From global to regional sea level trends: a joint GRACE and Jason-1/-2 inversion

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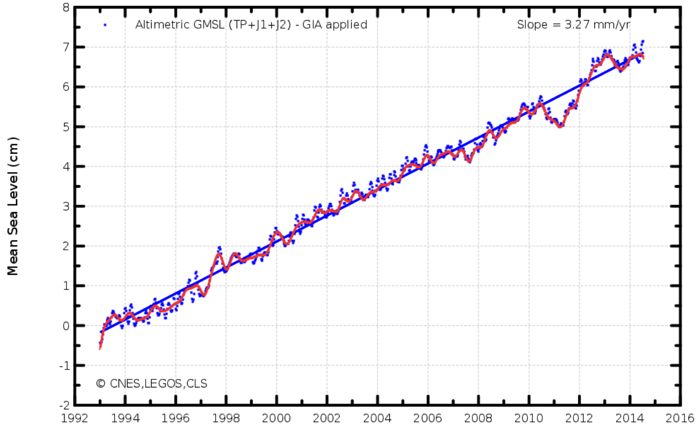
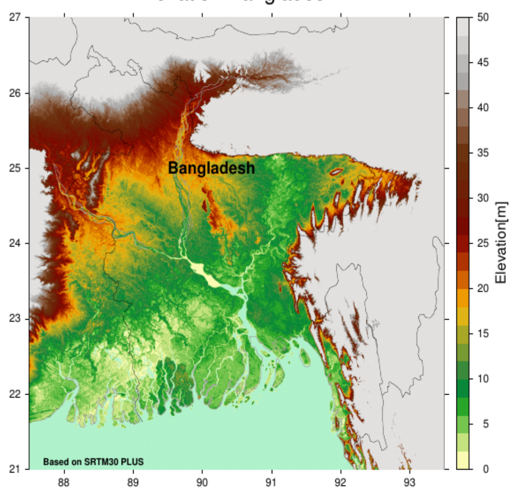
Global and Regional Sea Level Trends

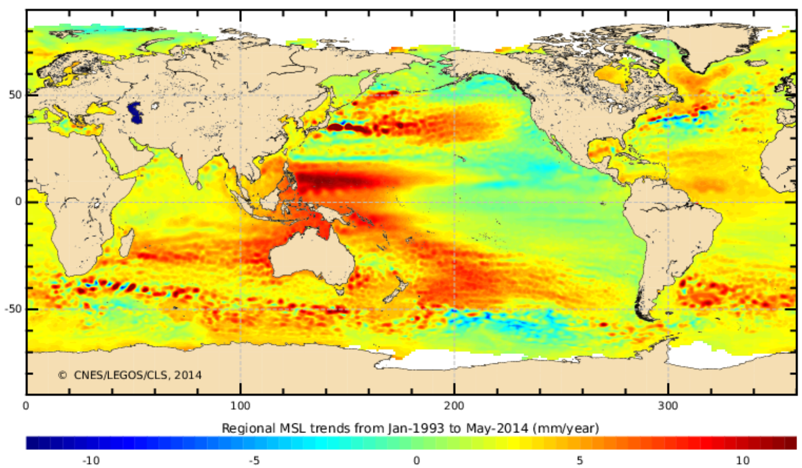
- Total sea level rise ~3.2 mm/yr
- Spatial and temporal variability
- Regional factors (e.g. land subsidence) can intensify the impacts of sea level rise
- What are the main contributors to the total sea level rise?



Elevation Bangladesh

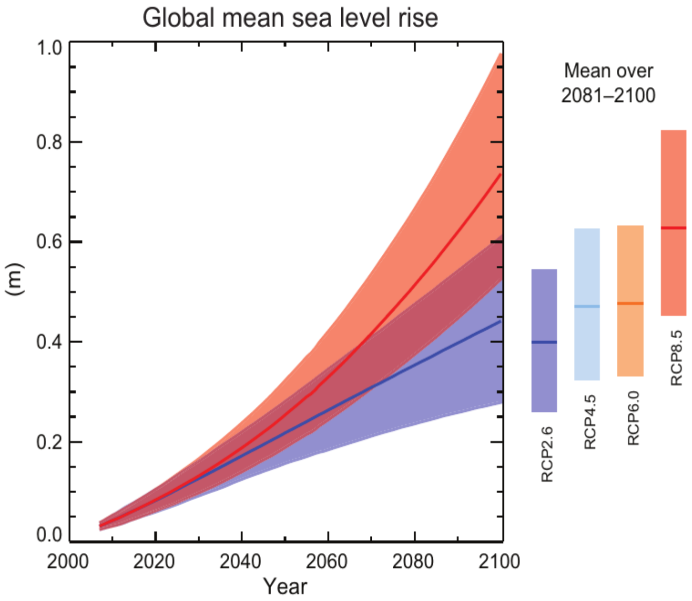


AVISO



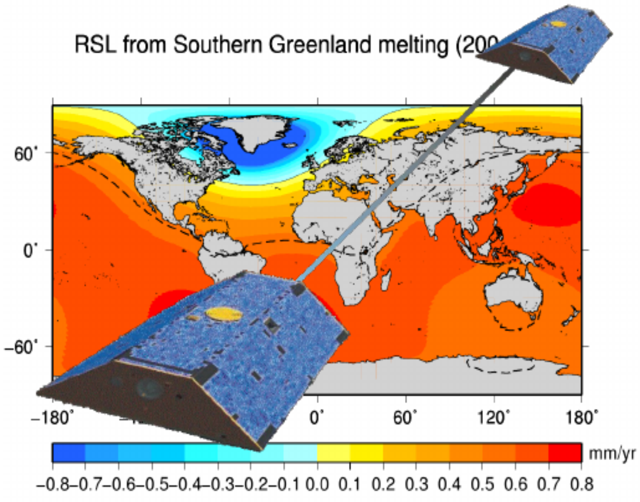
Overview

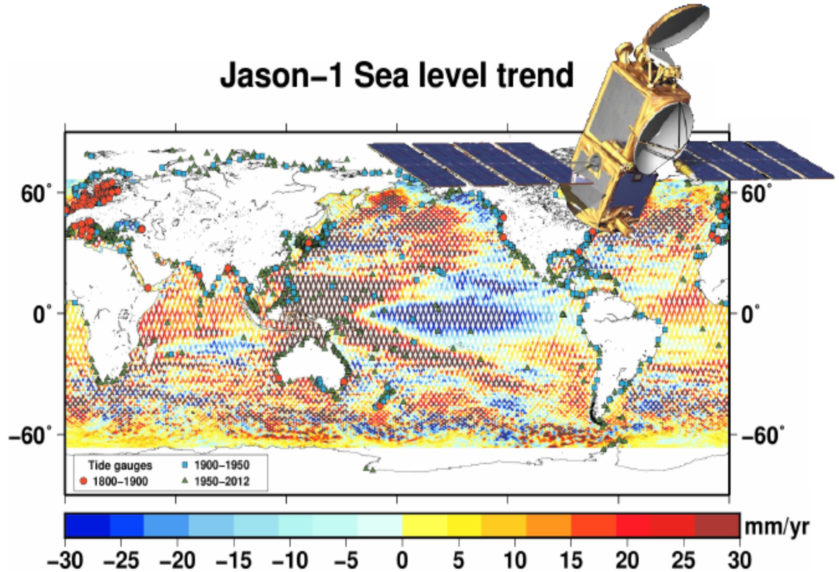
- Observations
- Fingerprint Inversion for separating total Sea Level
- Global Sea Level Budget
- BanD-AID project
- Preliminary Results in the Bay of Bengal
- Conclusion



Source: IPCC-AR5, 2013

GRACE & Jason-1/-2 Altimetry





- GRACE → mass changes
- Altimetry (Jason-1 & -2) → geometrical sea level

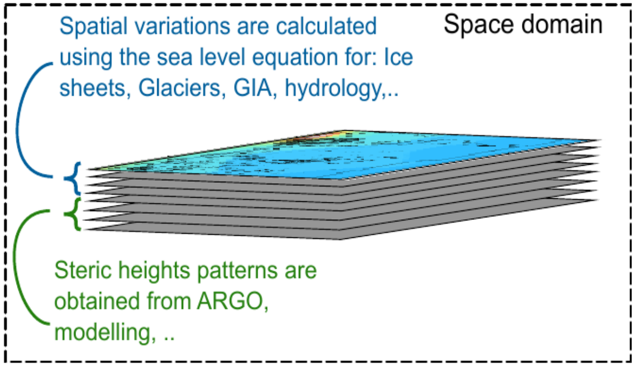
Highly complementary datasets

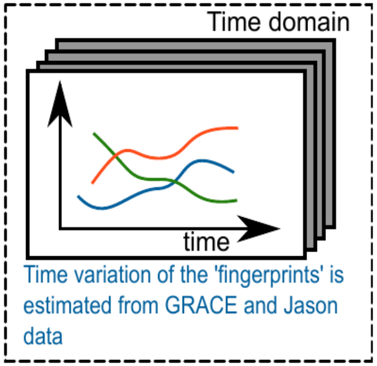
- Classic way: Altimetry – GRACE - GIA → separate mass and steric changes (e.g. Lombard et al. 2007)
- Here: joint inversion of GRACE (GFZ) and altimetry (OpenADB)
  → parameterization invariant spatial patterns (fingerprints)

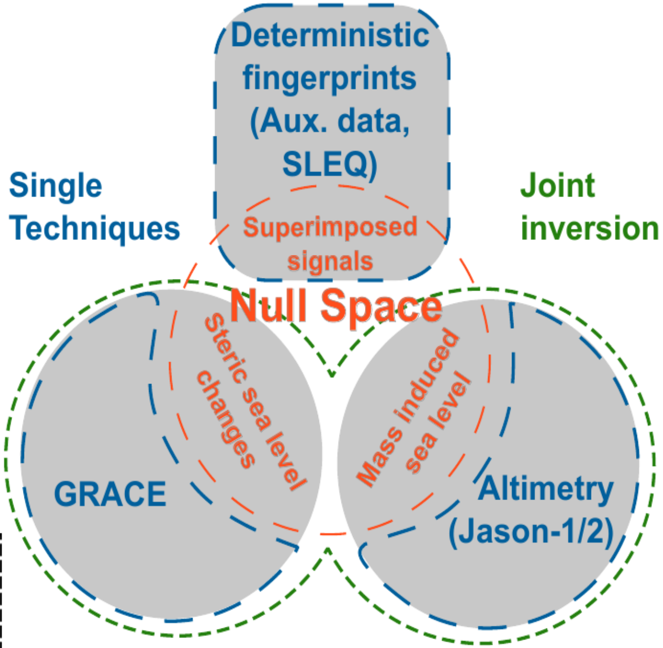
'Fingerprint' Inversion Method

Idea of the global fingerprint inversion (Rietbroek et al., 2011)

- Modelling of sea level patterns (Greenland, Antarctica, glaciers, land hydrology, steric changes) gravitationally-elastic-rotationally consistent
- Normalized pattern amplitudes fitted to GRACE and altimetry observations
- No filtering of GRACE data and no external data (e.g. degree 1 coefficients)



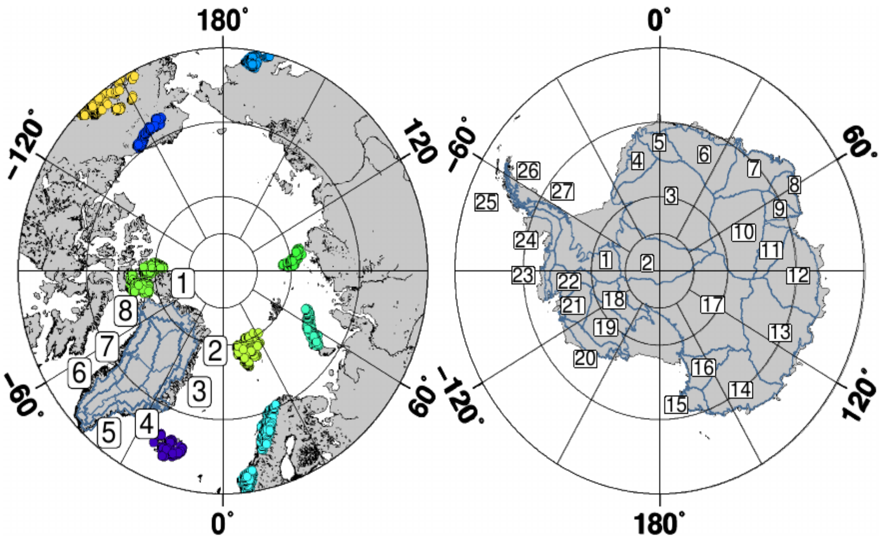




Time invariant fingerprints, but no constraints on trends and amplitudes

Mass Fingerprints

- Greenland basins (16)
- Antarctic basins (27)
- Glacier clusters (16)
- Hydrology (60 EOF's)
  - WGHM (Doell et al. 2003)
- Glacial isostatic adjustment (5)
  - Based on Klemann et al. 2009
  - See also Rietbroek et al. 2014

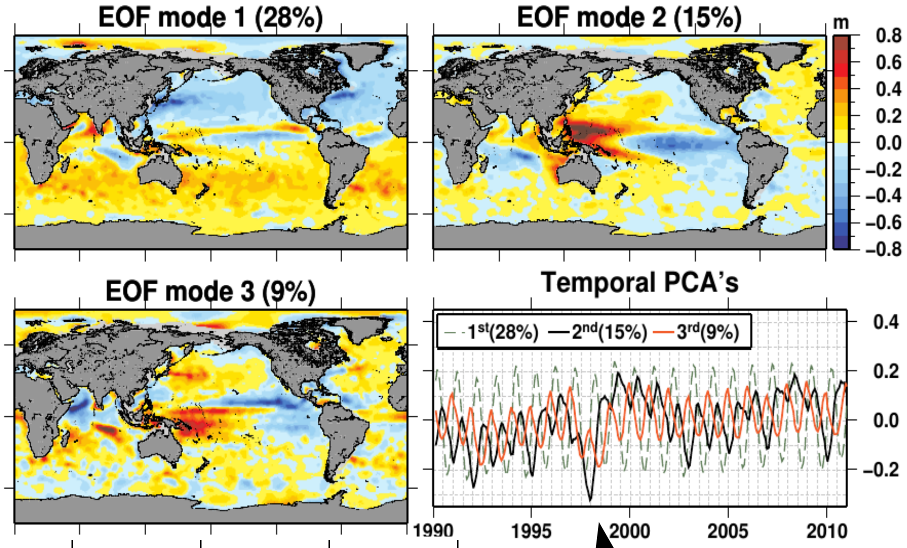


Compute “passive sea level response“ for varying drainage basins and glacier clusters utilizing the Sea Level Equation

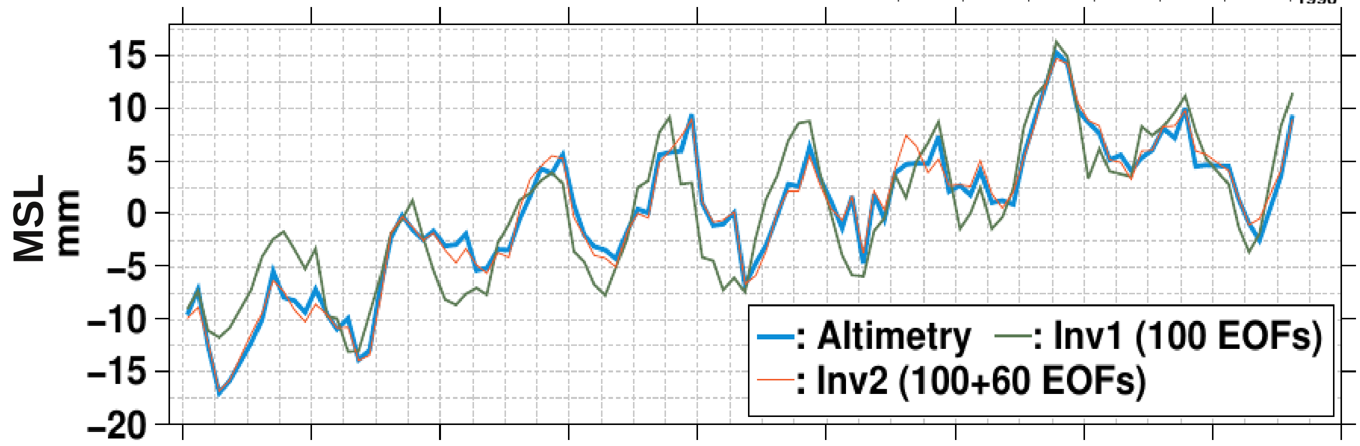
$$\delta s(\lambda,\theta,t) = O(\lambda,\theta)\int_\Omega G^L_{N-U}\left(\delta s\left(\lambda',\theta',t\right) + \delta h\left(\lambda',\theta',t\right)\right)d\omega + \int_\Omega G^T_{N-U}\,\delta\Lambda(\delta s,\delta h)\,d\omega + \frac{\Delta V}{g}.$$

Steric Fingerprints

- Volume change from temperature and salinity in the upper 700m (Ishii et al., 2009)
- Additional patterns for 'deep' ocean from altimeter residuals
- 100 shallow EOF's + 60 bootstrapped (deep ocean) EOF's

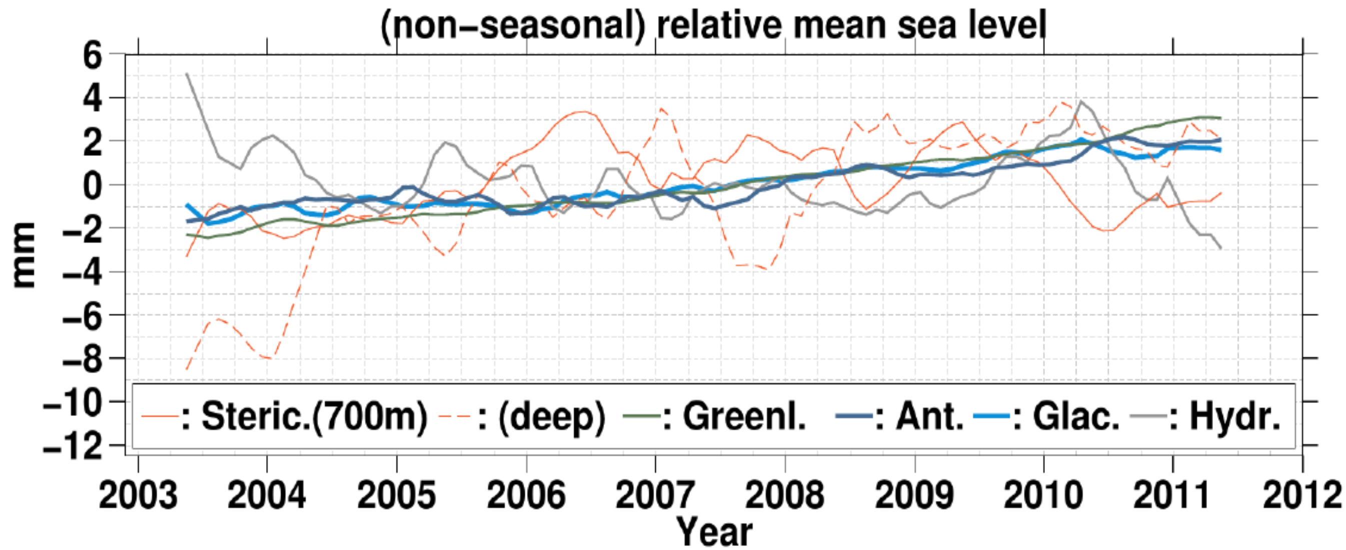


El Niño



Global Inversion Results: Partitioning of the Total Sea Level

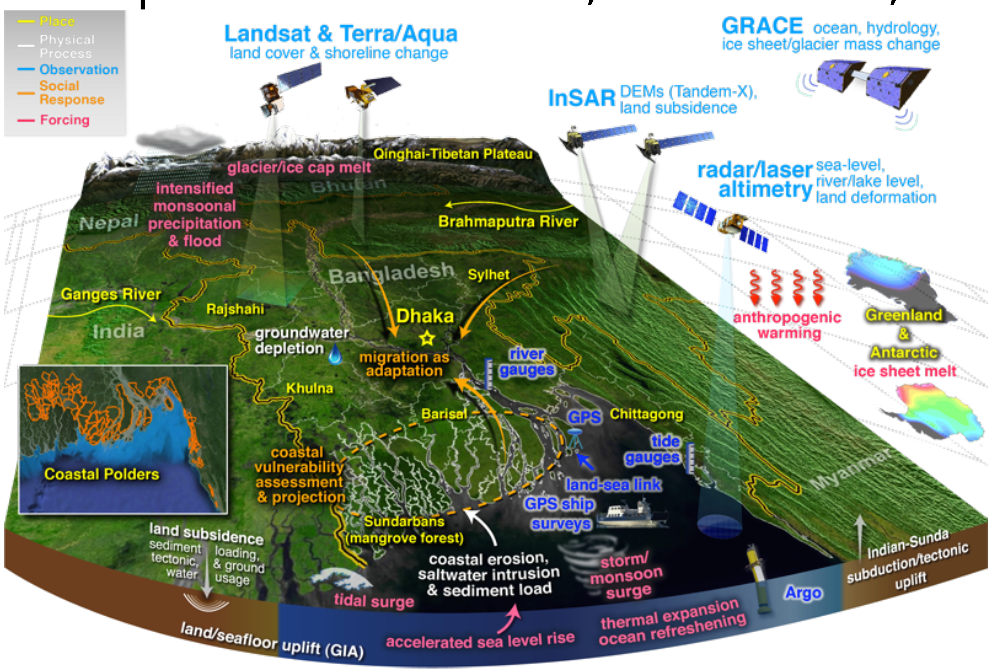
Contribution [mm / yr]	Our Result (2003 - 2011)	IPCC AR5 (1993 - 2010)	Church 2011 (1993 - 2008)	Jacob, 2012 (2003 - 2011)	Chen, 2013 (2005 - 2011)
Antarctica	0.40 ± 0.03	0.27 ± 0.11	0.43 ± 0.20	0.45 ± 0.19	1.8 ± 0.47
Greenland	0.66 ± 0.01	0.33 ± 0.08	0.31 ± 0.17	0.60 ± 0.02	
Glaciers	0.43 ± 0.02	0.76 ± 0.37	0.99 ± 0.04	0.41 ± 0.08	
Hydrology	-0.20 ± 0.09	0.38 ± 0.11	-0.08 ± 0.19		
Steric	1.20 ± 0.14	1.10 ± 0.30	0.88 ± 0.33		0.60 ± 0.27
Total	2.50 ± 0.11	2.80 ± 0.50	2.54 ± 0.46		2.40 ± 0.54



Largest interannual variations from steric changes and terrestrial hydrology

Regional Sea Level in Bangladesh: BanD-AID

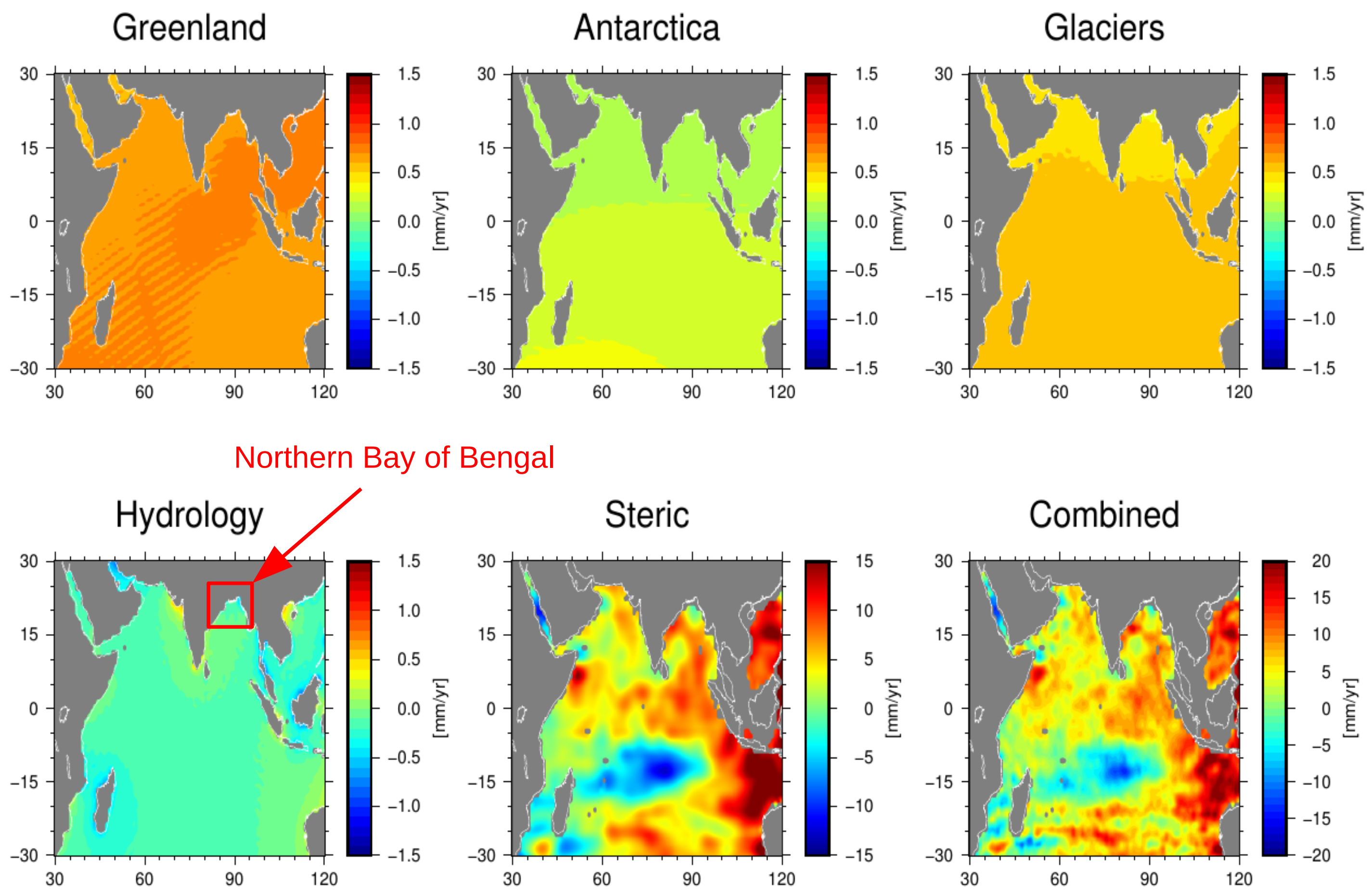
- Project in response to Belmont call on 'coastal vulnerability' (2012) (US/Germany/France/Bangladesh/Australia)
- Collaboration of natural & social sciences
- Topics: Sea level rise, salinization, storm surges, adaption strategies



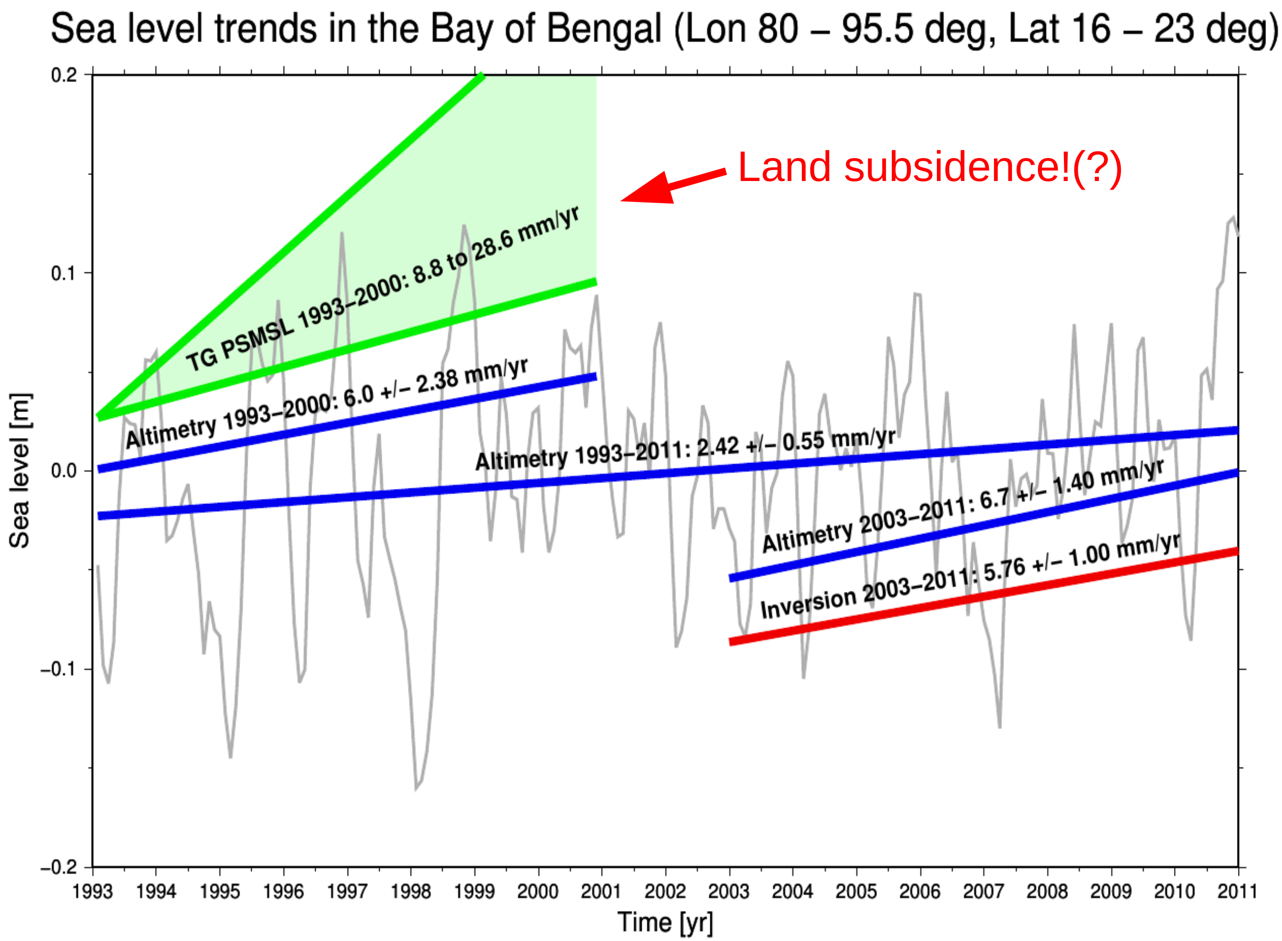
This cartoon is composed by Generic Mapping Tools (GMT), True Marble imagery, NASA/ESA/JAXA satellite illustrations, and Google Earth image. By K.-H. Tseng and J.W. Kim, OSU

Courtesy: Boris Braun & Amelie Bernzen

Contributions to Total Sea Level Changes in the Bay of Bengal



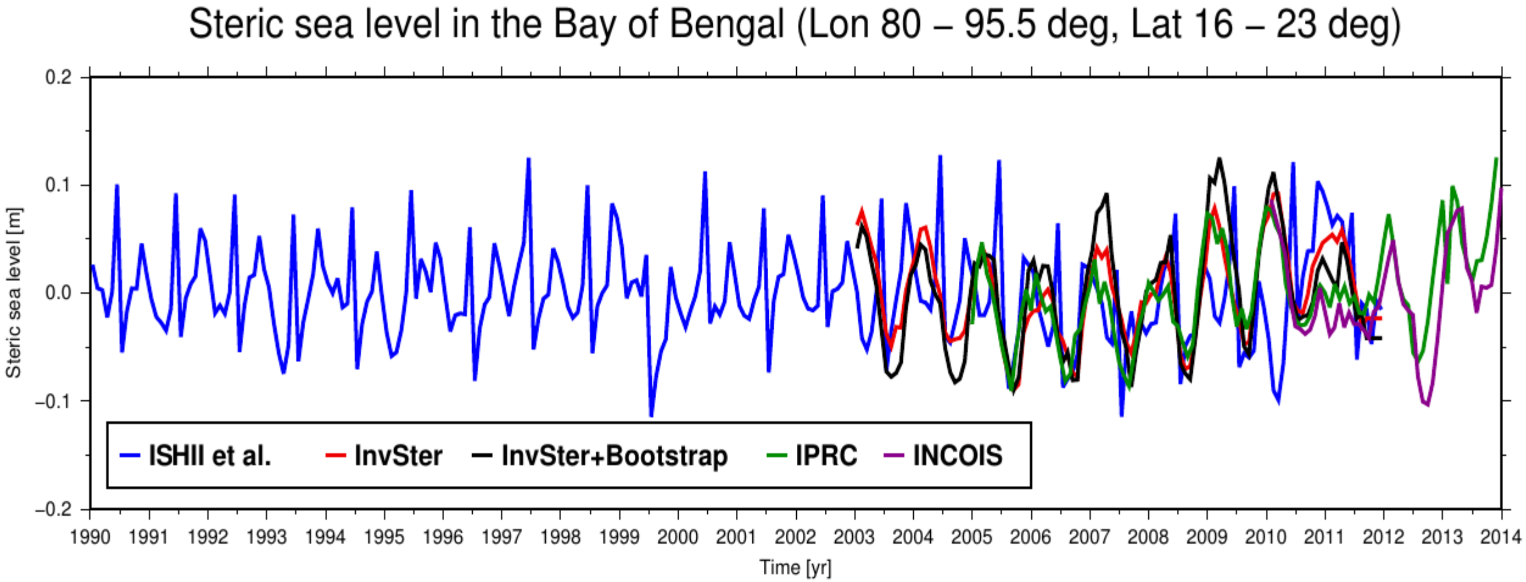
Comparison with local measurements



Steric Sea Level in the Bay of Bengal

Steric sea level height trends: GRACE/Jason vs. ARGO/modeling

- From gridded ARGO data (http://www.argo.ucsd.edu/Gridded_fields.html).
  - IPRC (International Pacific Research Center), INCOIS (Indian National Centre for Ocean Information Services)
- Similar results when compared to Llovel et al. 2011 (different depths, IOD)



Inversion tries to separate shallow (<700m) and “deep“ steric effects (bootstrap)

Conclusions and Outlook

- Fingerprint inversion improves sea level monitoring by merging different geodetic techniques (GRACE, Altimetry, …?)
  - Seperation of different contributions
  - Interannual variability dominated by hydrology and steric sea level changes

    → steric sea level: largest contribution, but also largest uncertainty
- Total inversion sea level rise in the Bay of Bengal explains 5.8 (+/-1) mm/yr (2003 – 2011) of the 6.7 mm/yr observed from altimetry data
- Strong land subsidence effects cause large spread of tide gauge estimates
- Future work: Including tide gauge rates, GPS rates, Envisat altimetry and possibly other data in the inversion and estimate the land subsidence.