Comparability of coastal altimetry with tide gauges and application for vertical land motion detection

J. Oelsmann, M. Passaro, D. Dettmering, L. Sanchez, C. Schwatke, F. Seitz

Deutsches Geodätisches Forschungsinstitut
Technische Universität München
(DGFI-TUM)

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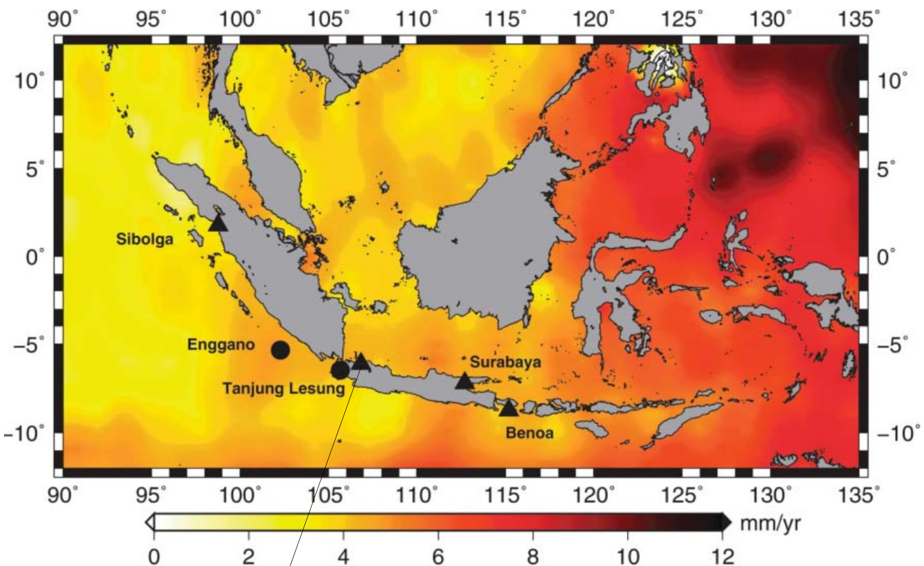
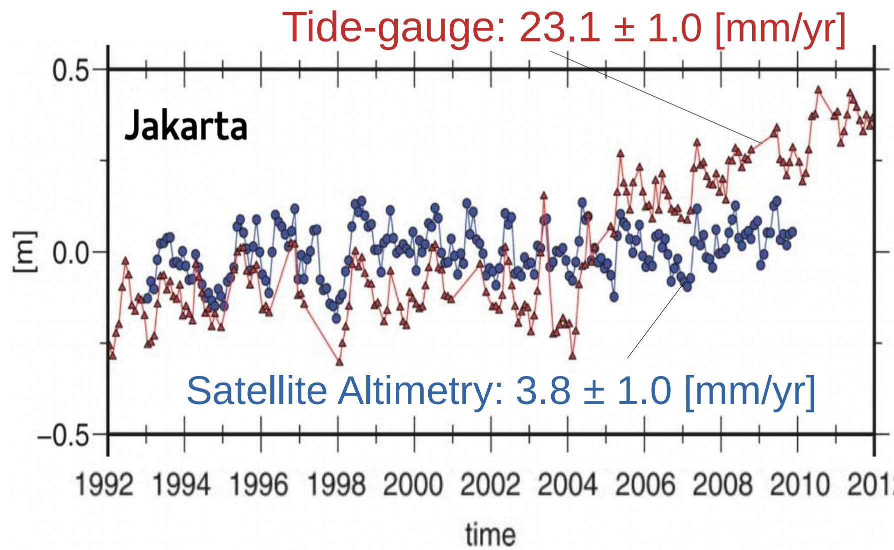
18.09.2019

Vertical land motions influence relative sea level change

Mean sea level trends (1993-2011)





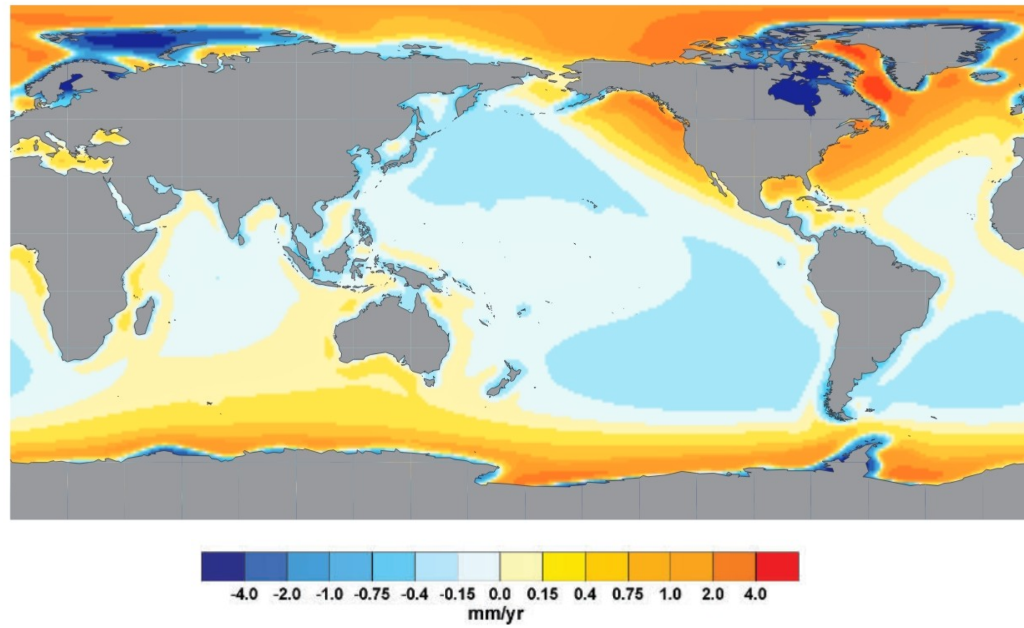
Jakarta

(modified from Fenoglio-Marc et al., 2012)

Causes of Vertical Land Motions

- Glacial isostatic adjustment (GIA)
- Tectonic movements
(e.g subsidence)
- Local effects (e.g. groundwater extraction, erosion ...)

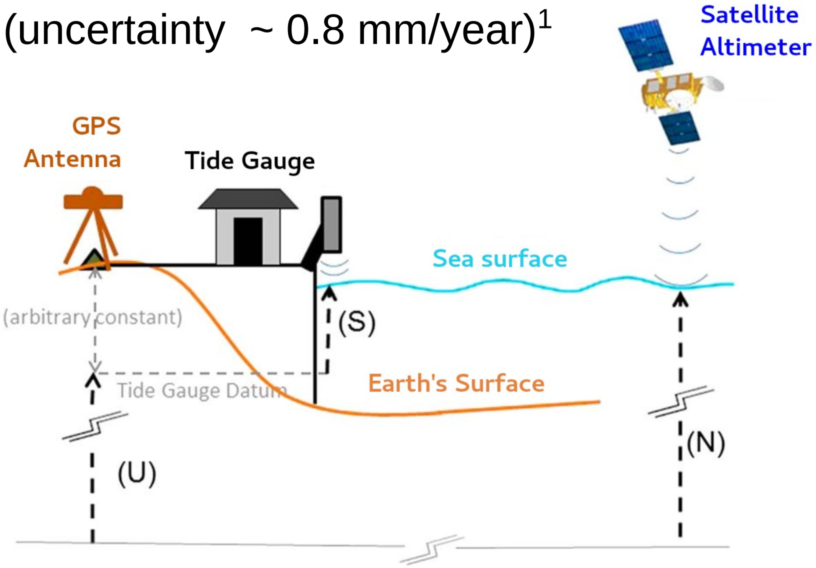
Impact of GIA on relative sea level



(GIA-model prediction with ICE-5G and VM2 (Peltier, 2004) modified from Tamisiea, M.E., and J.X. Mitrovica, 2011)

Methods of vertical land motion trend determination

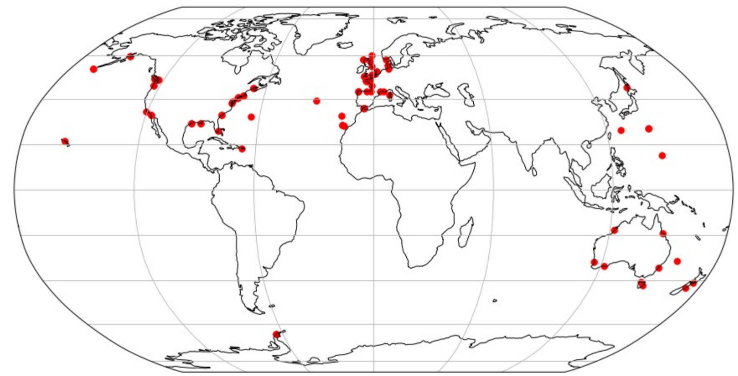
- GNSS (GPS)
  (uncertainty ~ 0.2 mm/year)[1]
- Satellite-Altimetry and
  Tide Gauge Difference
  (uncertainty ~ 0.8 mm/year)[1]



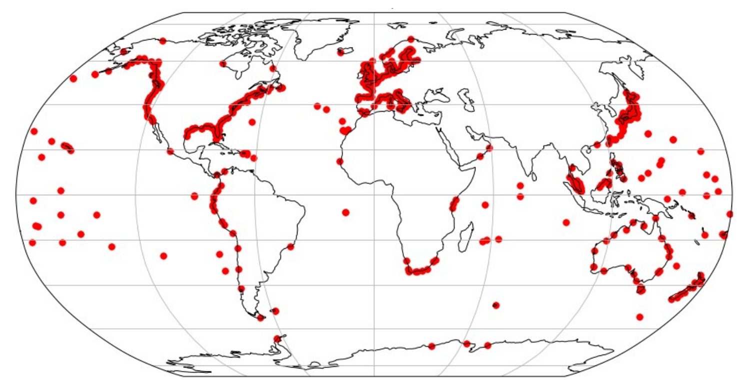
U = S – N

Vertical land motion = relative – absolute sea level change

GPS stations near tide-gauges (<1km)



Tide-gauges (>15 years of data)



(Data from GESLA[2] and SONEL[3])

[1] Wöppelmann and Marcos (2016)

Vertical Land motion by satellite Altimetry and tide-gauge Difference (VLAD)

Enhancing comparability of altimeter and in-situ observations

Reduction of vertical land motion trend uncertainties estimated by ALT-TG difference

Advanced Datasets:

- High-rate along-track altimetry data (optimized for coastal applications)
- High-frequent (hourly) tide-gauge measurements (GESLA)
- Extended GPS-Datasets (1997-present) (homogeneously processed in ITRF2014, L. Sanchez)

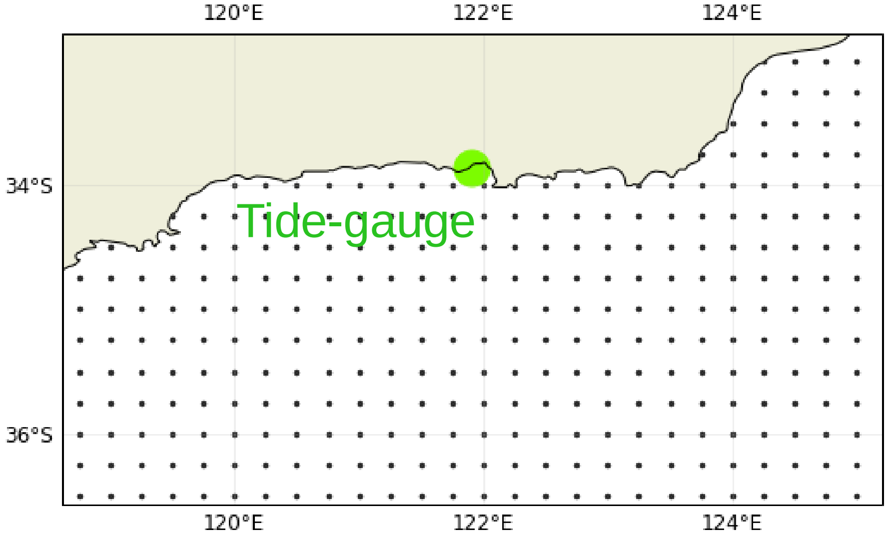
Previous studies[1] :

- Gridded, monthly product (AVISO Dataset)
- Monthly tide-gauge data (PSMSL)
- GPS-timeseries processed in ITRF2008 (1997-2014, SONEL)

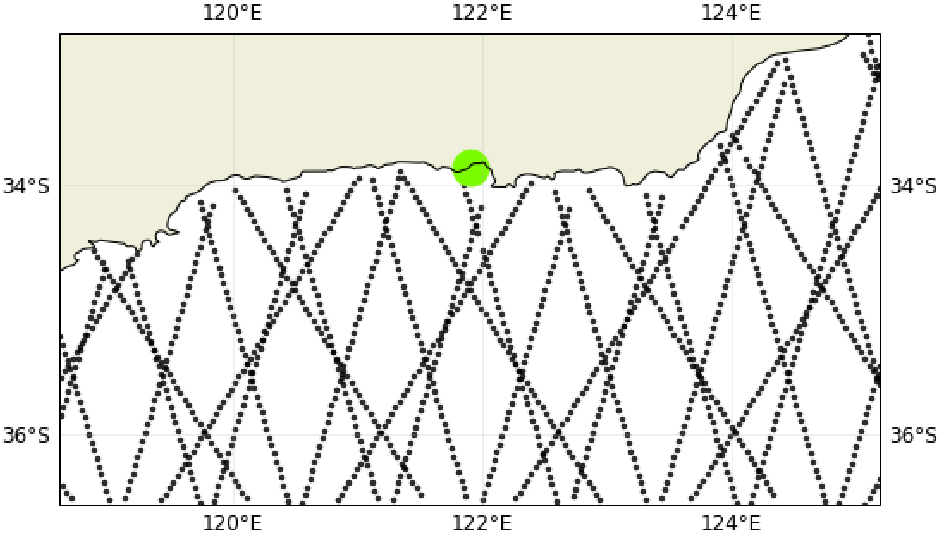
[1] Wöppelmann and Marcos (2016)

Comparing altimetry and tide-gauges

1/4° gridded-Data ⟷ along-track data



previous studies[1]

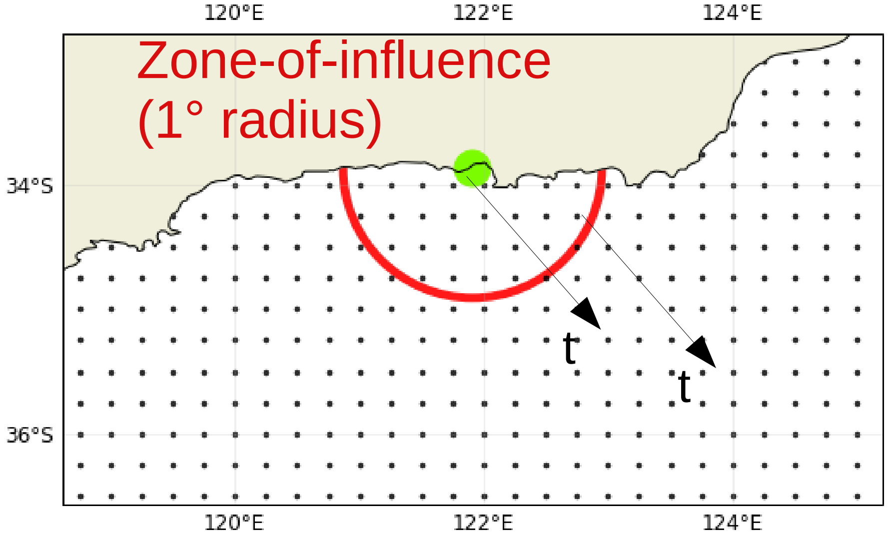


our approach

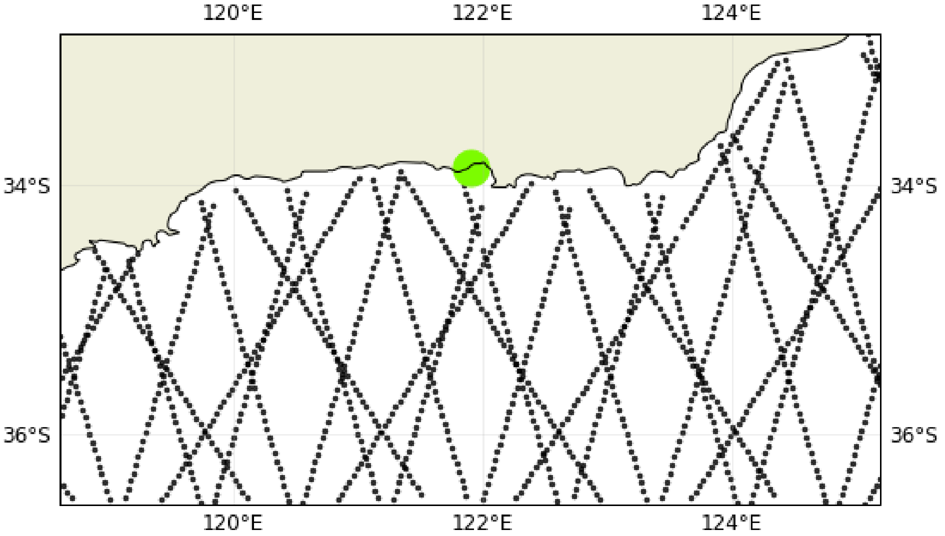
[1] Wöppelmann and Marcos (2016)

Comparing altimetry and tide-gauges
The Zone-of-Influence

1/4° gridded-Data ⟷ along-track data



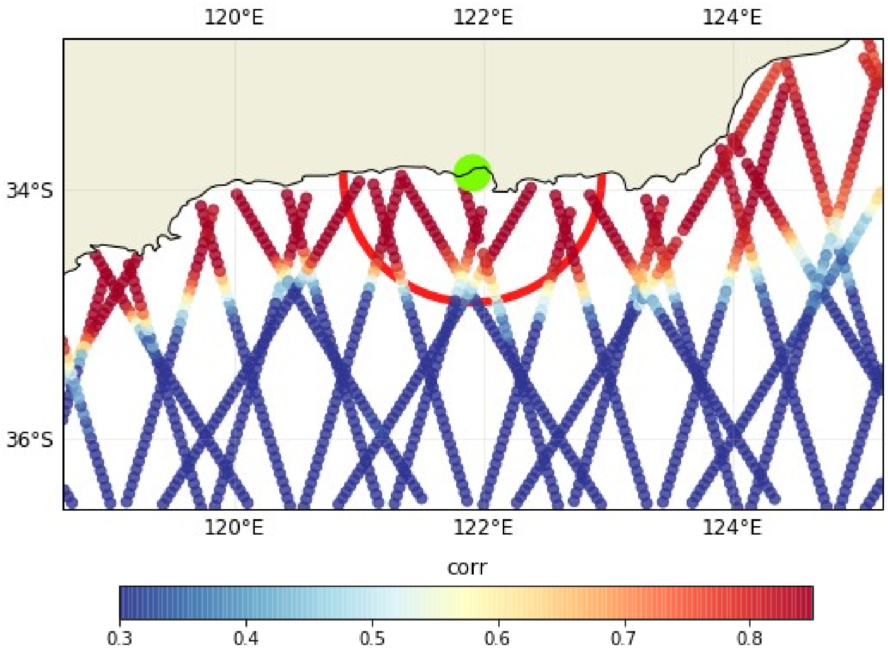
previous studies[1]



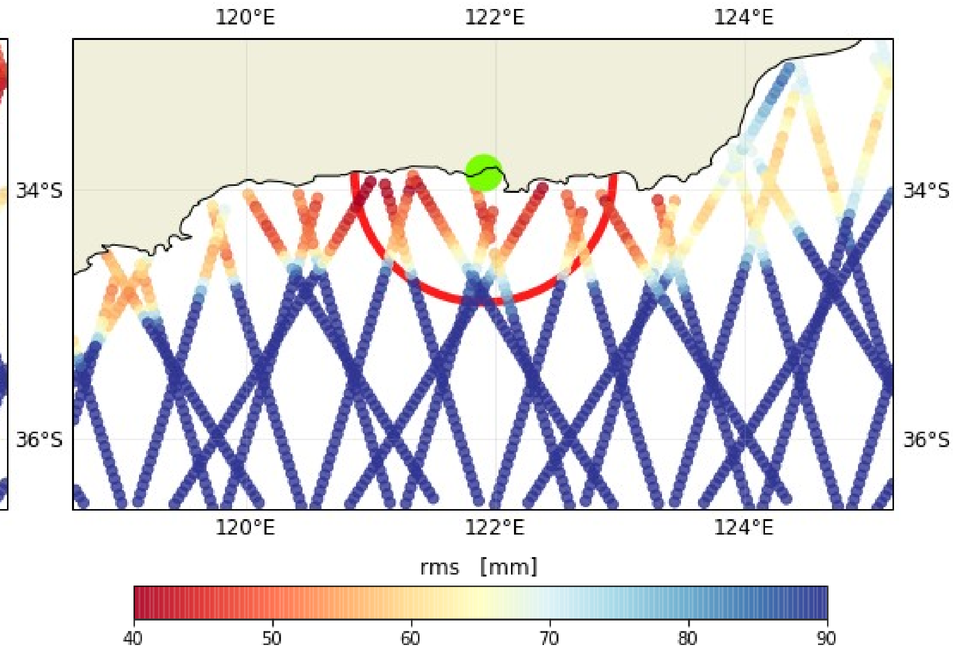
our approach

Comparing altimetry and tide-gauges
The Zone-of-Influence

Correlation coefficient



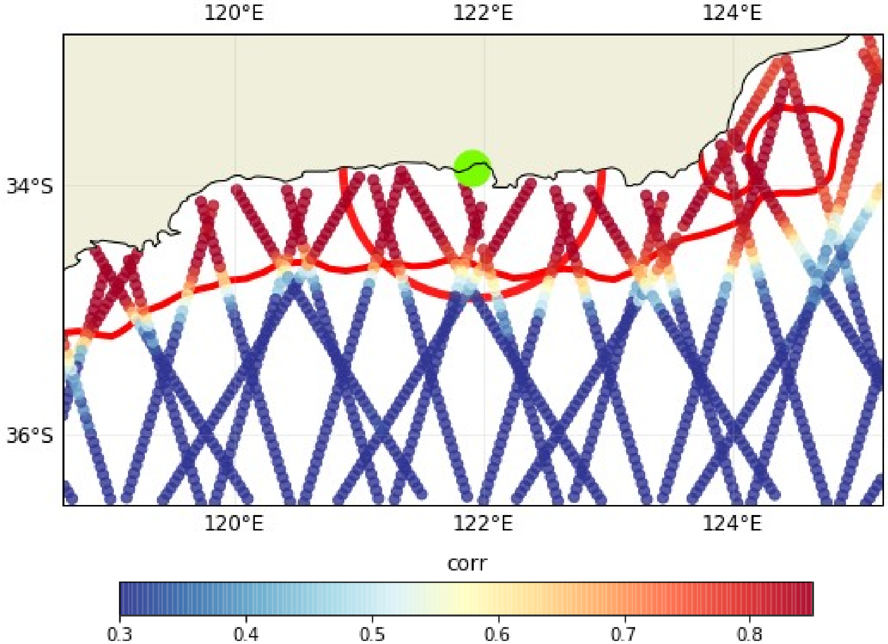
RMS



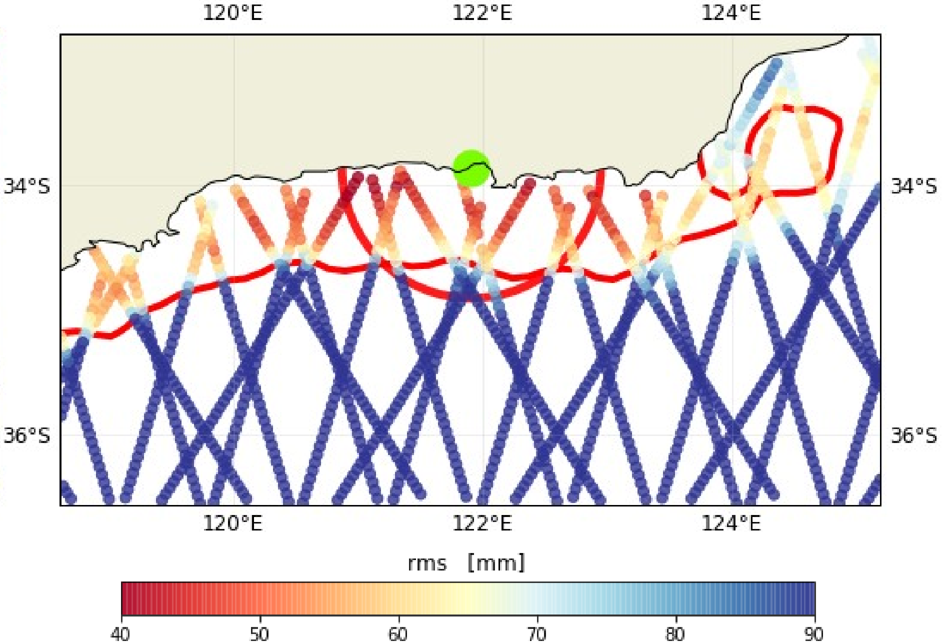
→ Identifying criteria of comparability (e.g. cc, rms, annual cycle)

Comparing altimetry and tide-gauges
The Zone-of-Influence:

Correlation coefficient



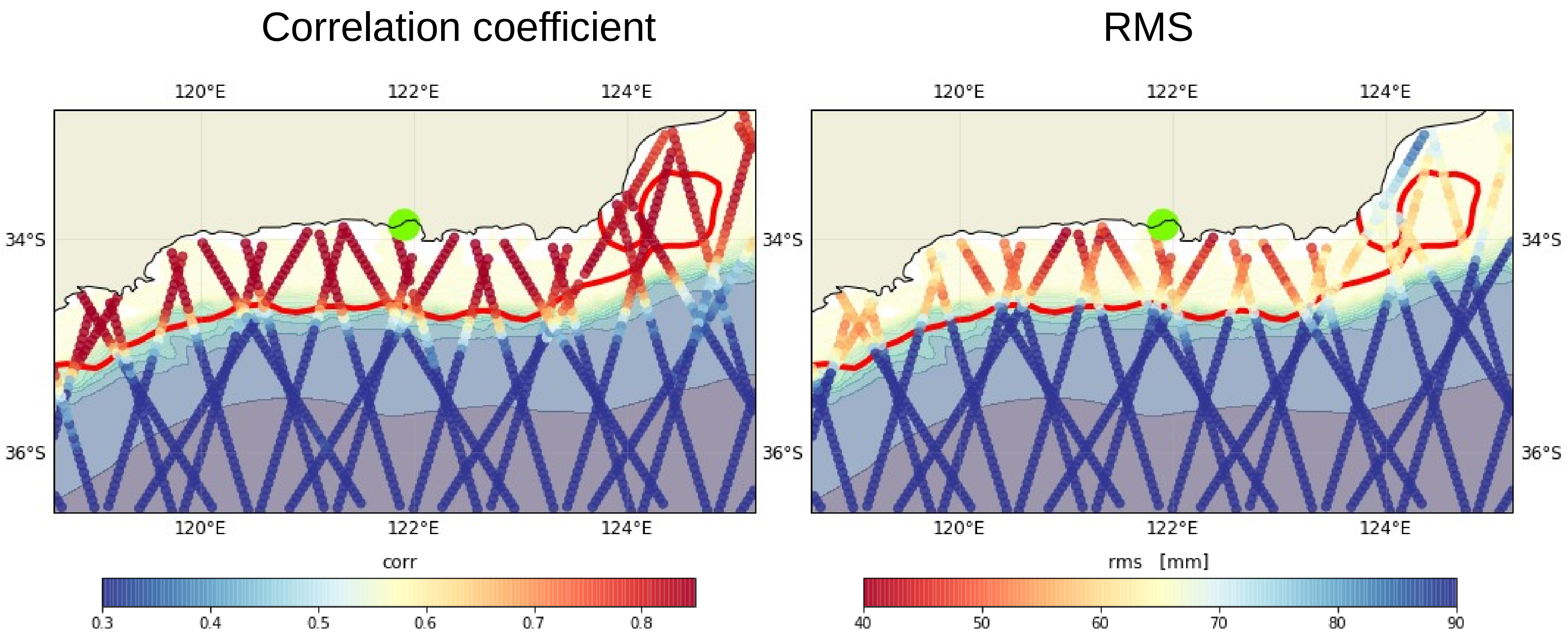
RMS



→ Identifying criteria of comparability (e.g. cc, rms, annual cycle)

→ Selecting a sub-set of best-performing sat-alt measurements to define the Zone of influence

Comparing altimetry and tide-gauges
The Zone-of-Influence:



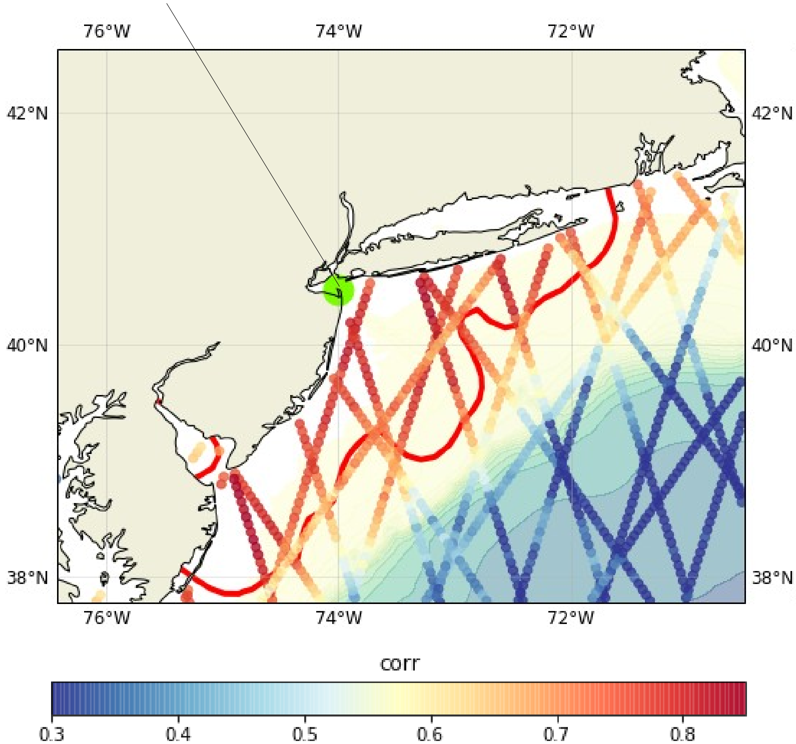
→ Identifying criteria of comparability (e.g. cc, rms, annual cycle)

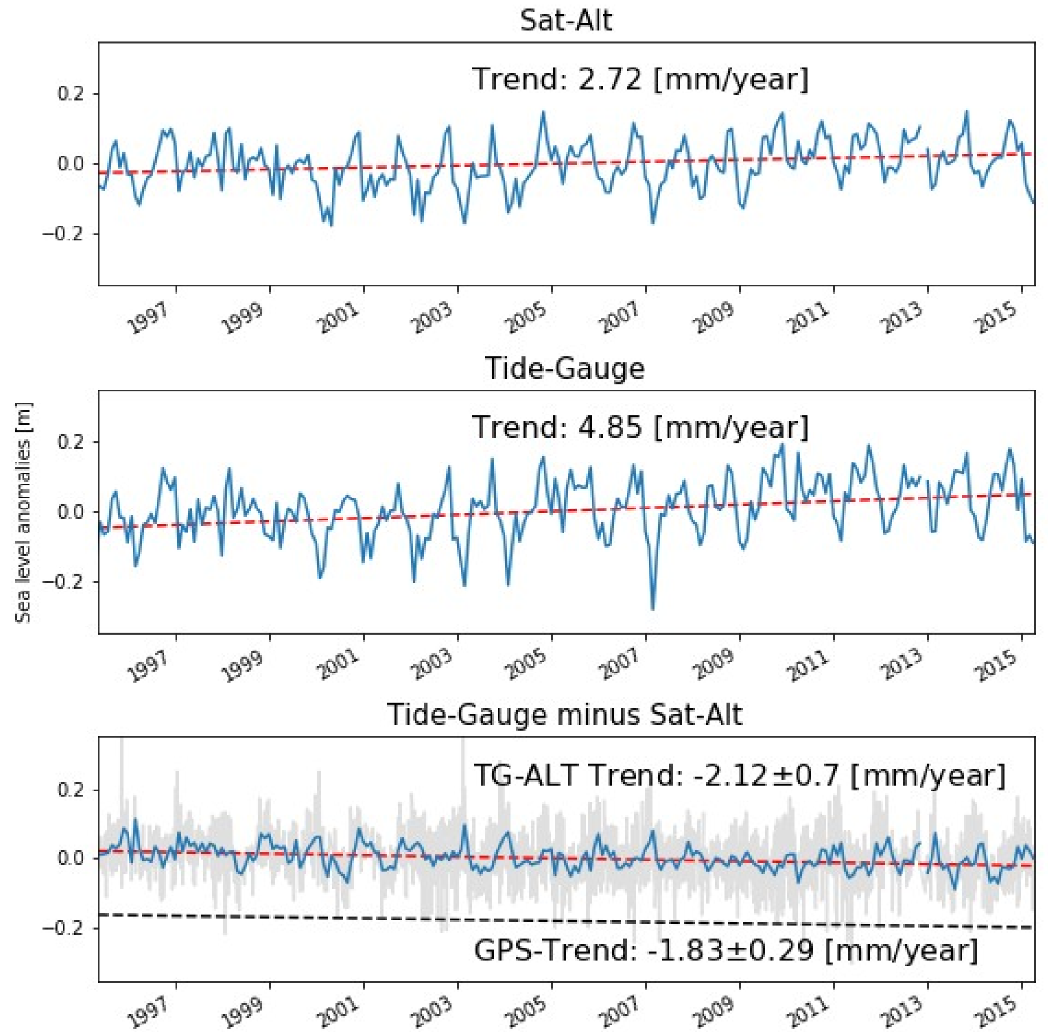
→ Selecting a sub-set of best-performing sat-alt measurements to define the Zone of influence = Zone of coherent sea-level variability

Altimetry and tide-gauge difference

Application:

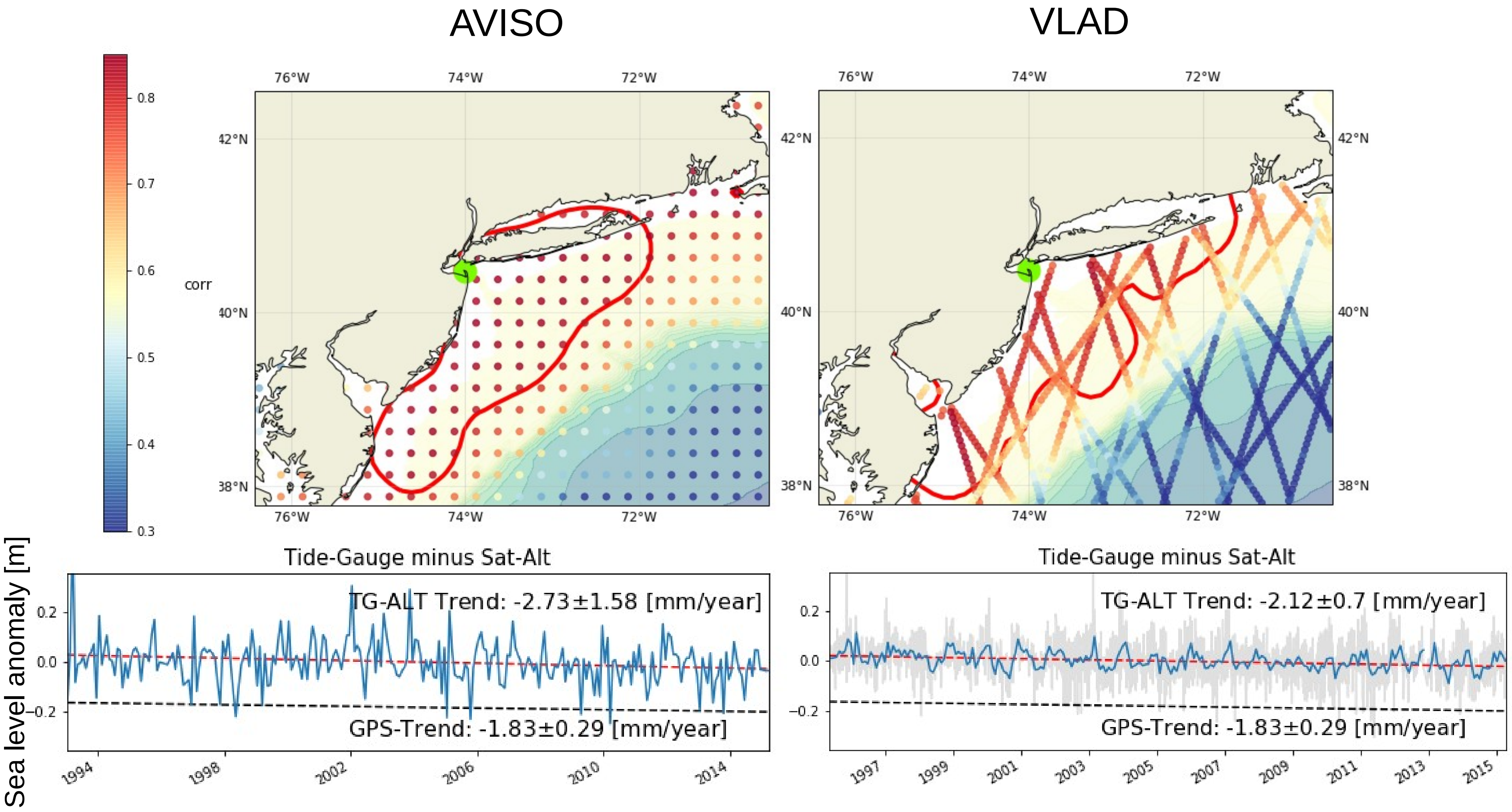
Tide-gauge: Sandy Hook (New Jersey)





Altimetry and tide-gauge difference

Application:



Outlook

- Improving the **comparability of altimetry and tide-gauges** by advancing the Zone-of-influence defintion ↔ Validation with GPS
- Intercomparison with the AVISO Dataset:

  → What is the advantage of using the optimized coastal altimetry product?
- Expanding GNSS station data

➡ Global coastal vertical land motion trend assessment

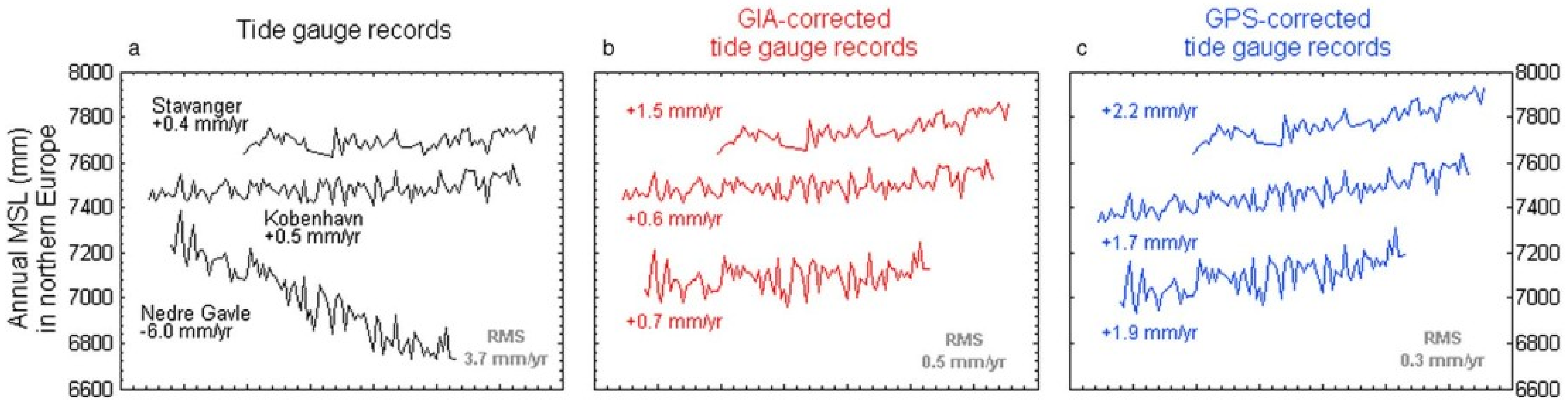
➡ Improved understanding of future relative sea level change

Thank you!

[2] Tide-Gauge data from GESLA database: https://gesla.org
[3] GPS-stations from SONEL: https://www.sonel.org/
DGFI-TUM altimetry data are available on OpenADB at: https://openadb.dgfi.tum.de

Appendix

GIA-models and GPS measurements



(modified from Wöppelmann and Marcos, 2016)

Vertical Land motion by satellite Altimetry and tide-gauge Difference (VLAD)

Enhanced comparability of altimeter and in-situ observations

Reduction of Vertical Land Motion trend uncertainties

Advanced Datasets:

- High-rate along-track altimetry data:
  - **ALES** (Adaptive Leading Edge Subwaveform retracker) altimetry product [Passaro et al. 2014]
  - Optimized set of geophysical corrections
- High-frequent tide-gauge measurements (GESLA) + PSMSL
- Extendet GPS-Datasets [Laura Sanchez]
  - homogeneously processed in ITRF2014 (1997-present)
  - Colocated with PSMSL and GESLA sites

Previous studies[1] :

- Gridded, monthly product (AVISO Dataset)
- PSMSL tide-gauges (monthly means)
- SONEL GPS-timeseries processed in ITRF2008 (1997-2014)

[1] Wöppelmann and Marcos (2016)

Appendix – Altimetry data

SSHA =
Satellite Altitude − Corrected Range − Mean Sea Surface −
(Solid Earth Tide + Pole Tide + Ocean Tide + Load Tide)

Corrected Range =
Range - Wet Tropospheric Correction - Dry Tropospheric Correction -
Ionospheric Correction - Sea State Bias - Dynamic Atmosphere Correction

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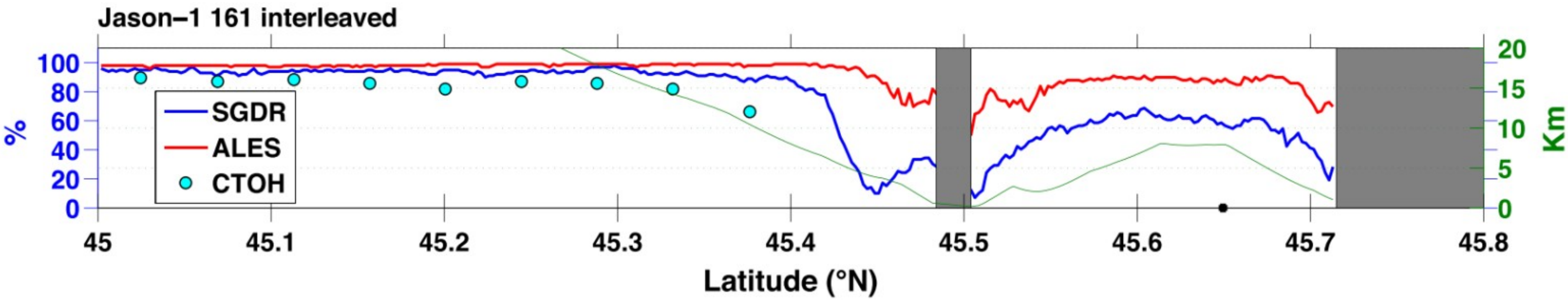
- **FES2014** (Tidal model, Lyard F., et al., 2016)
- **GPD+** (WTC) from Fernandes, M. J.; et al., 2016
- **DAC** (based on Mog2D-G), Carrère and Lyard, 2003
- **ALES** (Retracking, M. Passaro)

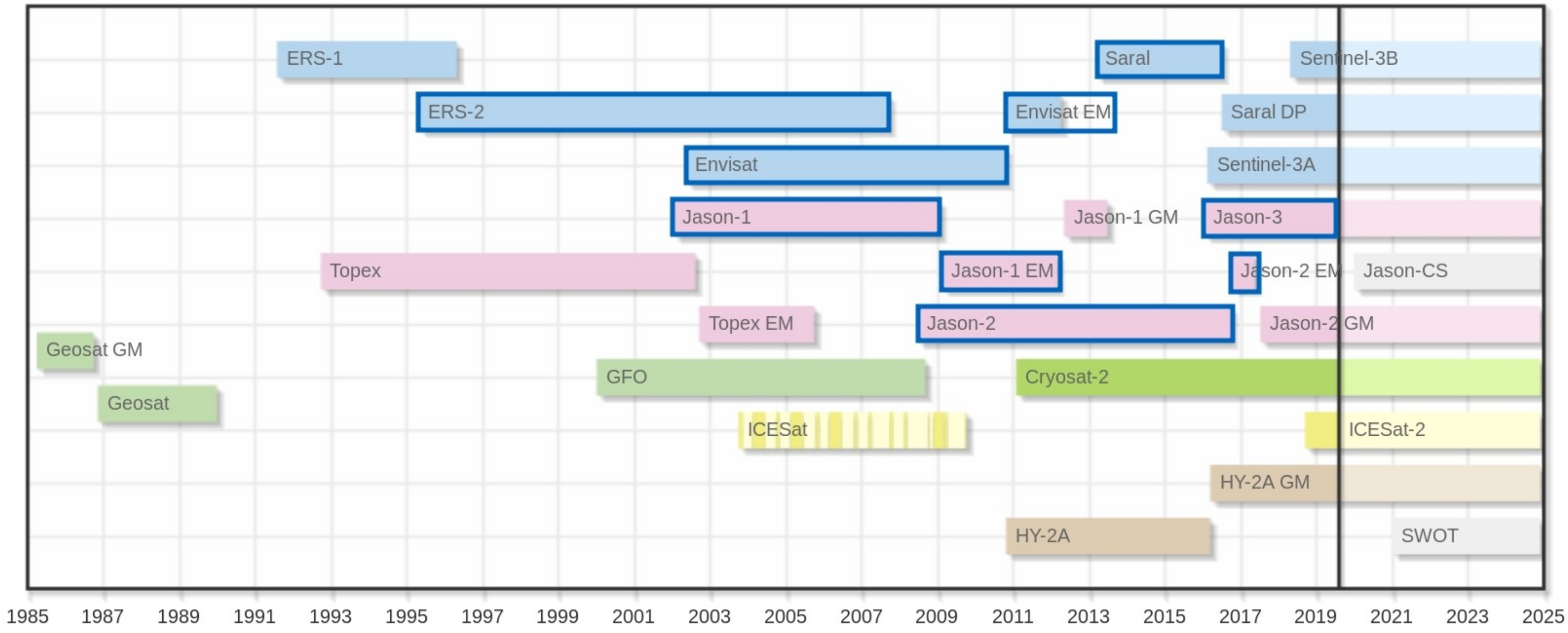
Appendix – Altimetry data

ALES: Adaptive Leading Edge Subwavefrom retracker



Correlation coefficient of sea level data (including tidal signal) between Trieste TG and Jason-1 track 161 (centre). On the x-axis the along-track latitude of the nominal tracks is shown and the latitude of the TG is highlighted with a black dot. Land is shaded in grey. The distance up to 20 km from the closest coastline is specified by a thin green line which refers tothe y-axis on the right. (Adapted from Passaro et al., 2014)

Appendix



ERS-1
ERS-2
Envisat
Jason-1
Topex
Topex EM
Geosat GM
Geosat
GFO
ICESat
Saral
Envisat EM
Jason-1 GM
Jason-1 EM
Jason-2
Cryosat-2
HY-2A
Sentinel-3B
Saral DP
Sentinel-3A
Jason-3
Jason-2 EM
Jason-CS
Jason-2 GM
ICESat-2
HY-2A GM
SWOT
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025

Appendix – Zone of influence

Criteria (C)			
CORR	RMS	Annual cycle	Distance to tide gauge

Relative levels (R)	Absolute levels (A)
(5-30% best combinations)	(e.g. minimum 0.5 correlation)

→ Zone-of-Influence (ZOI) for C!*(R+A) combinations

Performance ~ (trend in ZOI – GPS trend)

Best ZOI

Training data to find dependence on features

Depth	Latitude	Coastline	Distance to tide gauge
CORR	RMS	Annual cycle	...

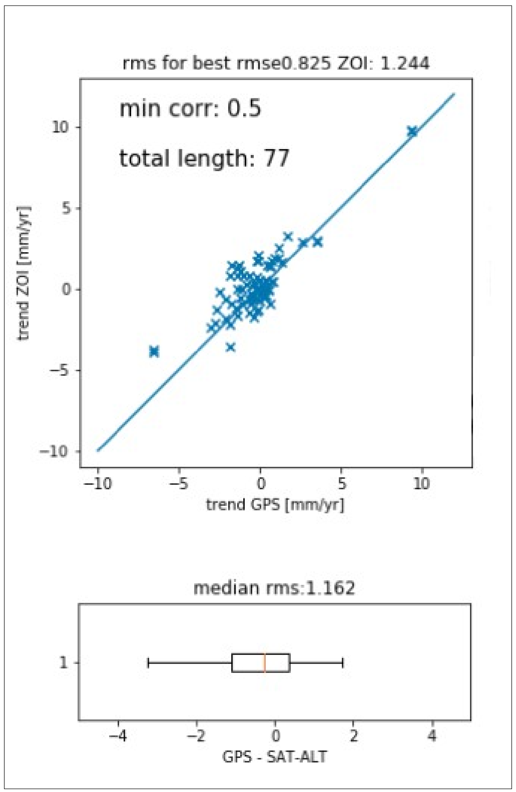
ZOI selection depending on features

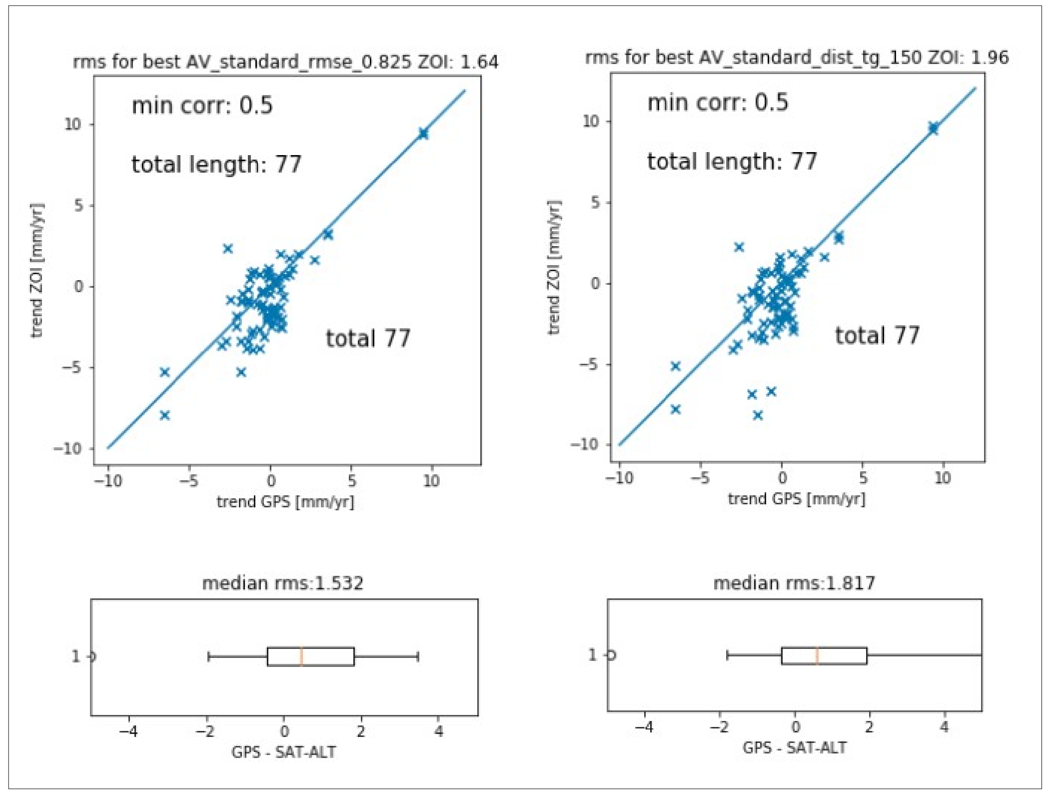
Appendix

Preliminary performance of estimated VLMs (SAT-ALT and TG Differences) in VLAD:

VLAD

AVISO



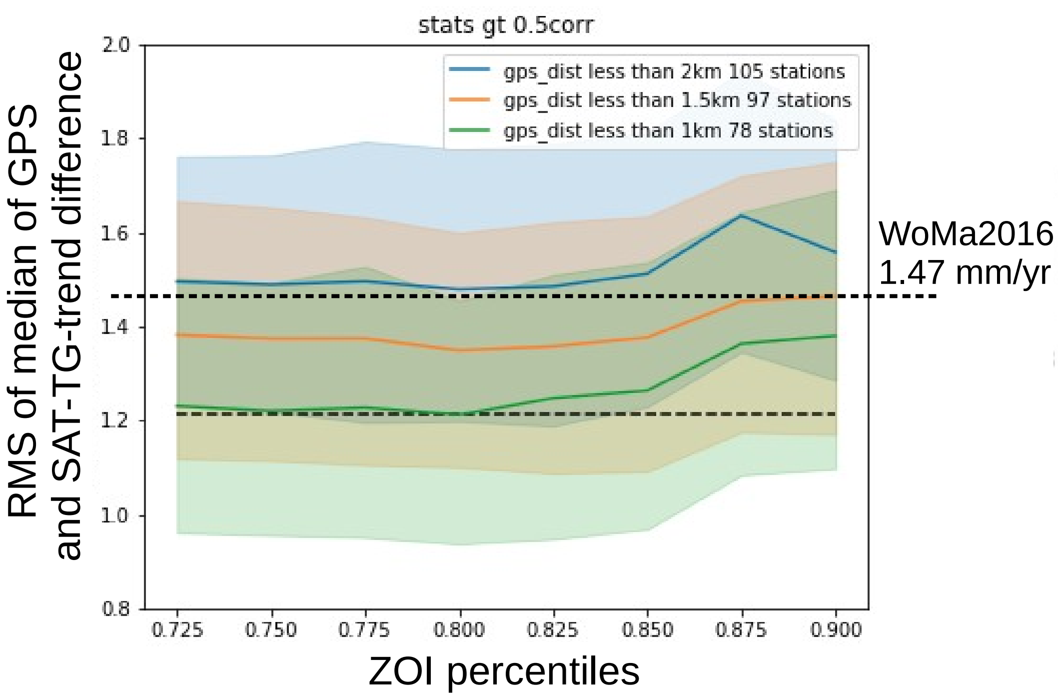


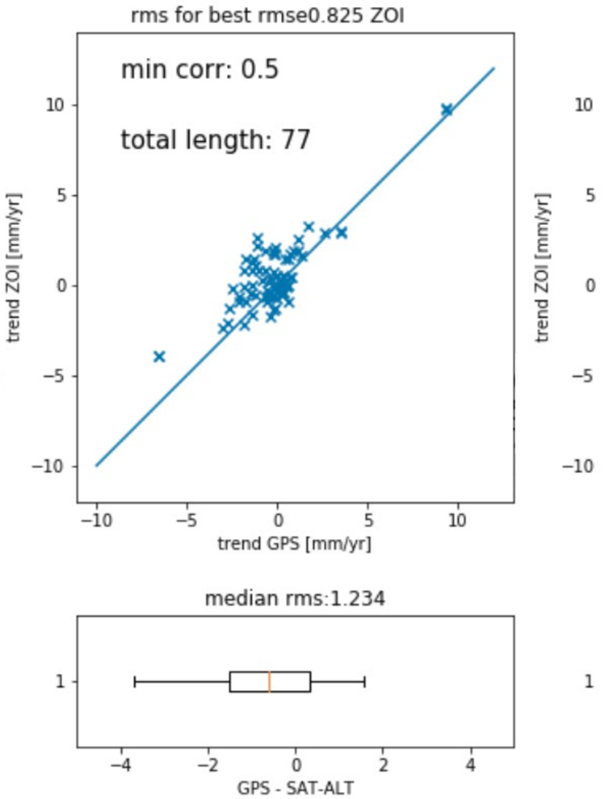
17.75 % best rmse　　17.75 % best rmse　　<150 km distance to TG

RMS of median: 1.162　　1.532　　1.817 [mm/year]

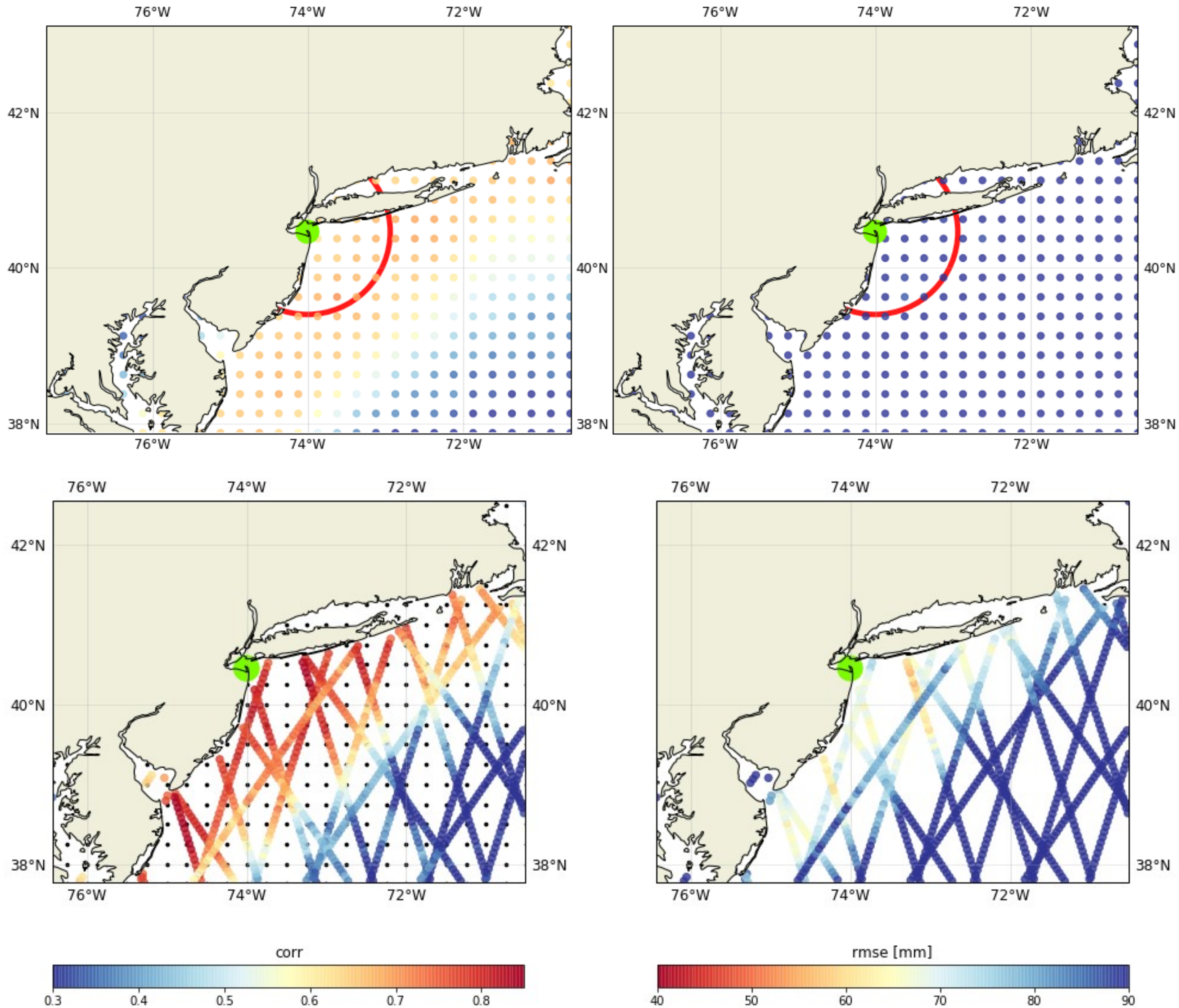
Appendix

Preliminary performance of estimated VLMs (SAT-ALT and TG Differences) in VLAD:



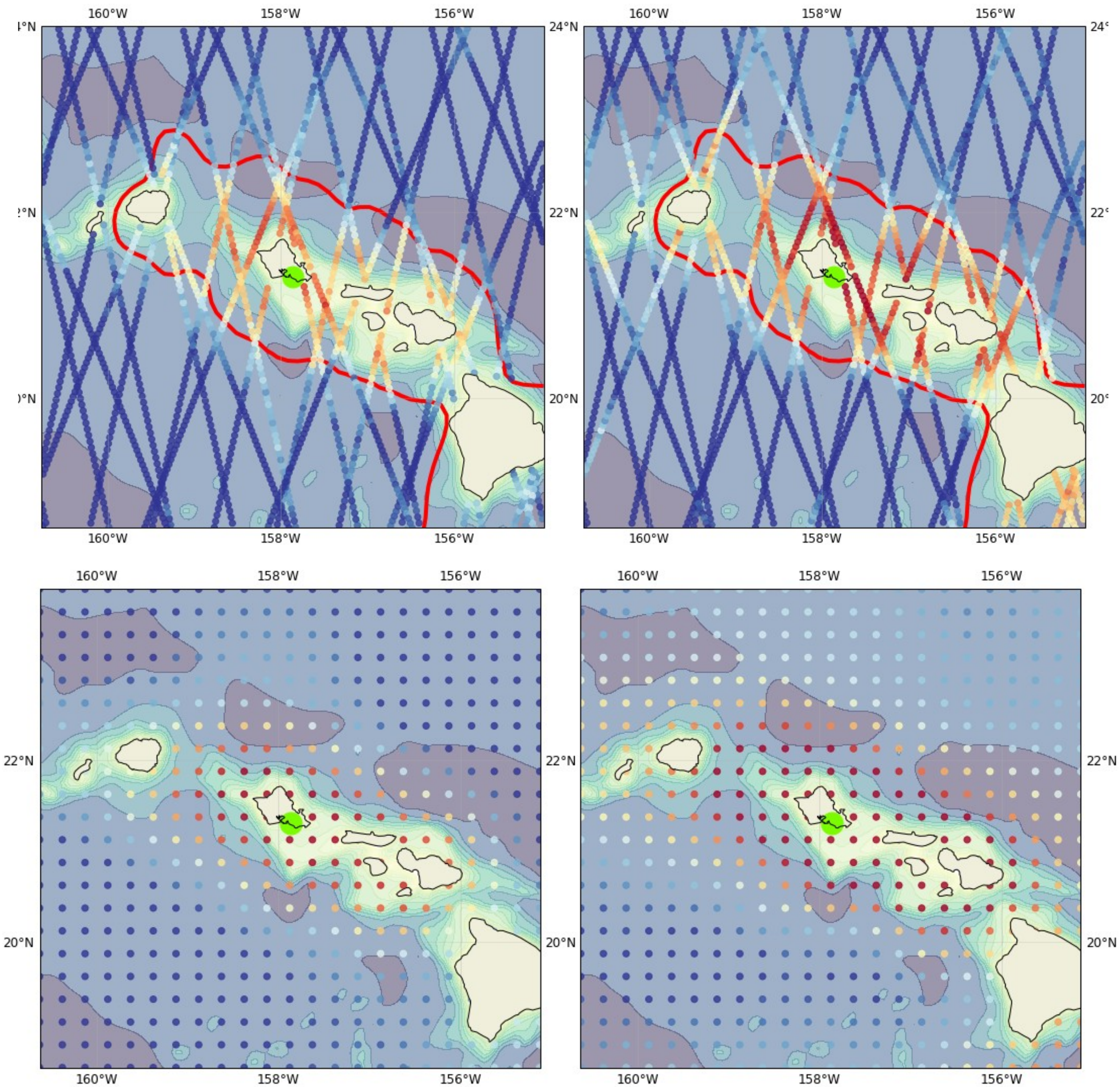


Appendix



76°W
74°W
72°W
42°N
40°N
38°N
corr
0.3
0.4
0.5
0.6
0.7
0.8
rmse [mm]
40
50
60
70
80
90

Appendix

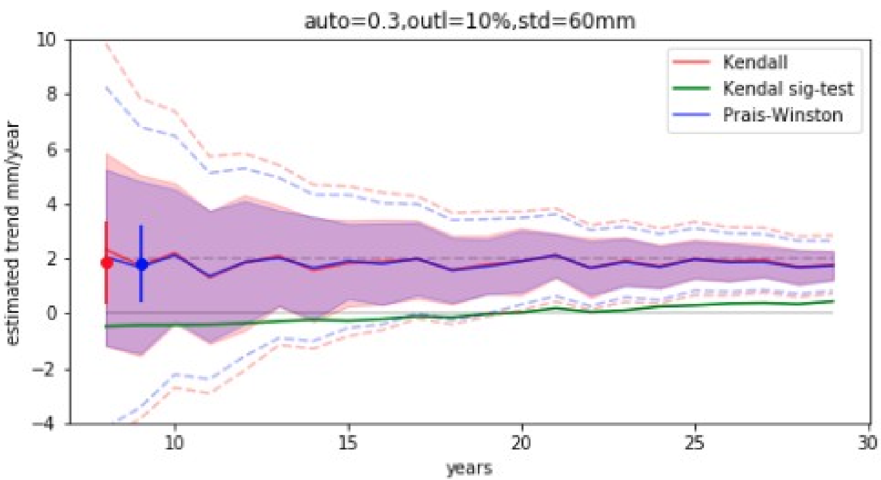


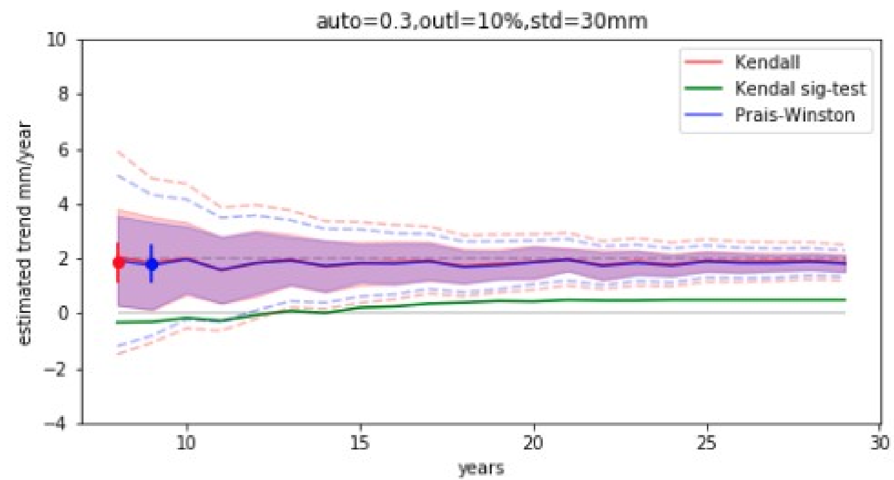
Appendix – Trend Estimation

- Prais-Winsent estimation:
  - Minimizes serial correlation by Cochrane–Orcutt transformation in a linear model of type AR(1)
- Seasonal Mann-Kendall test:
  - Nonparametric test for monotonic trend
  - Test for serial dependence

Appendix – Trend Estimation

- Test of trend-detection techniques simulation 50 representative timeseries (imitation of SAT-TG residual timeseries)
  - Trend + residual annual cycle + AR(p) + noise(std) + outliers + missing data
  - 10D frequency





Kendall (red) and Prais-Winston (blue) trend estimation of a linear model with 2mm/yr trend. Trend (solid line), standard deviation (shadings) and 95% confidence intervals (dashed) are computed for different simulated lengths of the timeseries. St-dev is set to 60mm (left) and 30mm std (right)

Appendix

- **GLOSS: Global Sea Level Observing System (established by UNESCO)**
  - Data centers: PSMSL, UHSLC, BODC, IOC
- **IGS**: International GNSS Service for Geodynamics
  - **TIGA**: Tide Gauge Benchmark Monitoring Working Group
- **SONEL**: Systeme d'Observation du Niveau des Eaux Littorales
  - GLOSS GNSS data center
  - Primary data centre for the **TIGA** project
  - assembles, archives, and distributes GNSS observations and metadata from GLOSS and non-GLOSS tide gauge sites
- **GESLA**: Global Extreme Sea Level Analysis
- **PSMSL**: Permanent Service for Mean Sea Level

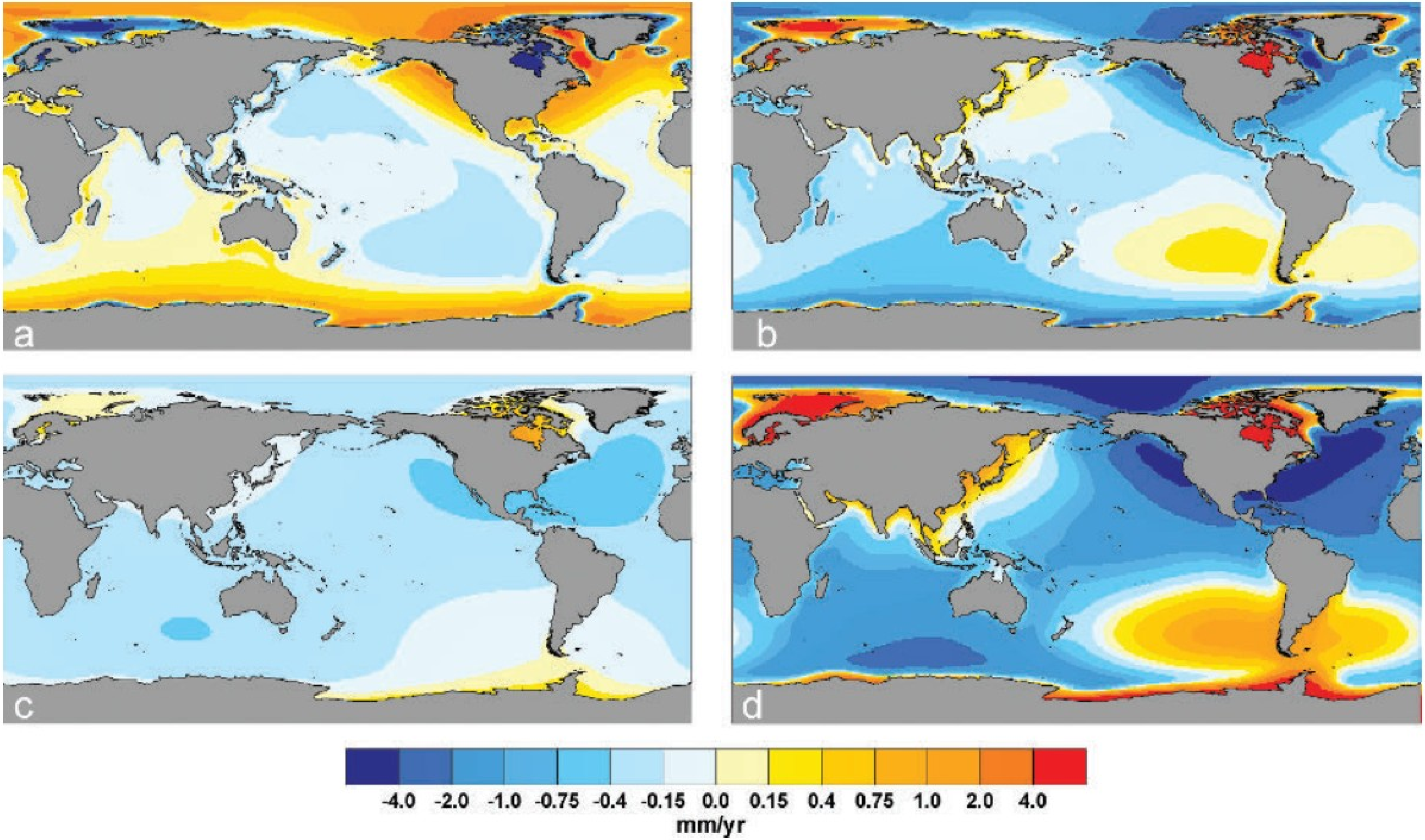


Figure 11.10 Predictions from a GIA model of the present-day rates of change of (a) relative sea level as would be measured by a tide gauge, (b) vertical crustal movement as would be measured by GPS, (c) geocentric sea surface height as would be measured by an altimeter, and (d) estimated change in water thickness as would be inferred from a gravity satellite mission. The non-linear colour scale has been chosen to highlight the far-field changes. Figures by Mark Tamisiea, National Oceanography Centre following [19] and [38].