
- 0.5°x 0.5° grid
- Region: 4°W - 9°E, 51°N - 60°N

Tide Gauges

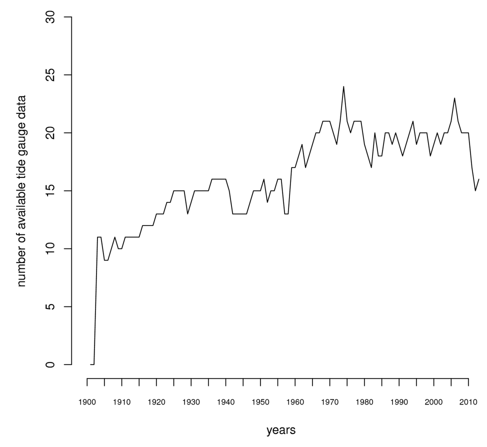


Fig. 2: Number of tide gauges avaible each year.

- Yearly mean time series from PSMSL (www.psmsl.org)
- 28 tide gauges
- Period 1900-2012
- GIA correction from PSMSL

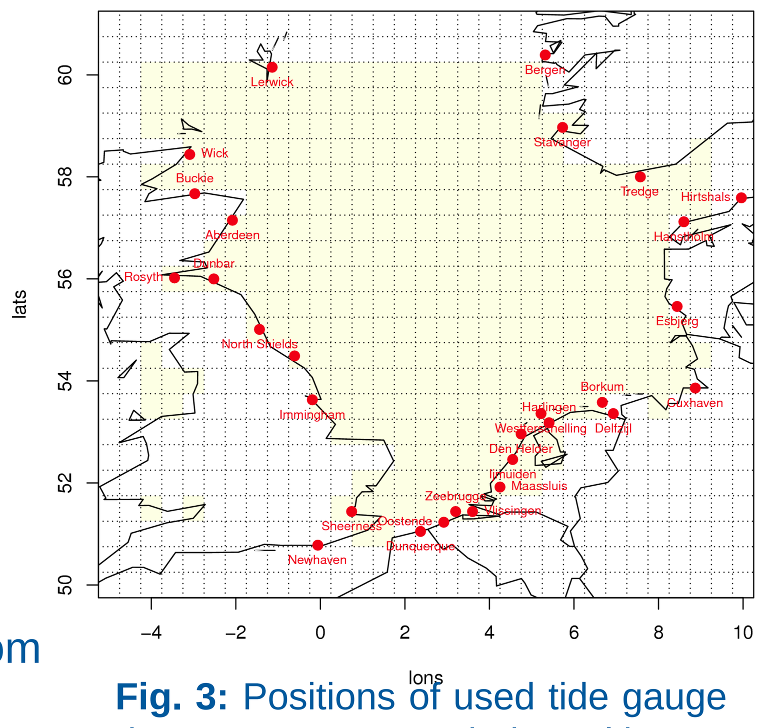


Fig. 3: Positions of used tide gauge data, area covered by altimetry (shaded) and altimetry grid.

Reconstruction

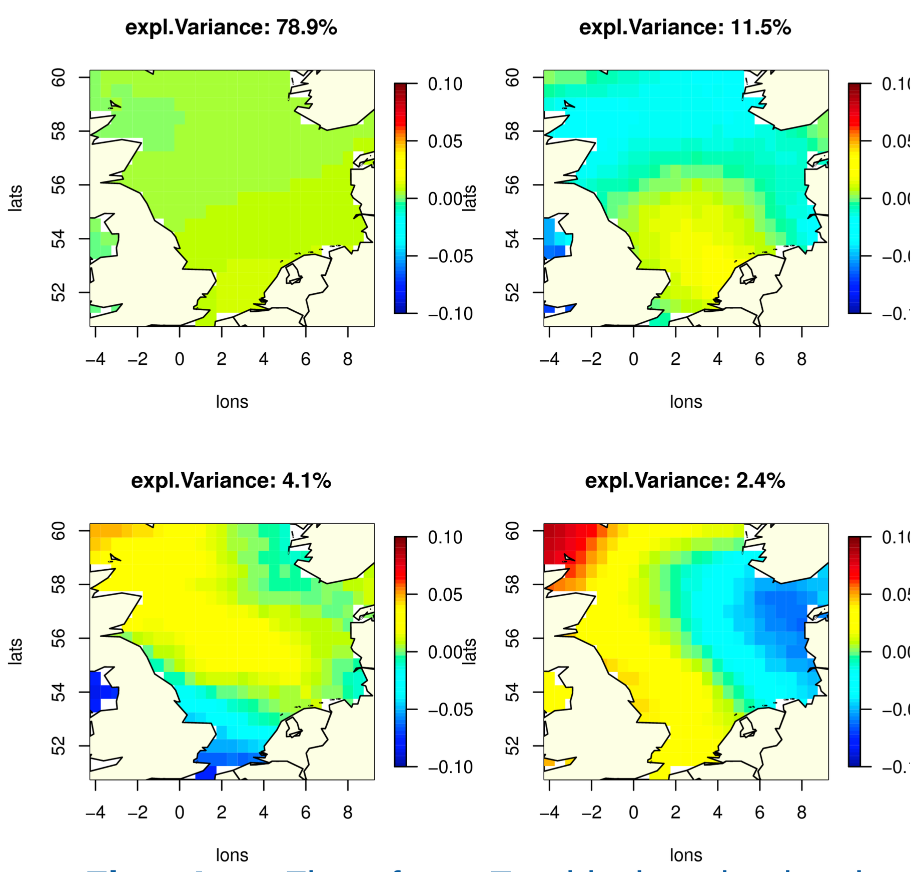


Fig. 4: First four Empirical orthogonal functions (EOF) of the altimetry data [m] and their explained variance.

For the reconstruction of the sea level the altimetry data is decomposed in dominant patterns and the corresponding time series are fitted from the tide gauge data (Church et al., 2004). The dominant EOF pattern of sea level variability from the altimetry data in the North Sea accounts for almost 80% of the variance, the first four EOFs for more than 96%. At most tide gauges the agreement with collocated altimeter data is good during the last 20 years. The amplitude of the first EOF pattern is well fitted by the tide gauge data. The amplitudes of the EOFs 2-4 are not yet sufficiently reconstructed. The reconstructed mean sea level of the North Sea coincides with the mean sea level for the German Bight (SE of the North Sea) reconstructed by Albrecht et al. (2011) from tide gauge data.

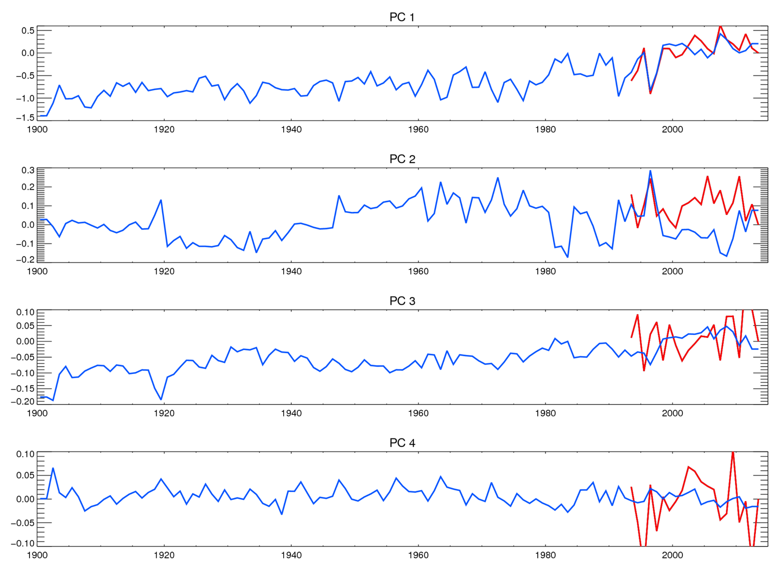


Fig. 5: Principal components (PC) of the altimetry (red) and reconstructed amplitudes from tide gauge data (blue) for the first four EOF patterns.

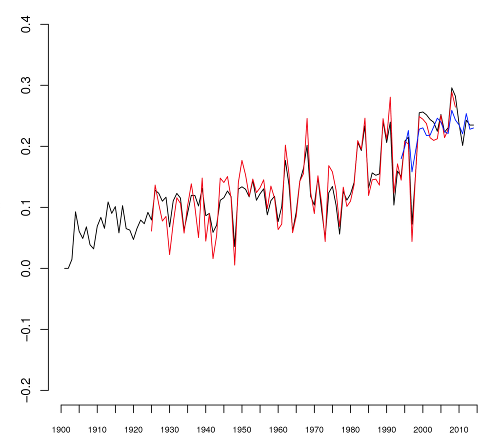


Fig. 6: Spatial mean sea level for the North Sea from the reconstruction (black), from altimetry (blue) and for the German Bight from a tide gauge only reconstruction (red).

Summary

- Dominant pattern of annual sea level variability accounts for almost 80% of the variability
- Mean sea level trend and variability is consistent with reconstructed mean sea level of the German Bight
- Sea level variability in the validation period is reconstructed especially well in the eastern North Sea
- To improve the reconstructed trend pattern GPS-corrections for vertical tide gauge displacement are implemented

Validation

The quality of the reconstruction is validated against the altimeter data. The agreement between altimeter data and reconstruction is especially high at the eastern part of the North Sea. The spatial distribution of sea level trends needs to be further improved. First tests with GPS derived corrections for vertical land movement improve the trend pattern.

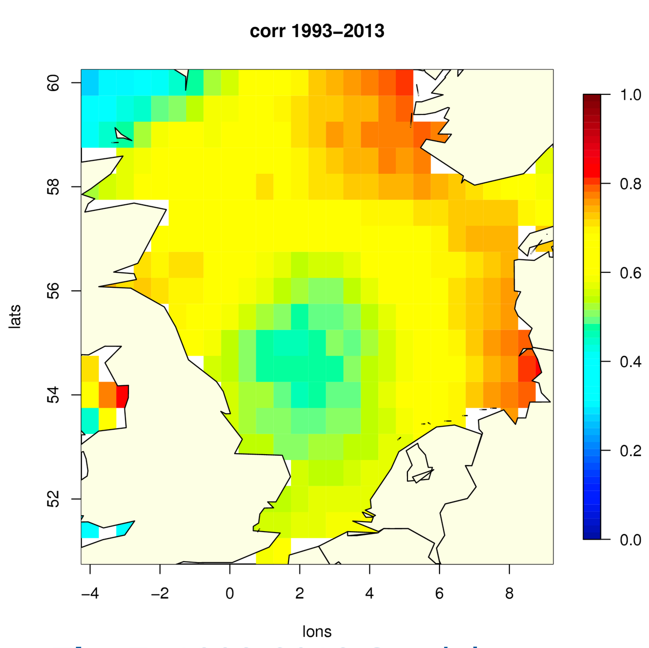
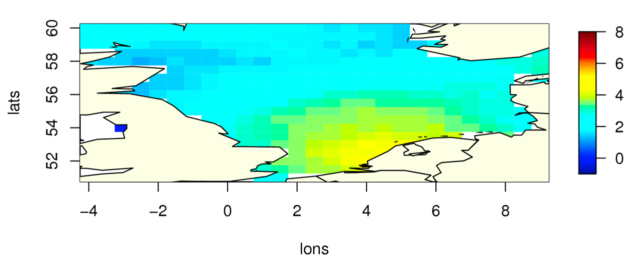
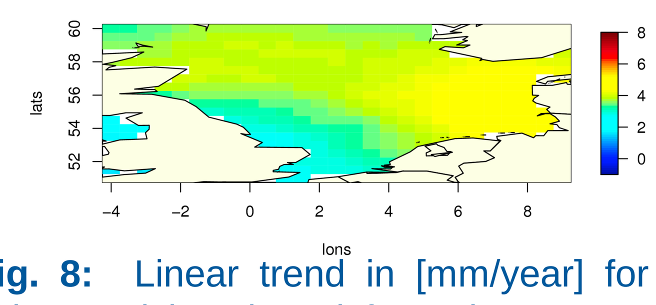


Fig. 7: 1993-2012 Spatial correlation between altimeter data and reconstruction.





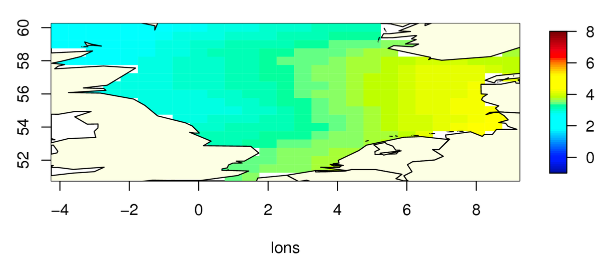


Fig. 8: Linear trend in [mm/year] for 1993-2012 by altimetry (above) and from the reconstruction (below) and from a reconstruction based on GPS corrected tide gauges (right).

Tab. 1: Relative sea level rise at 14 tide gauge stations from the GIA model by Peltier (www.psmsl.org) and vertical land movement from nearby GPS stations (IGS-TIGA tide gauge data reprocessing 2013)

Tide gauge	GIA correction [mm/year]	GPS station	GPS correction [mm/year]
Lerwick	-0.1	LWTG	0.8 ± 1.0
Aberdeen	-0.8	ABER	1.5 ± 0.8
North Shields	-0.4	NSTG	0.3 ± 0.9
Sheerness	-0.1	SHEE	2.3 ± 0.9
Newhaven	-0.1	HERT	0.6 ± 0.7
Dunkerque	-0.8	DGLG	-0.8 ± 1.0
Oostende	-0.1	OOST	-0.4 ± 0.5
Zeebrugge	-0.1	ZEEB	-0.7 ± 0.6
West-terschelling	0.4	TERS	-0.8 ± 0.6
Cuxhaven	0.4	TGCU	1.3 ± 1.3
Esbjerg	0.5	ESBH	-0.5 ± 0.8
Hirtshals	-1.3	HIRS	2.4 ± 0.6
Tredge	-1.0	TGDE	1.5 ± 0.7
Stavanger	-1.14	STAS	1.1 ± 0.6