



Sensor Inter-Comparison Analysis for Sea Level Evolution At Saint-Paul Island

Florence Henry

Supervised by Laurent Testut (LIENSs)

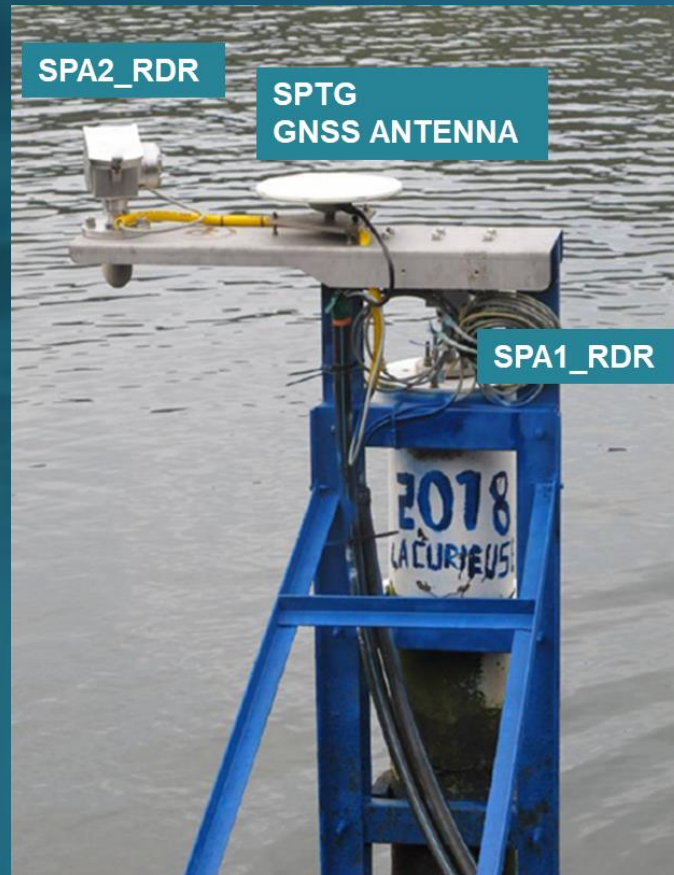
• Site Context

- ✓ Located in Southern part of Indian Ocean ($38^{\circ}41'S$, $77^{\circ}31'E$)
- ✓ Ancient volcanic island
- ✓ Automatic station with data transmitted by satellite



• Site Context

- ✓ Located in Southern part of Indian Ocean ($38^{\circ}41'S$, $77^{\circ}31'E$)
- ✓ Ancient volcanic island
- ✓ Automatic station with data transmitted by satellite



Ref: NIVMER Mission report

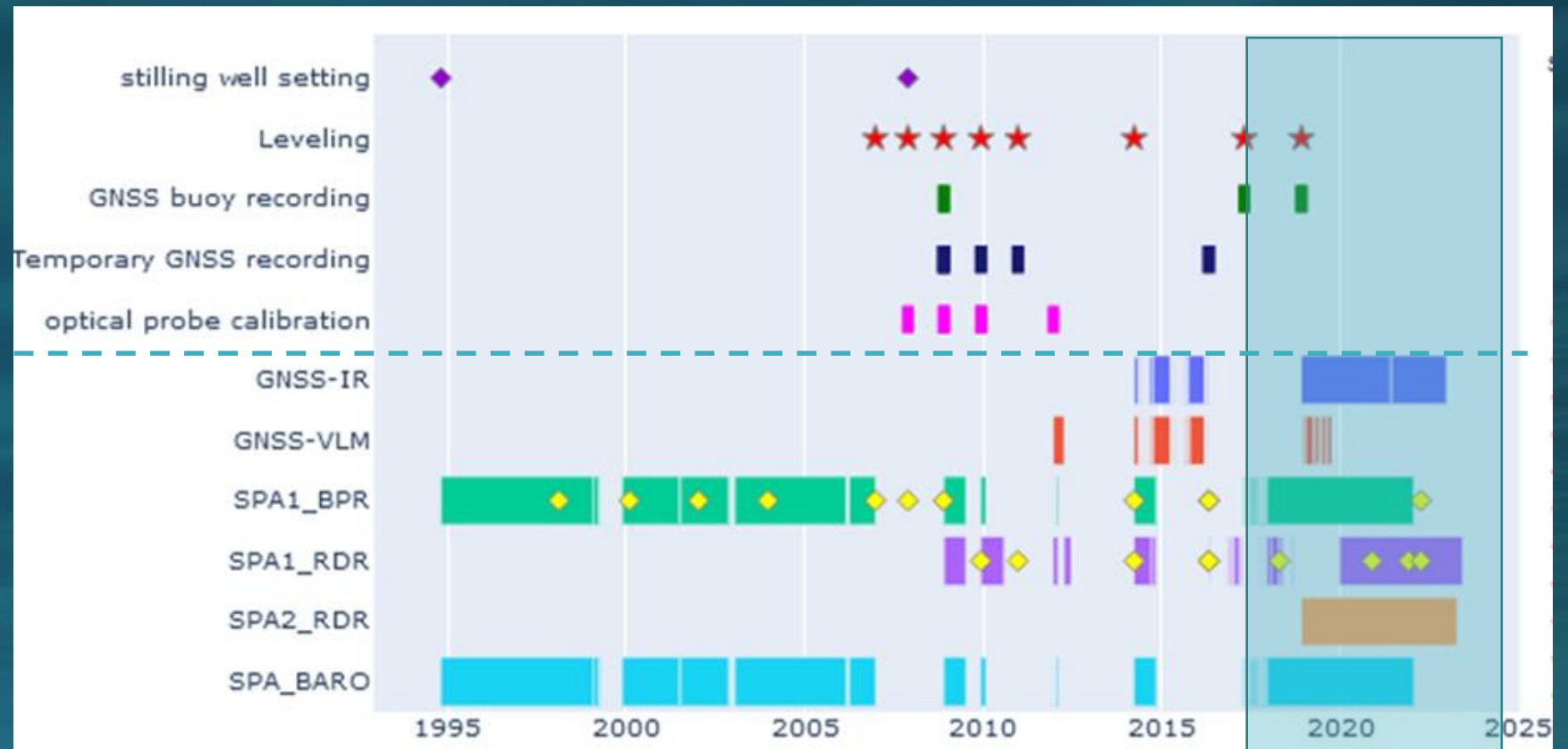
- **OBJECTIVES**

- ✓ Have a clear overview of the database over the period 1994-2023
- ✓ Assess the data quality by multi-sensor intercomparison
- ✓ Establish a reference gauge
- ✓ Investigate the ability of GNSS reflectometry approach (GNSSIR) to monitor Saint-Paul sea level

• Saint-Paul Sensor data Chronogram

Period of Analysis
2018 - 2023

Complementary
Measurements



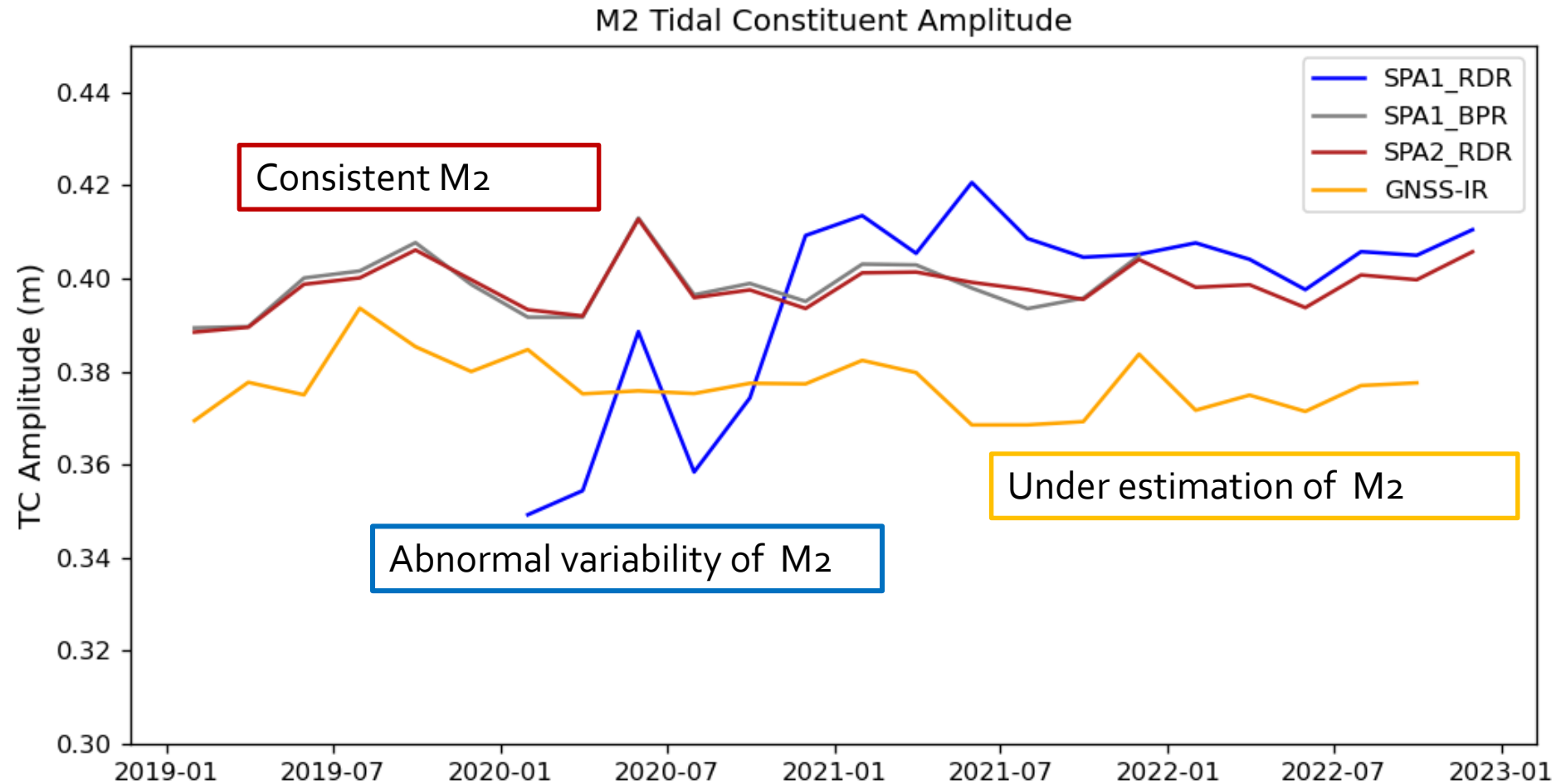
Permanent
Measurements



• Main data processing

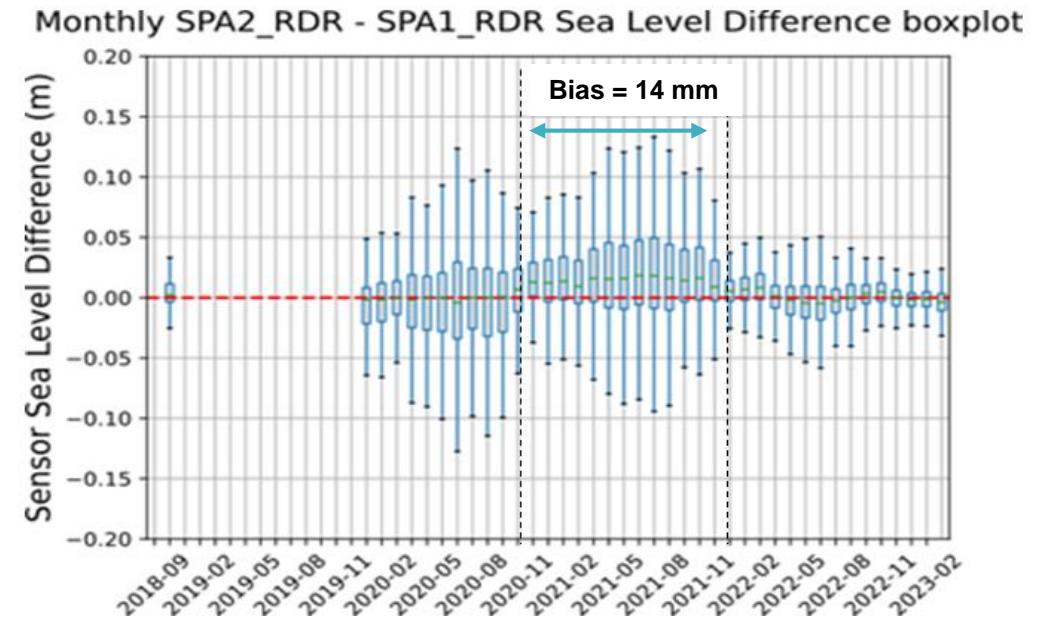
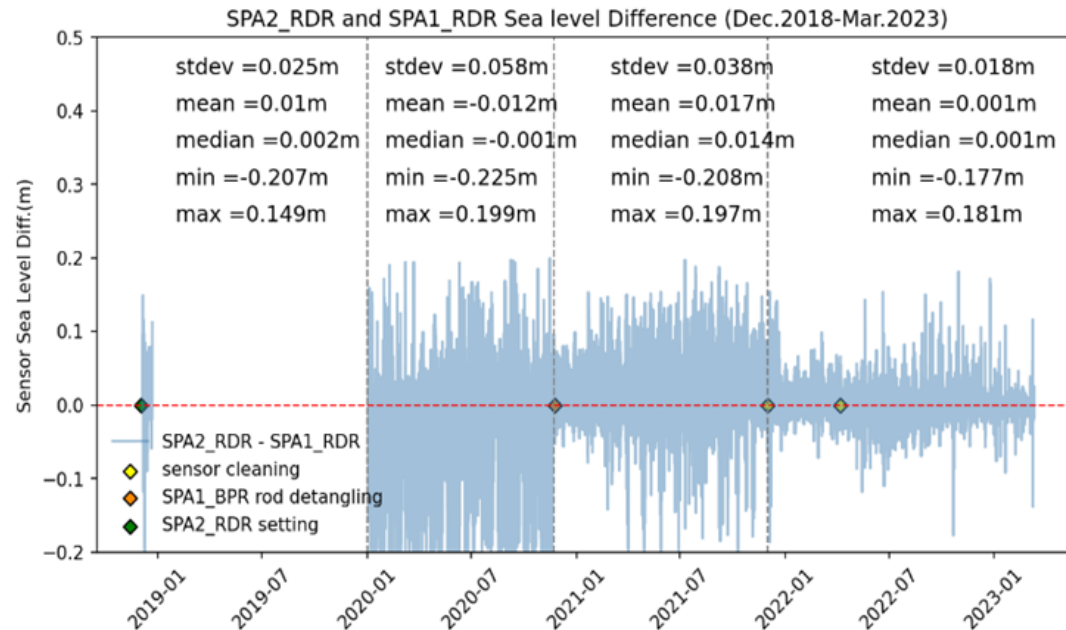
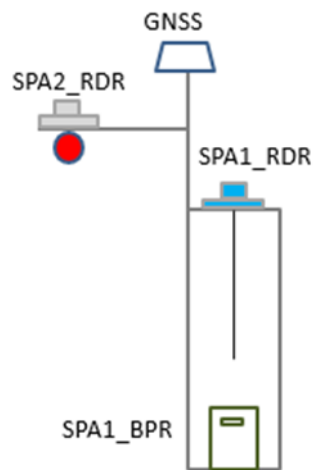
- Cleaning data
- Converting raw data (air draft, bottom pressure) to a sea level information
- Referencing data to a same datum

1. TIDAL CONSTITUENTS from HARMONIC ANALYSIS



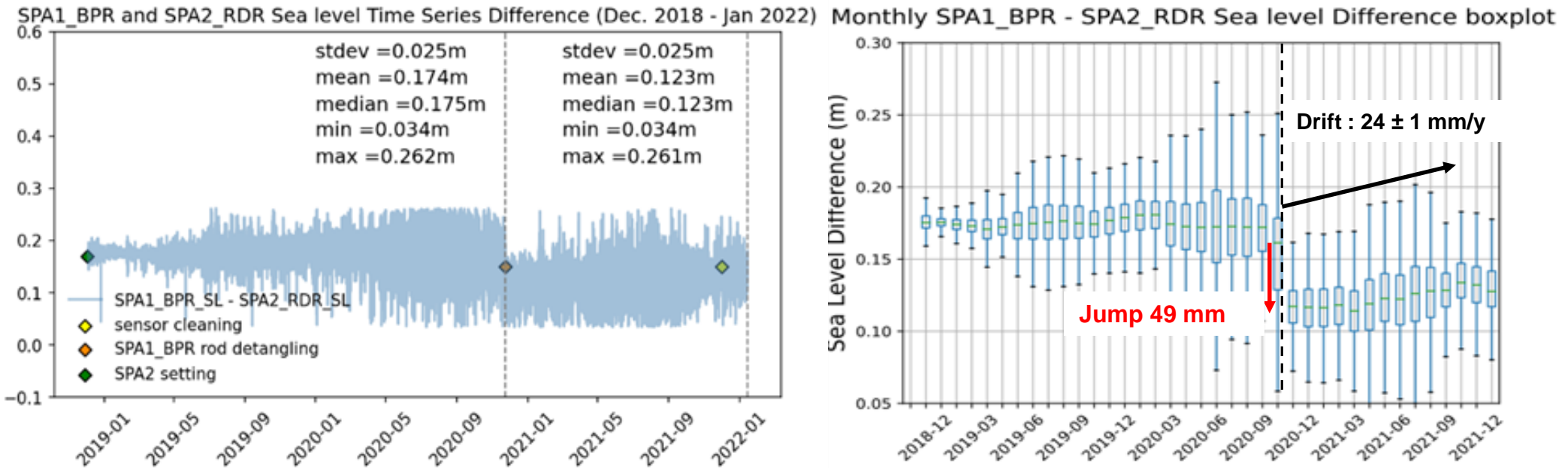
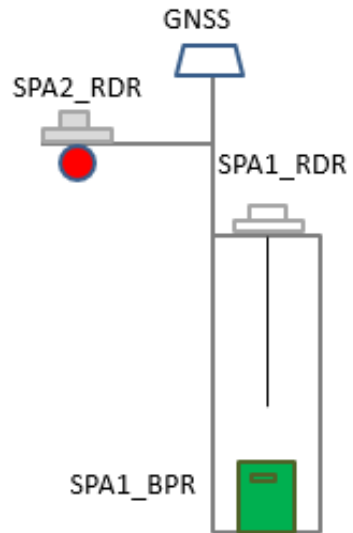
2. TIME SERIES DIFFERENCE ANALYSIS

- SPA1_RDR / SPA2_RDR Sensors



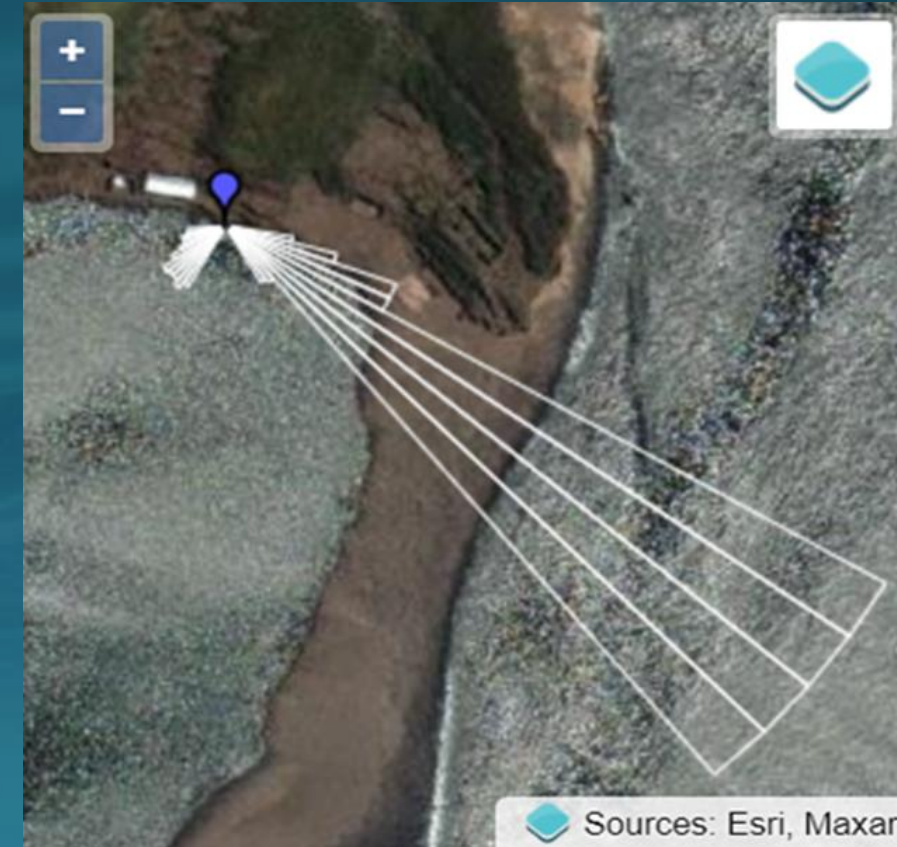
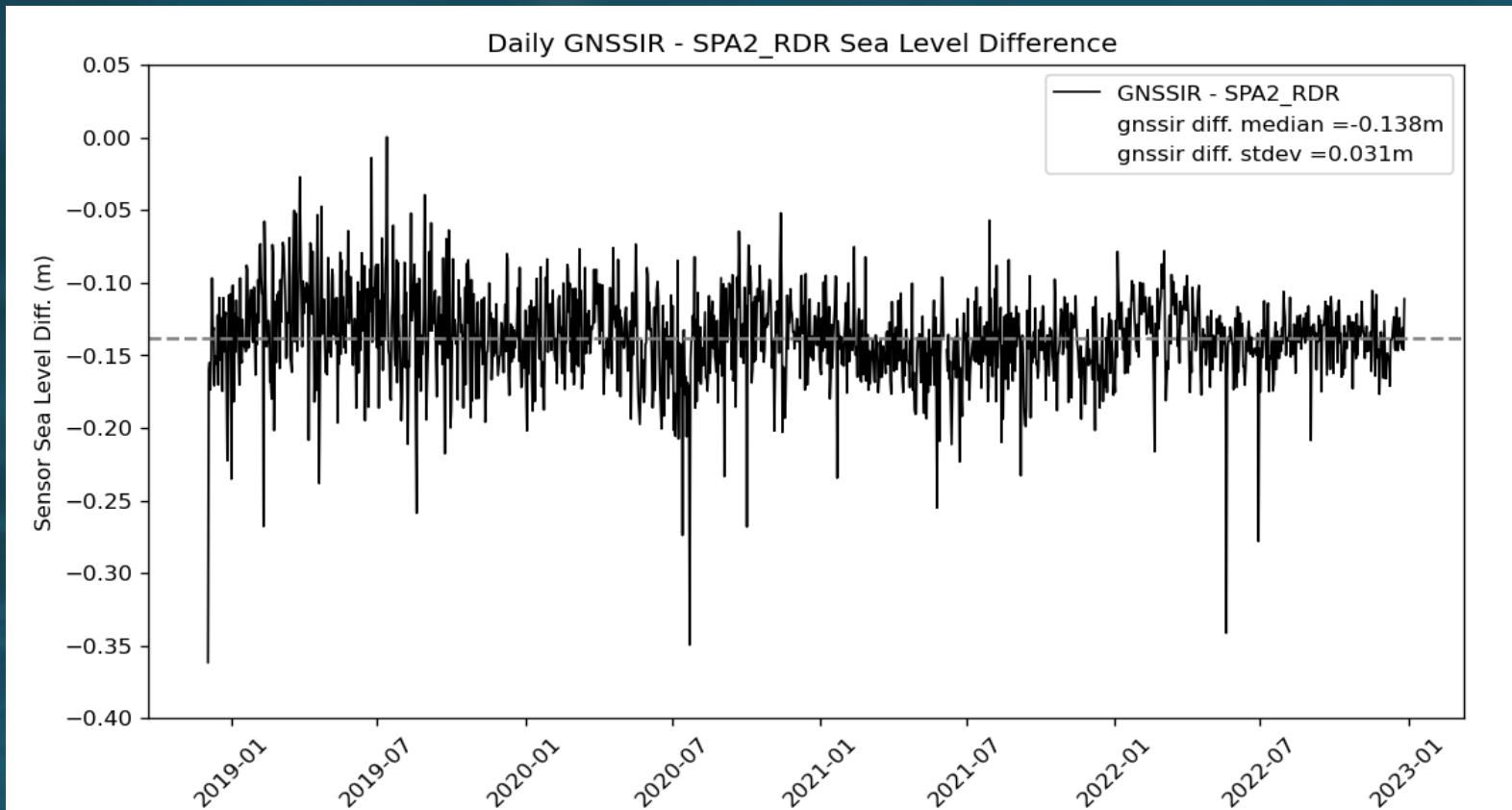
- ✓ Impact of site maintenance on sensor
 - Reduced standard deviation after SPA1_RDR cleaning
 - Sensor contact points different from levelling information

- SPA1_BPR / SPA2_RDR Sensors



- 49 mm shift down of the sea level difference in Nov. 2020
- Drift of the median post Nov. 2020 by a trend of 24 ± 1 mm/y

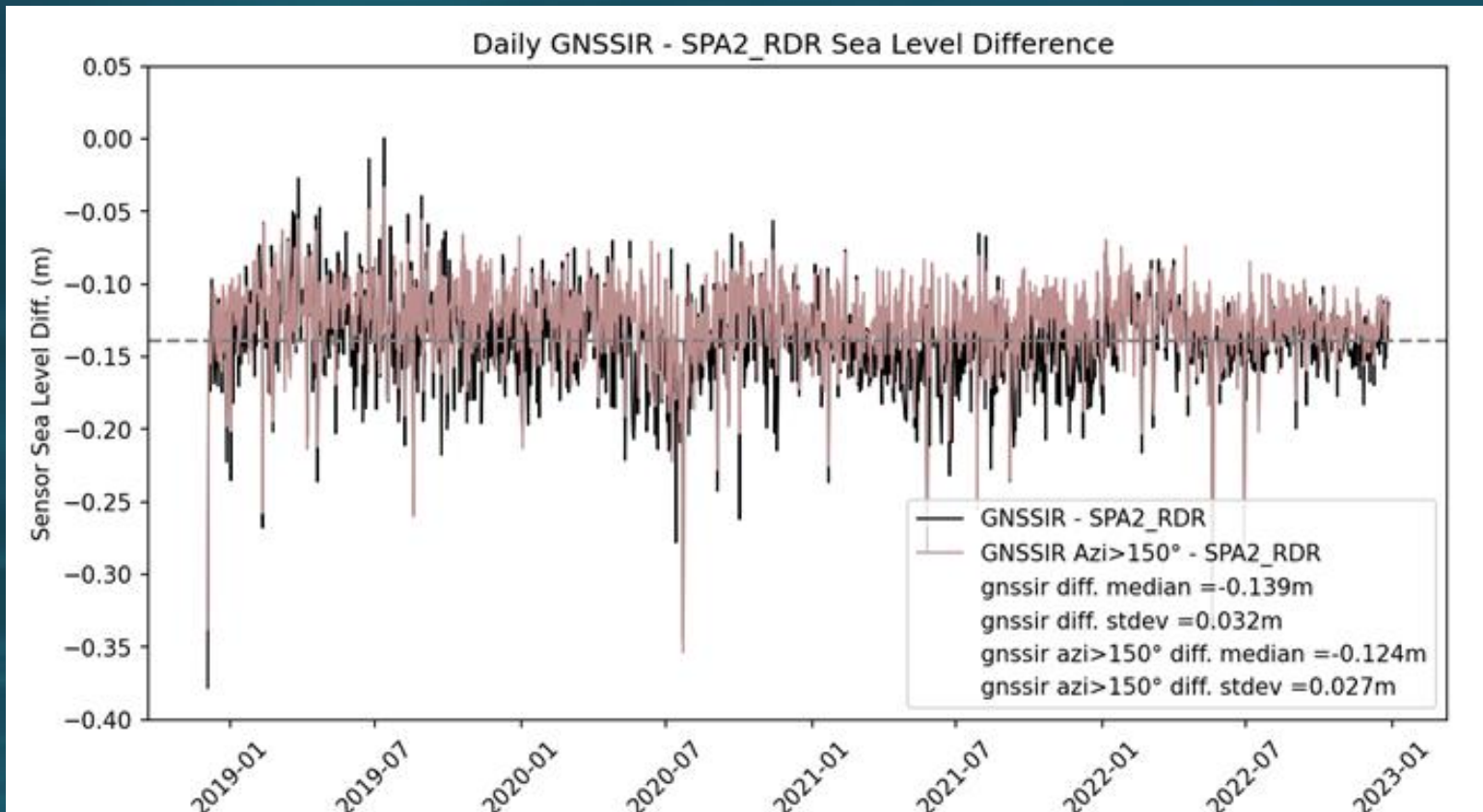
• GNSSIR / SPA2_RDR Time Series Difference



Ref: www.PSMSL.org/GNSSIR

➤ Bias of 138 mm between sensors related to GNSSIR measurement reference point

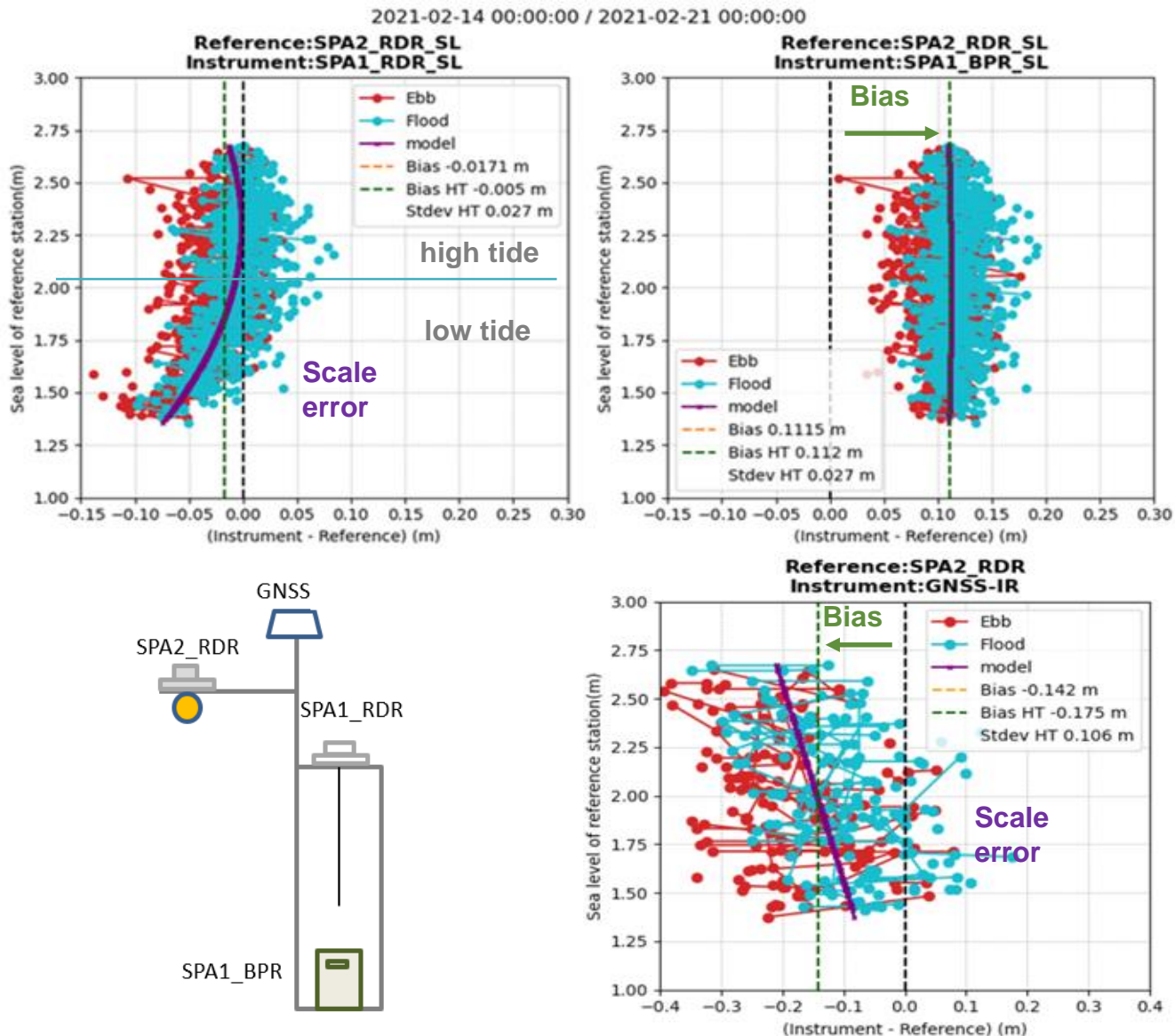
• GNSSIR / SPA2_RDR Time Serie Difference



Ref: www.PSMSL.org/GNSSIR

- Daily standard deviation improved significantly by removing GNSSIR data from outside of the crater
- Monthly standard deviation reaches 7 mm

3. VAN DE CASTEELE PLOT



➤ SPA2_RDR as reference gauge

➤ Scale error :

- SPA1_RDR over Dec. 2020 - Dec. 2021 occurring at low tide

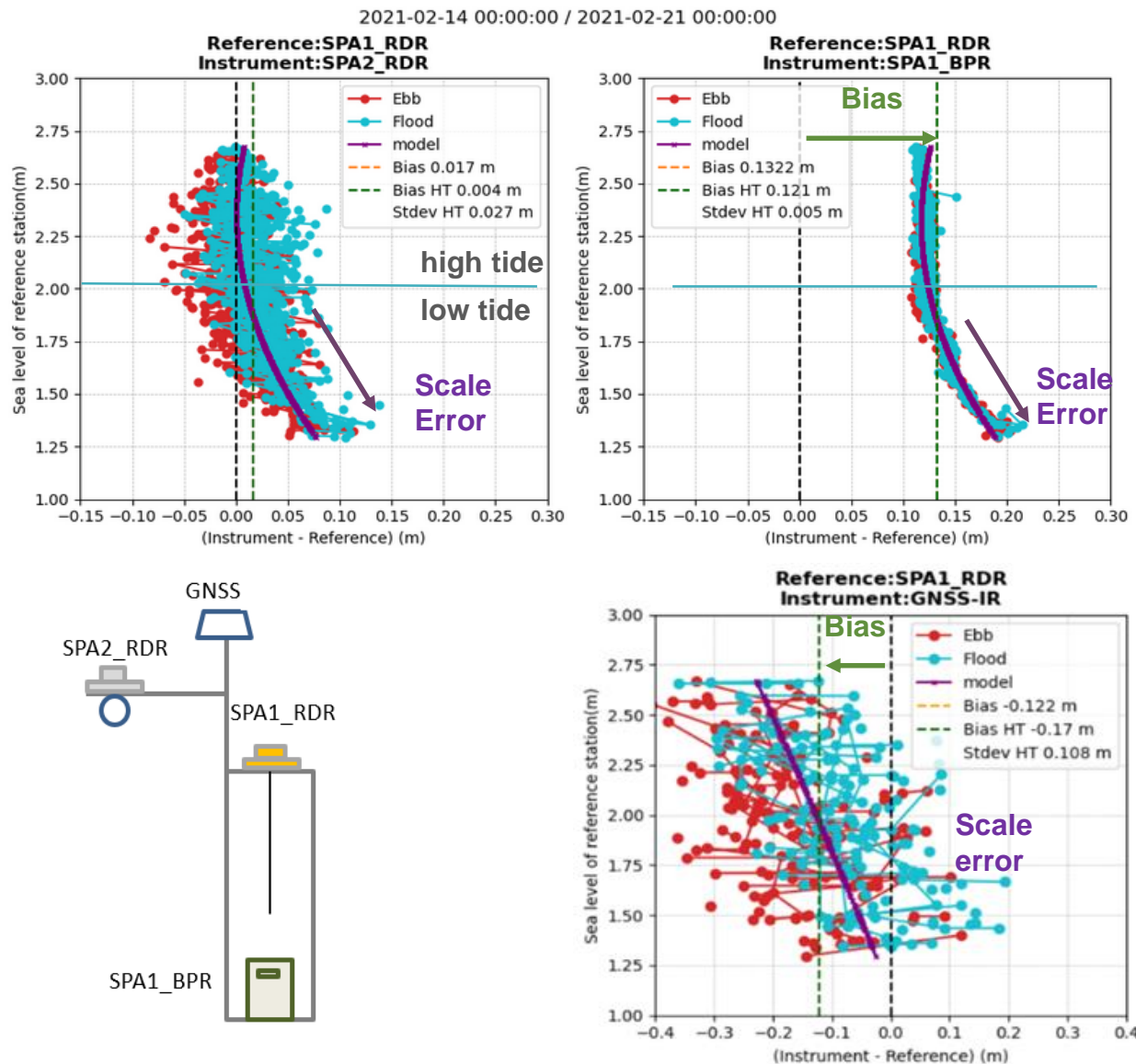
- GNSSIR over the full period

➤ Bias error:

- SPA1_BPR significant bias evolution with time from Dec. 2020 with a trend of 26.8 ± 2.2 mm/y

- GNSSIR over the full period

3. VAN DE CASTEELE PLOT



➤ SPA1_RDR as reference sensor

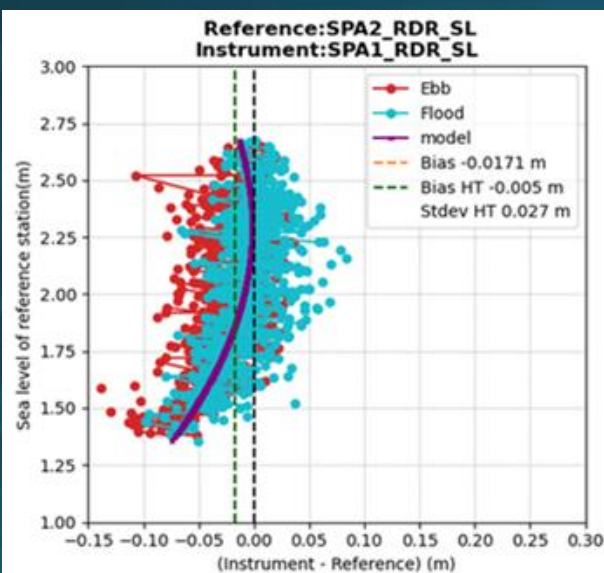
➤ Open-air vs stilling tube sensor set-up impacts:

- reduced standard deviation for both sensors in stilling tube
- shift between ebb and flood events

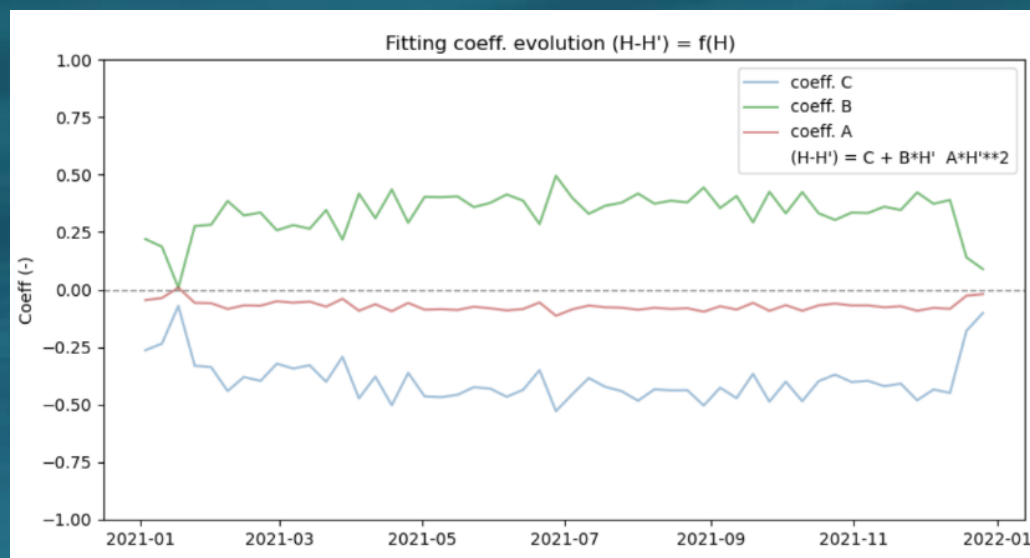
4. ERROR CORRECTION

- Example for SPA1_RDR scale error

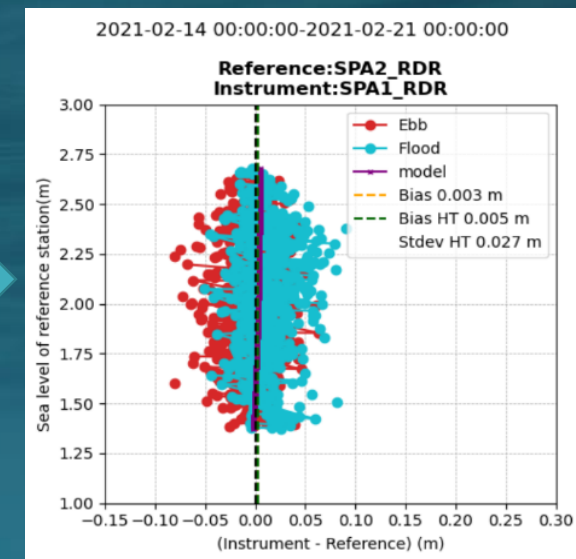
Original SPA1_RDR



Second order polynomial fitted by least square



Corrected SPA1_RDR



- Standard deviation from sea level difference with SPA2_RDR gets reduced from 38 mm to 17 mm over 2021

• CONCLUSIONS

- Several gauges operating in same time and different storing – transmission supports are worthwhile in remote site
- Identification and quantification of errors affecting the sensors such as scale factor, bias and drift
- Promising GNSSIR approach for monthly mean sea level even if Saint-Paul environment is not optimal
- High impact of site maintenance on sea level measurements

• CONCLUSIONS

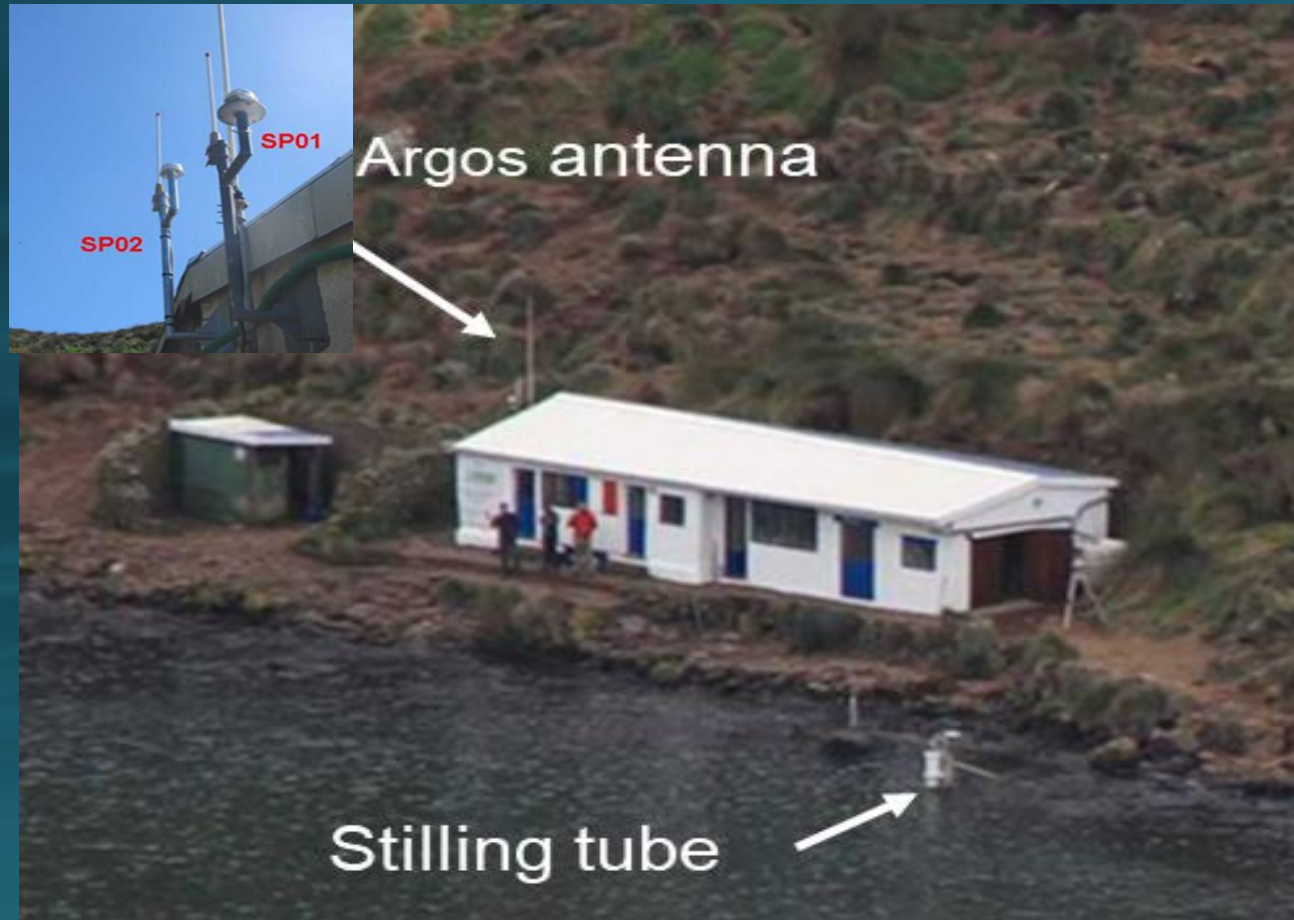
- ✓ Several gauges operating in same time and different storing – transmission supports are worthwhile in remote site
- ✓ Identification and quantification of errors affecting the sensors such as scale factor, bias and drift
- ✓ Promising GNSSIR approach for monthly mean sea level even if Saint-Paul environment is not optimal
- ✓ High impact of site maintenance on sea level measurements

• PERSPECTIVES

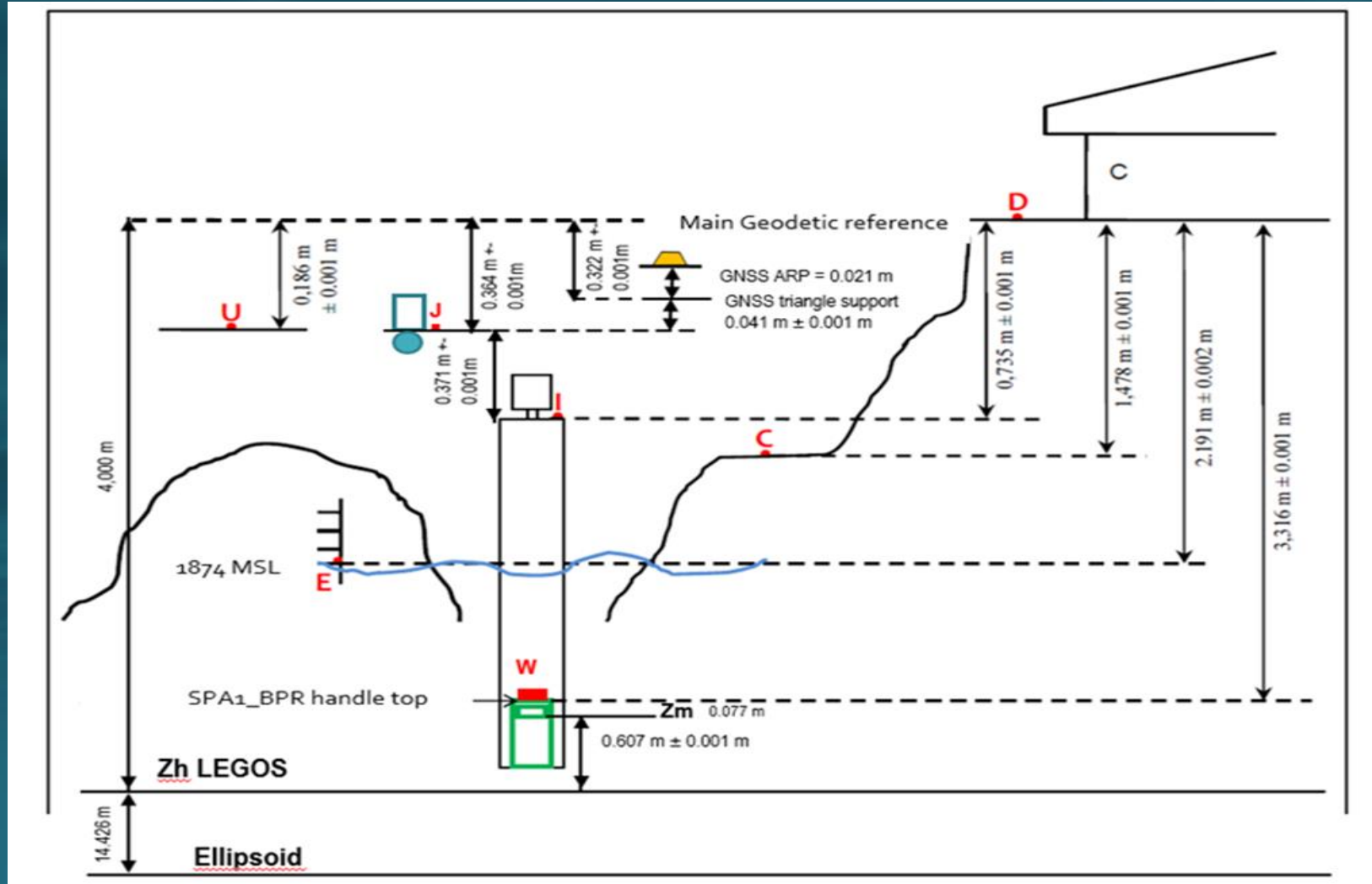
- ✓ Consolidating a mean sea level time serie
- ✓ Comparing the in-situ mean sea level with spatial altimetry

Thank you

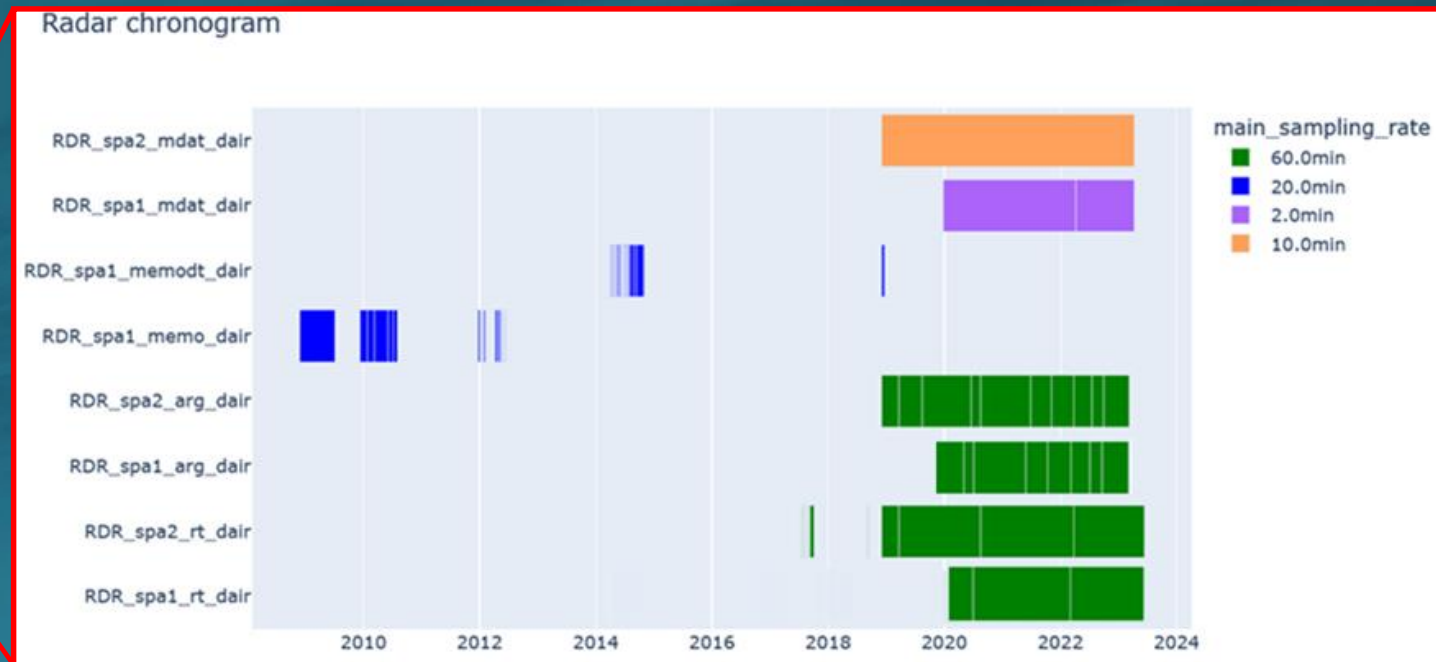
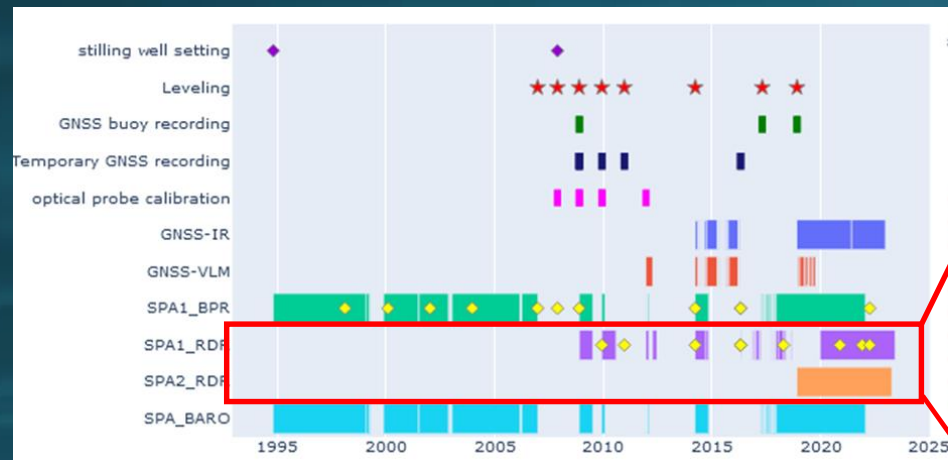
Back-Up Slides



Levelling

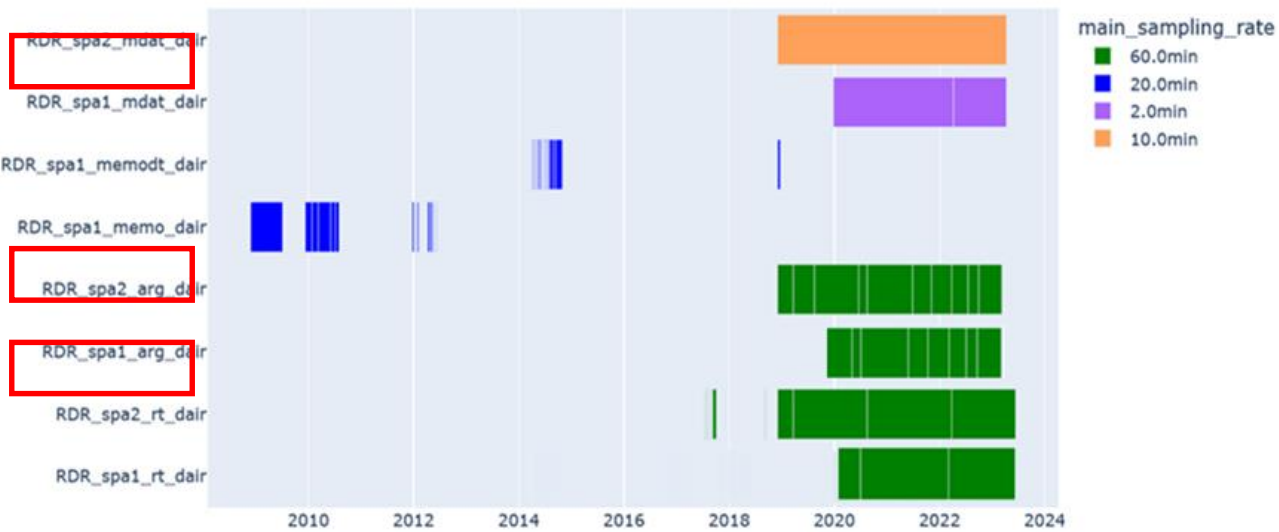


Validation and Identification of the most accurate dataset from various data flux

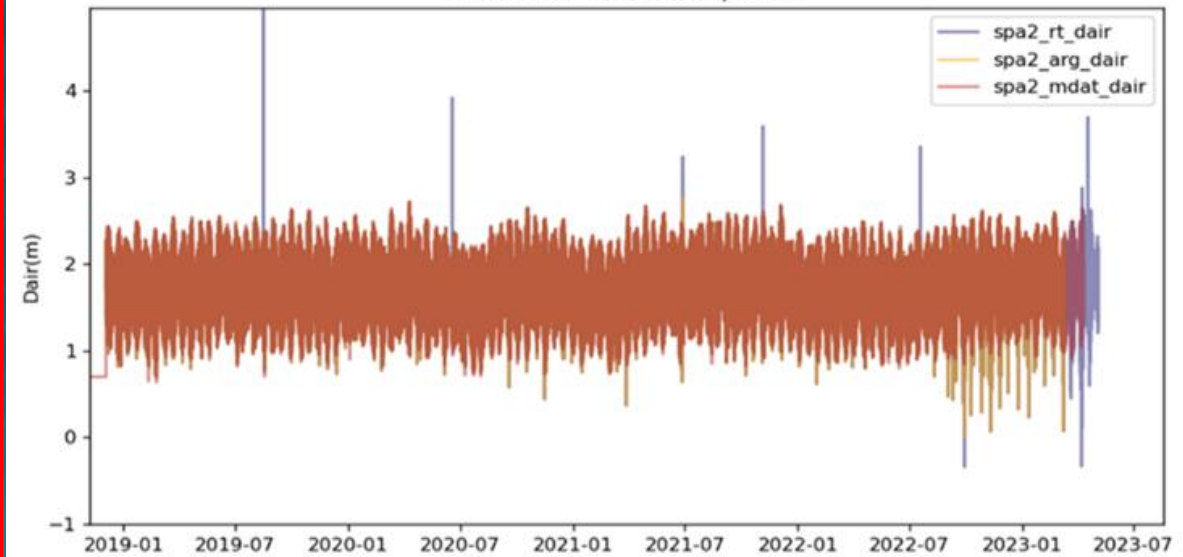


Validation and Identification of the most accurate dataset from various data flux

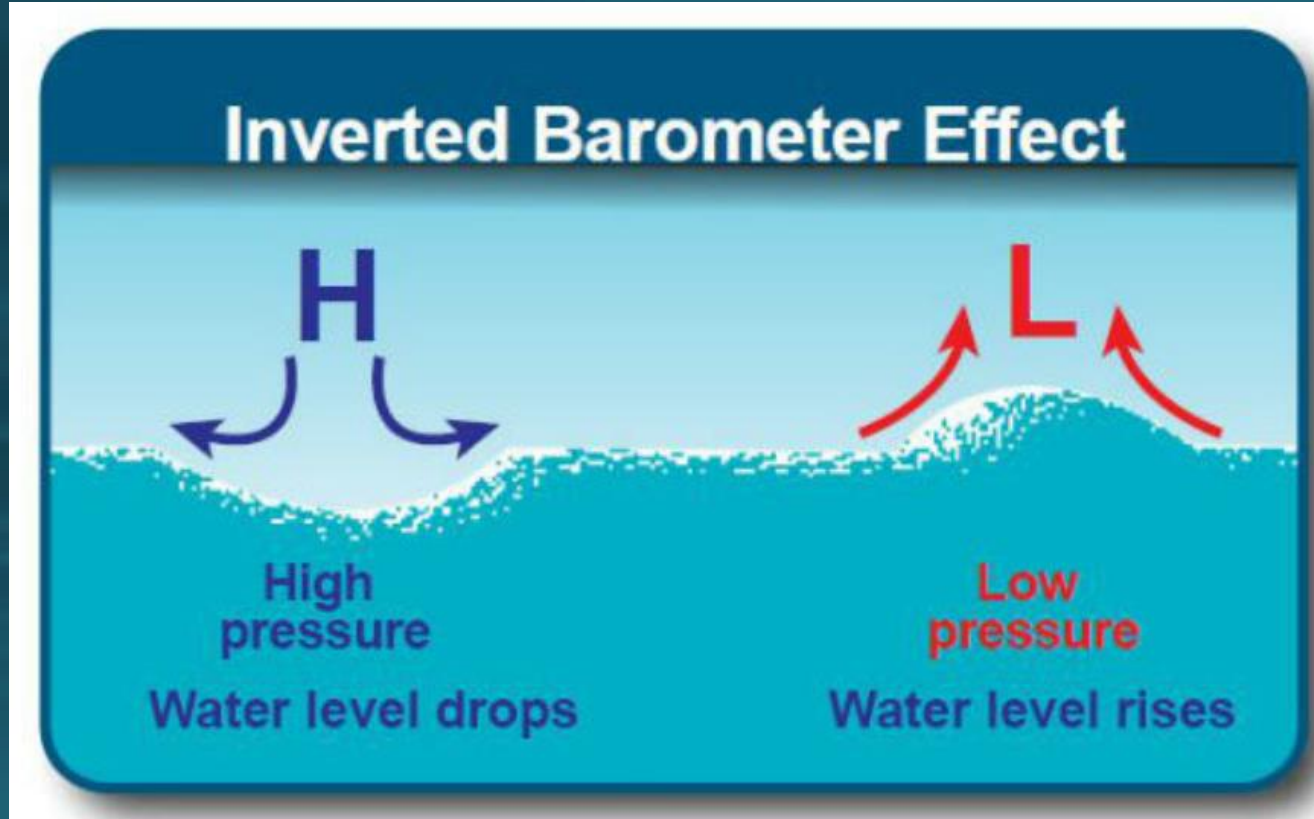
Radar chronogram



SPA2 Radar TG file Comparison



Inverse Barometer



$$\eta_{ib} = -\frac{P_a - \overline{P_a}}{\rho \cdot g}$$

- η_{ib} : the sea level rise at a given point (m)
- P_a : atmospheric pressure at this point (Pa)
- $\overline{P_a}$: atmospheric pressure average over the ocean (Pa)
- ρ : ocean water density ($\text{kg}\cdot\text{m}^{-3}$)
- g : gravity acceleration ($\text{m}\cdot\text{s}^{-2}$) defined as function of the latitude and equals to 9.78 in Saint-Paul.

From Bottom Pressure to Sea Level

$$\eta_{BPR} = \frac{P_b - P_a}{\rho \cdot g}$$

η_{BPR} : the instantaneous bottom pressure sea level (m)

P_b : bottom pressure (Pa)

P_a : atmospheric pressure (Pa)

ρ : ocean water density (kg.m⁻³) computed with constant salinity (34 psu)

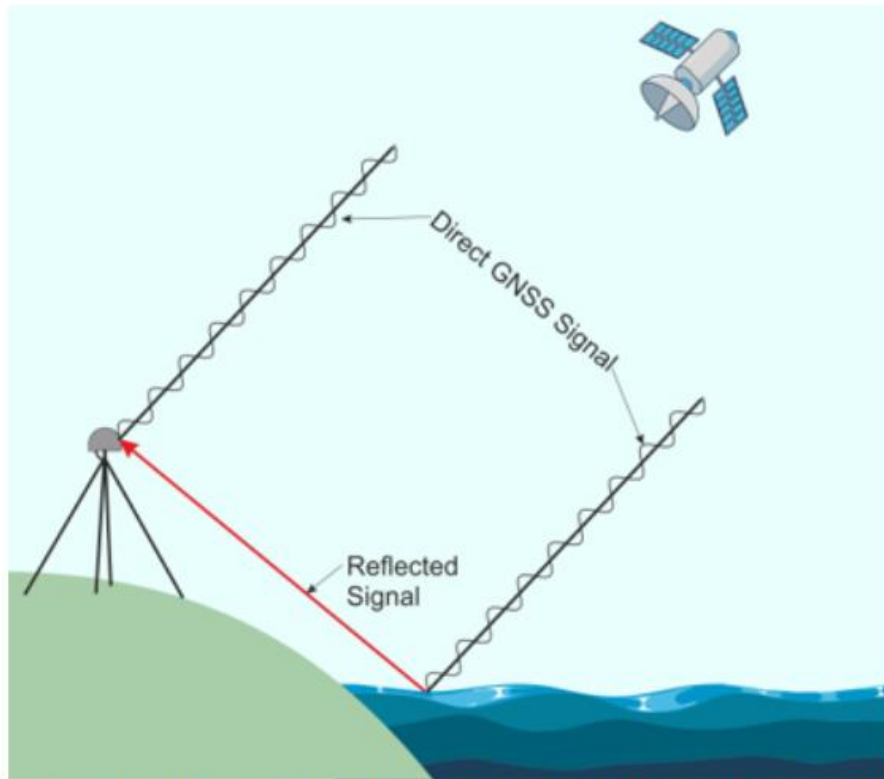
g : local gravity acceleration (m.s⁻²) defined as function of the latitude and equals to 9.78 in Saint-Paul.

The BPR sea level referenced to Zh_LEGOS is given by adding the levelling estimate of measurement reference point (Z_m) of the bottom pressure gauge (SPA1_BPR):

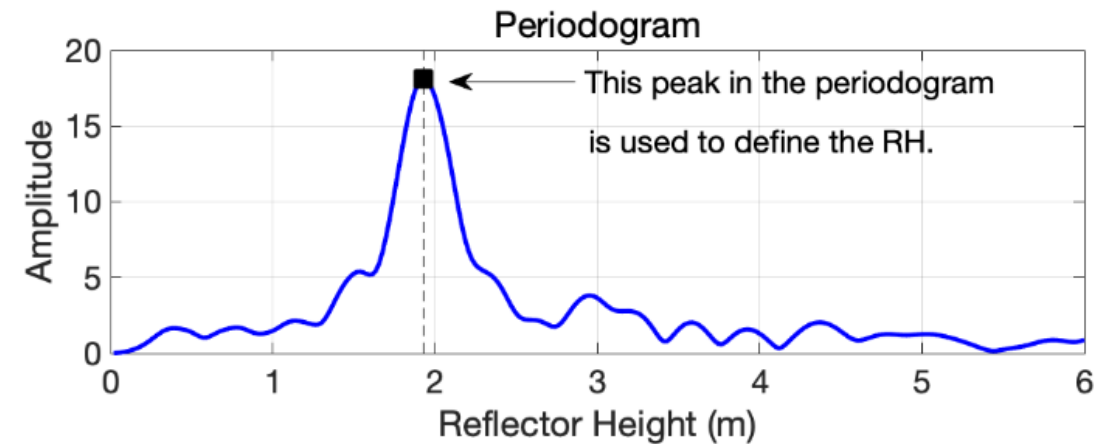
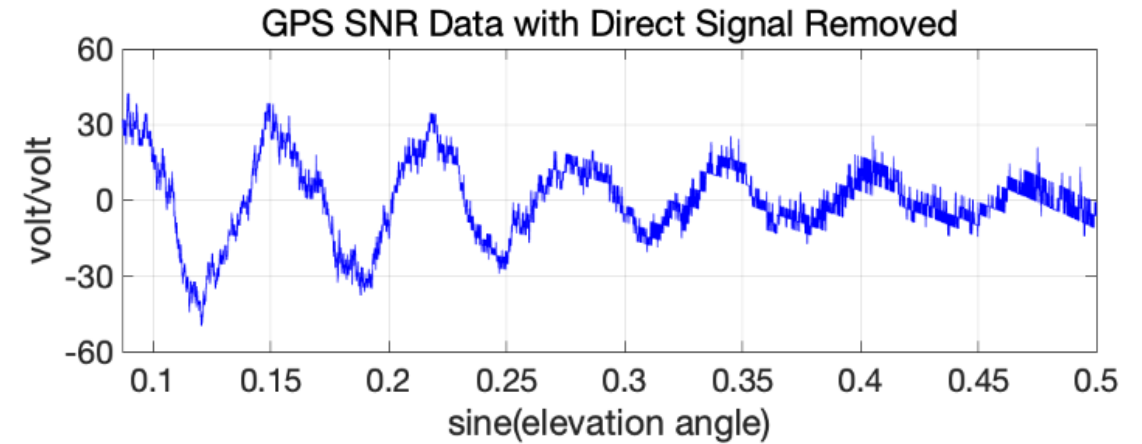
$$\eta_{Zh_BPR} = \eta_{BPR} + Z_m$$

where Z_m is 0.607 m.

GNSSIR General

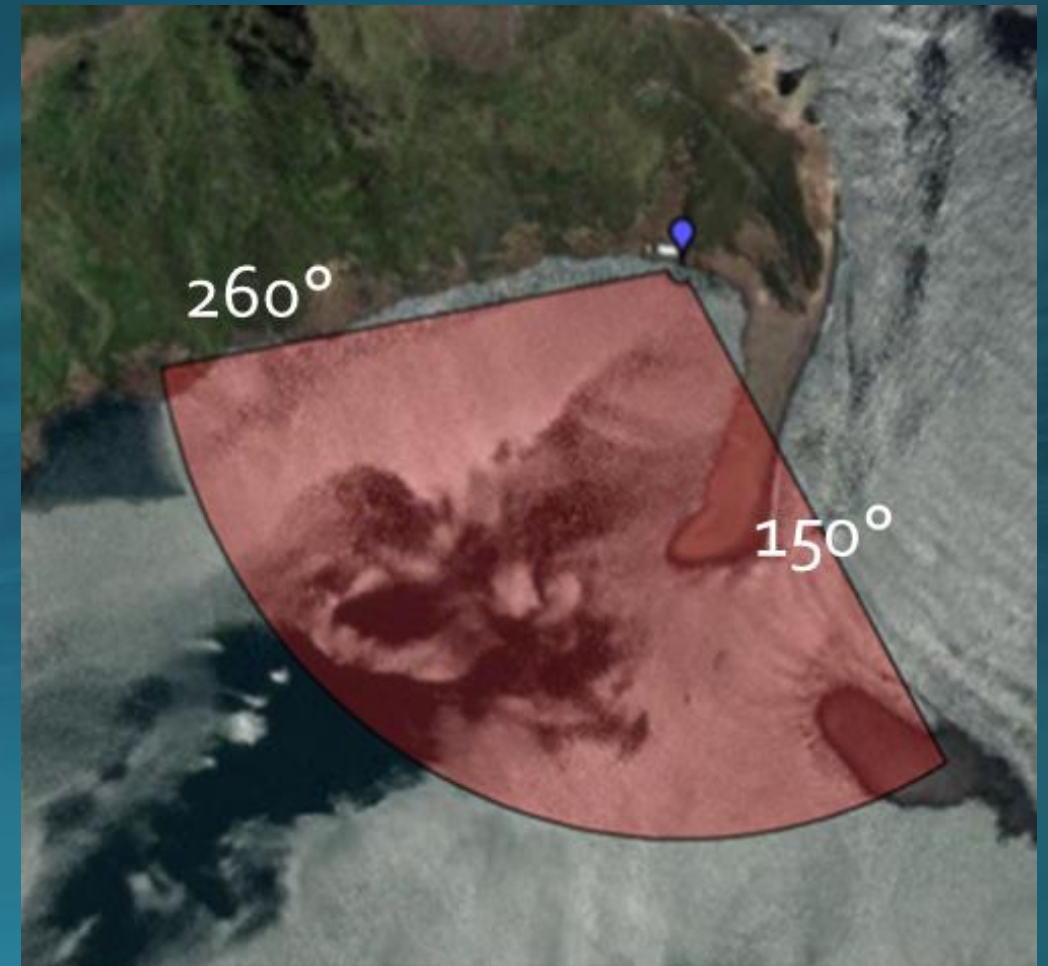
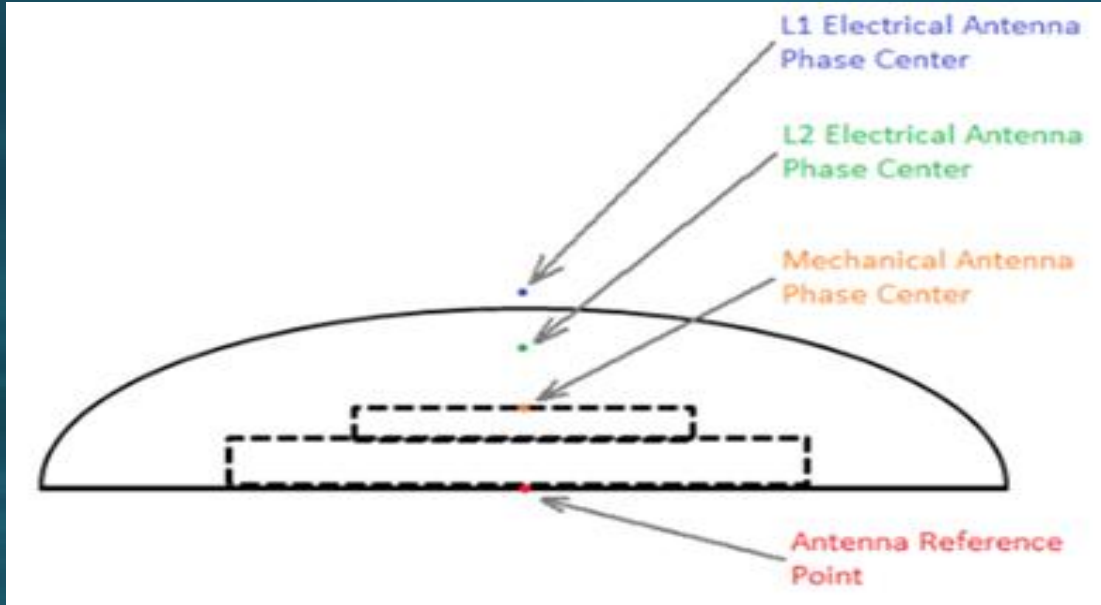


Multipath caused by GNSS signals reflecting off a body of water. Image: Simon Williams

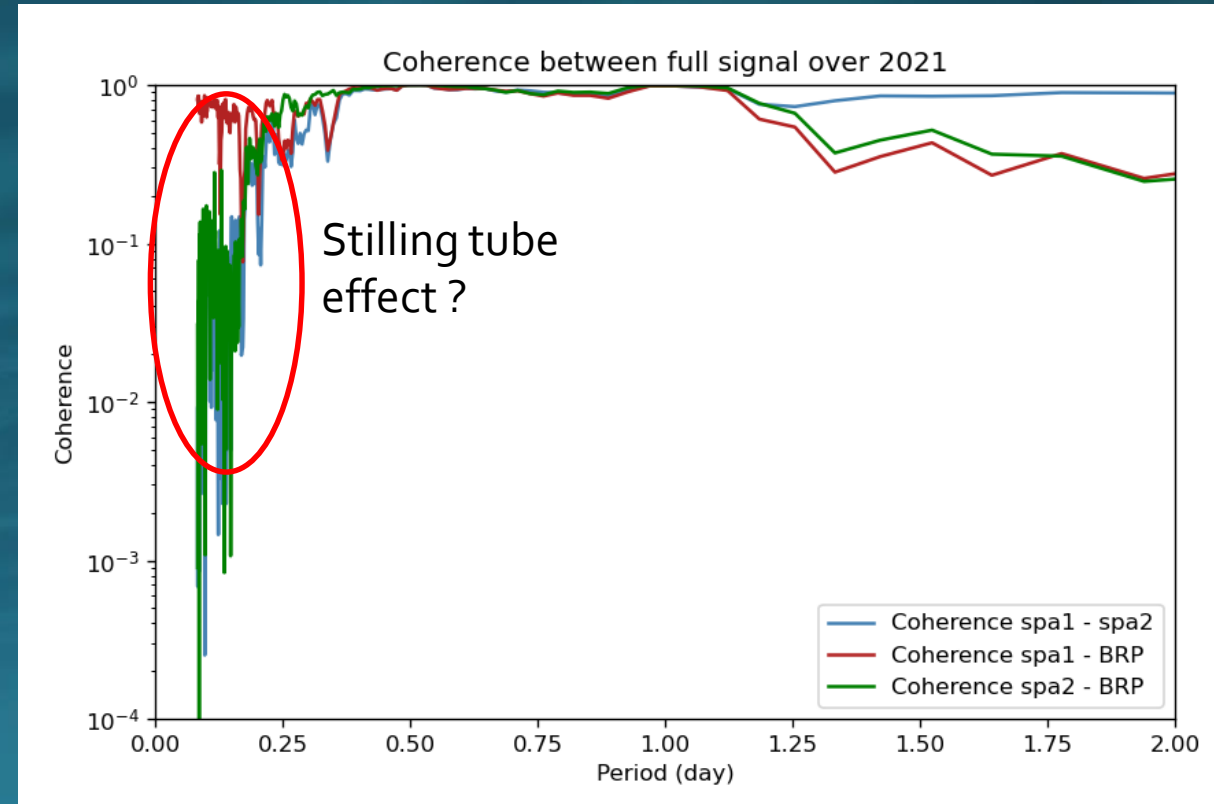
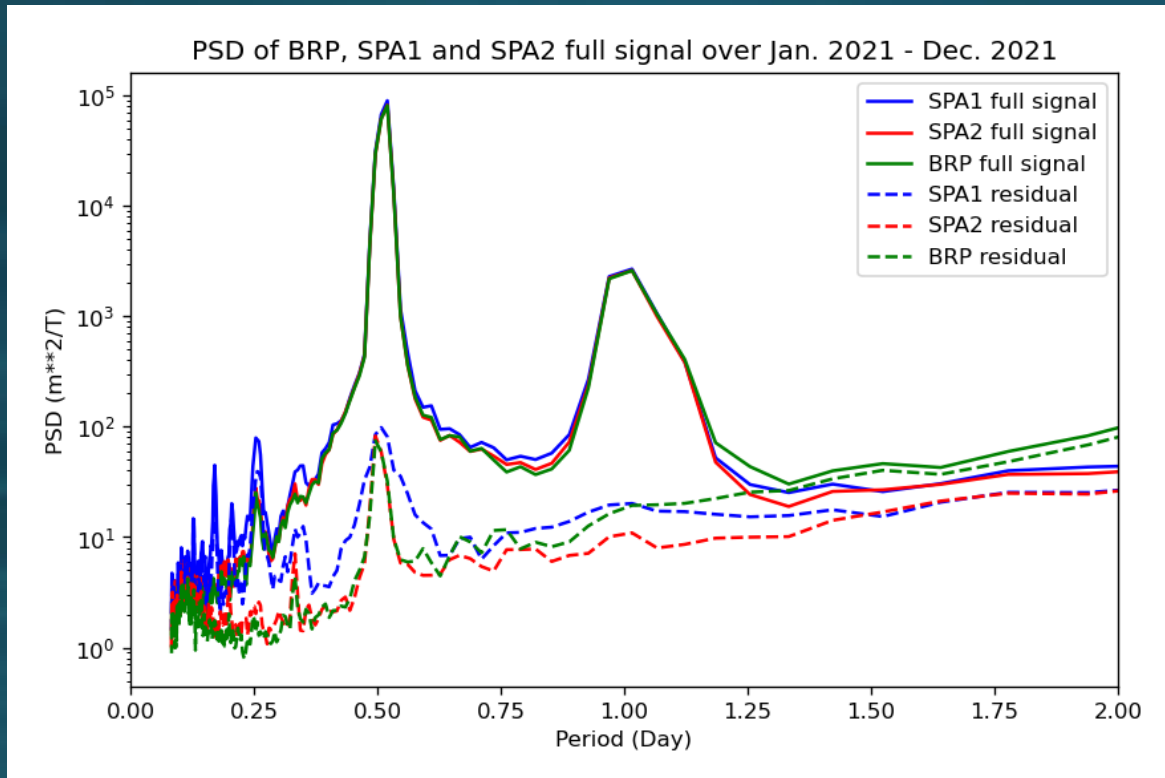


Estimating the relative height (RH) of the surface with a periodogram. Image: Kristine Larson

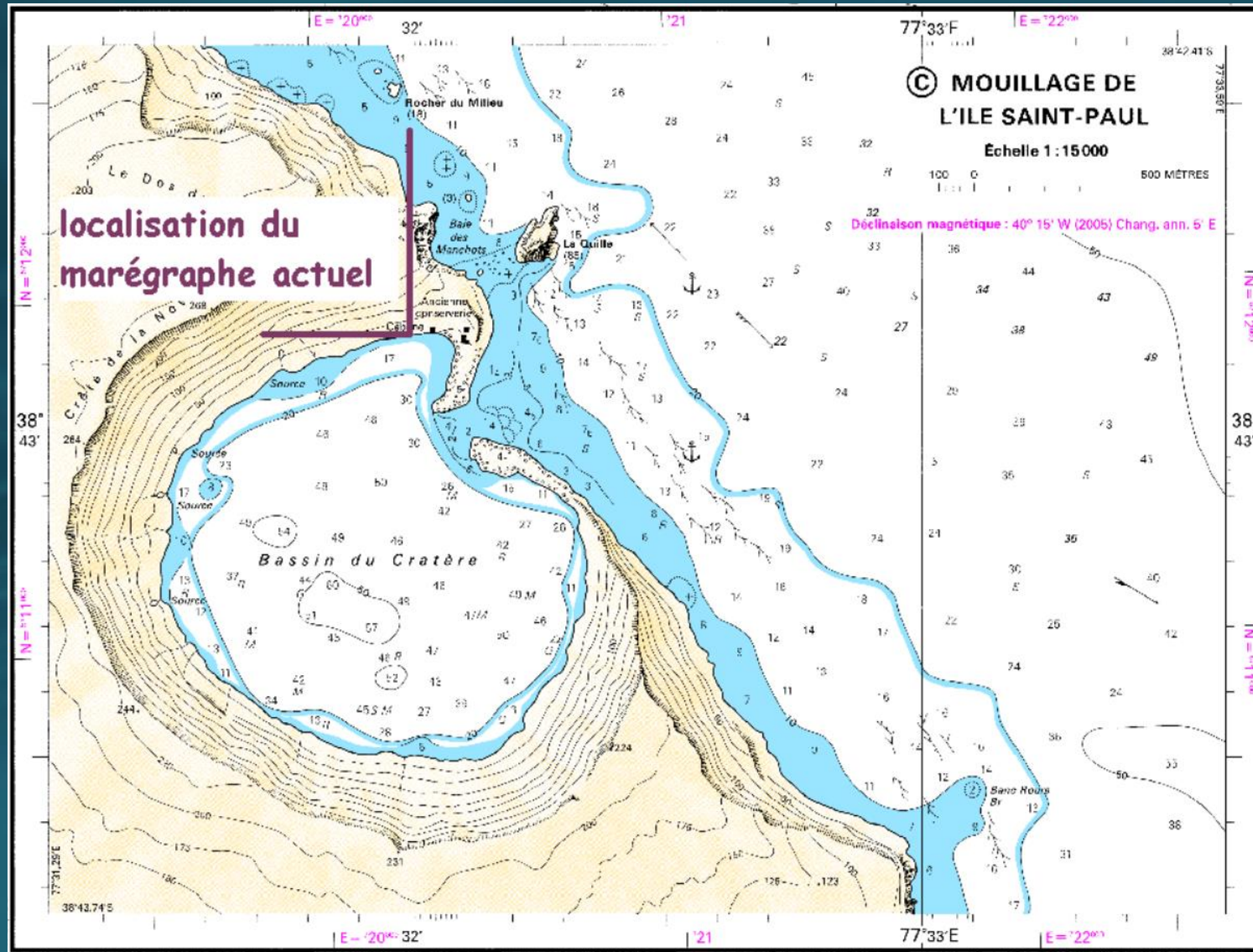
GNSSIR



Spectral Analysis



Seiche



SEICHES _ BASIL W.WILSON

5 mm = 100m

radius = 32mm -> 650 m

Bathymetry max = 40 m

Free Oscillation 2,5 min

$2.220[2 * L / (g * h)^{1/2}] = 145 \text{ sec}$

Where $g = 9.87$