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Airborne system for coastal sea state estimation using GNSS-Reflectometry

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Climate change has been a major worldwide concern over the last decades. One of its consequences is an acceleration of the coastal erosion in littoral areas such as the Opal Coast, North of France. In this regard, one of the topics of the multidisciplinary, state funded, project MARCO (Recherche marine et littorale en Côte d'Opale) is the highly space and time resolved study of sea state in the English Channel.

As part of MARCO, this study has been focused on Global Satellite Navigation Systems Reflectometry (GNSS-R), a bistatic radar technique that uses the signals broadcasted by GNSS satellites as signals of opportunity. A GNSS-R receiver analyzes the signals reaching the receiver directly as well as the signals previously reflected off the Earth surface. Remote sensing application of GNSS-R considers today properties of water bodies, land and ice surfaces. In this work, the objective is to retrieve sea state and related wind speed information from the analysis of direct and reflected GNSS signals.

Several sets of GNSS front-end data have been recorded along the Opal Coast, between the cities of Calais and Boulogne-sur-Mer, between the 12th and 19th of July 2019. The signals were sensed by a dual polarization (Right-Handed and Left-Handed Circular Polarizations) antenna mounted on a gyrocopter. Four datasets of ~18min obtained at an altitude of ~780m above sea level at a speed of ~95 km/h are analyzed by studying the RHCP signals received from 9 GPS satellites for each flight. Considering the altitude of the copter, the major axis of the observed first Fresnel zone is of 25m, 70m and 950m for respective satellite elevation angles of 85° (maximum observed), 30° (regular) and 5° (minimum observed). The raw data is sampled at a frequency of 16.368MHz. The in-phase and quadrature components, for both the direct and reflected signals, are obtained at a rate of 50 Hz. The sea state dependent surface reflectivity is estimated every minute.

The signals are processed using a software receiver by means of Delay, Phase and Frequency Locked tracking Loops (DLL, PLL, FLL), aided by a modeling of the difference between the direct and reflected paths for the DLL of the reflected signal. The phasors of the resulting in-phase and quadrature components of the reflected signal are analyzed in the spectral domain in order to

determine their coherency and subsequently retrieve the sea state. A rough sea yields reflections from a large surface area, resulting in a non-coherent mixture of phasors and a spread peak in the reflected signal spectrum. A calm sea yields specular reflection from small surface area resulting in a spectrum with a sharp peak. Preliminary results show Pearson correlation coefficients between the spectral spread of the peak and ERA5 wind speeds of 0.61 (high elevations) to 0.94 (low elevations).

An important contribution of the airborne GNSS-R system applied in this work is the high spatial resolution of the data. The main perspective of this work is to further improve its time resolution, up to 50Hz.