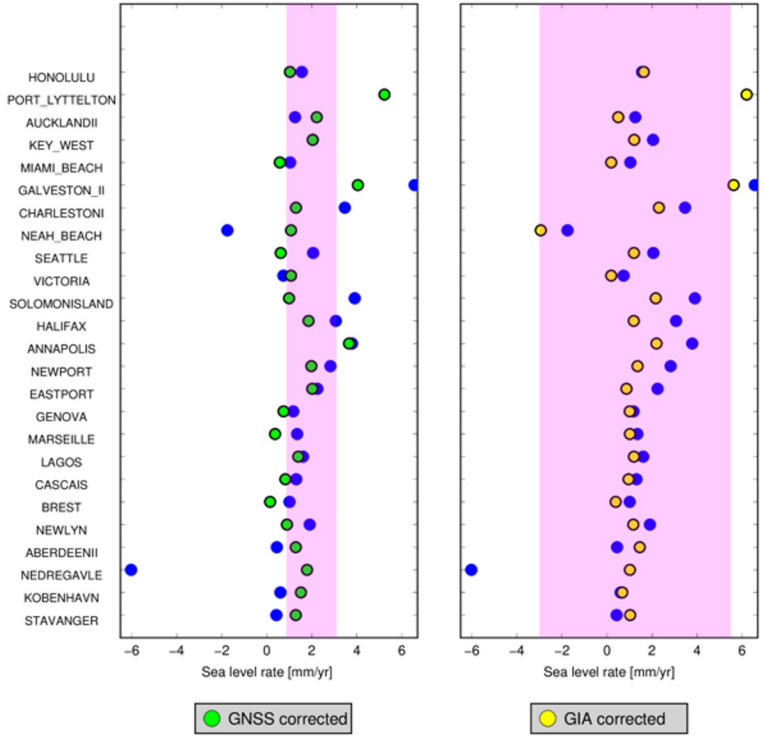
Geodesy and Geospatial Engineering

First Results of the GNSS Reprocessing at the University of Luxembourg for an Updated Global Vertical Land Movement Data Set

Eshetu Erkihune, Addisu Hunegnaw and Norman Teferle

Geodesy and Geospatial Engineering
Department of Engineering
University of Luxembourg

IGS INTERNATIONAL GNSS SERVICE



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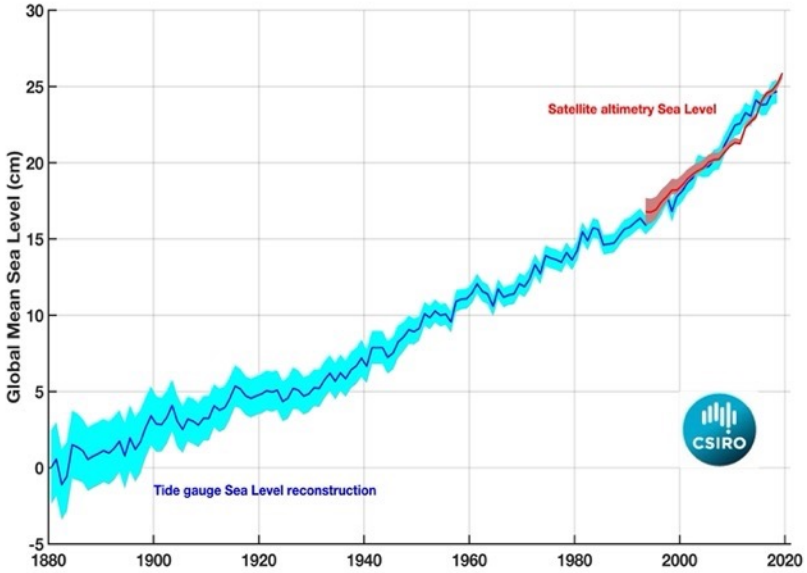
Outline

- Motivation and Objective
- The Reprocessing of GNSS Observations
- University of Luxembourg (UL) Reprocessing Strategy
- Time Series Analysis
- Results of the PPP Run
  - Cross-evaluation with NGL time series
  - Evaluation of VLM impacts on sea level trend
- Conclusions

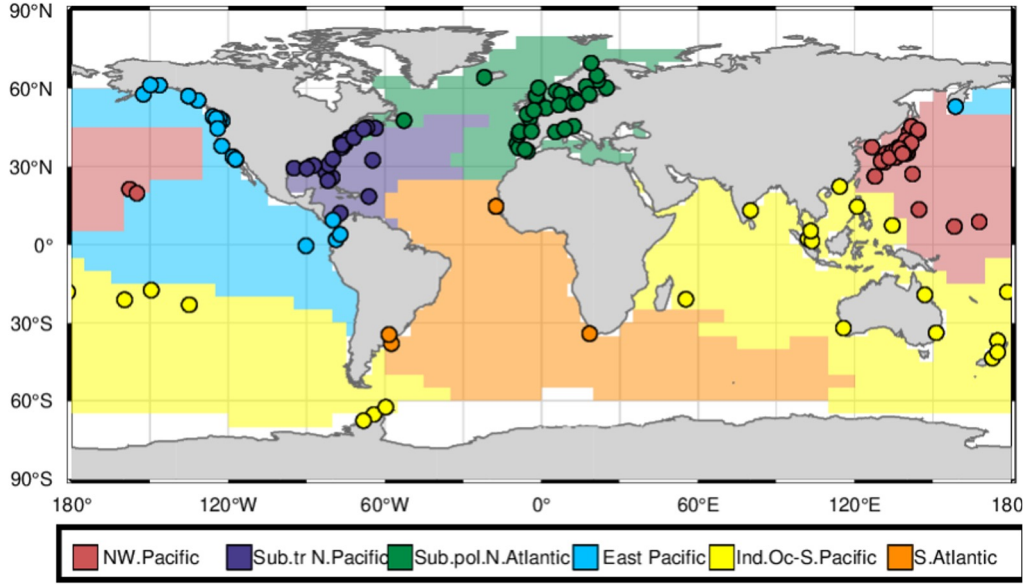
Motivation and Objective

- Sea level rise is accelerating with much evidence for this coming from tide gauges (TG) located around the world.
- Mean Sea Level (MSL) records from TGs are sensitive to vertical land movements (VLM) and need to be corrected for these.
- In the past, when computing globally averaged sea level rise, MSL records were excluded or glacial isostatic adjustment (GIA) models were used to correct for VLM.
- As the VLM stem not only from geophysical processes, GNSS is the most efficient technique capable of providing global VLM data sets.
- The determination of VLM for sea level studies is the most challenging application for GNSS and Geodesy as millimetre level accuracy is required over decades.
- The objective of this study is to provide a new state-of-the-art VLM data set based on multi-GNSS observations for future sea level studies.

Global Mean Sea Level (GMSL)
1880 to the end of 2019

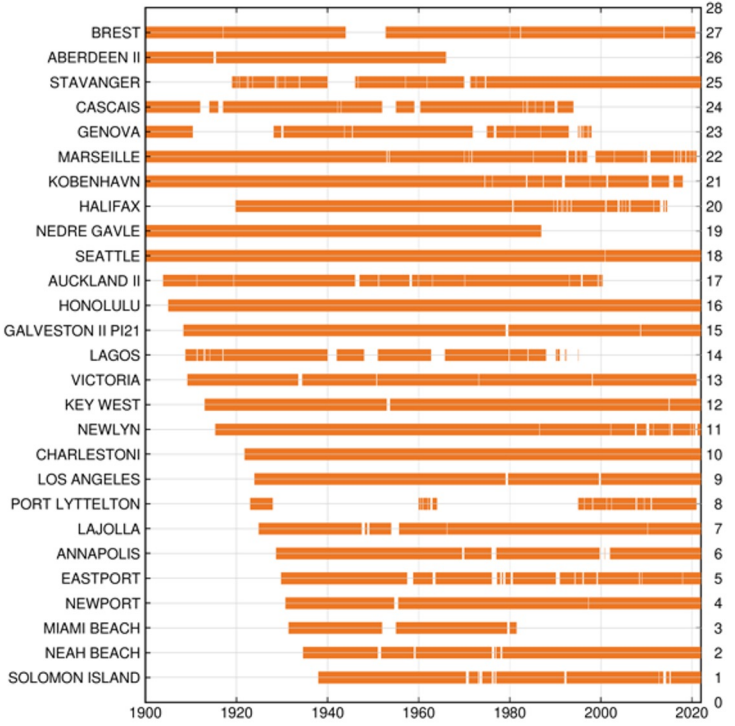


Clusters of Selected Tide Gauges



- TG locations and the corresponding ocean basins are coded in different colors.
- TG records are from the Permanent Service for Mean Sea Level (PSMSL) revised local reference (RLR) data set.

Record Length for selected TGs



Selected PSMSL RLR TG records availability for 1900-2022.

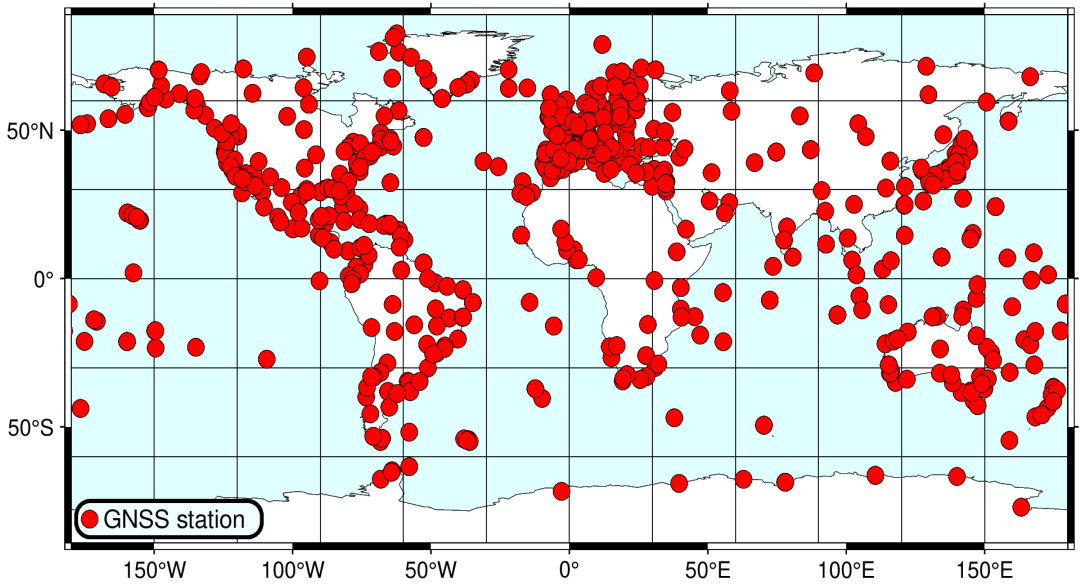
Reprocessing of GNSS Observations

Summary of IGS GNSS data reprocessing.

Description	1st Reprocessing	2nd Reprocessing	3rd Reprocessing
Data span	1994-2007	1994-2014	1994-2021
Reference Frame	IGS05 (ITRF2005)	IGS08(ITRF2008)	IGS20 ITRF2020 (Rebischung, 2021)
IERS Convention	IERS 2003	IERS 2010	IERS 2010
Geopotential Field	EGM96	EGM08	EGM08
Antenna calibration	IGS05 ANTEX	IGS08 ANTEX	IGS20 ANTEX (absolute calibration)
Tropospheric delay model	GPT/GMF	GPT2/VMF1	GPT2/VMF1
Higher order Ionosphere	Not applied	IERS 2010 (2nd order)	IERS 2010 (2nd order)
Orbit Dynamics	No Earth Albedo model	Earth Albedo model	Earth Albedo model

The University of Luxembourg (UL) is currently reprocessing a global GNSS data set following the most recent effort of the International GNSS Service (IGS).

UL repro3 GNSS Network

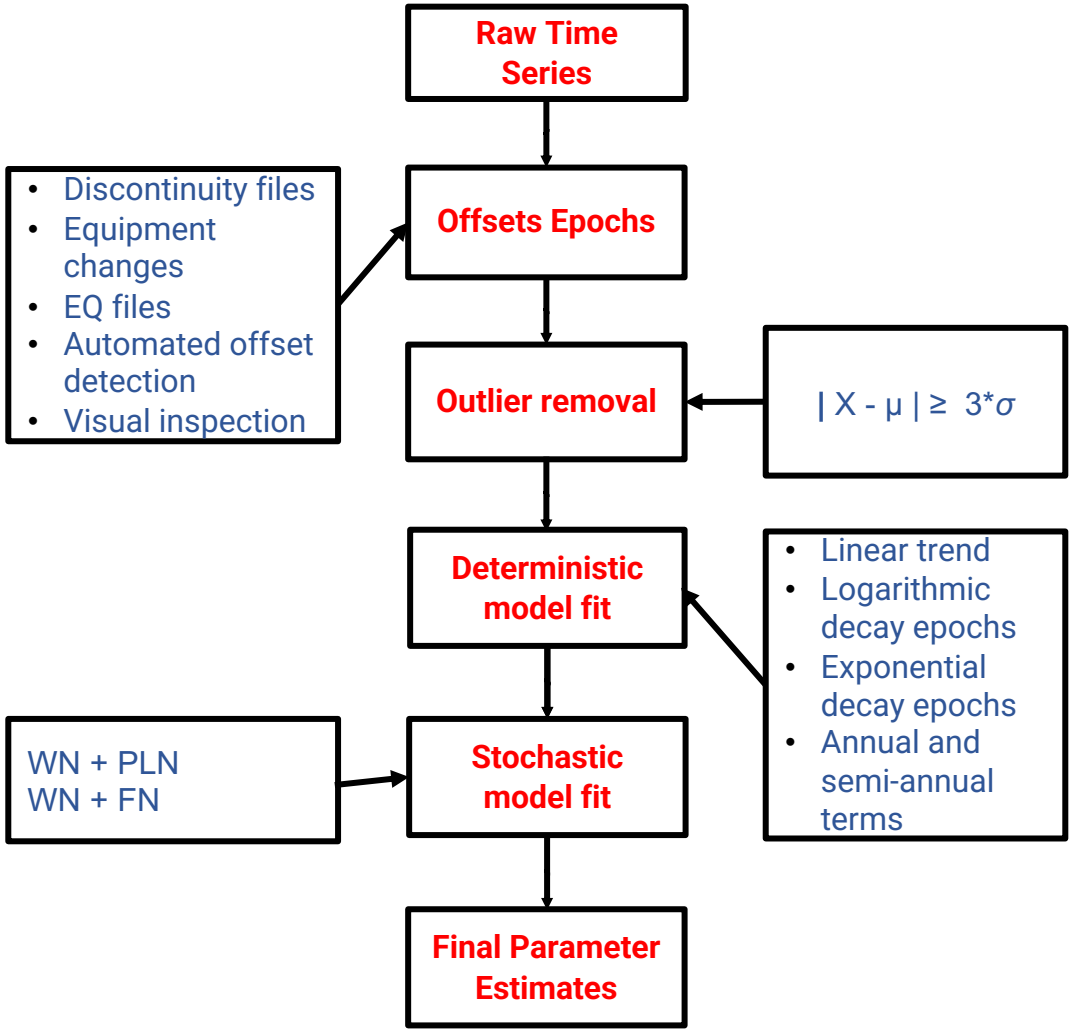


Spatial distribution of 700+ stations used for the reprocessing.

- The GNSS data were retrieved from the IGS, TIGA (www.sonel.org), BIGF and other providers
- The data processing implemented using the Bernese GNSS Software (BSW) v5.2 (Dach et al., 2015)
- Switch to BSW v5.4 is anticipated
- Observations from GPS, Glonass and Galileo
- 1st run using a PPP and 2nd run using a double-difference network strategy

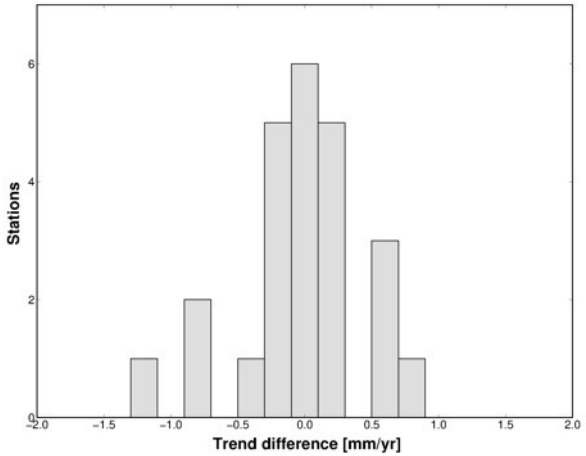
Time Series Analysis Workflow

Time series analysis was performed on the daily series using an updated Coordinate Time Series Analysis (CTSAna) software (Teferle, 2013) and Hector (Bos et al., 2013). It includes both deterministic and stochastic parameter estimates to obtain more realistic uncertainties than for a white noise (WN) only assumption.



Results: Cross-evaluation with 25 selected NGL time series analysed with MIDAS (Blewitt et al. 2016)

	NGL		UL	
Station	**Trend** [mm/yr]	**RMS** [mm/yr]	**Trend** [mm/yr]	**RMS** [mm/yr]
STAS	1.42 ± 0.39	5.72	0.86 ± 0.35	4.90
BUDP	0.73 ± 0.48	7.05	0.91 ± 0.37	5.70
MAR6	8.05 ± 0.49	7.45	7.82 ± 0.36	6.41
ABER	0.79 ± 0.45	6.80	0.84 ± 0.33	5.68
NEWL	-1.16 ± 0.39	5.83	-1.01 ± 0.24	5.04
BRST	-1.06 ± 0.40	5.42	-0.86 ± 0.26	4.16
CASC	-0.58 ± 0.35	5.31	-0.48 ± 0.17	4.32
LAGO	-0.26 ± 0.36	5.27	-0.21 ± 0.19	4.72
MARS	-1.32 ± 0.52	7.53	-0.98 ± 0.40	6.01
GENO	-0.54 ± 0.48	7.55	-0.43 ± 0.31	6.23
EPRT	0.65 ± 0.78	7.82	-0.23 ± 0.59	6.14
NPRI	-0.92 ± 0.56	6.97	-0.85 ± 0.41	5.48
USNA	-0.91 ± 0.83	8.03	-0.13 ± 0.23	6.73
HLFX	-1.27 ± 0.40	5.78	-1.21 ± 0.25	4.83
SOL1	-3.73 ± 0.86	8.52	-2.92 ± 0.50	6.56
ALBH	0.62 ± 0.40	6.20	0.34 ± 0.27	4.95
SEAT	-1.47 ± 0.40	5.81	-1.44 ± 0.27	5.11
NEAH	3.11 ± 0.56	7.78	2.83 ± 0.54	7.20
SCCC	-1.56 ± 0.76	6.34	-2.17 ± 0.64	5.69
GAL1	-5.58 ± 5.04	11.45	-2.52 ± 1.77	6.04
VTIS	0.22 ± 1.14	9.10	-0.46 ± 0.22	4.89
SIO3	0.13 ± 0.56	6.75	-0.01 ± 0.34	6.41
TAKL	-0.30 ± 1.66	7.78	0.96 ± 1.35	5.90
LYTT	-1.54 ± 0.74	6.74	-1.72 ± 0.48	5.20
HNLC	-0.47 ± 0.60	8.52	-0.53 ± 0.30	7.59



Trend difference between NGL and UL.

- Differences are expected between NGL and UL due to analyses and methods.
- Good agreement with RMS of 0.33 mm/yr.

Results: Trend estimates for 25 selected Tide Gauges (TG), GIA and GNSS, as well as the VLM-corrected TG trend

- TG rate is from Hector using a Gauss-Markov noise model
- GIA rates are from the ICE-6G_C (VM5a) model (Peltier et al., 2015).

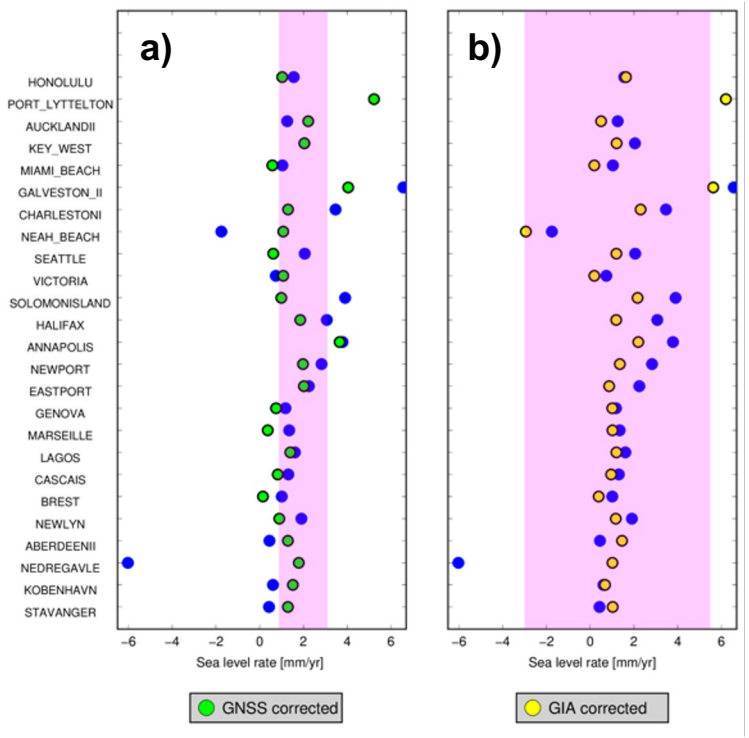
	TG rate	GIA rate	GNSS rate	TG+GIA	TG+GNSS
Station	Trend [mm/yr]	Trend [mm/yr]	Trend [mm/yr]	Trend [mm/yr]	Trend [mm/yr]
STAS	0.43 ± 0.14	0.60	0.86 ± 0.35	1.03	1.29 ± 0.26
BUDP	0.61 ± 0.12	0.07	0.91 ± 0.37	0.68	1.52 ± 0.26
MAR6	-6.03 ± 0.25	7.05	7.82 ± 0.36	1.02	1.79 ± 0.38
ABER	0.45 ± 0.22	1.01	0.84 ± 0.33	1.46	1.29 ± 0.33
NEWL	1.91 ± 0.12	-0.74	-1.01 ± 0.24	1.17	0.90 ± 0.18
BRST	1.01 ± 0.12	-0.62	-0.86 ± 0.26	0.39	0.15 ± 0.19
CASC	1.31 ± 0.2	-0.35	-0.48 ± 0.17	0.96	0.83 ± 0.23
LAGO	1.61 ± 0.26	-0.41	-0.21 ± 0.19	1.20	1.40 ± 0.04
MARS	1.35 ± 0.12	-0.33	-0.98 ± 0.40	1.02	0.37 ± 0.28
GENO	1.18 ± 0.07	-0.17	-0.43 ± 0.31	1.01	0.75 ± 0.17
EPRT	2.25 ± 0.24	-1.38	-0.23 ± 0.59	0.87	2.02 ± 0.59
NPRI	2.83 ± 0.16	-1.47	-0.85 ± 0.41	1.36	1.98 ± 0.33
USNA	3.79 ± 0.22	-1.59	-0.13 ± 0.23	2.20	3.66 ± 0.27
HLFX	3.07 ± 0.16	-1.88	-1.21 ± 0.25	1.19	1.86 ± 0.22
SOL1	3.91 ± 0.22	-1.74	-2.92 ± 0.50	2.17	0.99 ± 0.47
ALBH	0.74 ± 0.14	-0.55	0.34 ± 0.27	0.19	1.08 ± 0.21
SEAT	2.06 ± 0.11	-0.86	-1.44 ± 0.27	1.20	0.62 ± 0.18
NEAH	-1.75 ± 0.19	-1.19	2.83 ± 0.54	-2.94	1.08 ± 0.48
SCCC	3.47 ± 0.24	-1.16	-2.17 ± 0.64	2.31	1.30 ± 0.65
GAL1	6.57 ± 0.16	-0.94	-2.52 ± 1.77	5.63	4.05 ± 3.29
VTIS	1.04 ± 0.15	-0.85	-0.46 ± 0.22	0.19	0.58 ± 0.20
SIO3	2.05 ± 0.15	-0.84	-0.01 ± 0.34	1.21	2.04 ± 0.27
TAKL	1.26 ± 0.17	-0.76	0.96 ± 1.35	0.50	2.22 ± 1.99
LYTT	6.95 ± 1.78	-0.74	-1.72 ± 0.48	6.21	5.23 ± 2.01
HNLC	1.56 ± 0.13	0.08	-0.53 ± 0.30	1.64	1.03 ± 0.22

Results: Evaluation of VLM Impact on Sea Level Rates

Mean and standard deviations of individual sea level change estimates

	No Corrections	VLM Corrections	
	TG Trend [mm/yr]	TG+GIA Trend mm/yr]	TG+GNSS Trend mm/yr]
GMSL	1.75 ± 0.23	1.35	1.60 ± 0.55
RMS	2.47	1.69	1.18

- There is a large spread of GIA estimates relative to GNSS (see Figure).
- There is improved agreement between the sea level rise estimates after correction with the observed rather than modelled VLM.
- The 25 tide gauges shown are exposed to VLM due to different processes, not just GIA.



GNSS-corrected (a) and GIA- corrected (b) sea level rates for 25 tide gauges. The pink bands indicate the 1-σ spread of the sea level rise estimates after correction.

Conclusions

- We presented the reprocessing effort at the University of Luxembourg using the repro3 products from the IGS AC CODE
- The PPP run has been largely completed and the double difference network run is planned to start after switching to the Bernese GNSS software v5.4
- A largely automated time series analysis strategy has been implemented in parallel to the processing, which allows both deterministic and stochastic parameter estimates
- The preliminary time series analysis shows good agreement with an independent data set and will fulfill the objective of this study to provide an updated VLM data set

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Thank you for your attention!

Acknowledgements

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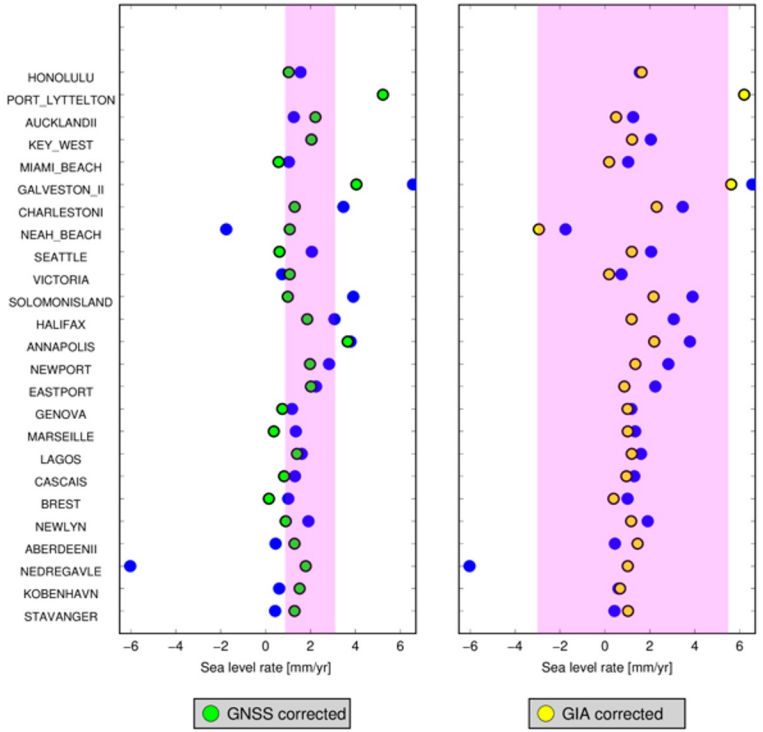
Data and products provided by the IGS and its ACs (Johnston et al., 2017), TIGA@sonel.org and PSMSL (PSMSL, 2022; Holgate et al., 2013) are highly appreciated.



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