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IN-ORBIT REAL TIME INLAND WATER DETECTION BY A FUTURE SPACEBORNE GNSS-R RECEIVER

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ABSTRACT

Earth's inland water monitoring is probably the main promising application of Global Navigation Satellite Systems Reflectometry (GNSS-R) techniques. The ultimate spatial resolution under the coherent scattering regime deserves further investigation. The new Cyclone Global Navigation Satellite System (CYGNSS) raw Intermediate Frequency (IF) data product with a temporal resolution down to 2 ms could help to further understand this. In the framework of climate change the "water" is the "new gold". In-space water monitoring could help final users to make decisions with impact in several topics including geopolitics. The use of GNSS-R techniques by future constellations of SmallSats could overcome several limitations of more classical remote sensing techniques. In this work, a novel real-time inland water detector by a future GNSS-R receiver is presented. This detector, the so-called fast entropy E_{fast}, shows the capability to detect small water bodies under thick biomass ~ 450 ton/ha in the Congo basin.

***Index Terms*—** CYGNSS, GNSS-R, inland water bodies, biomass, coherent scattering

1. INTRODUCTION

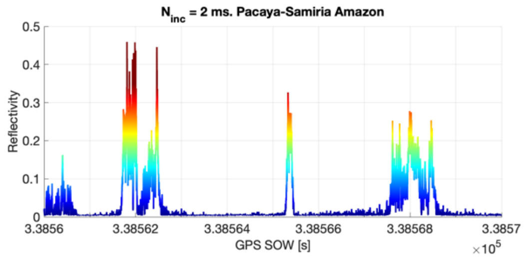
Accurate and reliable determination of Earth's surface inland water extend in real-time with high spatial resolution would revolutionize scientific, commercial, and geopolitical implications of remote sensing. Future GNSS-R satellites and constellations are expected to be launched in the upcoming years [1]. In this work, a GNSS-R inland water detector for a future spaceborne GNSS-R receiver is developed and tested using the National Aeronautics and Space Administration (NASA) CYGNSS raw IF data. The on-board operation of such detector would generate inland water mapping of the Earth in real-time.

Raw IF samples collected on-board contain the highest possible resolution over delay and Doppler space. The access to the raw IF samples enables ground processing of this high-resolution data stream. CYGNSS raw IF data (2018-present) are processed [2,3] on-ground to generate calibrated Delay Doppler Maps (DDMs) with high delay $\Delta\tau$ = 1/16 chip and Doppler Δf = 50 Hz resolution, with a coherent integration time T_c = 1 ms and a variety of incoherent integration times down to N_{inc} = 2 ms. From these DDMs several observables are generated including reflectivity Γ, normalized bistatic radar cross-section $NBRCS$, and signal-to-noise ratio SNR. Additionally, in-phase I and quadrature Q components at the peak of the complex DDMs (T_c= 1 ms) are used to obtain the reflected signal phase ϕ.

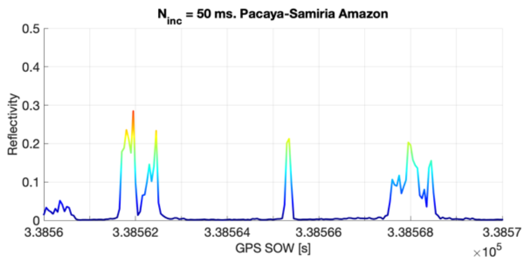
The use of GNSS-R for detection and monitoring of inland water bodies has shown a strong performance, even over tropical forests. The signal dynamic range is high enough so as to detect even small water bodies such as small rivers. The foundation of such strong sensitivity is in the nature of the coherent scattering. The phase at the peak of the reflected complex DDMs is highly sensitive to the presence of surface water in such a way that over inland water bodies the scattering process is coherent, and the phase can be tracked. The phase derivative is used here as the fundamental observable to classify the surface type: inland water vs. land.

2. METHODOLOGY

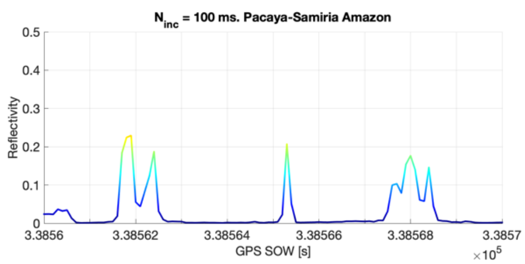
Several inland water detectors have been implemented and applied to the CYGNSS raw IF data product, including the so-called power ratio P_{ratio}[4], the full entropy E_{full} [5] and the fast entropy E_{fast}. The phase derivative is used to validate the full entropy detector E_{full}, which is the detector with the highest performance. Then, the full entropy E_{full} method is used to assess the performance of the Receiver Operating Characteristic (ROC) curves of all the other observables (Γ, $NBRCS$, SNR) as coherence detectors (Fig. 1), as well as E_{fast} and P_{ratio}. A ROC curve shows the capability of diagnosis of a binary classifier as a function of the selected system threshold.



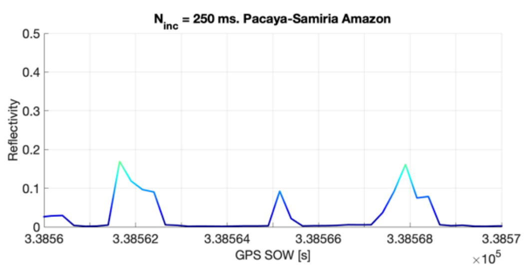
(a)



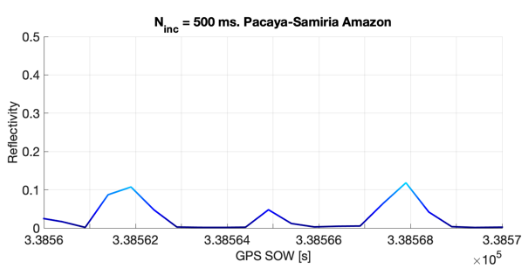
(b)



(c)



(d)



(e)

Fig. 1. GNSS-R raw IF reflectivity time series in Pacaya-Samiria (track acquired on 16/2/2022) for N_{inc}: (a) 2 ms, (b) 50 ms, (c) 100 ms, (d) 250 ms, and (e) 500 ms.

3. RESULTS

Results show that the fast entropy E_{fast} method provides a performance comparable to the full entropy E_{full}. Real time signal processing requirements on-board a new spaceborne receiver are then generated for its implementation in a future GNSS-R mission [6]. Final results will be presented at the conference along with a companion paper ["An improved inland water detector using standard L1 data: application to CYGNSS"].

4. CONCLUSION

The use of E_{fast} by future GNSS-R SmallSats constellations could revolutionize advanced hydrological studies thanks to the capability to detect small inland water bodies (~ meters) under thick biomass (~ 450 ton/ha) with an unprecedented revisit time (~ minutes), and with improved latency.

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