Centimeter-Level Lake Altimetry from Airborne GNSS Reflectometry

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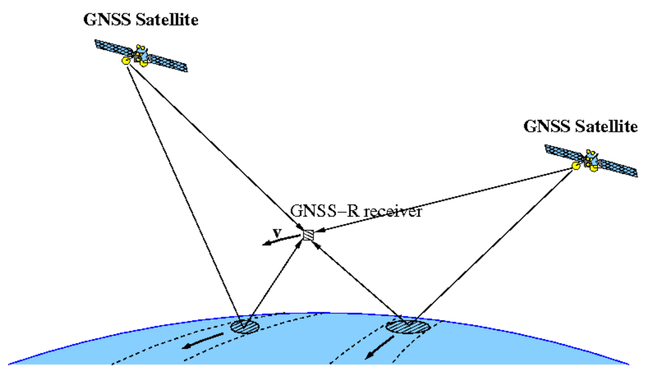
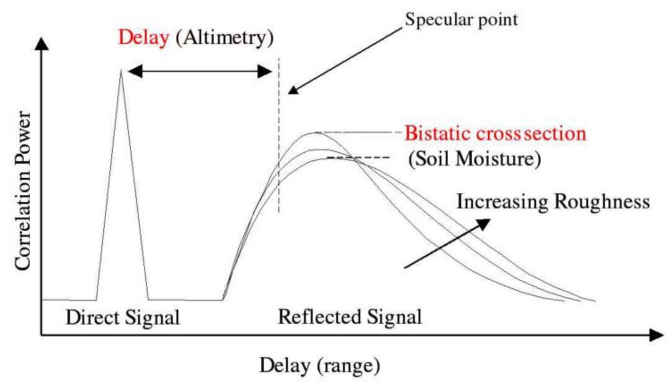
Introduction

Global navigation Satellite Systems – Reflectometry (GNSS-R) is a branch of remote sensing using freely available L-Band satellite signals as multistatic radar sources [1]. Receivers measure both the direct signal from the satellite and the signal reflected on the ground. The study of the reflected signals relative shape gives information on the surface distance and surface characteristics.



The GNSS-R Multistatic configuration



Basic observable: Correlation Waveform

Objectives

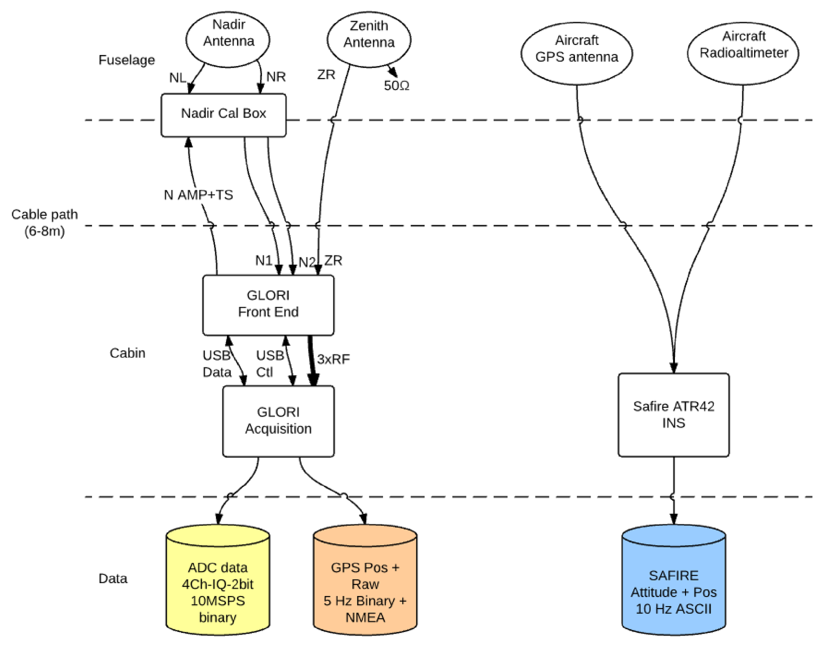
The airborne GLORIE campaign (GLObal navigation satellite System Reflectometry Instrument Experiment) took place in 2015 in the south west of France in order to assess the capabilities of airborne dual-polarization GNSS reflectometry for the estimation of land parameters such as soil moisture, vegetation biomass and water reservoir height.

In this poster, we are presenting a first assessment of the instrument's altimetric precision based on the study of the signal phase variations during calm lake flyovers.

The Glori instrument

The GLORI receiver [2] is based on one up-looking and one down-looking dual polarization hemispherical active antennas feeding a low-cost 4-channel SDR direct down-conversion receiver tuned to the GPS L1 frequency. The raw measurements are sampled at 10MHz and stored as 2-bit, IQ binary files.

The aircraft inertial Measurement Unit records attitude information and an additional commercial GPS receiver records ancillary information such as estimated Doppler and code phase, receiver location, satellites azimuth and elevation.



Instrument set-up

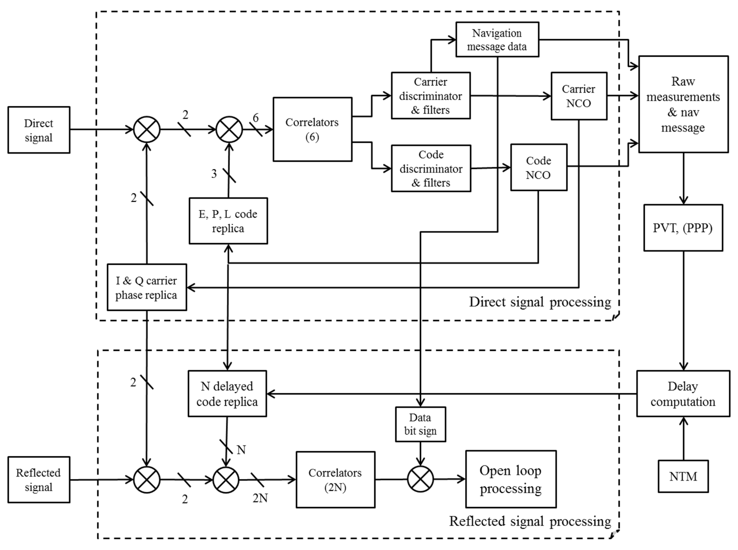
The GLORI instrument is installed as a permanent payload aboard the ATR42 experimental aircraft from the French SAFIRE fleet, with a nominal flight speed of about 100 m/s, max endurance of 6 hours and altitude range up to 7500m.

The SAFIRE ATR-42 Aircraft

Data Processing

GNSS-R Processing

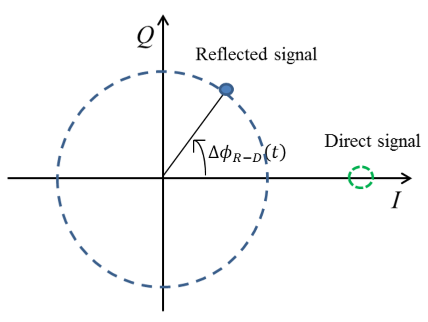
The direct signal is processed by traditional GNSS carrier phase and code tracking, and the reflected signal is processed in a master-slave configuration, by using exactly the same carrier replica computed for the direct channel. The code replica are generated by adding the estimated reflected signal delay to the direct code loop. The sign of the reflected signal is removed, allowing for coherent averaging time larger than 20ms. The reflected signal complex correlator outputs give a direct measurement of the Carrier Phase Difference (CPD) between the direct and reflected signals, which is one of the main observables for carrier phase altimetry.



GNSS-R Master Slave Processing

Accurate aircraft location

Accurate airplane position is computed using double differencing with the RTKlib freeware package and data from the nearby reference stations. As th GNSS-R data takes were too short to have an accurate positioning, we used the RINEX data recorded by the single frequency aircraft GPS receiver that was also connected to the direct antenna. We correct tides effect, the tropospheric effect using the calculated Zenithal Delay, the ionospheric effect by using the IONEX TEC corrections and the precise ephemeris (SP3 from the IGS center). The obtained trajectory solutions of the aircraft are quite accurate with horizontal RMS components better than 3cm and vertical RMS component better than 10cm which decrease with the baseline length.



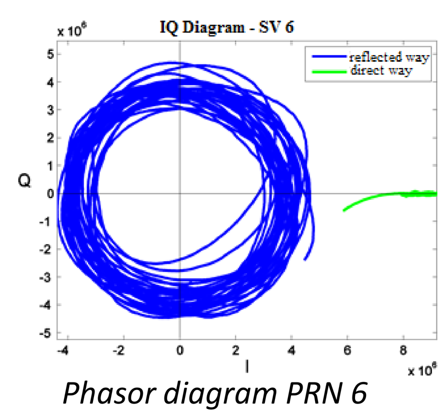
IQ Phasor diagram

First results

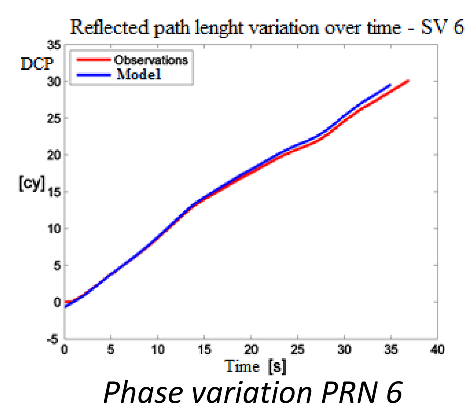
For the flyover of the 24 of June, we were able to observe up to 9 reflected signals. Every GPS satellite in view produced a reflected signal.

Illustrated below are the measurements from PRN 6 (elevation 26 deg). We observe a very clean wrapping of the reflected carrier phase on the IQ diagram. When comparing to a modeled phase variation from aircraft altitude, we have a very good correspondence, with a difference linearly increasing to 10 cm probably related to a relative frequency calibration error between the GLORI and the aircraft receiver.

After correction of the linear trend, the residuals are of the order of 0.1 cycles (2 cm).



Phasor diagram PRN 6

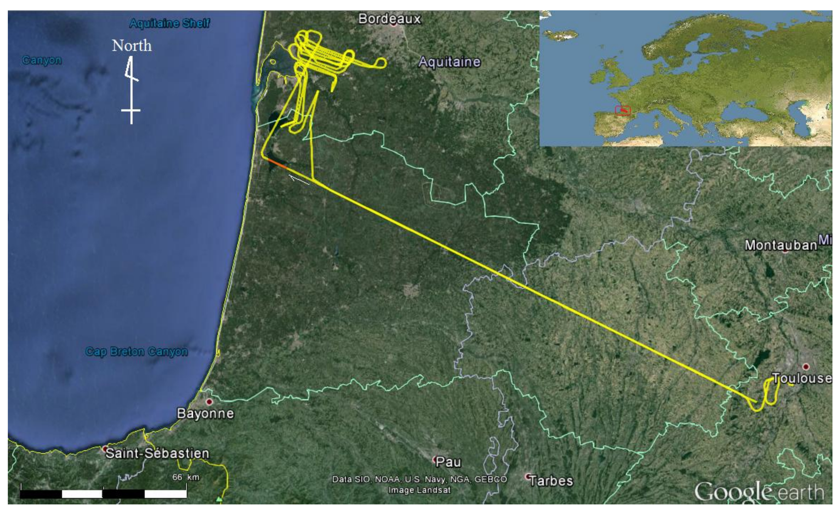


Phase variation PRN 6

Dataset

The GLORIE 2015 Campaign

Six flights were performed between June 19th and July 6th, representing more than 15 hours of polarimetric raw data recorded [2]. Several flyovers were performed above lakes such as the Biscarosse and Cazeau lakes. In total 11 transects were performed over continental water bodies.



Case Study: Flight of the 24 June

The ATR42 was flying at a 600 meter altitude above lake level at a 95 m/s velocity in the middle of a calm night , perfect conditions for observing specular reflections from the lake. The aircraft was stabilized and flying leveled over the lake. The GLORI instrument recorded single frequency GPS signal during 36 seconds.

Conclusions and outlook

- We demonstrated the feasibility of GNSS-R carrier phase measurement from an aircraft flying at 600m.
- The final obtained precision in the order of 2cm
- Investigation on the validity limit of this method is required (roughness vs. phase coherence)
- Additional methods are required in order to move from relative precision to absolute accuracy using the phase information

References

[1] Martin-Neira, M. "A Passive reflectometry and interferometry system (PARIS): Application to ocean altimetry". ESA J., 17:331-355, 1993

[2] Motte, E. et al. "GLORI (GLObal navigation satellite system Reflectometry Instrument)" in 2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2015, pp. 4773–4776.

[3] Lestarquit , L et Al. "Reflectometry with an open-source Software GNSS Receiver. Use Cases with Carrier Phase Altimetry". JSTARS 2016, In press.

Living Planet Symposium, 9-13 May 2016 - Prague