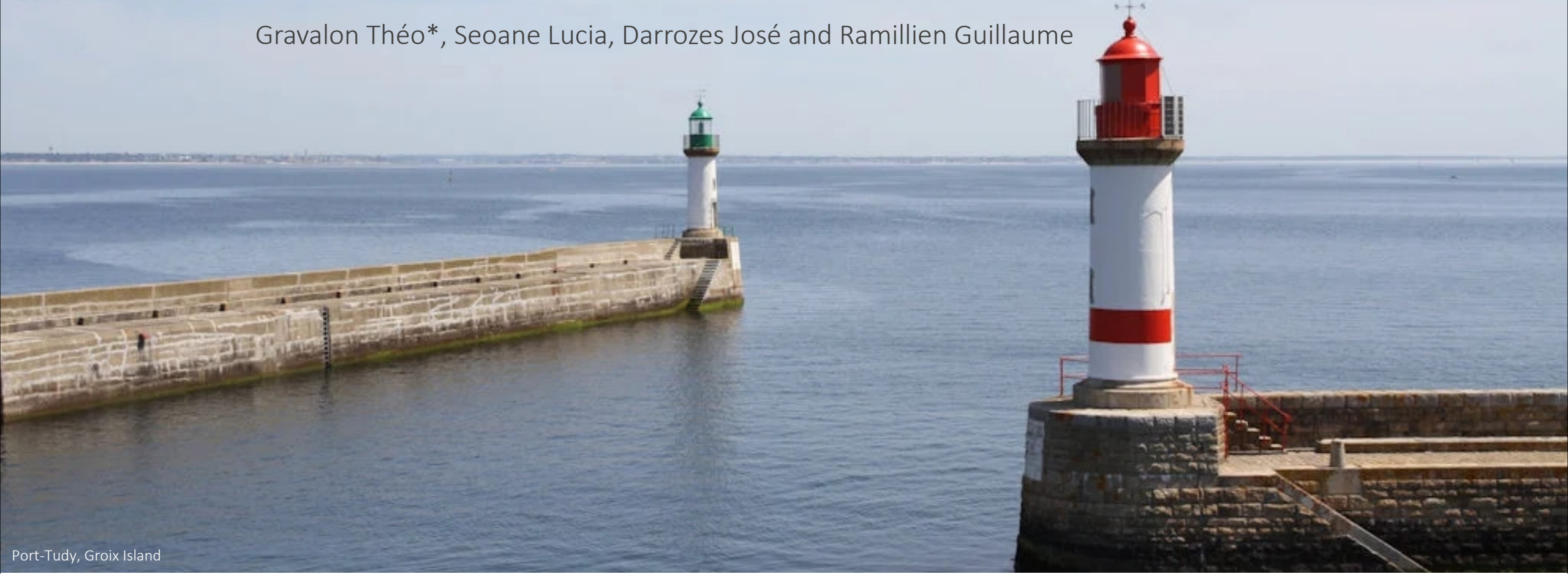


Can GNSS-R help us monitor the effect of inverse barometer in coastal areas ?

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Validation of the GNSS reflectometry technique in order to retrieve sea level variations due to inverse barometer* in coastal areas

*The response of the sea level to barometric variations or inverse barometer effect is the cause of most sea level variations at a subtidal level

How ?

- Through direct comparison with collocated tide gauges observations as a first validation
- And through comparison of the detided residual with an approximation of the inverse barometer effect on sea level

Why ?

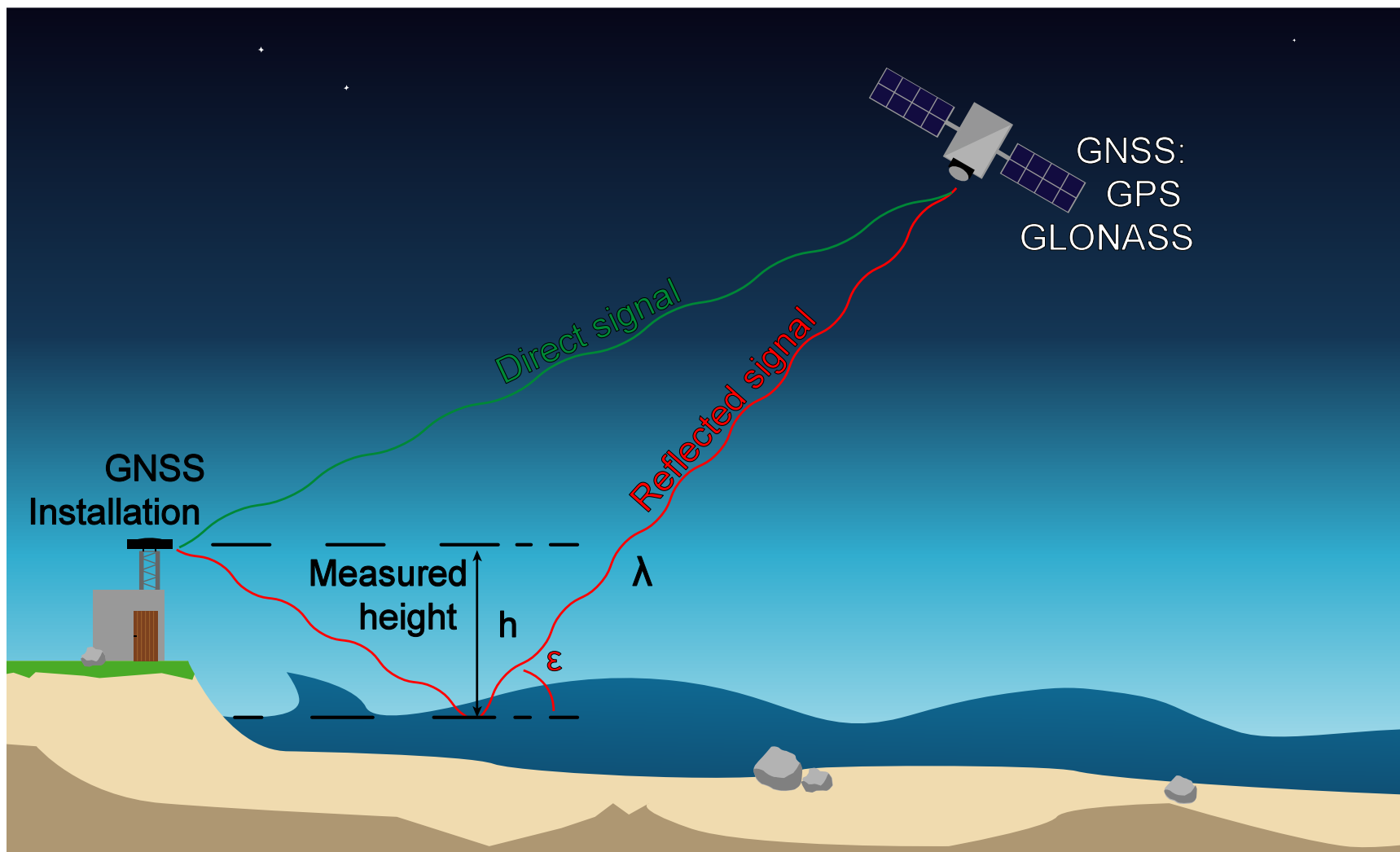
- Getting a better understanding of individual processes such as the inverse barometer
- Understanding how these complexes processes have an impact on coastal sea level
- Proving the capability of GNSS-R to retrieve subtidal phenomena

Summary

GNSS Reflectometry
Usual application in coastal areas
What does it represent ?
The Inverse barometer
Application to two sites
Data processing
Results

GNSS Reflectometry (GNSS-R)

The GNSS-R is an opportunistic teledetection technique based on the reflection of GNSS signals on water surfaces which allow to measure the height between the reflection surface and the antenna



$$\tilde{f} = \frac{4\pi}{\lambda} \left(h \frac{\tan \varepsilon}{\varepsilon} + h \right) \quad (1)$$

$\tilde{f}$: oscillation frequency of the multipath

h : height between the ant. and the water

λ : wavelength of the satellite signal

ε : elevation of the satellite

Several resolution methods:

Larson, K. M., Löfgren, J. S., & Haas, R. (2013). Coastal sea level measurements using a single geodetic GPS receiver. *Advances in Space Research*, 51(8), 1301-1310.

Roussel, N., Ramillien, G., Frappart, F., Darrozes, J., Gay, A., Biancale, R., ... & Allain, D. (2015). Sea level monitoring and sea state estimate using a single geodetic receiver. *Remote sensing of Environment*, 171, 261-277.

The one used

Use of a Periodogram (LSP) and least square resolution for (1)

What do we use the GNSS-R for ?



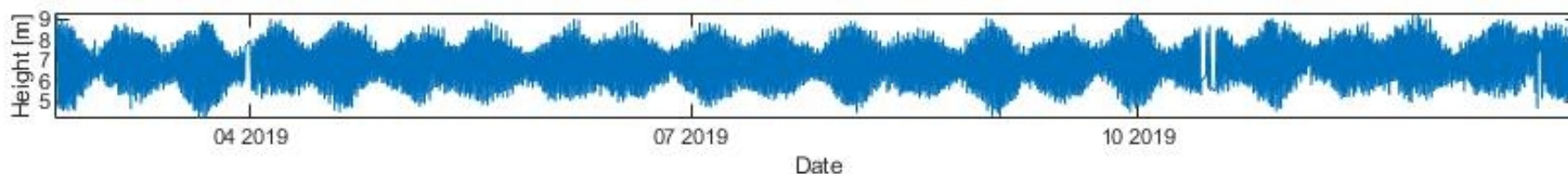
Use of GNSS-R (in our context)

Provide in-situ sea level variations observations

Use of tide gauge

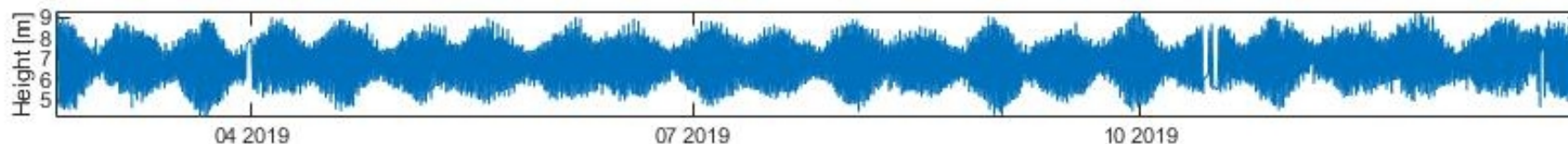
Why do we use it ?

- Alternative measurement method
- Cheaper and easier to install than a tide gauge
- Provide a direct link to reference datum (as GNSS installations are used to link tide gauge datum to reference datum)
- Provide other informations regarding the water surface
-



Sea level observations
obtained with GNSS-R

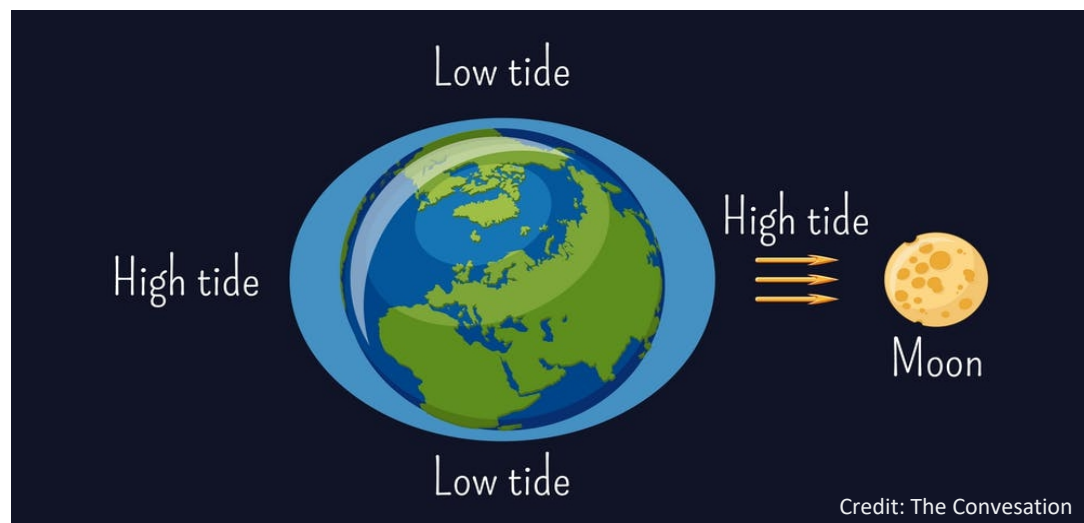
What does it represent ?



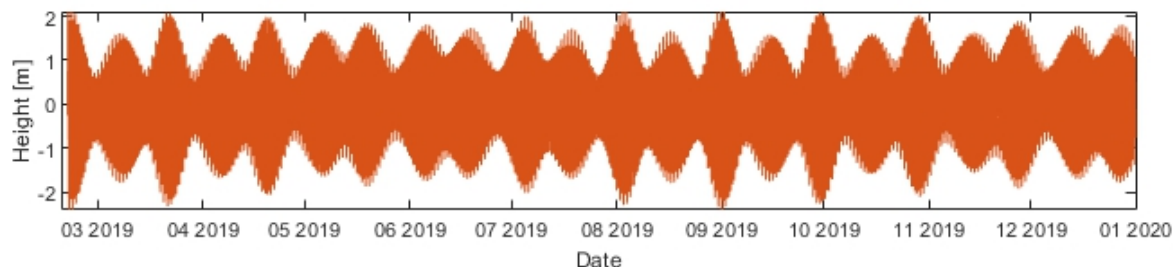
Sea level observations obtained with GNSS-R

But what's in this time serie ?

The tides

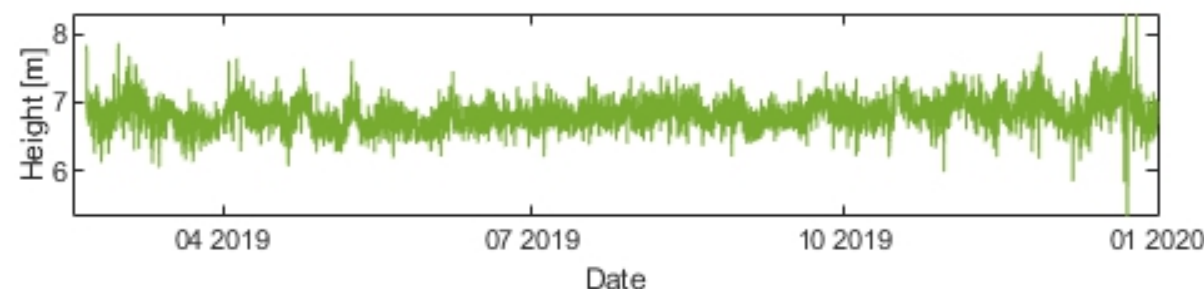


Tides can be modelled based on harmonic analysis¹



Tides modeled from the previous time serie using *T_Tide*

A subtidal residual



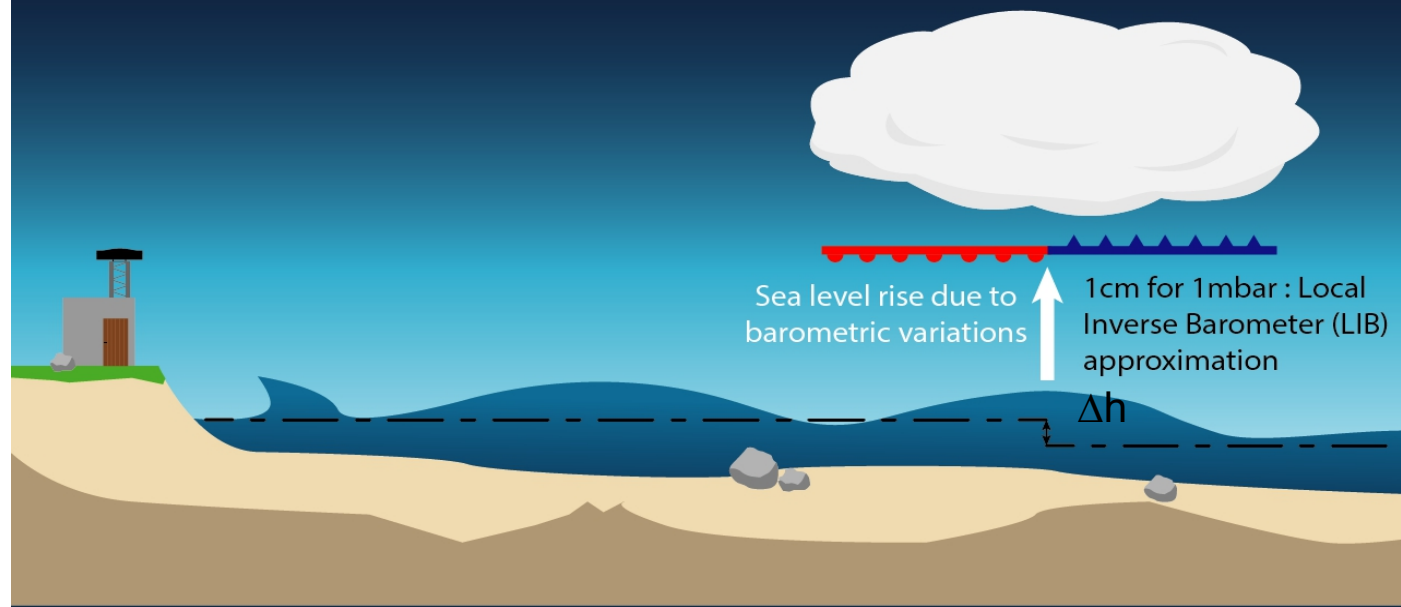
Residual issued from the soustraction of the original time serie by the tide model : **the detiding**
Due to several subtidal phenomena impacting the sea level

One of the most important subtidal phenomena impacting daily periods is the inverse barometer effect

¹ Pawlowicz, R., Beardsley, B., & Lentz, S. (2002). Classical tidal harmonic analysis including error estimates in MATLAB using *T_TIDE*. *Computers & Geosciences*, 28(8), 929-937.

EGU Inverse barometer effect: Local approximation

The inverse barometer effect corresponds to the response of the sea level to barometric variations.

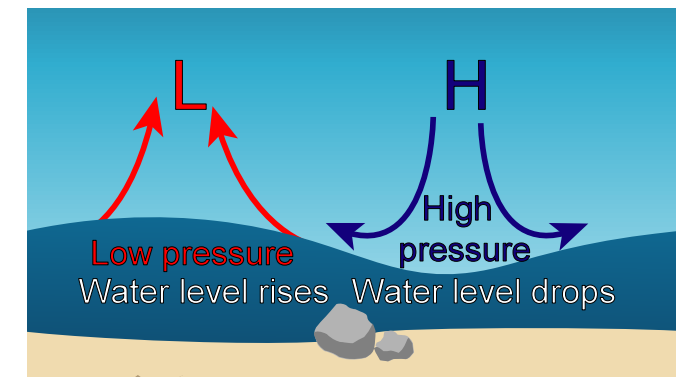


Complex relation between sea level and air pressure leads to several approximations of the inverse barometer effect as the:

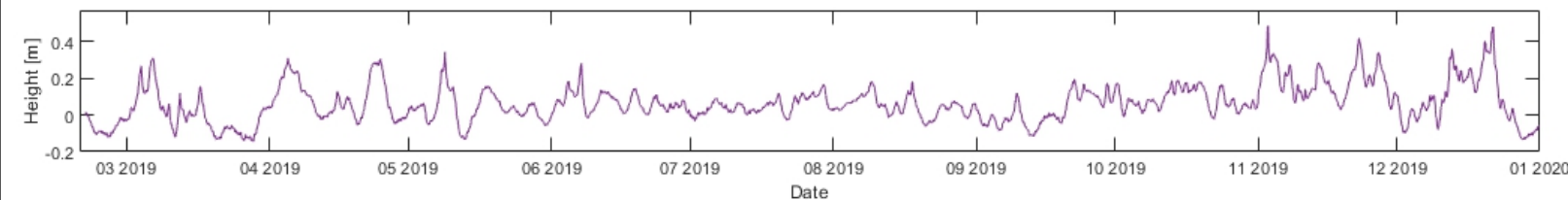
Local Inverse Barometer (LIB) approximation:

$$\begin{aligned}\Delta h &= -\Delta p / \rho g \\ &= a \cdot \Delta p \\ \text{with } a &= -1\text{cm/mbar}\end{aligned}\quad (2)$$

Valuable at period greater than 2 days

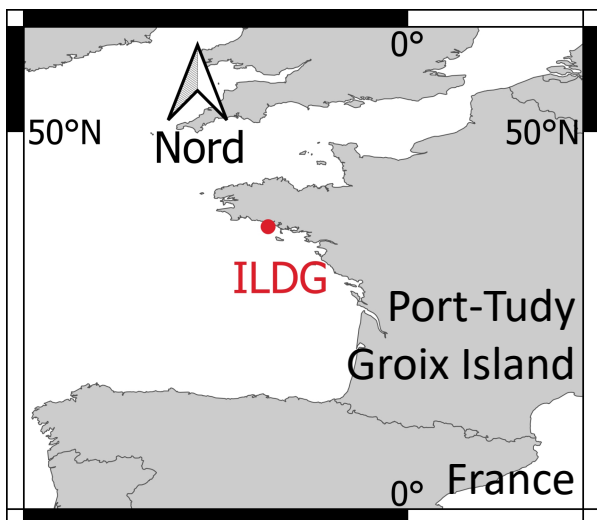


Ponte, R. M., Salstein, D. A., & Rosen, R. D. (1991). Sea level response to pressure forcing in a barotropic numerical model. *Journal of physical oceanography*, 21(7), 1043-1057.

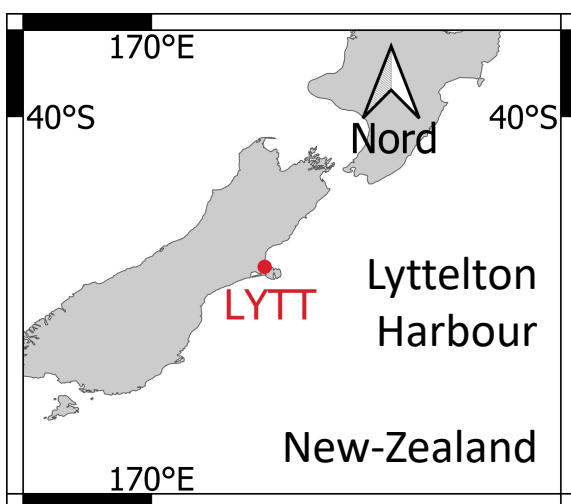
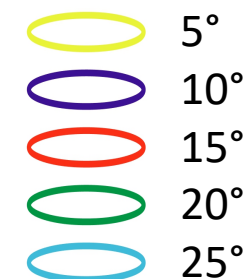


Height converted from barometric observations based on (2)

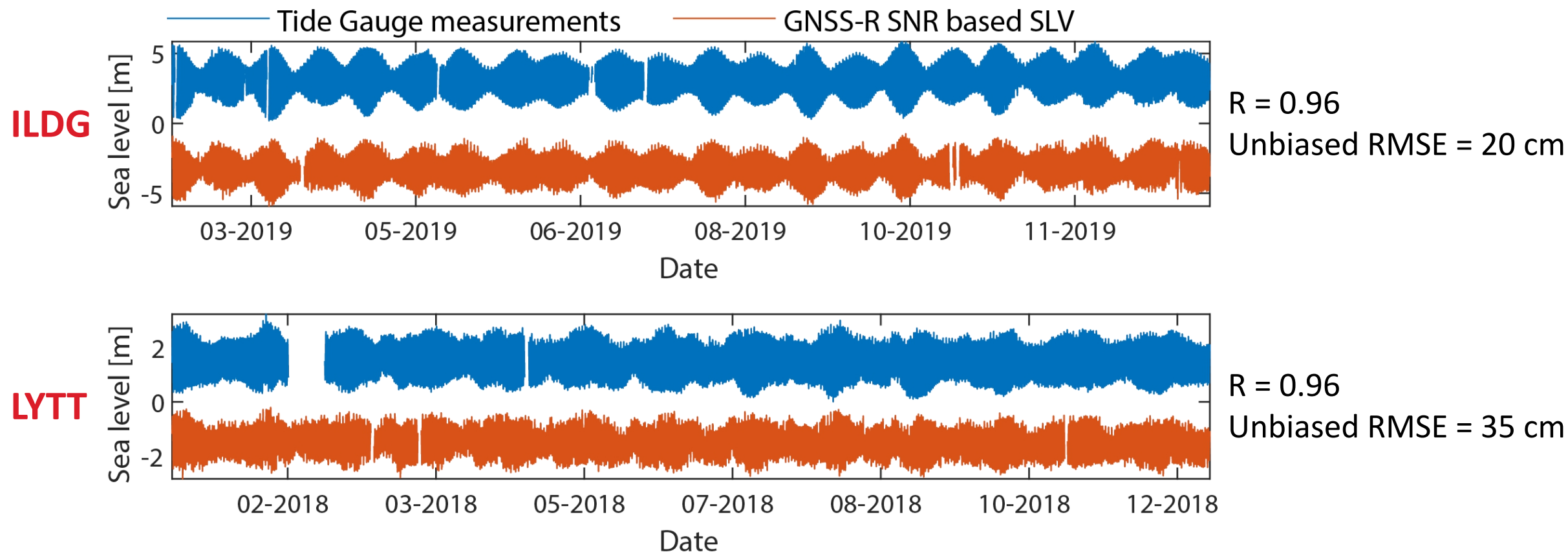
Sites of the study



First fresnel zone at elevation angle:

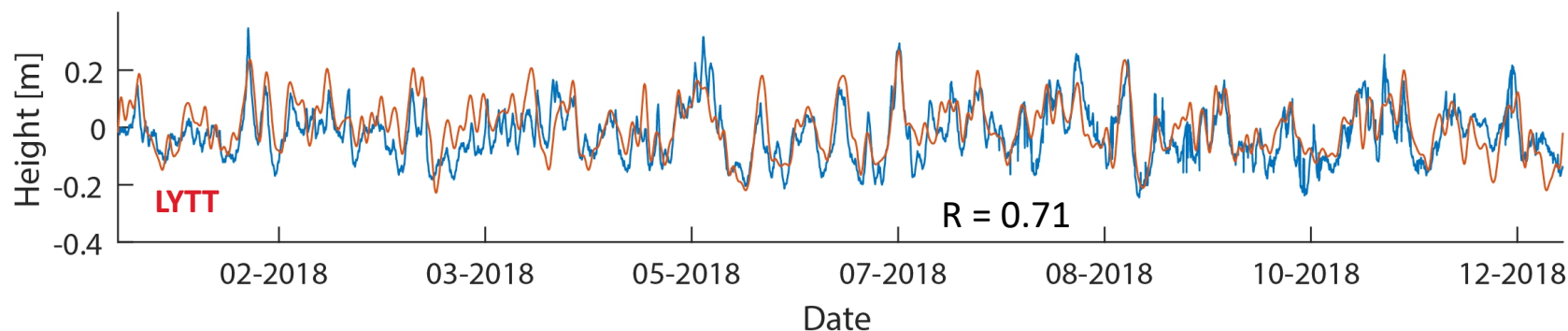
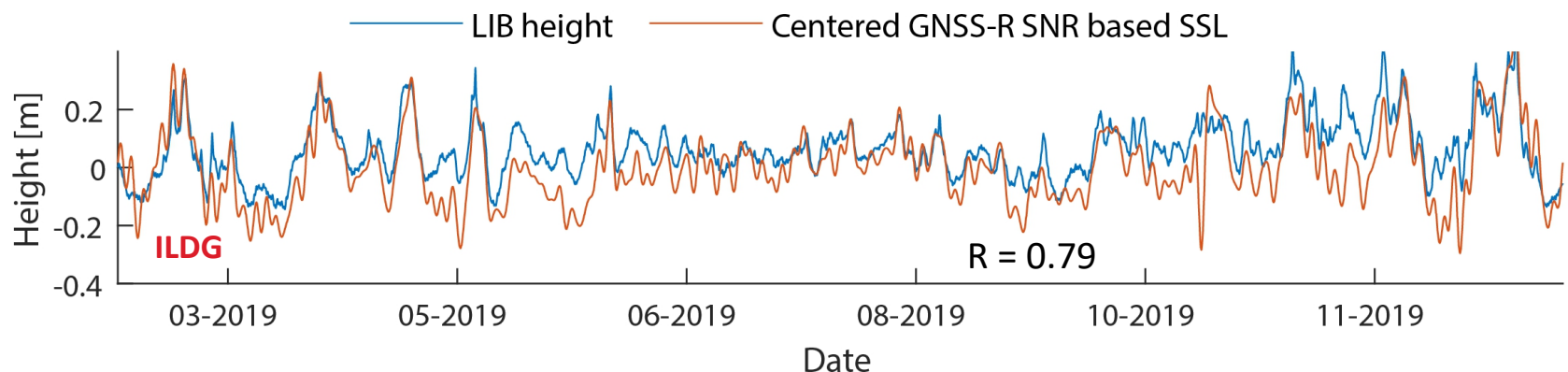


- Ideally placed for GNSS-R
- Collocated with tide gauge
- Accessibility of the data ...

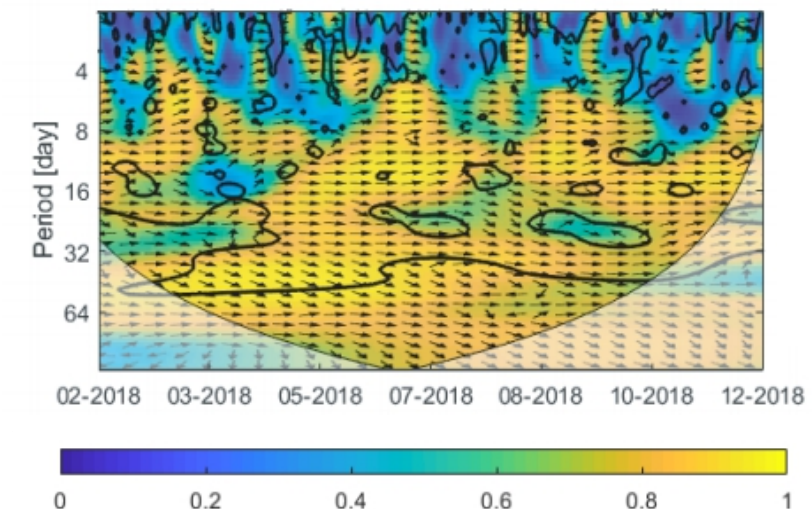
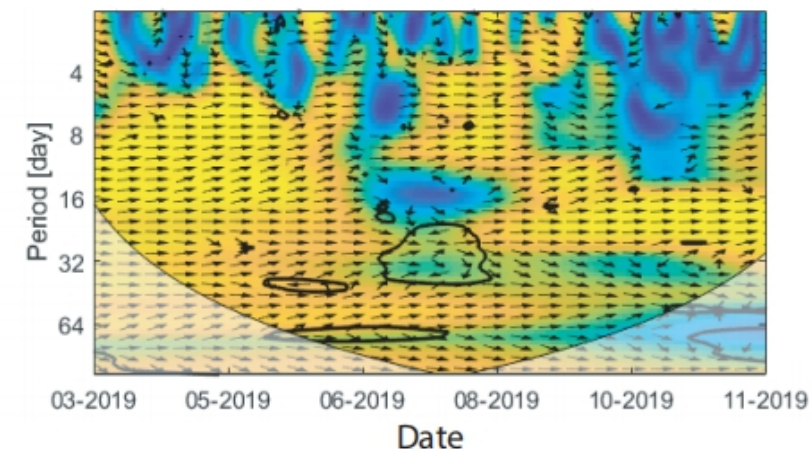


Excellent correlation achieved on a time serie of about a year !
Small error w.r.t the tidal range are found

A wavelet lowpass filter is applied on the GNSS-R subtidal residual as the LIB is not valuable a period lower than 2 days



Clear observation of the barometric variation effect in the GNSS-R time series



The GNSS-R allows to retrieve sea level observations for the whole timespan (about 1 year) with high precision

It also allows to study subtidal phenomena at a daily scale, as the Inverse Barometer

The inverse barometer explains most of the subtidal sea level variation at period greater than several days for the sites of the study

Perspectives

We are observing difficulties to isolate the sea level variations due to Inverse barometer from other subtidal phenomena due to frequency overlapping.

Thus, in order to observe and analyse other long term subtidal effects such as upwelling, steric variations, etc ..., in the time series, independant observations or models will be needed in order to reduce the subtidal sea level (like the reduction of the tide with a tide model).

Thank you !