The Zone of Influence
Matching along-track coastal altimetry data with high-frequent tide gauge observations for vertical land motion estimation

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

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

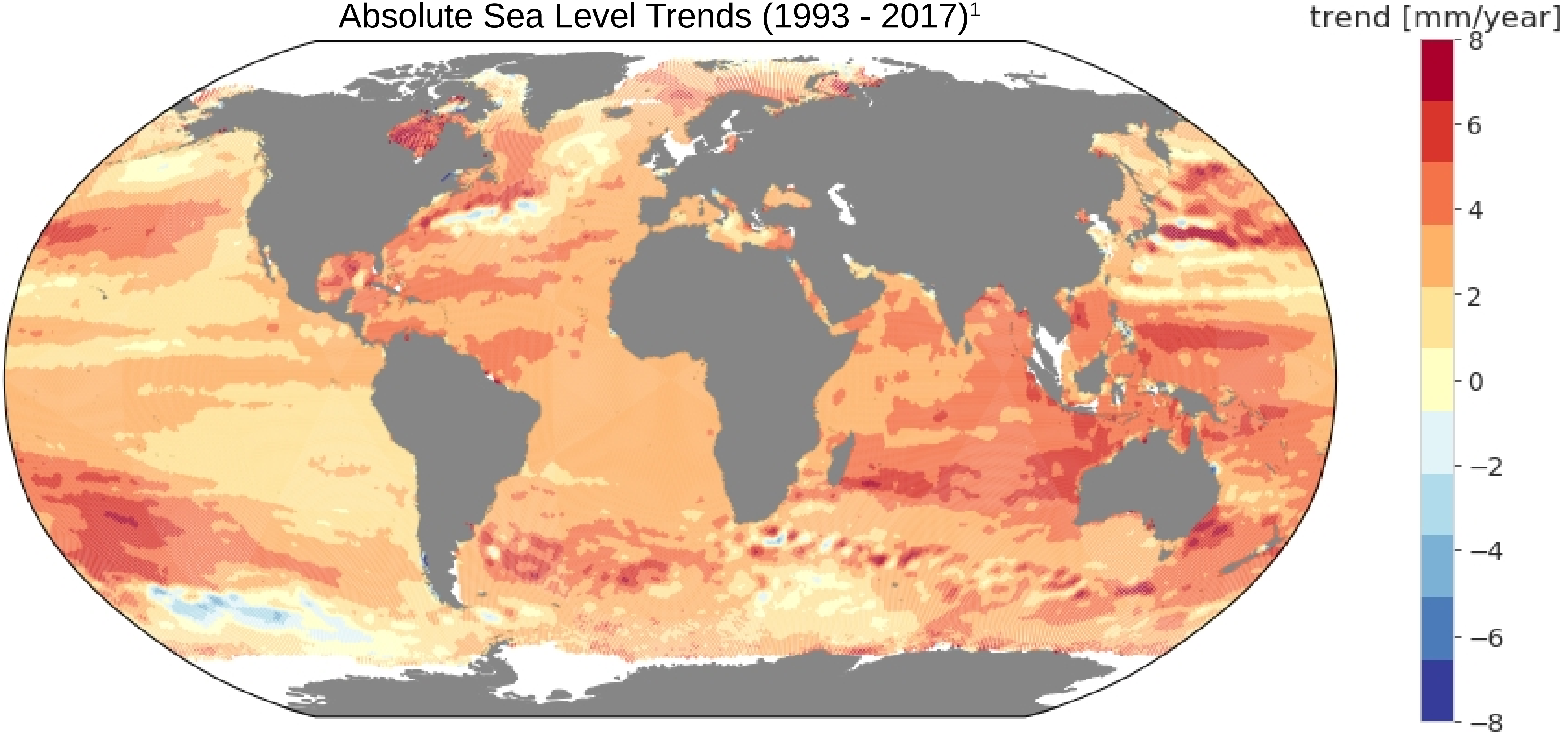
12th Coastal Altimetry Workshop 2020
Frascati, 06.02.2020

Outline

- Introduction - Vertical land motions
- Approach: Improving comparability of altimetry and tide gauges
- The Zone of Influence
- Results – Validation with GPS
- Conclusion

Absolute SL Trends vs. Vertical Land Motion

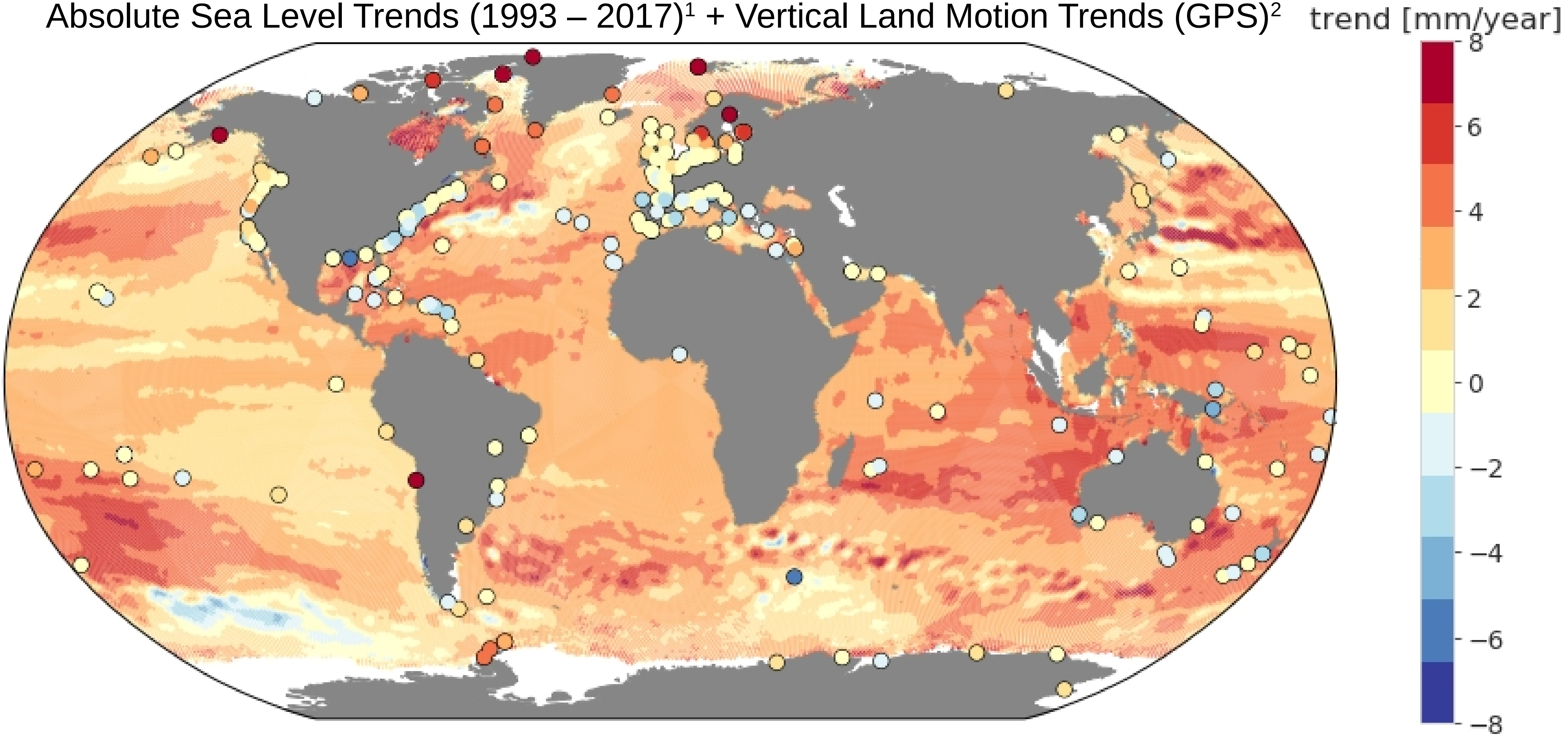
Absolute Sea Level Trends (1993 - 2017)[1]



[1] https://openadb.dgfi.tum.de/

Absolute SL Trends vs. Vertical Land Motion

Absolute Sea Level Trends (1993 – 2017)[1] + Vertical Land Motion Trends (GPS)[2]

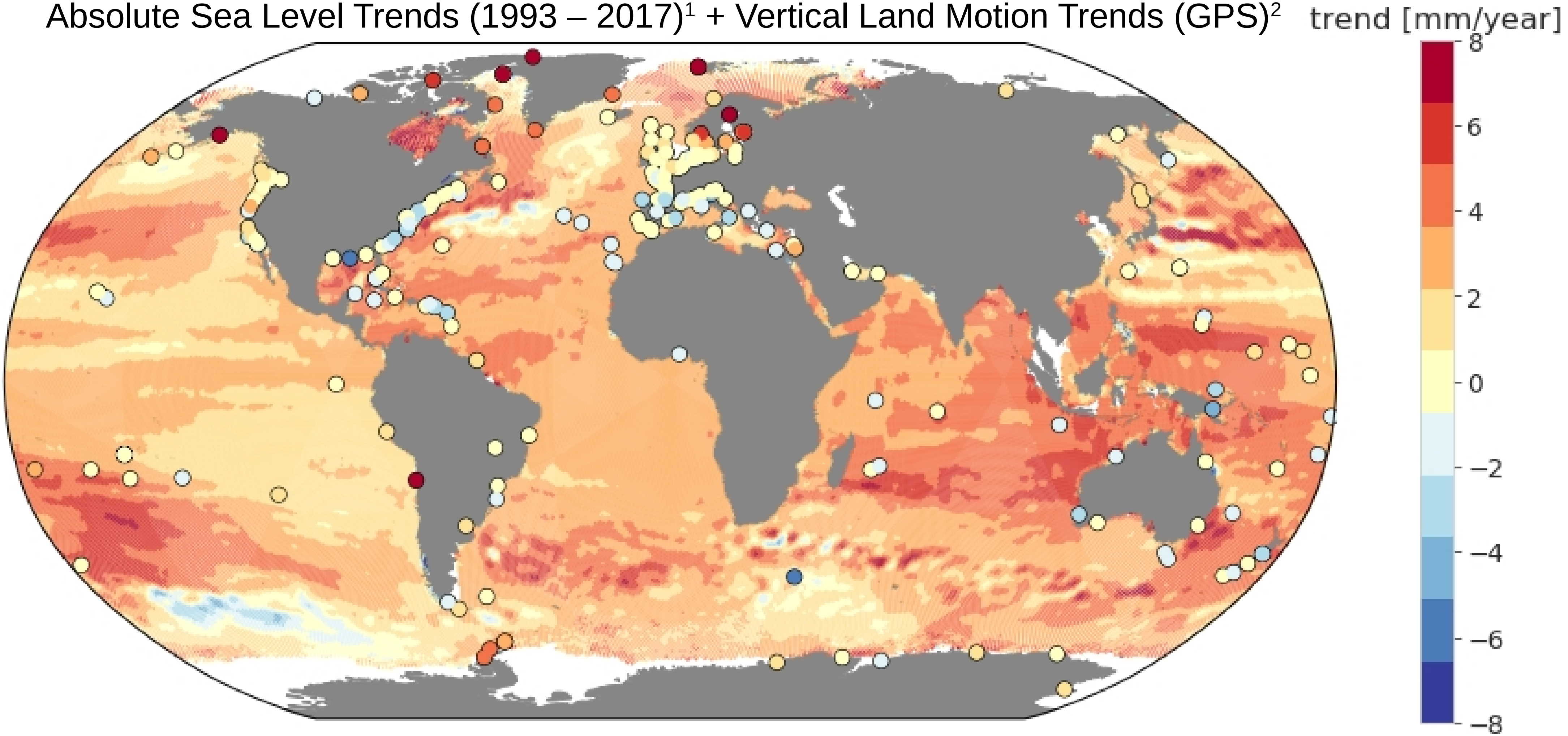


[1] https://openadb.dgfi.tum.de/

[2] SONEL

Absolute SL Trends vs. Vertical Land Motion

Absolute Sea Level Trends (1993 – 2017)[1] + Vertical Land Motion Trends (GPS)[2]



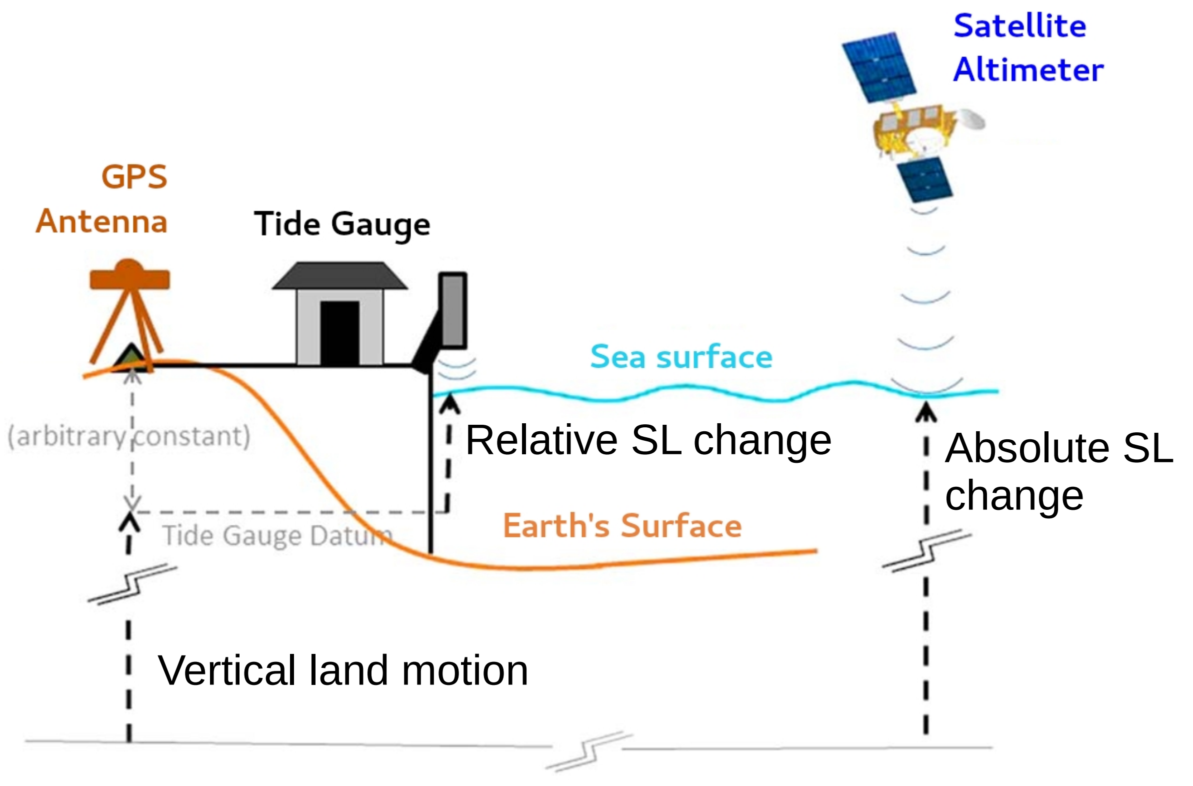
We need more vertical land motion trend estimates !

Observing Vertical Land Motion

- **GNSS (GPS)**:
  Most precise technique, limited global coverage

- **Altimetry and tide gauge difference**

  - Higher uncertainties than GNSS measurements
  - Enhances global coverage



Vertical land motion = relative – absolute sea level change
(tide gauges) (altimetry)

(modified from Wöppelmann and Marcos, 2016)

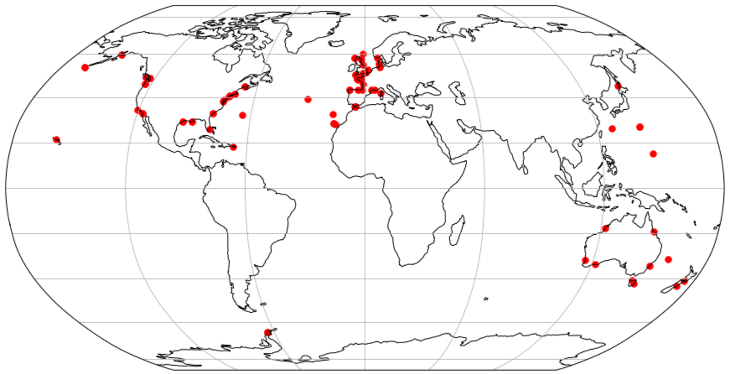
Observing Vertical Land Motion

- **GNSS (GPS)**:
  Most precise technique, limited global coverage

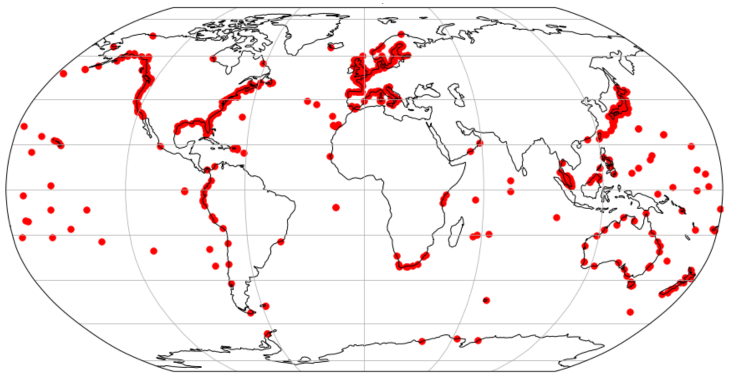
- **Altimetry and tide gauge difference**
  - Higher uncertainties than GNSS measurements
  - Enhances global coverage

Aim: Improving the methodology

GPS stations near tide-gauges (<1km)[1]



Tide-gauges (>15 years of data)



[1]Data from GESLA and SONEL

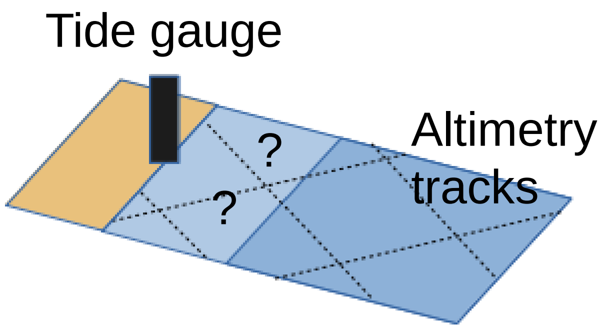
Improving VLM estimates
by satellite altimetry and tide gauge difference

Challenges and Motivation

previous studies (e.g. Cazenave et al., 1999; ...Wöppelmann and Marcos, 2016; Kleinherenbrink et al., 2018)

show that **Performance** of ALT-TG VLM trend estimates **depends on**

- **Data** (altimetry product and resolution, performance in coastal zones ...)
- **Selection scheme** of sea level anomalies around the tide-gauge (closest, area-average or highest correlated SLAs ...)



➔ Improve coastal performance of altimetry and comparability with tide-gauges

Data and Methods

- Improve **coastal performance of altimetry**
  - Coast-dedicated multimission along-track altimetry (1Hz) ALES + corrections

- and **comparability** with tide-gauges
  - High-frequent tide gauge observations from GESLA between 1995-2015 (Woodworth et al. 2016)
  - Redefined coupling procedure of altimetry and tide gauges

Comparison with:

- Gridded data (AVISO, 0.25° resolution) (best selection[1])
- Monthly tide gauge data from PSMSL
- 250km-radius-averages of SLAs

set-ups: **ALES-GESLA** **AVISO-PSMSL**

[1]Wöppelmann and Marcos, 2016

Data and Methods

- Improve **coastal performance of altimetry**
  - Coast-dedicated multimission along-track altimetry (1Hz) ALES + corrections

- and **comparability** with tide-gauges
  - High-frequent tide gauge observations from GESLA between 1995-2015 (Woodworth et al. 2016)

  - Redefined coupling procedure of altimetry and tide gauges

Comparison with:

- Gridded data (AVISO, 0.25° resolution) (best selection[1])
- Monthly tide gauge data from PSMSL
- 250km-radius-averages of SLAs

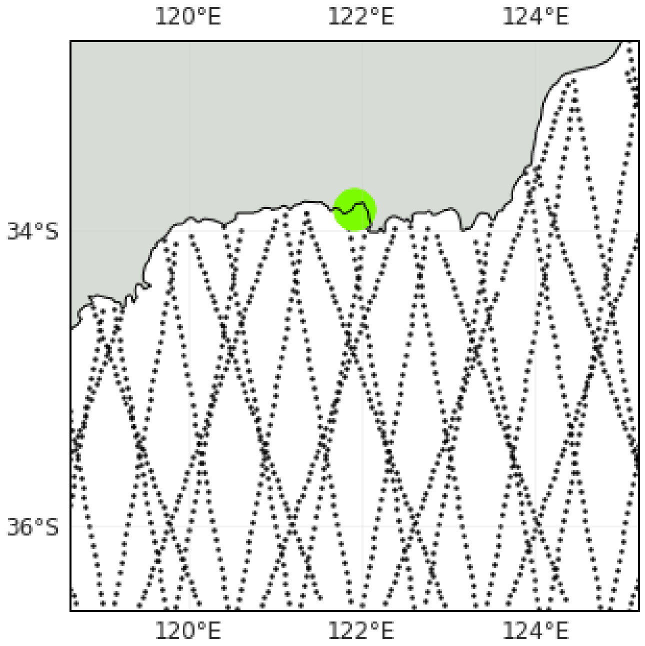
set-ups: **ALES-GESLA** **AVISO-PSMSL**

[1]Wöppelmann and Marcos, 2016

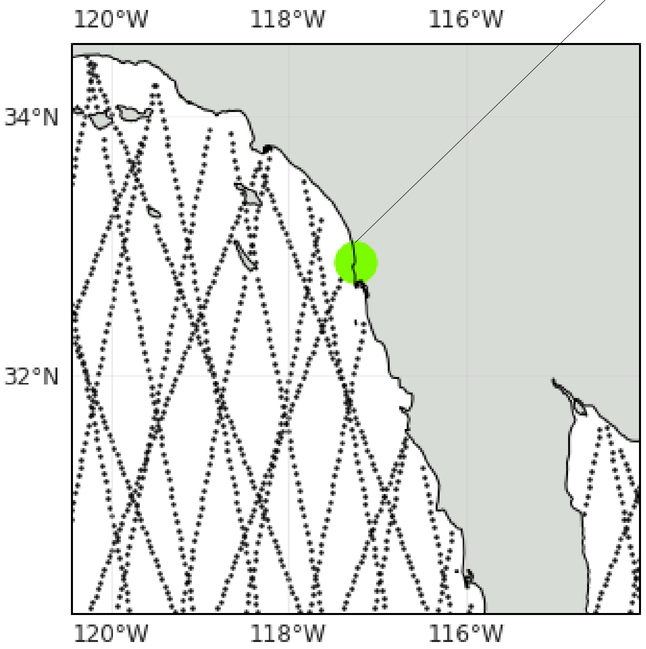
Matching altimetry and tide gauges: The Zone of Influence

Which SLAs to select?

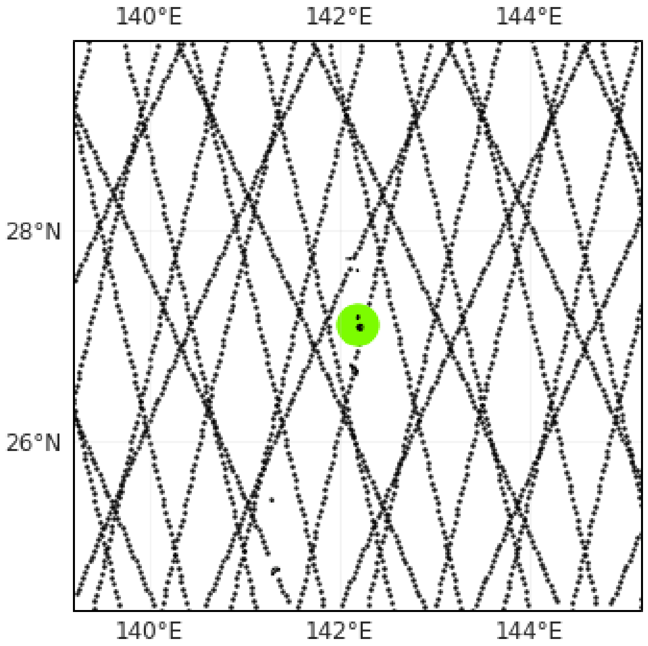
Tide gauge



South-western Australia

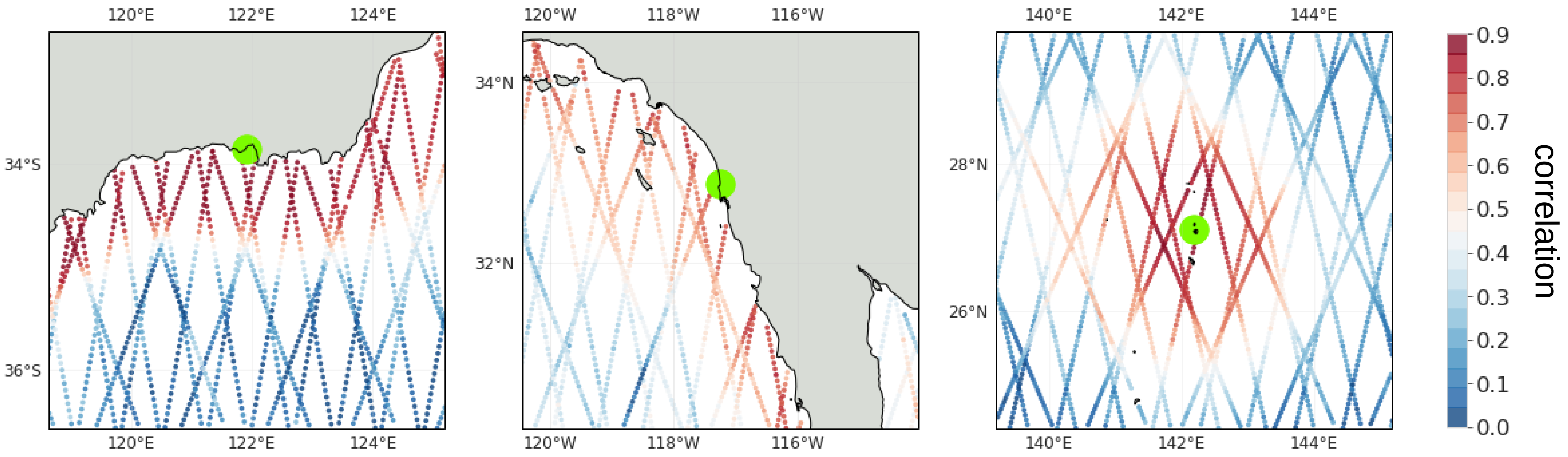


North-western America



Japan (Chichijima)

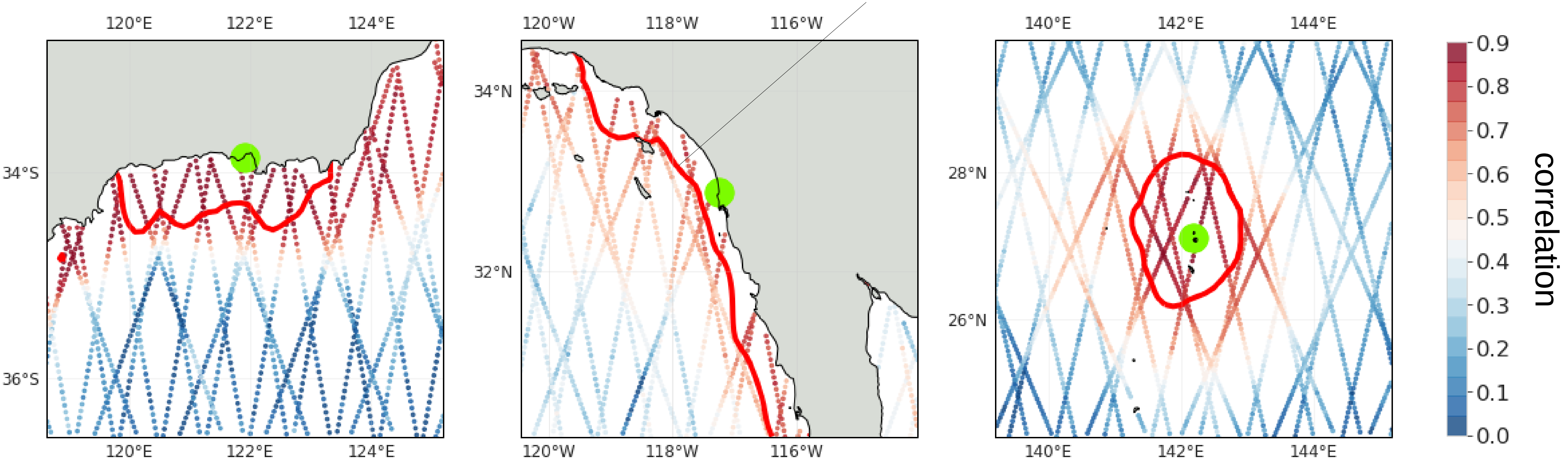
Matching altimetry and tide gauges: The Zone of Influence



Derive point-wise statistics of comparability between SLAs and tide gauges records (correlation, rms …)

Matching altimetry and tide gauges: The Zone of Influence

20% highest correlated data

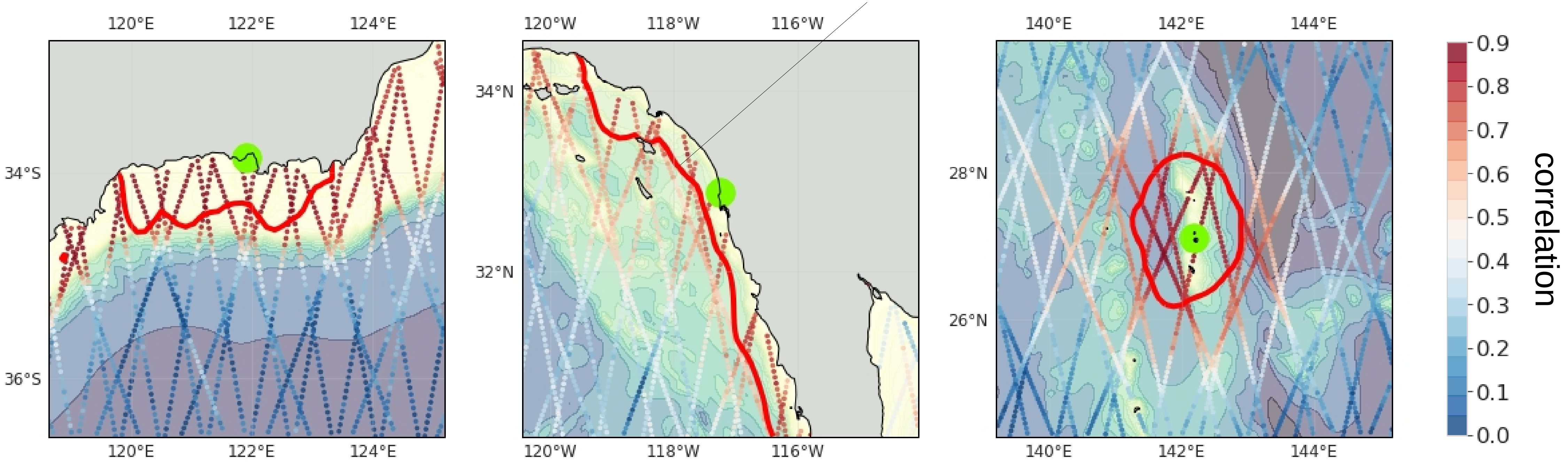


Derive point-wise statistics of comparability between SLAs and tide gauges records (correlation, rms …)

Select sub-set of best-performing SLAs using relative thresholds in a 300km radius

Matching altimetry and tide gauges: The Zone of Influence

20% highest correlated data



Derive point-wise statistics of comparability between SLAs and tide gauges records (correlation, rms …)

Select sub-set of best-performing SLAs using relative thresholds in a 300km radius

Zone of Influence represents coherent zones of coastal, high-frequent sea level variability

Validation of SAT-TG trend estimates

- Combine all SLA within a Zone of Influence for various relative thresholds
  → derive VLM_{SAT-TG} time series

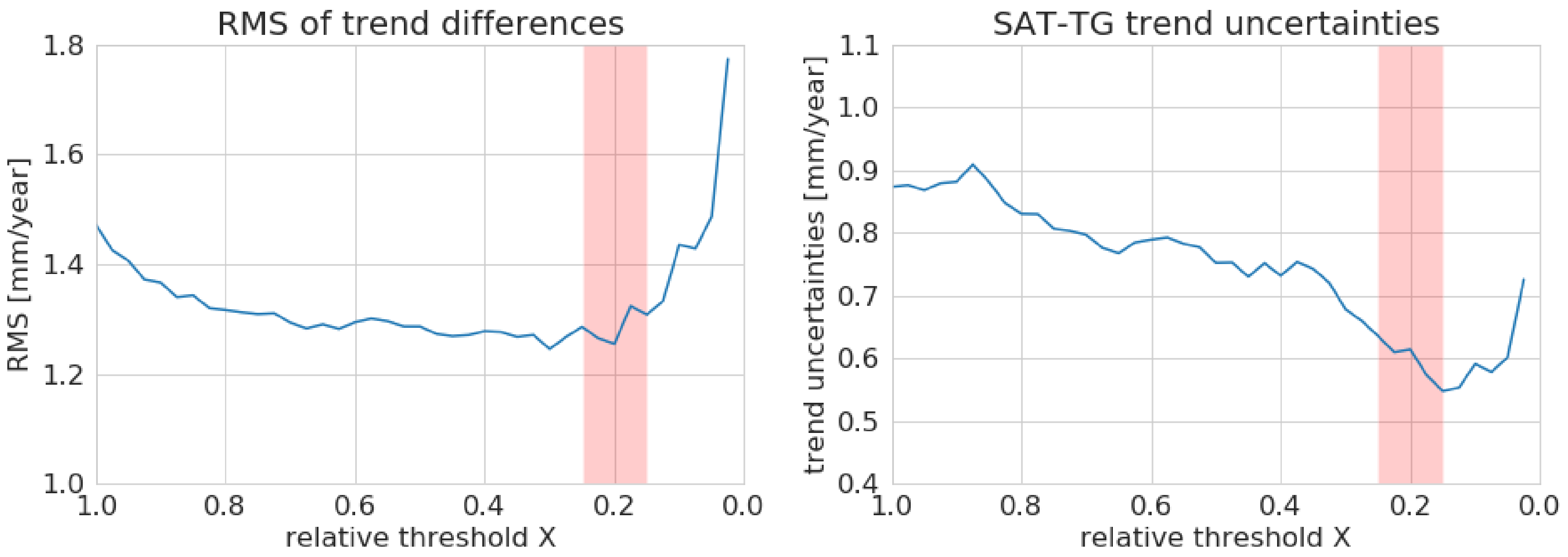
- Compute VLM_{SAT-TG} trends and formal uncertainties
  (using the Hector Software from Bos et al. 2013)

- Validate against ULR6-GPS trend estimates (from SONEL) at 72 common stations (i.e. within a 1km distance)

Common GESLA and PSMSL tide gauges with co-located GPS stations

Results: ALES-GESLA

- Validation with respect to
  - RMS of VLM_{SAT-TG} minus VLM_{GPS}
  - Median uncertainties of VLM_{SAT-TG} trends



Low → High comparabiliy

➔ Optimal Zone of Influence is comprised of 20% of best performing SLAs

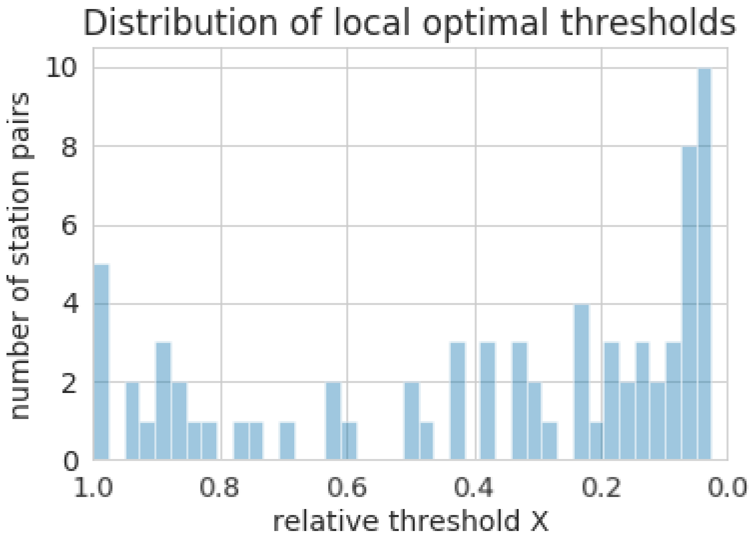
Results: ALES-GESLA vs. AVISO-PSMSL

- Validation with respect to
  - RMS of $VLM_{SAT\text{-}TG}$ minus VLM_{GPS}
  - Median uncertainties of $VLM_{SAT\text{-}TG}$ trends

	AVISO PSMSL	ALES GESLA
RMS [mm/yr]	1.55	**1.25**
Trend Uncertainties [mm/yr]	0.82	**0.61**

➔ Optimal Zone of Influence is comprised of 20% of best performing SLAs

Results: ALES-GESLA vs. AVISO-PSMSL



- Validation with respect to
  - RMS of $VLM_{SAT\text{-}TG}$ minus VLM_{GPS}
  - Median uncertainties of $VLM_{SAT\text{-}TG}$ trends

	AVISO PSMSL	ALES GESLA	ALES GESLA – local optima
RMS [mm/yr]	1.55	**1.25**	**0.86**
Trend Uncertainties [mm/yr]	0.82	**0.61**	

➔ Optimal Zone of Influence is comprised of 20% of best performing SLAs

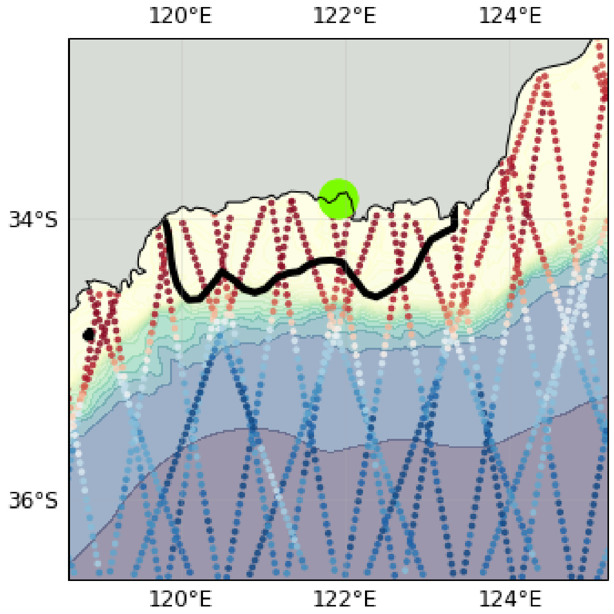
Conclusion

- Using the Zone of Influence improves VLM$_{SAT\text{-}TG}$ trend estimates (RMS: -20%, trend uncertainties: -25%, w.r.t. gridded alimetry)

- Zone of Influence captures small-scale, coherent coastal SL variability:

  - Facilitated by high coastal performance and spatio/temporal resolution (ALES + GESLA)

  - Offshore and non-representative SL dynamics can induce large uncertainties of VLM$_{SAT\text{-}TG}$ trends



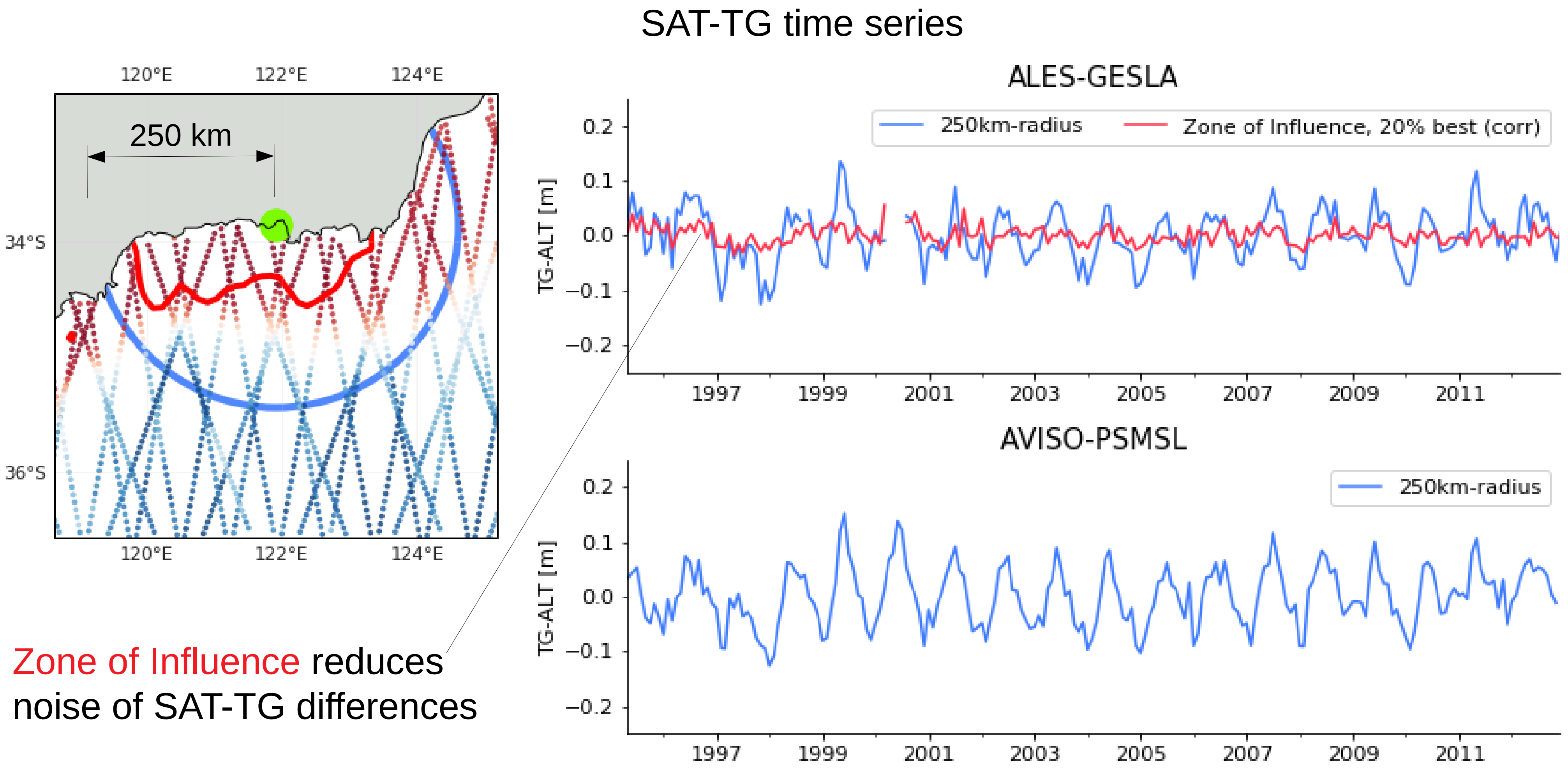
Outlook:

- Advanced adaption of the Zone of Influence to further features of coastal sea level dynamics!

Thank You!

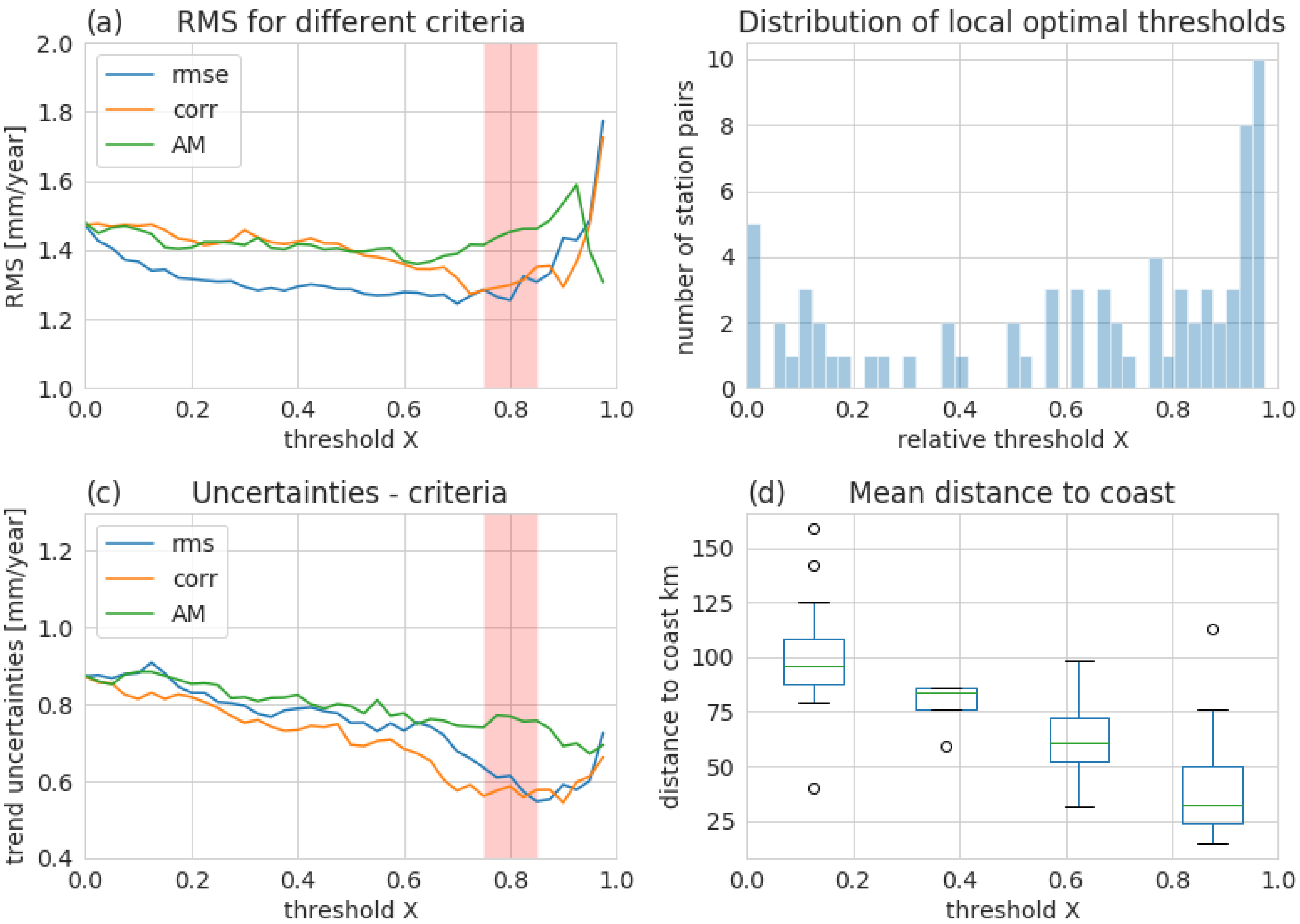
Tide Gauge data from GESLA and PSMSL:	https://gesla.org; https://www.psmsl.org/
GPS-solution from SONEL:	https://www.sonel.org/
DGFI-TUM altimetry data are available on OpenADB at:	https://openadb.dgfi.tum.de
AVISO altimeter product:	http://www.aviso.altimetry.fr/

Matching altimetry and tide gauges: The Zone of Influence



Zone of Influence reduces noise of SAT-TG differences

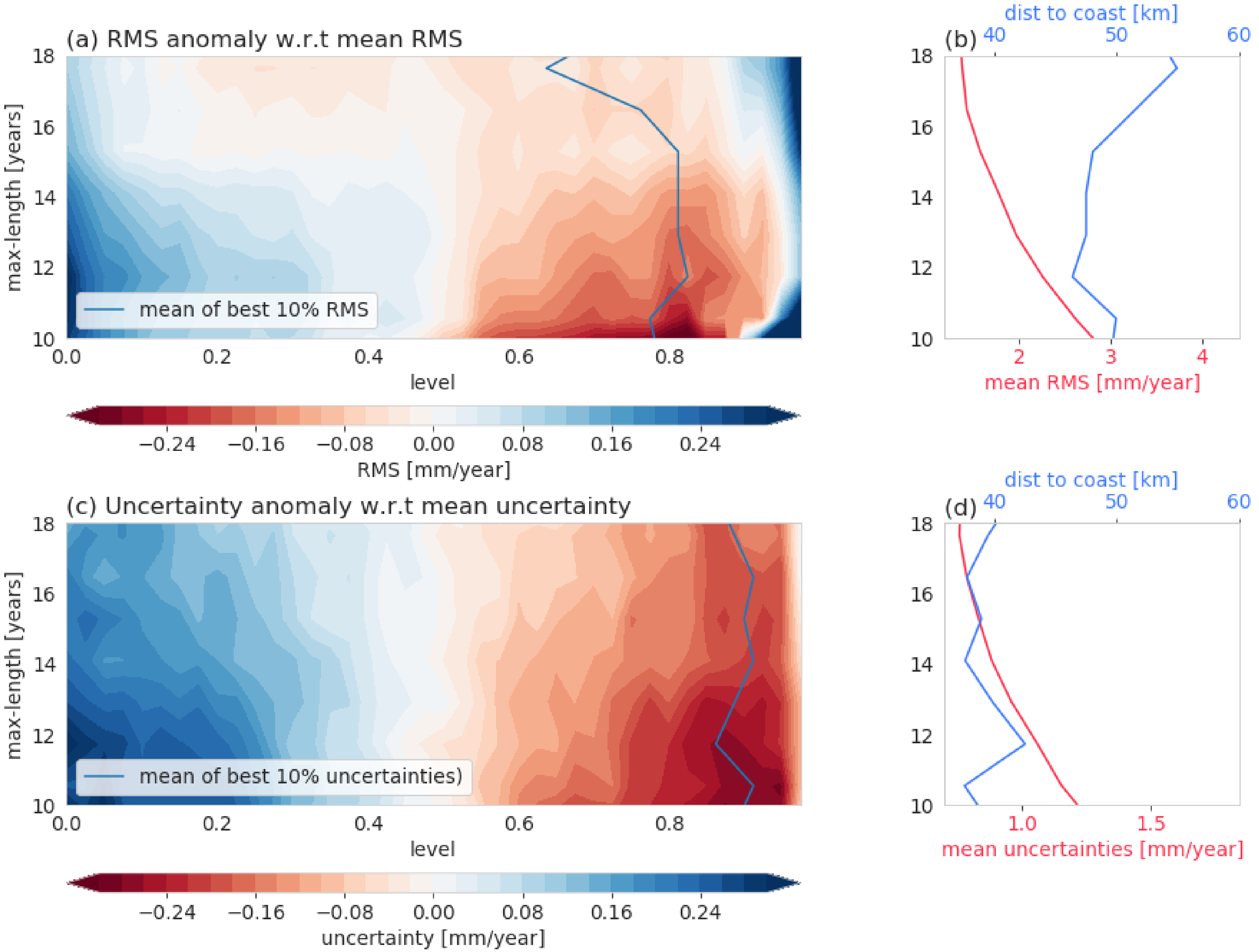
and thus trend uncertainties!


(a) RMS for different criteria
RMS [mm/year]
threshold X
rmse
corr
AM
Distribution of local optimal thresholds
number of station pairs
relative threshold X
(c) Uncertainties - criteria
trend uncertainties [mm/year]
threshold X
rms
corr
AM
(d) Mean distance to coast
distance to coast km
threshold X

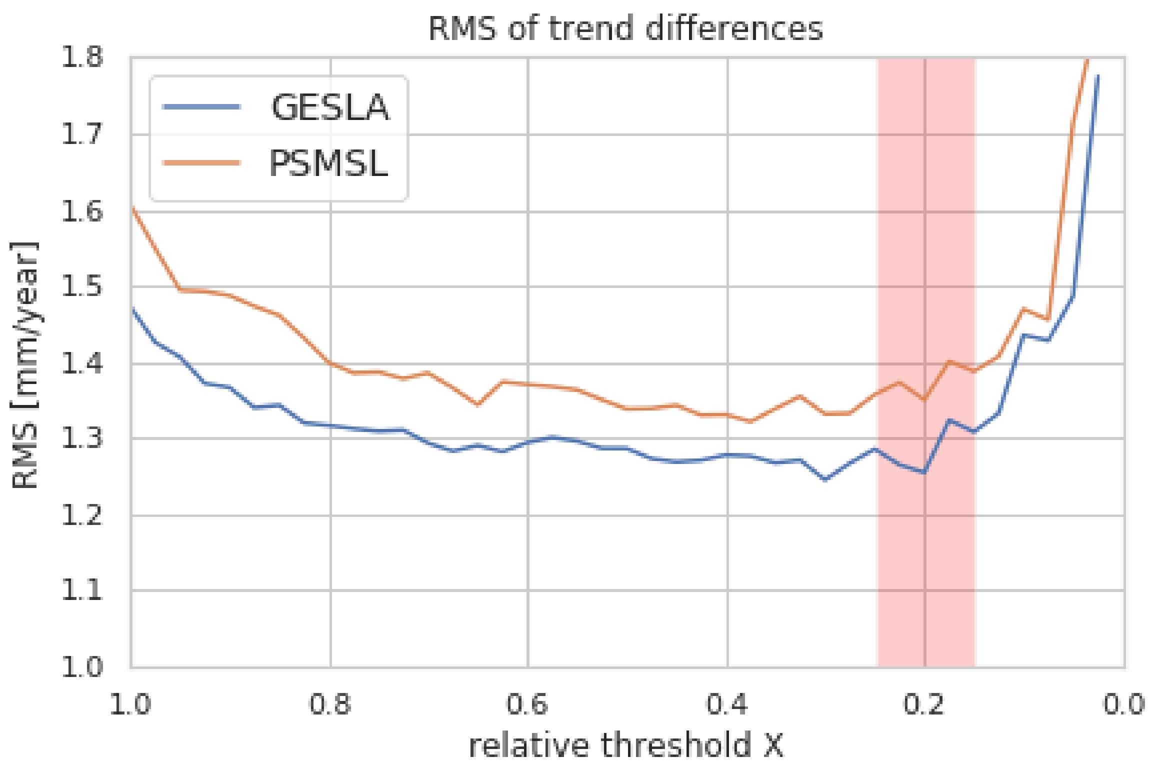
Range and Sea State Bias	ALES	Passaro et al., 2014
Inverse barometer	DAC-ERA, DAC-MOG2D	Carrere et al., 2016, Carrere and Lyard, 2003
Wet troposphere	GPD+	Fernandes et al., 2015
Dry troposphere	VMF3	Landskron and Böhm, 2018
Dry troposphere	NIC09	Scharroo and Smith, 2010
Ocean and Load tide	FES2014	Carrere et al., 2015
Solid Earth and Pole Tide	IERS 2010	Petit and Luzum, 2010
Mean Sea surface	DTU18MSS	Andersen et al., 2018

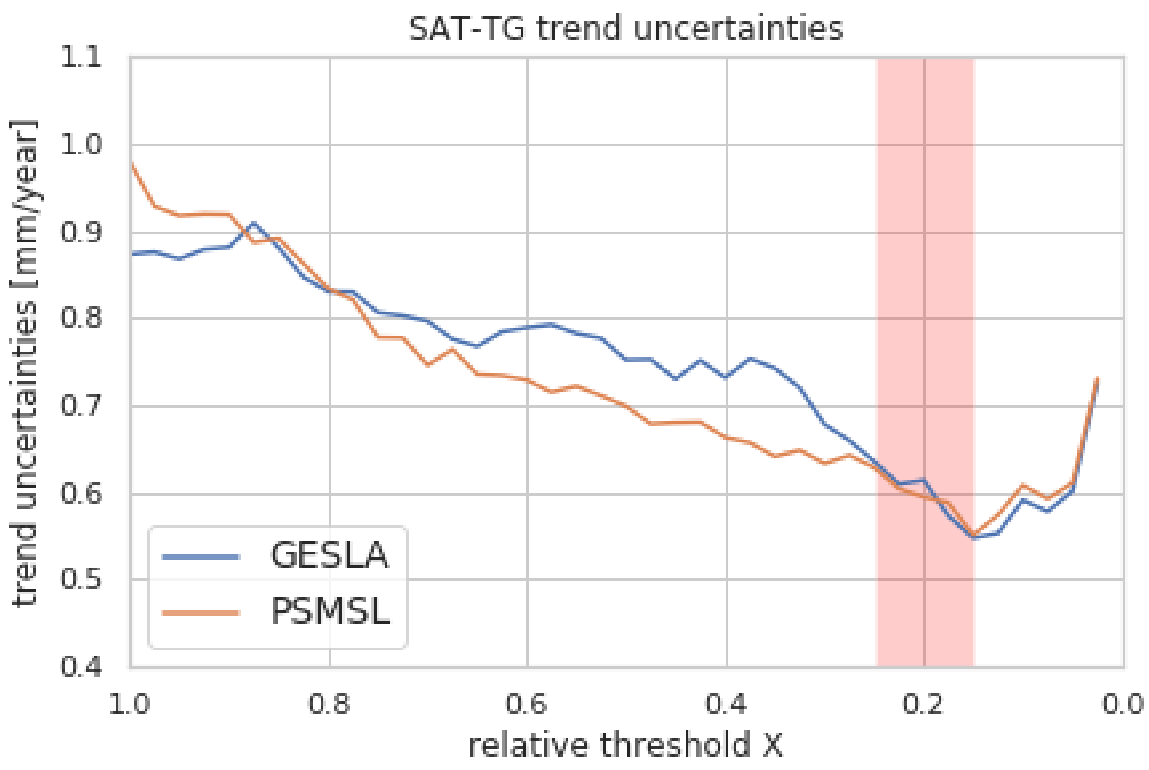
X	RMS mm/yr	median $|VLM_\Delta|$ mm/yr	median-bias VLM_Δ mm/yr	uncertainties mm/yr	spectral index κ
ALES-PSMSL 250km					
	1.59	1.22	-0.42	0.72	-0.41
AVISO-PSMSL 250km					
	1.55	1.25	0.67	0.80	-0.60
ALES-GESLA 250km					
	1.45	1.11	-0.19	0.82	-0.42
ALES-GESLA-ZOI, rms criterium					
0	1.47	1.12	-0.42	0.87	-0.5
0.1	1.37	0.94	-0.25	0.88	-0.47
0.2	1.32	0.94	-0.34	0.83	-0.48
0.3	1.29	0.92	-0.38	0.80	-0.53
0.4	1.29	0.92	-0.33	0.79	-0.50
0.5	1.29	0.91	-0.22	0.75	-0.50
0.6	1.28	0.86	-0.23	0.73	-0.50
0.7	1.25	0.83	-0.14	0.68	-0.50
0.8	1.25	0.87	-0.32	0.61	-0.49
0.9	1.44	0.86	-0.32	0.59	-0.46

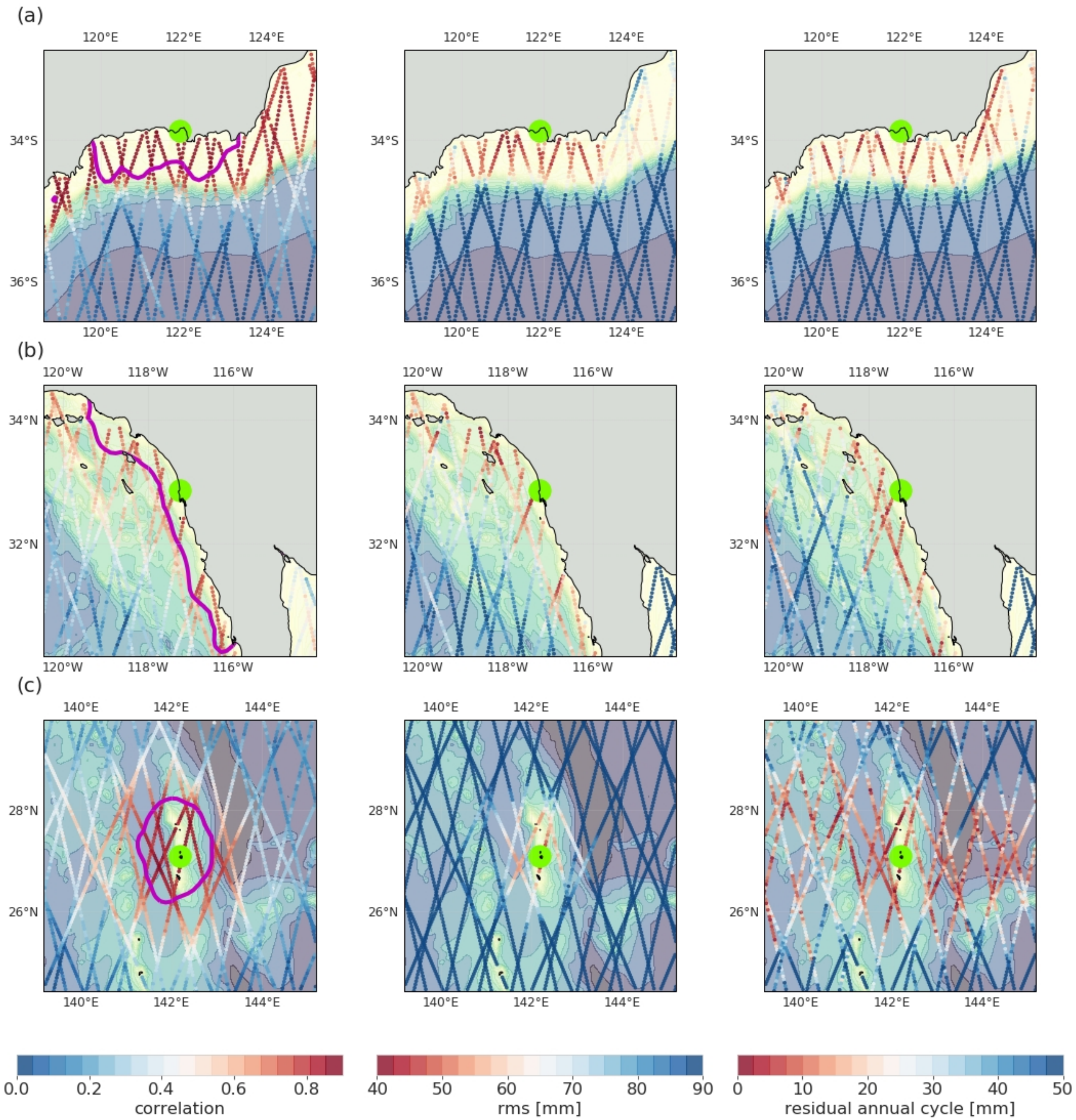
Dependency of RMS of (VLM_{SAT-TG} - VLM_{GPS}) and trend uncertainties on time series length



High-frequent (GESLA) vs. monthly tide gauges (PSMSL)

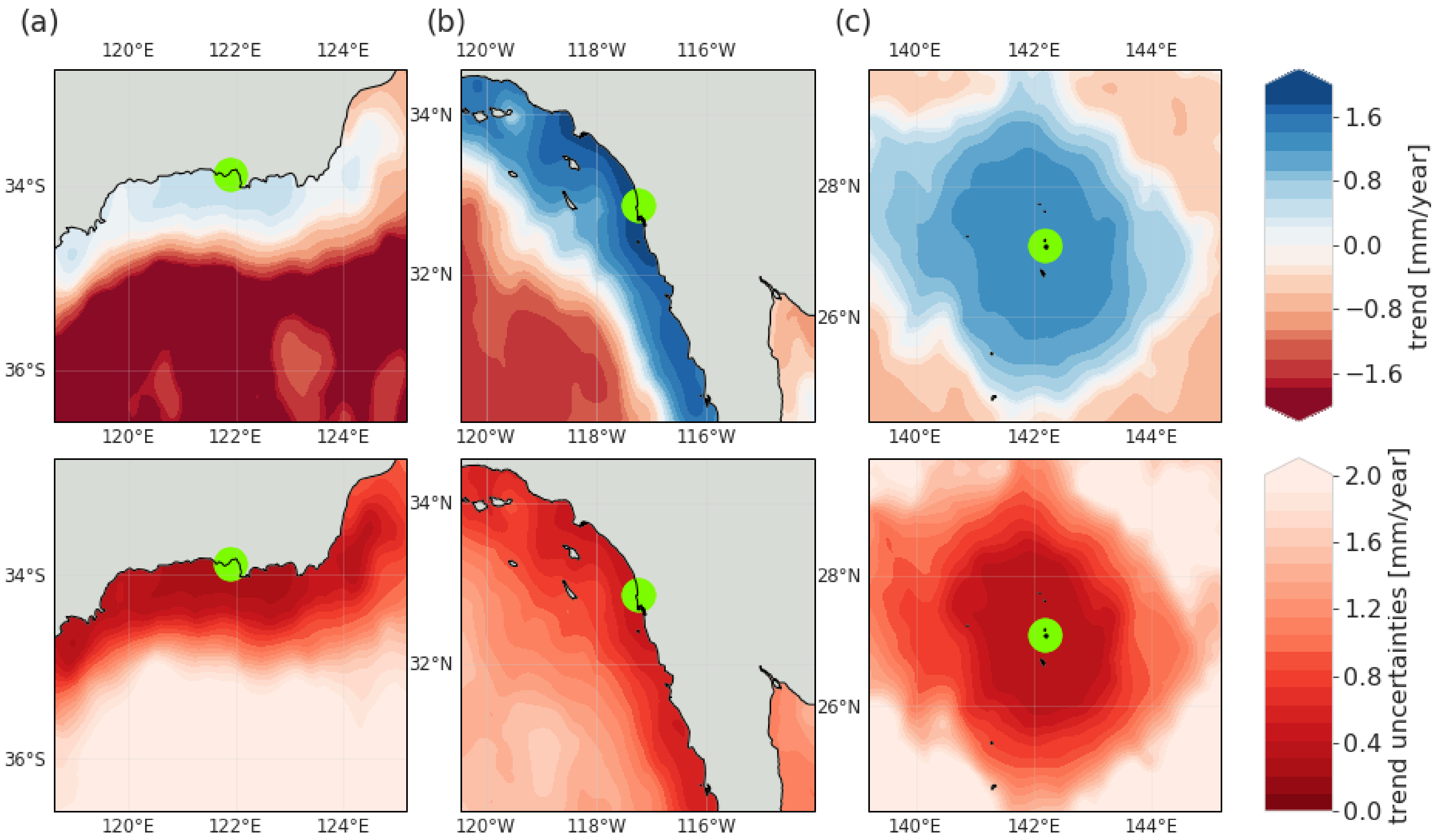




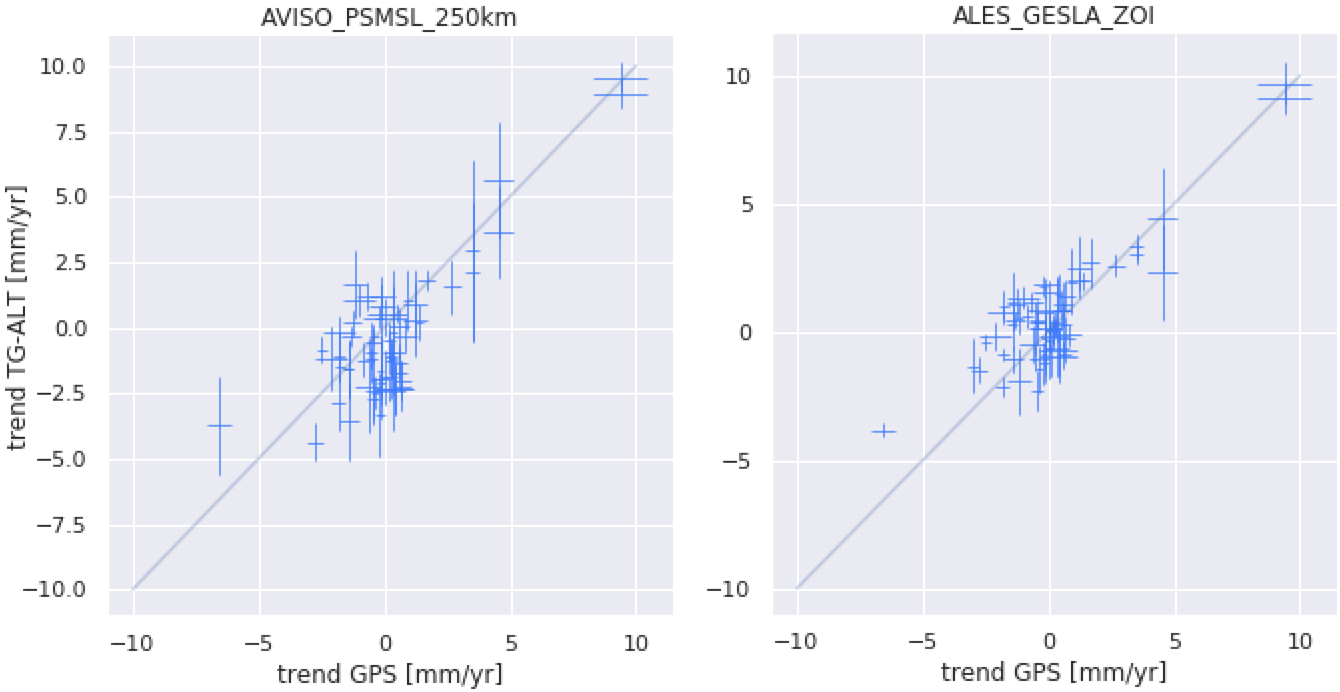

(a)
(b)
(c)
120°E
122°E
124°E
34°S
36°S
120°W
118°W
116°W
34°N
32°N
140°E
142°E
144°E
28°N
26°N
0.0 0.2 0.4 0.6 0.8
correlation
40 50 60 70 80 90
rms [mm]
0 10 20 30 40 50
residual annual cycle [mm]

Dependency of VLM$_{SAT\text{-}TG}$ and trend uncertainties on level of comparability of altimetry and tide gauges:

Trend and uncertainties are computed for correlation-dependent level ranges (0-20%, 20%-40%, 40%-60% …).

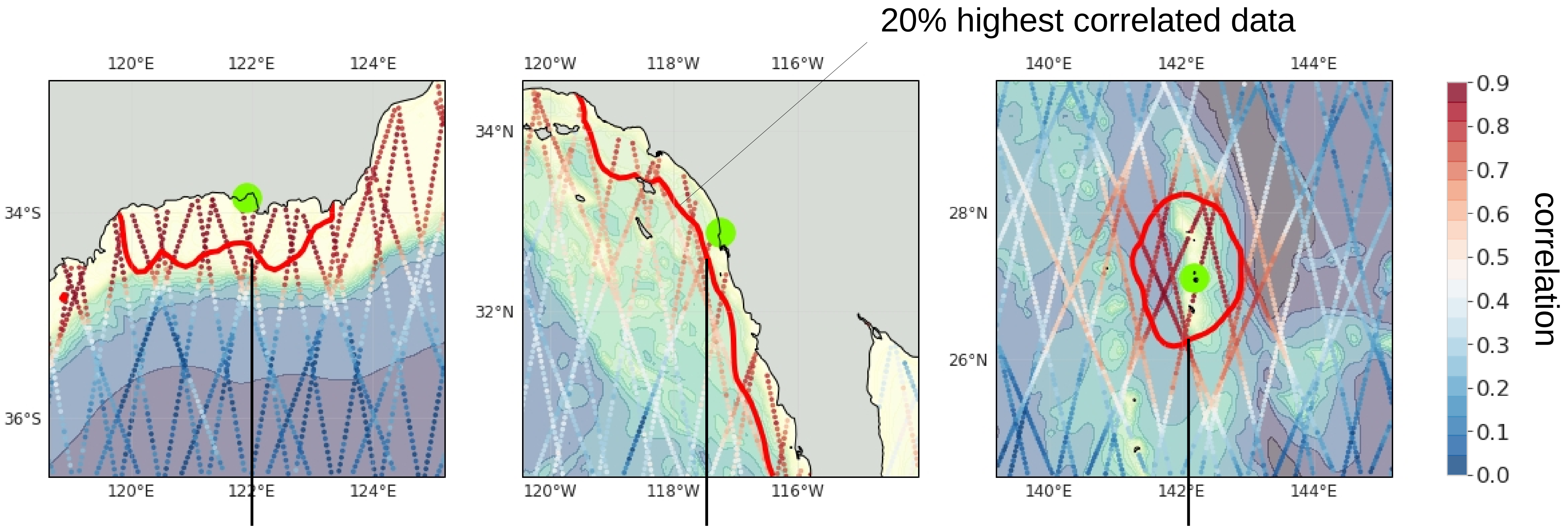


- Comparison: AVISO-PSMSL vs. ALES-GESLA (+ Zone of Influence)



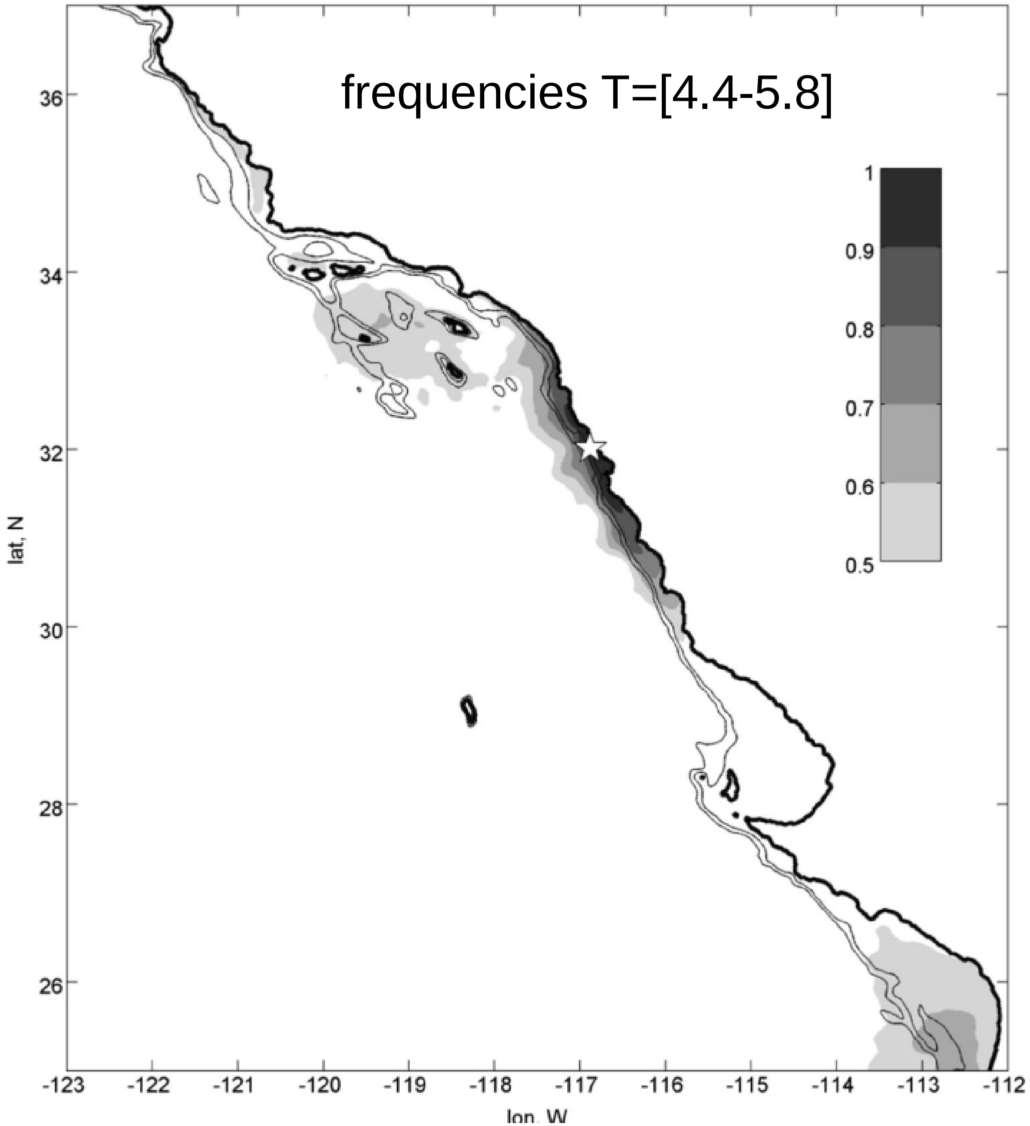
	AVISO-PSMSL	ALES-GESLA
RMS	1.55	1.25
Trend uncertainties	0.82	0.61

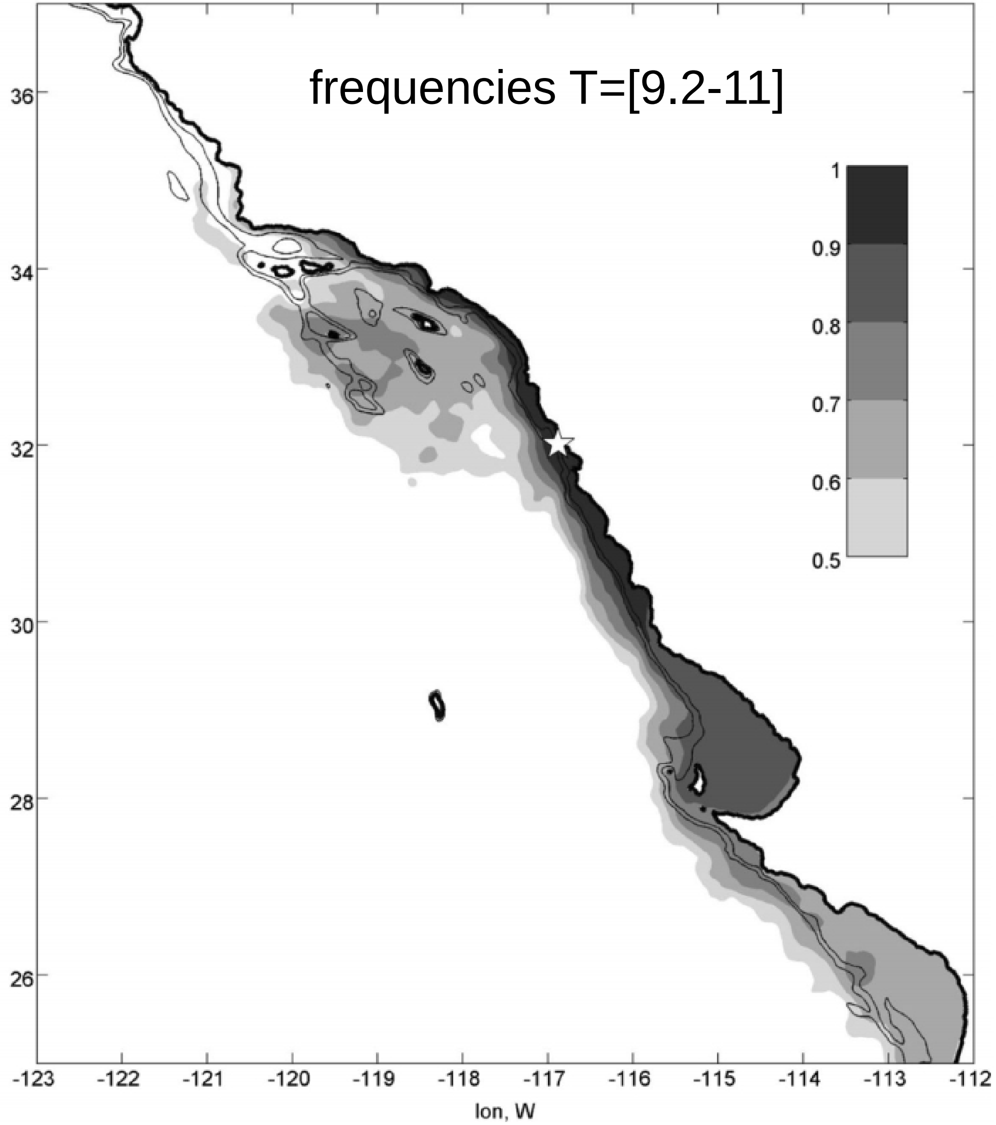
Matching altimetry and tide gauges: The Zone of Influence



Median corr.: 0.91 0.77 0.84

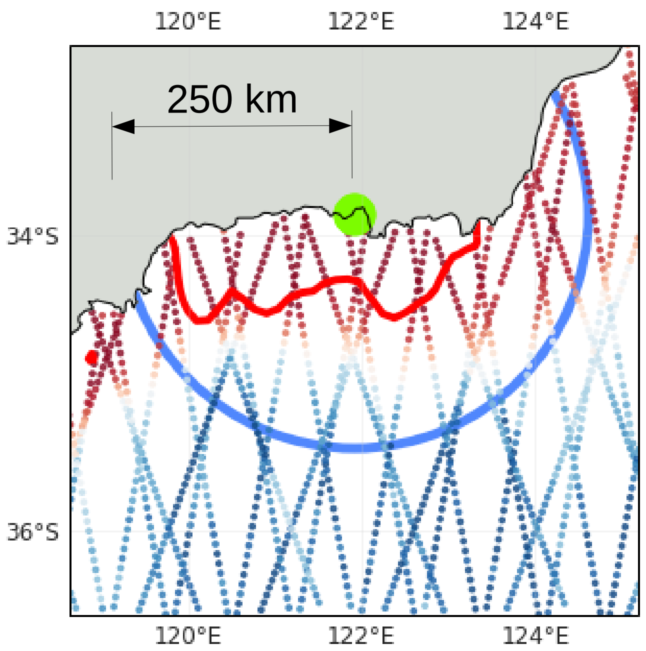
Along-shore coherence and frequency dependencies

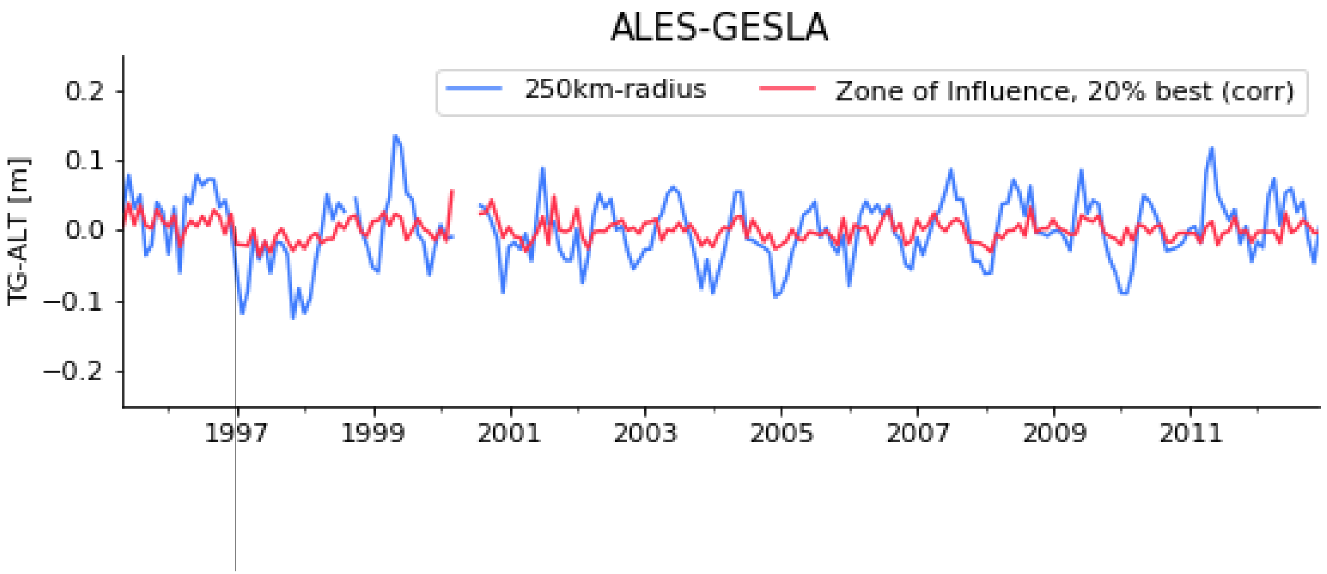




Kurapov et al., 2017

Matching altimetry and tide gauges: The Zone of Influence





Zone of Influence reduces noise of SAT-TG differences and thus trend uncertainties!