CAMEO-WAGST: Cameroon Advanced Measurements for Enhanced Observations of Water levels using Affordable GNSS-IR and Sentinel-3&6 Technology

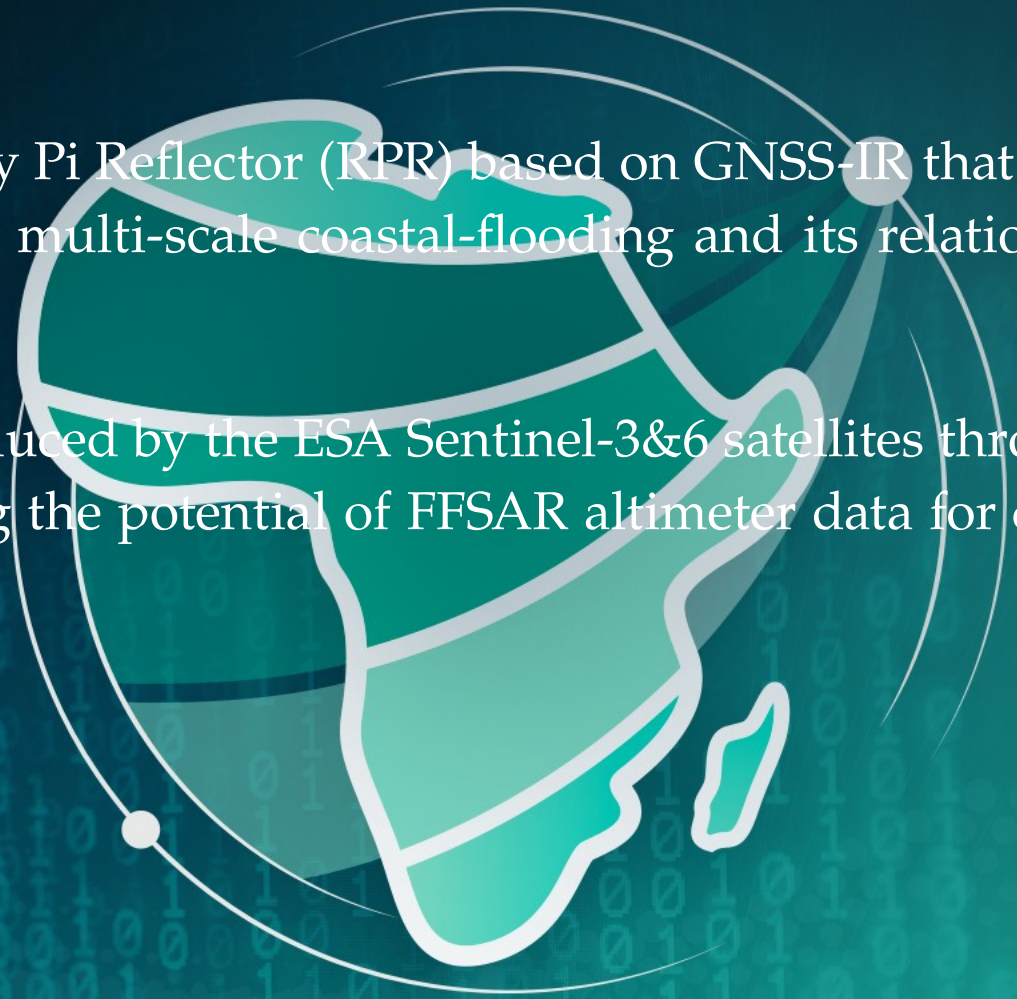
Loudi Yap[1], Makan Karegar[2], Jürgen Kusche[2], Abdou Nasser Ngouh[1], Jiaming Chen[2], Chrétien Ngouanet[1], Ludovic Houetchak Kandé[1], Joseph Kamguia[1]

[1]National Institute of Cartography, Cameroon.
[2]Institute of Geodesy and Geoinformation, University of Bonn, Germany.

Objectives:

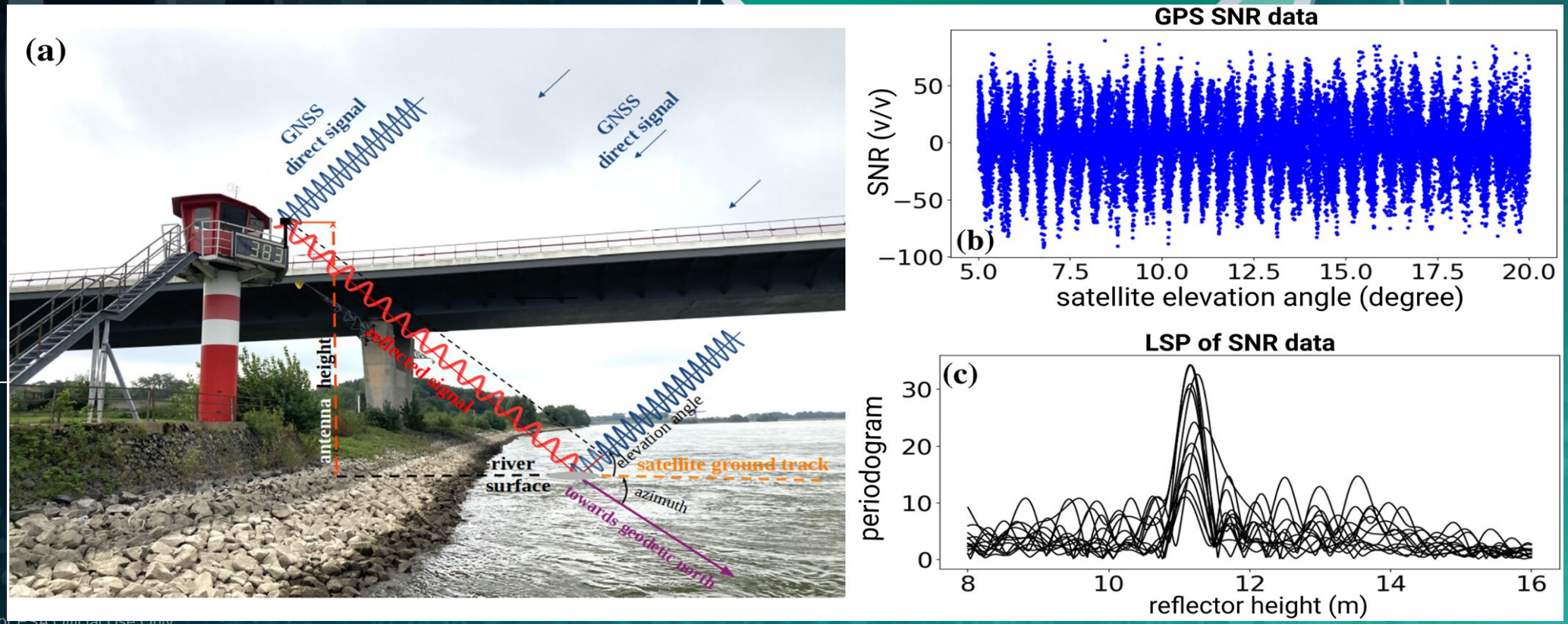
1) Monitoring sea and river levels with Raspberry Pi Reflector (RPR) based on GNSS-IR that supports a national network for managing water resources, multi-scale coastal-flooding and its relation to storm surges, tides and sea-level rise.

2) Validate the water and sea level estimates produced by the ESA Sentinel-3&6 satellites through direct comparisons with RPR measurements. Assessing the potential of FFSAR altimeter data for coastal and estuarine monitoring.



What is GNSS-IR?

* GNSS Interferometric Reflectometry is a technique that turns a GNSS site into a bistatic radar.
* It uses low elevation angles and forward scatter (multipath) from planar surfaces near the antenna.
* In standard GNSS-IR practice, it uses consumer off-the-shelf GNSS instruments, usually geodetic-quality, with no modifications (i.e. the antennas are zenith pointing).



Raspberry Pi Reflector

* Cost-effective (~ 150 $)
* 1-2 cm level accuracy
* Operating safely in extreme weather with lower operational costs
* Streaming near real-time SNR data allowing continuous water level measurement
* Installing only requires a single-time visit
* No on-site calibration
* Applicable to a variety of areas including rivers, lakes, dams and sea

RPR GitHub

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021WR031713

AGU ADVANCING EARTH AND SPACE SCIENCE

Water Resources Research

RESEARCH ARTICLE
10.1029/2021WR031713

Raspberry Pi Reflector (RPR): A Low-Cost Water-Level Monitoring System Based on GNSS Interferometric Reflectometry

Makan A. Karegar[1], Jürgen Kusche[1], Felipe Geremia-Nievinski[2], and Kristine M. Larson[1,3]

[1]Institute of Geodesy and Geoinformation, University of Bonn, Bonn, Germany, [2]Department of Geodesy and Postgraduate Program in Remote Sensing, Federal University of Rio Grande do Sul, Porto Alegre, Brazil, [3]Aerospace Engineering Sciences, University of Colorado, Boulder, CO, USA

Key Points:

- We present a prototype for tracking water levels called the Raspberry Pi (RPi) Reflector with centimeter level accuracy
- It consists of cost-effective single-frequency Global Positioning System module and navigation antenna connected to RPi microcomputer
- It uses interferometric reflectometry technique and can be operated safely in extreme weather with lower operational costs

Supporting Information:

Supporting Information may be found in the online version of this article.

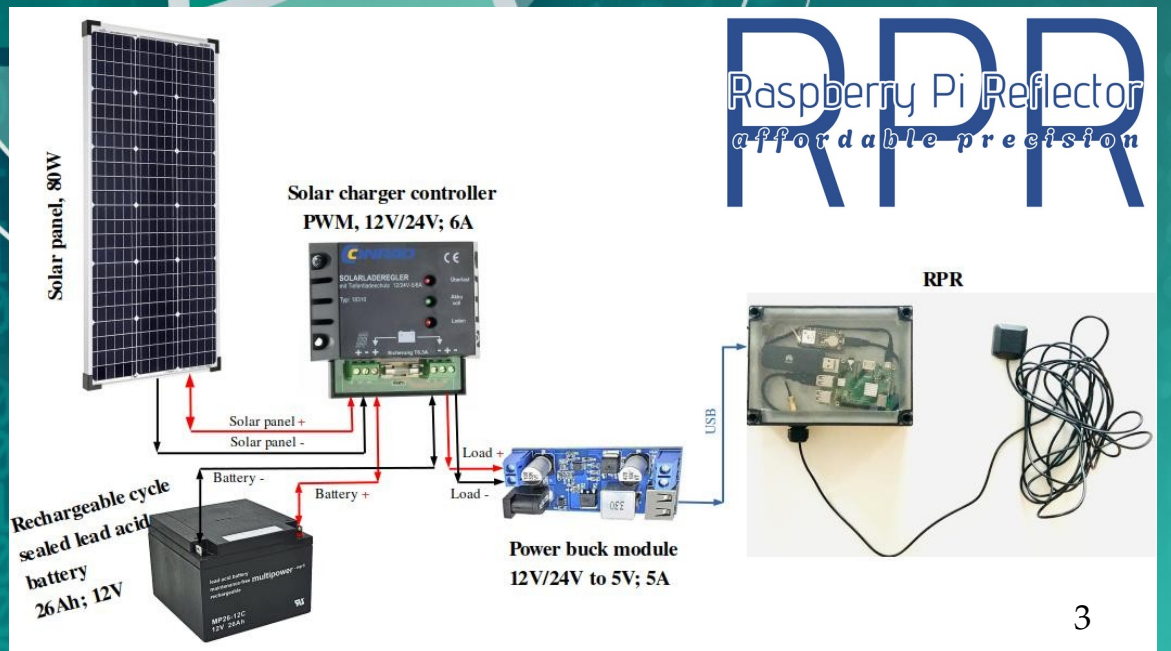
Correspondence to:

M. A. Karegar,
karegar@uni-bonn.de

Citation:

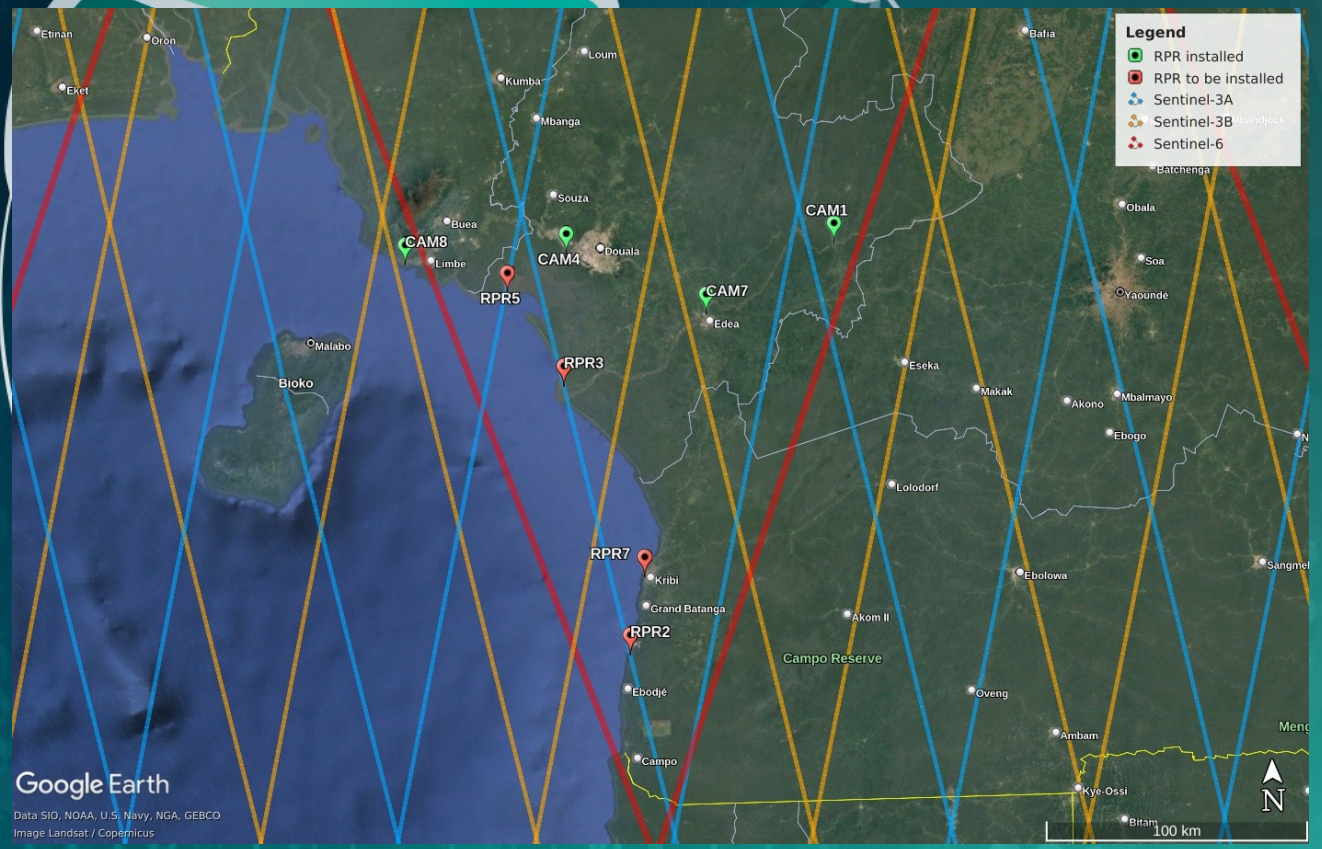
Karegar, M. A., Kusche, J., Geremia-Nievinski, F., & Larson, K. M.

Abstract Although reflectometry is not the primary application of Global Positioning System (GPS) and similar Global Navigation Satellite Systems (GNSS), fast-growing GNSS tracking networks has led to the emergence of GNSS interferometric reflectometry technique for monitoring surface changes such as water level. However, scientific-grade or geodetic GNSS instruments are expensive, which is a limiting factor for their prompt and more widespread deployment as a dedicated environmental sensor. We present a prototype called Raspberry Pi Reflector (RPR) that includes a low-cost and low-maintenance single-frequency GPS module and a navigation antenna connected to an inexpensive Raspberry Pi microcomputer. A unit has been successfully operating for almost 2 years since March 2020 in Wesel (Germany) next to the Rhine river. Sub-daily and daily water levels are retrieved using spectral analysis of reflection data. The river level measurements from RPR are compared with a co-located river gauge. We find an Root-Mean-Square Error (RMSE) of 7.6 cm in sub-daily estimates and 6 cm in daily means of river level. In August 2021, we changed the antenna orientation from upright to sideways facing the river. The RMSE reduced to 3 cm (sub-daily) and 1.5 cm (daily) with the new orientation. While satellite radar altimetry techniques have been utilized to monitor water levels with global coverage, their measurements are associated with moderate uncertainties and temporal resolution. Therefore,



Equipment assembled and shipped for deployment in Cameroon

RPR network in Cameroon



Eight RPR installations:

Sanaga River: Song Mbengué (site of a planned major hydropower dam), Edea Dam

Coastline: Wouri estuary (near Douala, a large tidal estuary with river convergence), Limbé

Gulf of Guinea coastline: 5 RPRs

Intensive field work led by Dr. Loudi Yap

First campaign: inspection phase (04/02 - 03/03/2025)

Identify site location, meetings with local administrative authorities ,

GSM signal verification

Second campaign: installation process (05/05 – 04/06/2025)

Four RPRs installed, issue with GSM signal strength

Third campaign: installation process (23/06-29/06/2025)

Four RPRs is being installed.

Fieldwork photos

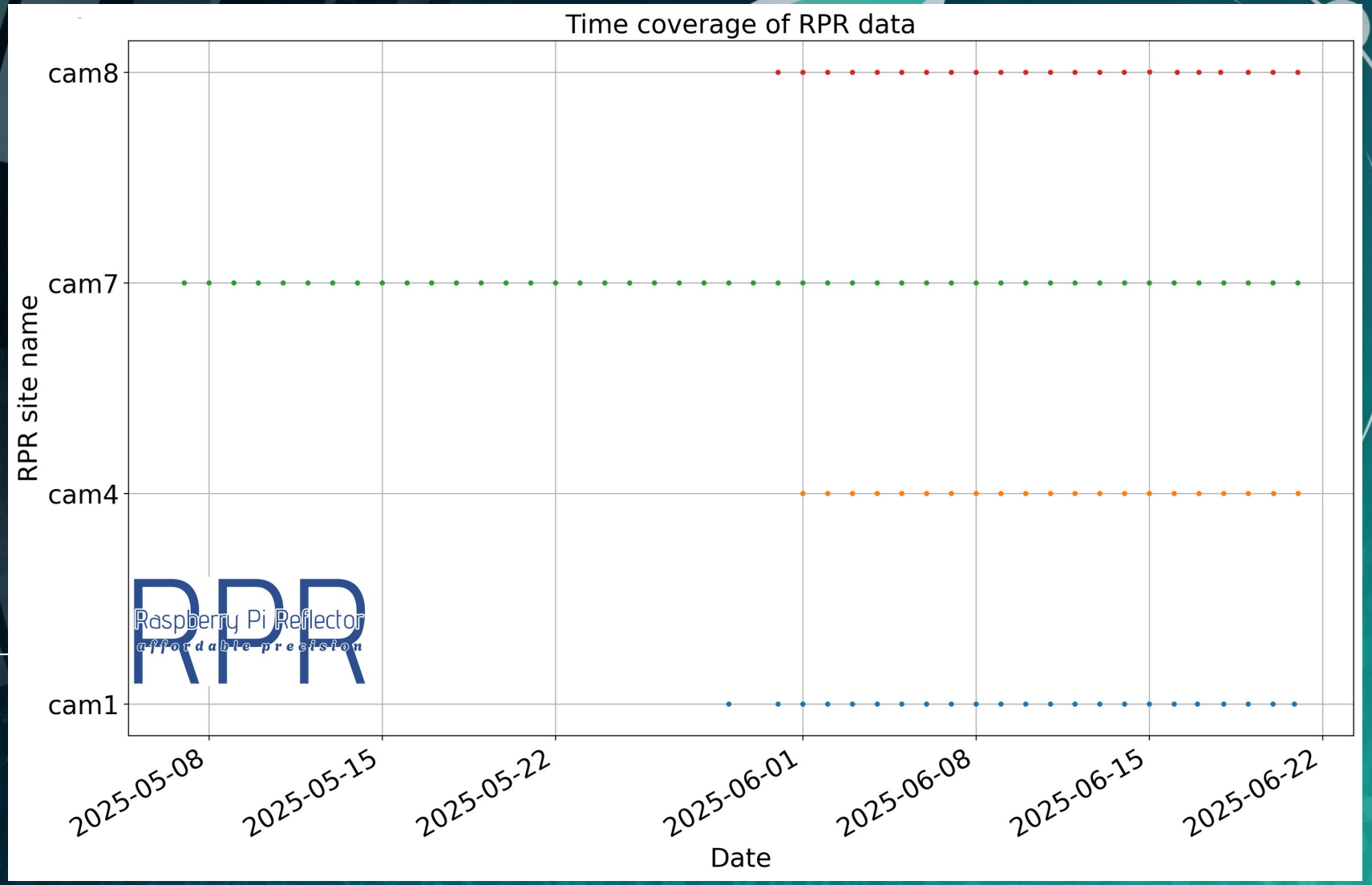
Sanaga River, dam

Sanaga River, dam

Limbé coast

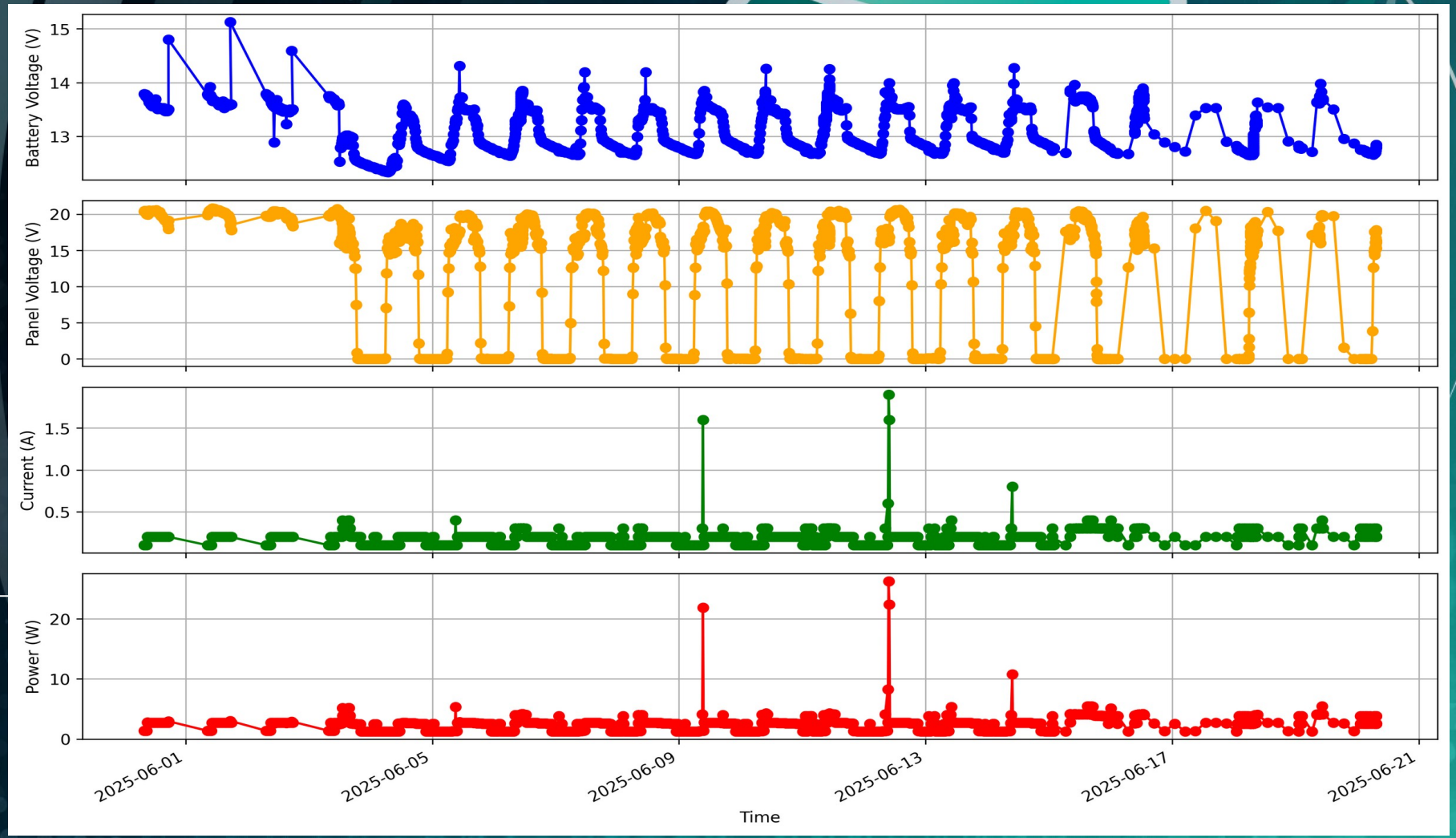
Wouri estuary

RPR record lengths

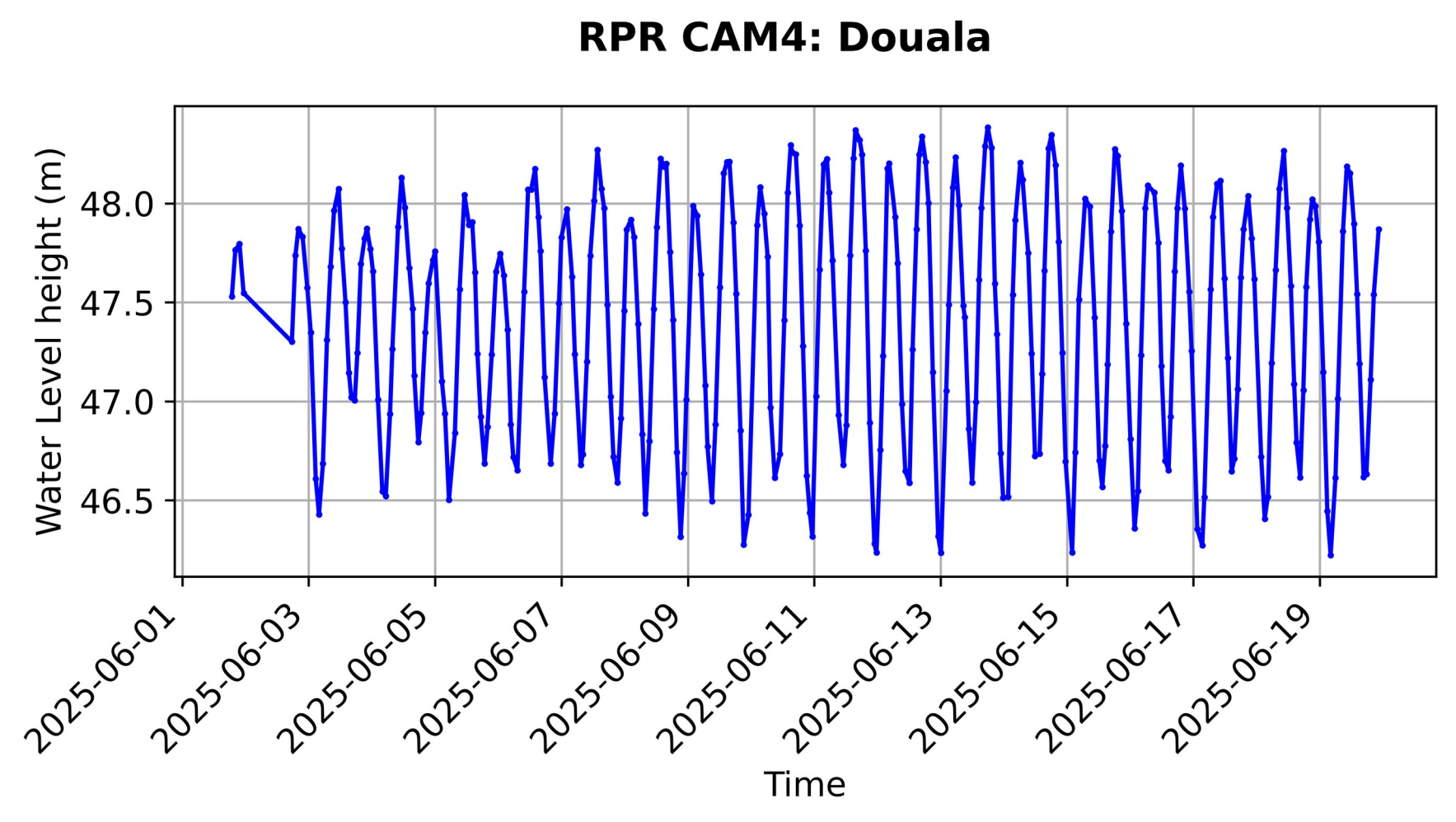


Power system performance of RPR

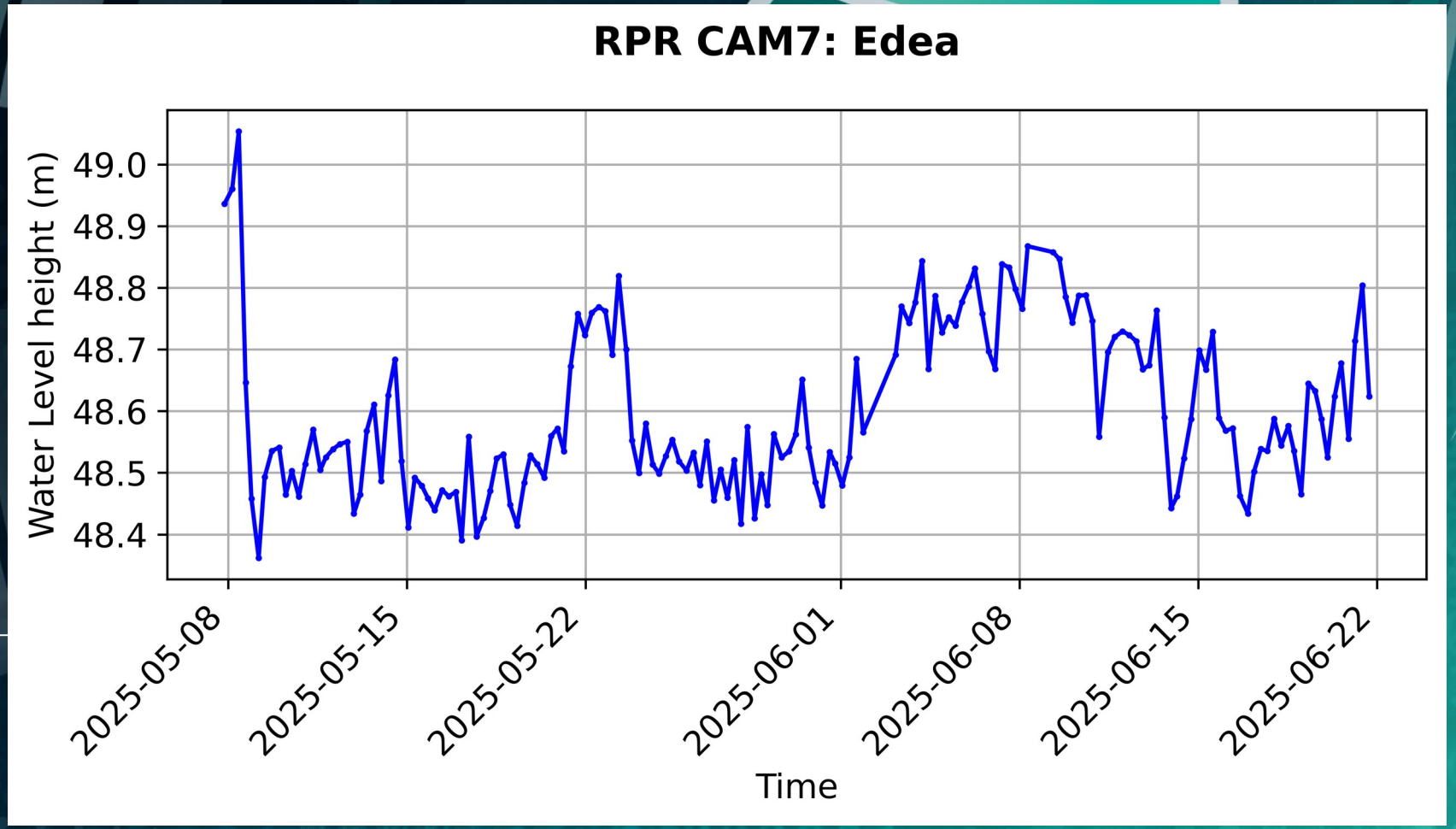
Tracking solar input and battery health for power issues.



Water levels at coastal sites show clearly resolved tidal signals



River site water levels show lower variability compared to coastal sites



Key takeaway

* Some RPRs are co-located with tide/river gauges, cross-comparison is possible.

* Sentinel-3&6 Level 1 data have been acquired, spatially cropped and are ready for processing through the workflow chain.

* The RPR network allows geographically comprehensive tidal estimates for coastal Cameroon.

* We will remove tidal predictions from the observed water levels to isolate the non-tidal residuals by storms, winds, waves and currents.