GNSS - Interferometric Reflectometry, sea level measurements and spectral artifacts

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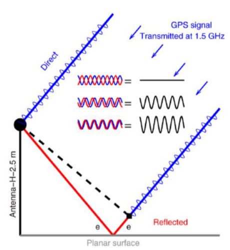
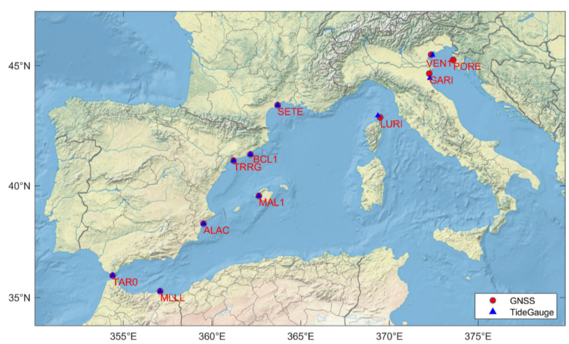
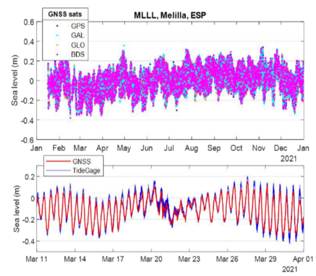
Sea-level results in the Mediterranean



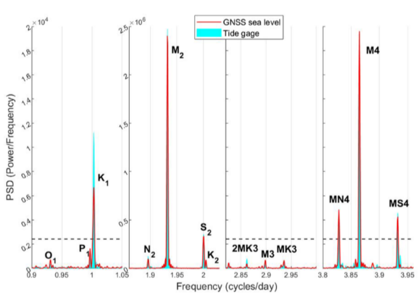
GNSS-IR fundamentals: the direct GNSS signal (blue) travels a shorter distance than the reflected signal (blue plus red). Depending on the extra path travelled by the reflection (shown in red), the direct and reflected signals will interfere (shown for three examples in the center of the figure). This interference (shown in black) is what is measured by the GNSS unit.

Modified from Larson & Small, 2014, IEEE J. Sel. Topics Appl. Earth Observ. doi:10.1109/JSTARS.2014.2300116.





Map of the GNSS stations analyzed in this work. On the right panel, one year of GNSS-IR Sea level estimates (colors indicate each satellite constellation) at Melilla station (MLLL, IGNE network). At bottom, a zoom at mid of March for the same data compared with sea level data observed at the collocated Tide Gauge (Meli).

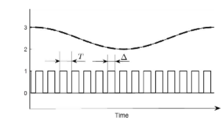


Spectra of one year of sea level determinations at TAR0 (Tarifa, ESP) GNSS station and tide gage data. Tidal frequencies of the diurnal, semidiurnal, terdiurnal and quarter diurnal constituents are shown respectively from left to right panels. Red line refers to the GNSS data and cyan line to the tide gage data. The horizontal dashed line represents the 1% confidence level of the spectral amplitudes.

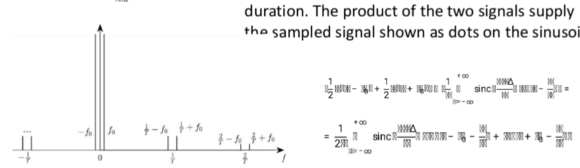
Place	Site ID	Net	Sats	Lat (°)	Lon (°)	N.obs per day	Tide Gage	Corr (%)	Noise (cm)
Barcelona, ES	BCL1	IGNE	G,R,E,C	41.3418	2.1657	112	Barcelona,ES	96.2	2.9
Melilla, ES	MLLL	IGNE	G,R,E,C	35.2907	-2.9285	218	Melilla, ES	94.8	2.9
Tarifa, ES	TAR0	EUREF	G,R,E	36.0086	-5.6027	132	Tarifa, ES	98.4	4.8
S.Severa, FR	LURI	RGP	G,R	42.8884	9.4759	66	Centuri, FR	90.4	5.0
Tarragona, ES	TRRG	IGNE	G,R,E,C	41.0790	1.2132	55	Tarragona,ES	84.9	5.7
Alicante, ES	ALAC	EUREF	G,R,E,C	38.3389	-0.4812	126	Alicante, ES	81.5	7.4
Mallorca,ES	MAL1	IGNE	G,R,E,C	39.5602	2.6375	63	Mallorca,ES	81.0	8.3
P.Garibaldi,IT	GARI	EUREF	G,R,E,C	44.6769	12.2494	67	Ravenna, IT	91.2	8.4
Sète, FR	SETE	RENAG	G,R,E	43.3976	3.6991	68	Sète, FR	79.5	8.4
Poreč, HR	PORE	EUREF	G,R,E	45.2260	13.5951	58	Venezia19, IT	88.9	12.4
Venezia, IT	VEN1	EUREF	G,R,E,C	45.4306	12.3541	128	Venezia19, IT	85.1	15.4

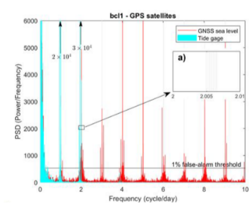
GNSS – Tide Gauge correlation coefficients and relative precisions obtained from GNSS-IR analysis

Aliasing caused by GNSS satellites sampling

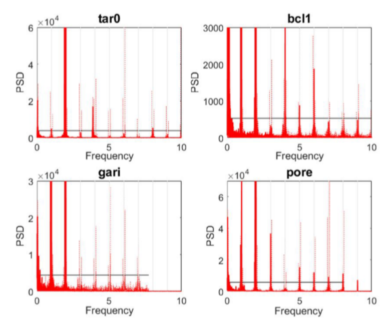


Synthetic sinusoid (on top) sampled with a recursive pattern. The train of square pulses depicts the sampling pattern, i.e. observing periods (crest) and missing samples (through), T being the sampling period and Δ the pulse duration. The product of the two signals supply the sampled signal shown as dots on the sinusoid.





Spectrum of BCL1 sea level data (red) and tide gage data (cyan) at Barcelona harbor obtained with different constellation data (GPS, GLONASS, GALILEO and BEIDOU). Grey vertical lines indicate the family of system resonances for the given constellation, the inlet a), zooming at 2 cpd, shows the fine structure of the resonance for the GPS constellation)



Spectra of Sea level data obtained from GPS data at four different stations. The periodograms show twin frequencies repeating at multiples of the sidereal frequency. The sea level data, as estimated at "real" epochs, i.e. dictated by satellite passes, provide the dotted spectral lines whereas the same data interpolated at regular time intervals supply spectral elements marked by a solid line. The effect of sampling leakage disappears below the significance level when the signal is re-sampled at evenly spaced time stamps.

Conclusions: The GNSS-IR sea level estimation is currently feasible at the level of a few (up to 15) centimeters precision. All GNSS satellite signals have the potential to contribute to the sea level estimation. Satellite motion induce strong aliasing effects in the spectral output of sea-level estimates, especially for GPS satellite sampling frequency.