Oceanpal Experimental Campaigns

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Abstract – **We report on recent experimental campaigns carried out with Oceanpal, a GNSS-R instrument dedicated to sea-surface/ice monitoring. We describe in this paper the permanent station deployed at the Barcelona Port for a real time web-based service, and the successful long-term comparison made with buoy observables. We then address the deployment of Oceanpal on top of a lighthouse during the OPIF Campaign, an Ifremer contract also dedicated to coastal monitoring. Finally, we report on a test flight carried out as a first opportunity airborne campaign in the scope of the CryoVEx 2006 (ESA cal/val experiment for CrySat mission) to demonstrate the relevance of GNSS-R for ice monitoring.**

I. INTRODUCTION

Oceanpal® is an offspring of technologies developed within several ESA/ESTEC and Starlab projects targeted on the exploitation of GNSS Reflections (GNSS-R) from low altitude platforms and space. Oceanpal® is essentially a commercial, operational instrument concept for low altitude GNSS-R applications, such as sea-surface height and sea-state (SWH) monitoring, e.g. in harbours. It also offers a strong potential for ice, soil moisture and salinity measurements.

In this paper, we present recent experimental campaigns dedicated to research and operational services for coastal monitoring. Section II provides a brief overview of the system, including the architecture and the main L2 observables. We then describe in Section III the permanent station of the Barcelona Port, Spain, providing a real time coastal monitoring through a web-based service. Section IV reports on the OPIF experimental campaign carried out at Le Conquet, France, within an Ifremer contract. Finally, in Section V, we address the deployment of Oceanpal in a test flight during the CryoVEx 2006 Campaign.

II. INSTRUMENT OVERVIEW

Oceanpal® employs two antennas to collect GPS signals: one antenna (the "direct" or "up-looking" antenna) is zenith looking to collect the direct GPS signal, while the other one (the "reflected" or "down-looking" antenna) is nadir looking to recover the reflected signal. The output from each antenna is digitised and recorded at a sufficiently high sampling frequency. The data is then fed into Oceanpal's GPS-Reflections processor, StarLight, which retrieves the reflected electromagnetic field and measures two main parameters (Level 2 products):

- **Antenna Height over the reflecting surface**: this is measured by analyzing the delay between the reflected and direct signal. The precision of this measurement is of the order of 1~2 cm in calm waters (e.g., inside a harbour). In rough waters, performance is expected to be 2-5 cm.

- **SWH**: The reflected signal has a shorter coherence time than the direct one, due to surface motion. Coherence time can be related to SWH with accuracy of the order of 10 cm, using algorithms adapted to the coastal region of interest.

The instrument stores the data on the Data Management Unit (ODMU), which also acts as a web server to provide the information to the user via a web browser.

Oceanpal® is composed of the following parts:

- OAR: Antenna Rig. It consists of two antennas on a rig with a mast.
- ORFU: Radio frequency Unit. This component converts RF to digital data streams.
- ODMU: Data Management Unit. This unit captures the data, processes it using StarLight, stores it and provides the web interface for the user.
- OWL: Web Layer. This software server application is designed to give wide access to the instrument historical data through the internet to selected users (see Figure 1).

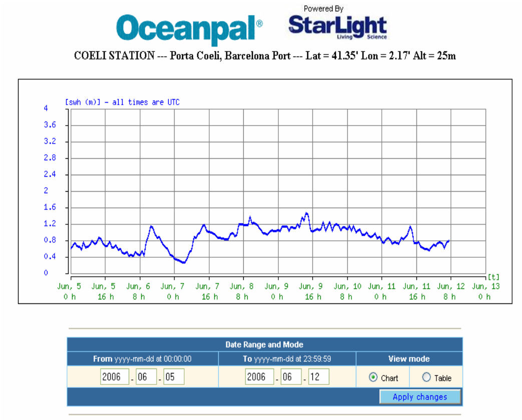

Figure 1 - Oceanpal GUI, displaying via the internet the instrument status as well as access to Oceanpal database L2 products (SWH, SSH).

III. BARCELONA PERMANENT STATION

The Oceanpal station has been deployed in Barcelona since 2004, in collaboration with the Barcelona Port Authority Environmental Monitoring Department (APB). The antennas and acquisition systems are installed near the main entrance of the port, as shown in Figure 2, at around 23 m over the sea-surface.

The system records 1 minute long acquisitions and provides hourly averages of the SWH solution. We refer the reader to *[Soulat et al., 2004]* for a complete description of the sea-state algorithm. The data are provided continuously and in real time to APB through the internet.

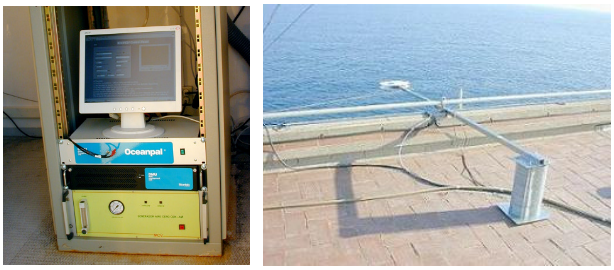

Figure 2 - Oceanpal set-up at the Barcelona Port.

Two nearby buoys owned by the Spanish Port Authorities (Puertos del Estado) allowed the validation of the sea-state measurements. Figure 3 shows an example of a very good agreement between the buoys and Oceanpal® SWH measurements, during a 13 day period. The main discrepancies occur when the buoy is under maintenance (in such case the buoy solution repeats the last available measurement as time goes by). The sea-state performance is a 18 cm precision after 1 minute acquisition.

In addition, specific data collections showed that precise mean sea level measurements can be provided for calm waters, using phase altimetry algorithms. We refer the reader to *[Caparrini et al., 2003]* and *[Dunne et al., 2005]* for a complete description of the altimetry algorithm.

According to the station's user, the Oceanpal® permanent station enables a very good monitoring of the port's entrance together with a low maintenance effort.

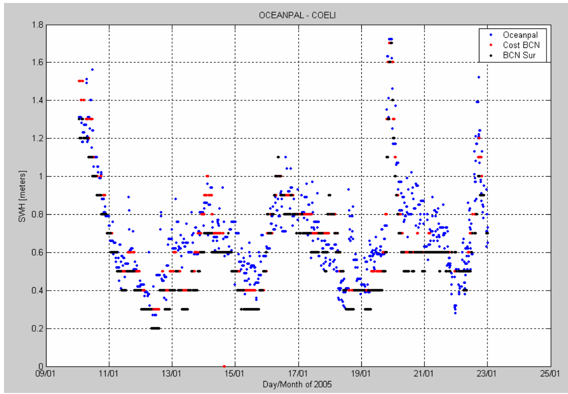

Figure 3 – Example of SWH comparison with nearby buoys during 13 days. Oceanpal (blue), buoy "Cost_BCN" (red) and buoy "BCN Sur" (black).

IV. OPIF CAMPAIGN

The Ifremer contract entitled OceanPal® installation at IFremer site (OPIF) was dedicated to collect GNSS-R data in view of the deployment of a permanent coastal station. The experiment took place at the Kermorvan lighthouse near Brest, France, in September 2006. During four days, the data recordings were carried out simultaneously with in situ observations provided by a Datawell buoy, owned by the French Ministry of Equipment (CETMEF).

Figure 4 - Oceanpal antennas deployed on top of the Kermorvan lighthouse. OPIF campaign.

A particular attention was put on the sea-surface vertical velocity estimated through the coherence time τ_I of the interferometric complex field, defined as the ratio between reflected and direct GNSS signals. The analysis consisted in comparing the measurements with the vertical velocity extracted from the buoy raw observables (SWH and the coherence time τ_z of the vertical displacements), as shown in **Eq. 1**:

$$V_{OP} \equiv \frac{\lambda}{\pi \tau_I \sin \varepsilon} = \frac{SWH}{\tau_z}, \quad \textbf{Eq. 1}$$

Where λ is the GNSS wavelength and ε the GPS elevation.

As observed in Figure 5, there was a very good consistency between Oceanpal (blue dots) and the Datawell buoy (red circles) during the first two days of the experiment. Some discrepancies started to occur in the morning of the third day: Oceanpal's estimations tended to lower significantly, while buoy measurements kept on increasing. This discrepancy remained until the end of the observation period, while the estimated vertical velocity followed periodic variations.

It was clearly shown in the study that the divergence between Oceanpal® and the buoy measurements occurred for very strong tidal currents (due to the very high tide coefficients). As observed for these regimes, the strong local sea-state un-homogeneities on the sea-surface explained perfectly this difference, given the distance (hundredths of meters) between the buoy and Oceanpal's area of observation. However, the surface velocity error measurement is most of the time less than 0.5 m/s.

Moreover, this data collection highlighted the strong potential of such parameter through the multiple and simultaneous reflections allowing for a two-dimensional observation of the sea-state in the vicinity of the lighthouse.

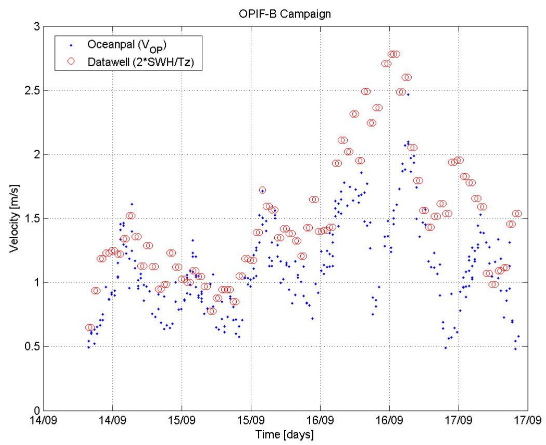

Figure 5 - Vertical surface velocity versus time. OPIF campaign.

V. PARIS ICE RETRIEVALS

In May 2006, a test flight was carried out to collect GNSS-R data over ice in the Svalbard region. This opportunity campaign was proposed by ESA under the PARIS contract series and the CryoSat validation programme, whose overall objective is to assess and quantify uncertainty in the CryoSat measurements of sea ice thickness and land ice thickness change. During the calibration/validation airborne campaign CryoVEx 2006, the measurements made by the airborne equivalent of the SIRAL altimeter (ASIRAS) and a laser scanner have been completed by Oceanpal® to gather GNSS signals reflected off the ice and snow with a view to determining the potential of these signals for cryospheric analysis.

The instrument has been adapted to fly on board the Twin Otter aircraft used in the campaign, as shown in Figure 6. The flight took place on May the 1st 2006 and the data analysis is under progress at the time of writing.

Figure 6 – Oceanpal deployment together with the ASIRAS instrument during the CryoVEx 2006 campaign.

This opportunity campaign and future data collections will enhance the understanding of GNSS-R strength for ice monitoring, as introduced in recent studies (e.g., *[Wiehl et al., 2003]*).

VI. CONCLUSIONS

In this paper, we reviewed recent experiments dedicated to GNSS-R and carried out with the Oceanpal® instrument. The realisation and analysis are presented for several scenarios, such as a permanent station in the Barcelona Port, a deployment on top of a lighthouse near the Ifremer site and an airborne campaign for ice monitoring applications.

Oceanpal® offers reliable sea-state products for coastal monitoring and altimetric solutions for calm waters. The former is provided with a 18 cm precision and the latter with a 3 cm precision. A web layer was developed to provide in real time the Level 2 products to the end-users for operational oceanography purposes.

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