FFSAR - COASTAL

Fully Focused SAR Altimetry and innovative river level gauges for Coastal Monitoring

In situ Data Campaign report
Deliverable D3.1

Fully Focused SAR Altimetry and innovative river level gauges for Coastal Monitoring

ESA Contract 4000136960/21/I-DT-Ir

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1 Introduction

1.1 The FFSAR Coastal Project

The project has applied the Fully Focussed (FF) SAR altimetry processor on Sentinel-3 data and evaluated its potential to make a significant new contribution to coastal and estuarine monitoring systems, when coupled with innovative water level gauges for validation.

Applications focused on the benefits offered by the very high along-track resolution in water level and backscatter that can be provided through Fully Focussed SAR processing. User agencies and groups from the two regions have been consulted to identify gaps and priorities for monitoring requirements.

Innovative in-situ water level gauges have been used to validate the satellite data. Time series were provided by autonomous gauges placed at fixed locations, gauges mounted on drones used to provide water level profiles between the fixed locations and satellite tracks.

1.2 Scope of this Document

The objective of this document is to report on all the activities carried out for the in-situ campaign performed in the framework of the FFSAR-Coastal project. The campaigns consist in installing 2 vorteX-io Micro-Stations in the Rhône estuary and 2 others in the Severn estuary. This document will be updated later with the drone campaigns on both sites as soon as they are completed.

1.3 Applicable Documents

AD-01: Fully Focussed Sar Altimetry And Innovative River Level Gauges For Coastal Monitoring (FFSAR-Coastal) - ESA Contract No. 4000136960/21/I-DT-lr

1.4 Reference Documents

RD-01 FFSAR-Coastal Proposal. V1.1 29/07/21, SatOC and FFSAR-Coastal team.

1.5 Overview of this Document

In addition to this Introduction chapter, this campaign report includes the following chapters:

- General considerations
- Campaign means
- Campaign logs
- First analysis of data collected
- Campaign synthesis

1 General considerations

1.1 Installation of vorteX-io Micro-Gauges

1.1.1 General technical considerations

The aim of the campaigns is to install 4 micro-stations on 2 sites: in the Rhône estuary (south of France) and in the Severn estuary (at the border between Wales and England). The objective is to provide in-situ measurement on estuaries as close as possible of the Sentinel-3 tracks to be used for the validation of the innovative FFSAR processing, taking advantage of the characteristics of the Micro-Station described in chapter 2.1 of this document. The sites have been chosen in collaboration with SATOC, NOC, CCO and DTU. On each site 2 micro-stations are installed. Figure 1 shows the map of the 2 sites with Sentinel-3 ground tracks. Figure 2 and Figure 3 show the description of the installation on both “super-sites”. Figure 4 shows the exact location of the 4 installation sites.

Figure 1: Map of the Rhône delta on the left and the Severn estuary on the right with Sentinel-3A ground tracks in red and Sentinel-3B ground track in green

Figure 2: Description of the installation in the Rhône delta sites with Fos-sur-Mer on the left and Port saint Louis du Rhône on the right

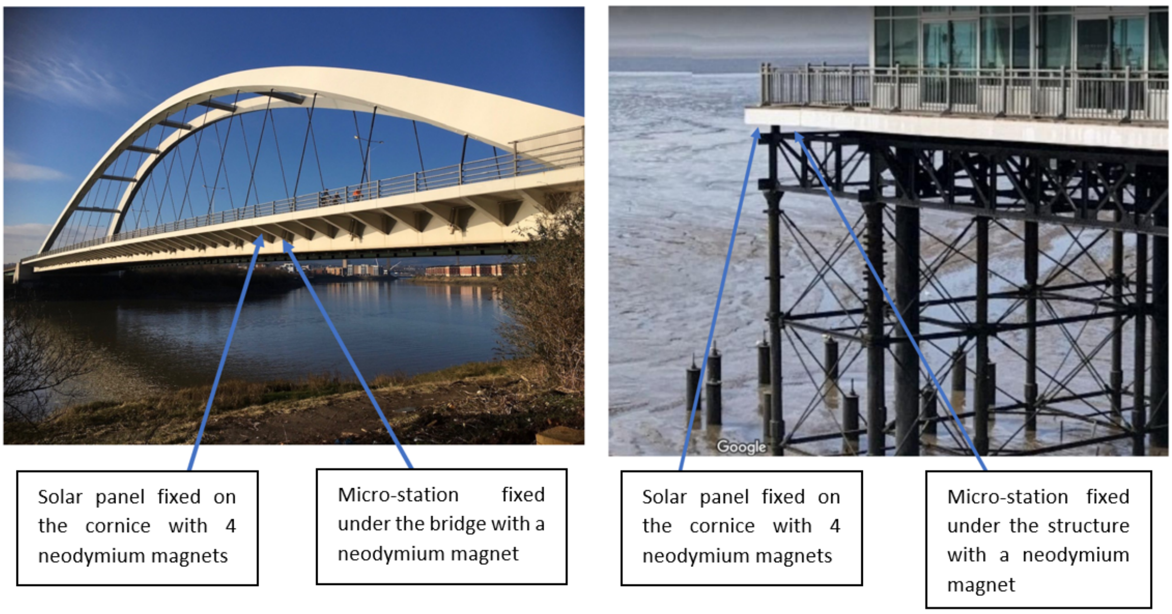

Figure 3: Description of the installation on the Severn estuary site with Newport on the left and Weston-Super-Mare on the right

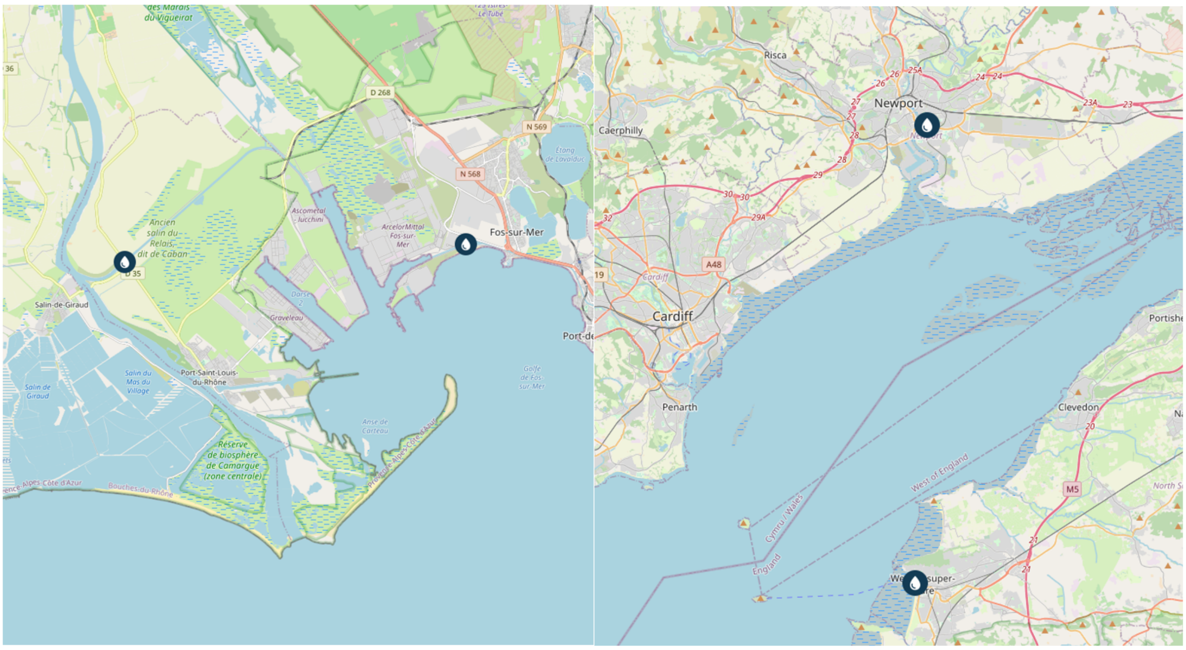

Figure 4: Location of the selected sites, left Rhône delta site and right Severn estuary site

1.1.2 General regulation points

To install the micro-stations, authorizations from local authorities are required. To get these permissions we need to contact the bridge owner. If the bridge is private (SNCF, etc …) we ask the permission to the company that owns the bridge. In case of a public bridge, we must identify the authority that maintain the bridge. In France for instance this information is given by the type of road on the bridge. The maintainer of the bridge can be the city, the department, or the regional road direction. Once the maintainer is identified we send him a CERFA sheet form to get the permission to install the micro-station. If we need to close a car lane to perform the installation another CERFA sheet form is send to the bridge maintainer to have this second permission.
For the installation in France, the road maintainer is the Fos-Marseille pier for Fos-sur-Mer and the Département des Bouches-du-Rhône for Port-Saint-Louis-du-Rhône. The next documents are the permissions granted for both installations.

Bonjour,
En réponse à votre demande et pour donner suite à notre conversation téléphonique de ce jour, je vous confirme l'autorisation pour la mise en place des équipements de mesure, avec fixation par aimants, **sans perçage des parties métallique de l'ouvrage.**
Notre service ne délivrera pas d'arrêté de circulation pour cette intervention qui sera réalisée depuis les trottoirs de l'ouvrage, aucun empiètement de la circulation ne sera autorisé conformément à notre entretien téléphonique.
En complément, vous voudrez bien me préciser la date d'intervention de mise en place.

Cordialement,

Jean-Pascal VAREILLAS
Port : 06.42.92.32.77
Tél : 04.42.48.68.93

Marseille Fos
Le port euroméditerranéen
Grand Port Maritime de Marseille
Direction de la Valorisation du Patrimoine et de l'Innovation
Département Valorisation Foncière et Immobilière
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Centre Vie de la Fossette – Bat. A
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CS 81965
13226 MARSEILLE CEDEX 02

DEPARTEMENT DES BOUCHES-DU-RHONE — REPUBLIQUE FRANCAISE
CONSEIL DEPARTEMENTAL
DIRECTION DES ROUTES ET DES PORTS

PERMISSION DE VOIRIE ORDINAIRE - ARRETE D'OCCUPATION
N° 2022-D035-S_BER-1-AOPEVO-061

sur la R.D. n° D035 du P.R. 5 + 768 au P.R. 5 + 768 de Catégorie Réseau local
D35
Commune de Port St Louis Du Rhone,

LA PRESIDENTE DU CONSEIL DEPARTEMENTAL DES BOUCHES DU RHONE

VU le Code de la Voirie Routière,

VU le Code de la Route,

VU le Code des Collectivités Territoriales,

VU le Code Général de la Propriété des Personnes Publiques

VU la loi n°82-213 du 2 mars 1982 modifiée relative aux droits et libertés des Communes, des Départements et des Régions,

VU la loi n° 2004-809 du 13 août 2004 relative aux libertés et responsabilités locales, notamment son article 18,

VU le décret n° 2005-1500 du 5 décembre 2005 portant application de l'article 18 de la loi n°2004-809 du 13 août 2004 relative aux libertés et responsabilités locales,

VU l'arrêté interministériel du 24 novembre 1967 relatif à la signalisation des routes et autoroutes et les textes subséquents qui l'ont complété,

VU l'arrêté de la Présidente du Conseil départemental des Bouches-du-Rhône en date du 28 juillet 2015 dont les dispositions annexées constituent le règlement de voirie du Département des Bouches-du-Rhône,

VU l'arrêté du Conseil départemental des Bouches-du-Rhône en date du 11 août 2006, du 31 mars 2017, du 27 juin 2019, et du 14 février 2020 fixant le tarif des redevances,

VU l'arrêté de la Présidente du Conseil départemental des Bouches-du-Rhône en date du 13 Mai 2022 n°22/33/SC donnant délégation de signature,

VU la demande n°2022-D035-S_BER-1 en date du 20/07/2022 de :

VORTEX.IO, VALLADEAU,

28 RUE DU TANNERON,

31400, TOULOUSE

dont le représentant est Madame / Monsieur VALLADEAU, joignable au , stephanie@vortex-io.fr; jeanchristophe@vortex-io.fr

SUR la proposition du Directeur Général des Services du Département

Figure 5: permissions granted by both organizations for the installations on the Rhône sites

For the installations in the United-Kingdom, the authorizations have been obtained by David Cotton and the SATOC team.

1.2 Drone deployments

1.2.1 General technical considerations

The aim of the two drone campaigns is to deploy the vorteX-io VTX-1 lightweight LiDAR altimeter embedded on the drone to measure water surface height along the satellite tracks, to link the satellite measurements to the vorteX-io Micro-Gauge measurements. The flight plans have been defined in collaboration with SATOC, NOC, CCO and DTU.

First, the drone flights are planned using Google Earth. Once the flight plan is validated, a complete analysis of all flight zones will be performed, including visiting the sites, and then the mission will be precisely scheduled with margins in case of unexpected events (bad weather, issue with any instrument, etc…). Then permissions/agreements are requested to the flight authorities (in France, French DGAC: Direction Générale de l'Aviation Civile; in UK, UK CAA: Civil Aviation Authority). When all permissions are obtained, the mission can be started. A go/no-go decision is taken 2 to 3 days before the planned mission date to check

weather conditions and if it is compatible with the drone constraints. Depending on the project decision, the mission can be delayed and performed a few days away from the actual satellite overflight as the objective is to provide the reference river topography for different specific heights.
On the deployment day, the field teams join the area of interest and the GNSS base is installed in the middle (as much as possible) of the deployment area. The drone must stay within a radius of 70 km from the base to ensure an accurate positioning (computed offline), which is always the case for these campaigns as the area is smaller than a radius of 70 km. Then, drone flights are performed following the local regulations concerning drone deployment. Typically, the drone must stay less than 1 km from the pilot (European regulations), keeping a clear line of sight. Drone flights are performed in automatic mode in accordance with the predefined flight plans, allowing the drone to keep constant speed and altitude. Before and after each flight, a set of checks is carried out on the drone to ensure the correct status of the UAV, but also of the lightweight altimeter, thanks to an on-board dashboard permitting to check the instrument status and the measurement quality.

Raw measurements are stored in the GNSS base itself and on a SD card for the lightweight altimeter and will be processed offline after the mission (within a few days) by the vorteX-io drone ground segment (a dedicated processing chain developed in python by vorteX-io). Data coverage and quality can be checked anytime during the mission thanks to web dashboards available through local Wi-Fi networks broadcasted by all instruments (the vorteX-io lightweight altimeter as well as the GNSS base).

The drone deployment is declared as “completed” when all the predefined flights have been performed and after a quality check of the lightweight LiDAR altimeter data to ensure that all needed data have been acquired.

1.2.1.1 Deployment in the Severn estuary

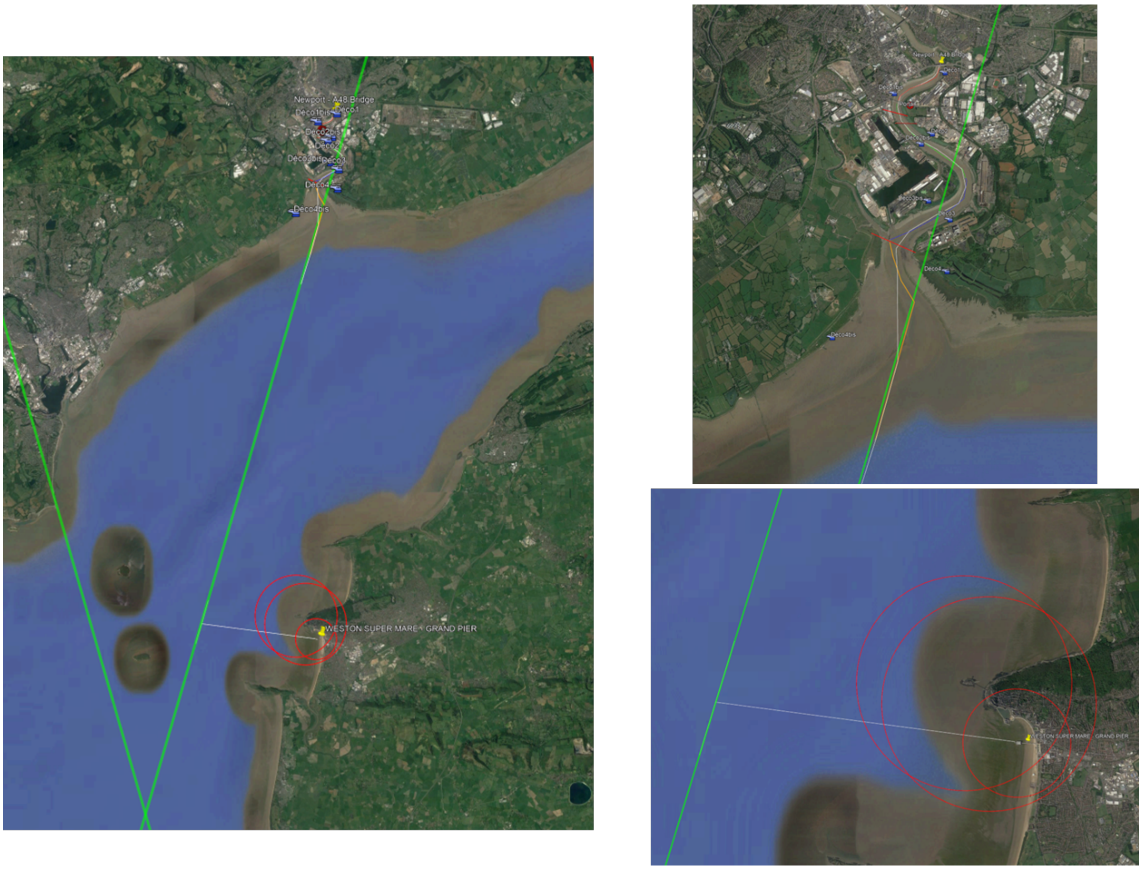

Figure 6: Flight plans for the drone deployment in the Severn estuary

The flight plans for the drone deployment in the Severn estuary are presented in Figure 6. The objective is to link satellite measurements to the 2 micro-gauges already installed in Weston (Weston Super-Mare) and Newport as indicated by the yellow pins on the maps. Satellite tracks are indicated by the solid green lines. The flight trajectories are represented by the solid white and orange lines on the maps. These trajectories have been defined to follow the Sentinel-3B track from the Weston super-mare to the Newport bridge where the micro-gauge is installed.

1.2.1.2 Deployment in the Rhône delta

Figure 7: Flight plans of the drone deployment in the Rhône delta

The flight plans for the drone deployment in the Rhône delta are presented in Figure 7. The objective is to link satellite measurements to the 2 micro-gauges already installed in Port-Saint-Louis-Du-Rhône (in the canal) and in Fos-Sur-Mer (also in the canal) as indicated by the yellow pins on the map. Sentinel-3B tracks are indicated by the solid green lines. The flight trajectories are represented by the solid white lines on the map. These trajectories have been defined to follow the Sentinel-3B tracks from the open ocean to the micro-gauges locations, both in canals.

1.2.2 General regulation points

Authorisations are mandatory to deploy drones in both the UK and France.

In the UK, each pilot needs a “Flyer ID” and the pilot in charge of the campaign must be registered to the CAA (UK Civil Aviation Authority) and have an “Operator ID”. Tests must be passed to obtain both IDs. The I-TECHDRONE team has passed the different tests and the declared Operator ID for this campaign is Laurent Cognet from I-TECHDRONE. The IDs have 1 year of validity duration.

In France, as I-TECHDRONE is a French drone company, all the declarations have already performed. The campaign and flight plans have been declared on the DGAC (French Direction Générale de l'Aviation Civile) website dedicated to professional drone campaigns. Additional permissions have been requested to the Préfecture des Bouches Du Rhône because of a natural park (Parc Naturel Régional de Camargue) and to the Harbour of Fos-Sur-Mer. Both permissions have been granted but a limitation has been made by the Parc Naturel Régional de Camargue at the extreme south zone (at the mouth of the Rhône River) because of the bird migration period. No flight have been performed in this area.

2 Campaigns means

2.1 The vorteX-io Micro-Station

Developed by vorteX-io, this innovative system may be used for both systematic and periodic field campaigns. It is based on a smart, compact & innovative remote sensing instrument combining a LiDAR and a camera to provide water surface height with the associated standard deviation, LiDAR amplitude and images of the water surface. Thanks to the camera, the Micro-Station also provides water surface speed estimates. The system is fully automatic and connected using either GSM or satellite IoT (Internet of Thing) system (ongoing development based on Kineis space IoT system). Measurements are inspired by satellite altimetry: each time measurements are transmitted by the station, a complete house-keeping telemetry (battery level, connectivity level, power provided by the solar panel, voltage and amperes of the different sensors and electronic cards, etc.) is also sent to perform a complete real-time health check of the station. The behavior of the micro-station is also inspired by IoT principles: the micro-station regularly sends messages, from 1 to 6 times per hour depending on the station configuration, can receive over the air (OTA) software updates, can be receive OTA configuration changes and is optimizing its power consumption by switching to standby mode as soon as possible. This feature allows remote maintenance and thus to intervene on the field only when a hardware problem has been diagnosed, which drastically lowers maintenance costs.

Figure 8: Illustration of a vorteX-io µVTX-1 installed under a bridge in the south of France

Concerning the measurement frequency, an alert threshold is defined on the water level for each Micro-Station. If the threshold is not exceeded, the Micro-Station typically performs one measurement per hour. Otherwise, the measurement frequency increases up to every 10 minutes (6 times per hour). Concerning more specifically Cal/Val activities for satellite altimetry, a dedicated mode has also been implemented, called the HydroSnap mode (cf Figure 9). In this mode, thanks to their precise localization and based on satellite ephemeris, each Micro-Station can perform a measurement exactly at the time of satellite overflight. This functionality allows to cancel any time difference that could occur between satellite measurements and in-situ measurements. Our field experience has demonstrated that this is of key importance, especially over estuaries impacted by tides, rivers impacted by reservoir management, etc.

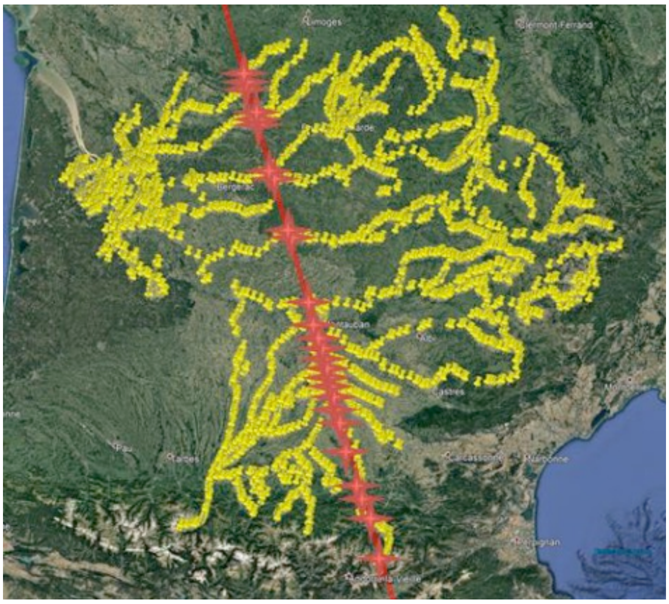

Figure 9: Example of the HydroSnap mode simulated for several vorteX-io Micro-Stations installed on bridges along a Sentinel-3A ground track in the Garonne basin. All Micro-Stations will perform their measurement when the satellite flies over them. Yellow dots identify the bridges available in this basin

The Micro-Stations are very easy to install. The installation on a bridge or on an existing infrastructure requires permits from the local authority responsible for it. The application for such permits can take time depending on the local authority, the country, and the infrastructure type (For example, in France, it takes an average of 1 month to obtain authorizations, but it can take longer if the installation is planned on a motorway bridge or a railway bridge).

An illustration of an installation is provided in Figure 8. With a compact form factor, a micro-station can be schematized by a cube with 10-cm sides, weighing 500 grams, and can be easily fixed to any stable structure close to a water body or on a bridge, using screws or a magnet if the structure is metallic. The Micro-Station is self-sufficient in terms of power thanks to a solar panel and a battery (if the solar panel is out of order, the battery is designed to ensure 15 days of autonomy).

Thus, thanks to all the information provided, it is possible to know in real time the status and the health of each Micro-Station, which allows to drastically reduce maintenance and interventions on the field. Interventions will only be carried out when necessary (hardware failures). Moreover, alerts on health parameters are raised automatically and in real time by an internal web monitoring system and dashboard as, for example, if the battery passes under 50% of load or if the solar panel is disconnected or not functional.

All the information sent by the Micro-Stations are directly collected and stored (with redundancy) on secured and remote cloud servers, processed in real-time and made visualizable through dashboards, or directly available through a dedicated API (Application Programming Interface) for automatic dissemination. Thanks to this robust system, measurements are available to users a few seconds after their acquisition. During the installation, the Micro-Station is referenced using a geodetic GNSS sensor: the Septentrio GNSS base described below. The measurements are provided with respect to an absolute reference, ellipsoid (WGS84) or local geoid.

2.2 The vorteX-io VTX-1 lightweight LiDAR altimeter

For one-shot or periodic field campaigns, vorteX-io proposes another innovative and interesting solution: a lightweight altimeter embedded on flying drones. The lightweight altimeter uses a combination of sensors like the one integrated in the Micro-Station. In addition, the altimeter embarks a precise GNSS sensor and an inertial measurement unit to correct for the drone movements and provide water surface height with centimetre-level accuracy all along the drone flight. Thanks to the flexibility and the ease of deployment of the drone, the system acquires data over long distances, even in difficult-to-access areas. Of course, the drone has also some limitations in terms of weather conditions (wind speed limit of ~50 km/h and no heavy rain conditions) which must be accounted for. The drone can also be deployed from a boat, allowing to perform measurements over large lakes or over the ocean. Orthophotos of the overflown zone can be performed thanks to the on-board camera (1 picture per second), which is very useful for assessing the water surface roughness, the water extent, the surrounding terrain, etc. This information has proven to be very valuable to derive higher level products. The drone deployment uses a GNSS base as reference, as illustrated in Figure 10.

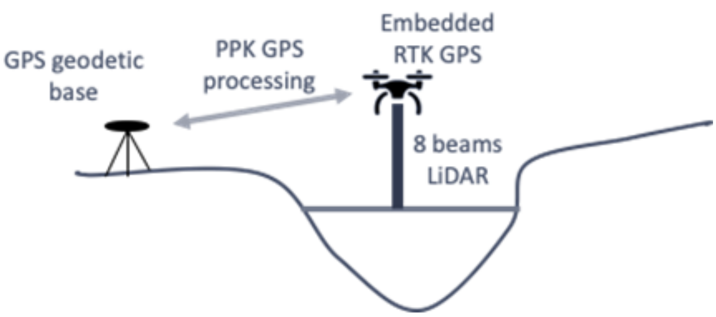

Figure 10: Illustration of the lightweight altimeter positioning system.

This GNSS base is required to perform the Kinematic Post-processing (PPK) needed to precisely position the lightweight altimeter and then to provide centimetre-level accuracy water surface height measurements. Thanks to the use of three constellations (GALILEO, GPS and GLONASS) and a two-frequency GNSS system, the positioning is valid for base length up to 70 km. The elevation measurements are provided on a specific wide swath LiDAR: 8 beams spread over a 16.3° aperture to guarantee the correct measurement of the surface during the drone flight. A dedicated post-processing is performed to eliminate outliers and unwanted data (land data, vegetation, etc.). Orthophotos are built from the images acquired by the camera and a water mask is derived. An editing is performed to remove all elevation data over land using this mask. An editing is also performed related to the flight quality: even if the UAV is programmed to follow a predefined flight plan with a specific constant altitude and velocity to provide the best possible measurements, it may happen for a few seconds and due to weather conditions (gust of wind) that the altitude and velocity values deviate too much from the requirements. In this case, an automatic editing removes those points from the time series. This post-processing guarantees the reliability of the measurements. Moreover, the light-weight altimeter has its own Wi-Fi network, and a specific dashboard allows the drone operator to check the measurement quality during the drone flight. Drone campaigns have been successfully conducted many times since several years in collaboration with CNES and ESA, over long distances, and different water bodies (32 km on the Saône River, 60 km on the Rhine River and surrounding lakes, 58 km over the Geneva Lake, etc.).

2.3 The DJI drone carrier

Two types of DJI drones are used to carry the lightweight LiDAR altimeter: the MATRICE 210 RTK V2 and the MATRICE 300 RTK. The main difference between the two drones is the autonomy. The MATRICE 300 RTK is an advanced version of the MATRICE 210 RTK V2 with an autonomy extended by 15 min. The autonomy of the MATRICE 210 RTK V2 is 38 min and the autonomy of the MATRICE 300 RTK is 55 min. Both drones can be controlled by a remote controller, or can execute an automatic flight program (programmed before the mission).

The drones can operate in any environment with wind speed slower than 50 km/h and with light rain. The maximum transmission distance is 15 kilometres between the drone and the remote controller. To perform long distance measurements, a vehicle can be used to keep the distance between the drone and the remote controller under 15 kilometres (technical limitations). Long-distance campaigns can be done by splitting flights into smaller flights. Small flights are performed one after the other. The drone operating team must move from a take-off point to another to perform the small flights.

2.4 The Septentrio GNSS base

The Septentrio GNSS base is used for both permanent and periodic campaigns. The Septentrio base includes a precise three-frequency GNSS chipset. The used constellations are: GPS, GLONASS and GALILEO. The autonomy of the GNSS base is around 8 hours with the same batteries. The autonomy can be extended manually by replacing the batteries without switching off the base during the campaign. The Septentrio base is used for the positioning of both Micro-Gauges and the VTX-1 lightweight LiDAR altimeter. The base must be installed in a place with a clear view of the sky, to track a maximum of GNSS satellites.

For Micro-Gauges the base is used during the installation activities. The base is located on the bridge above the Micro-Station. A Precise Point Positioning (PPP) processing is applied on the GNSS base raw data to reach a precise positioning, with a millimetre-level precision. The precise positioning of the Micro-Station is mandatory to get the exact altitude of the water height. The exact altitude of the Micro-Station is computed from the base position by subtracting the distance between the base and the Micro-Station. This distance is measured by the rope access technicians during the installation.

For the vorteX-io VTX-1 lightweight LiDAR altimeter the base is used for the same purpose: to get the exact position of the altimeter during the flight and get the water surface height by removing to the LiDAR measurement the altitude and movements of the drone. The base is used to measure a reference position to compute the exact altimeter position afterwards. All the flights must be contained into a 70 km radius from the base to have a valid altimeter positioning. The base is usually placed in fields, where no structure can obstruct the view of the sky. The GNSS processing is more complex than the one for the Micro-Station installion, and thus the recording time of the base last several hours. To compute the altimeter position, we apply a Precise Point Positioning (PPP) processing on the base data and then we apply a Post Processing Kinematic (PPK) on the altimeter GNSS measurements with the precise position of the base as reference.

2.5 Micro-Gauge equipment

During the campaigns the following equipment was used.

- The rope access technicians use their own material to ensure their security. This equipment includes all the ropes, harness, and other safety elements.
- To perform the precise GNSS positioning of the micro-station a Septentrio NR3 GNSS base is used. The distances between the GNSS base and the micro-stations were measured with a measuring tape. The GNSS measurements will be performed later in the United Kingdom.
- On each site, a micro-station and a solar panel are installed.

The equipment used to install micro-stations and solar panels is described in the following summary for each site:

<u>Rhône delta sites:</u>
Fos-sur-Mer:

ID	fos-sur-mer_1
Watercourse name	Rhône delta
Coordinates	LAT: 43.434024 LON: 4.921933
Altitude of the station (Ellipsoidal)	11.941 m
Date of the first measurement	07/27/2022
Power supply	Solar panel and internal battery
Mounting system	Solar Panel: 4 stainless steel screws of 8 mm on the deck cornice Steel plate: 4 stainless steel screws of 8 mm und er the bridge Micro-Station: 1 Neodymium magnet on the steel plate

Port-Saint-Louis-du-Rhône:

ID	port-saint-louis-du-Rhône_1
Watercourse name	Rhône delta
Coordinates	LAT: 43.428108 LON: 4.763323
Altitude of the station (Ellipsoidal)	10.262 m
Date of the first measurement	07/27/2022
Power supply	Solar panel and internal battery
Mounting system	Solar Panel: 4 neodymium magnets

		Micro-Station: 1 Neodymium magnet

<u>Severn Estuary sites:</u>

Weston-Super-Mare:

	**ID**	Weston _1
	Watercourse name	Severn estuary
	Coordinates	LAT: 51.347779 LON: -2.984121
	Altitude of the station (Ellipsoidal)	61.831 m
	Date of the first measurement	06/09/2022
	Power supply	Solar panel and internal battery
	Mounting system	Solar Panel: 4 neodymium magnets Micro-Station: 1 Neodymium magnet

Newport:

	**ID**	newport_1
	Watercourse name	Severn estuary
	Coordinates	LAT: 51.576861 LON: -2.974263
	Altitude of the station (Ellipsoidal)	67.027 m
	Date of the first measurement	06/09/2022
	Power supply	Solar panel and internal battery
	Mounting system	Solar Panel: 4 neodymium magnets Micro-Station: 1 Neodymium magnet

2.6 Field teams

2.6.1 For installing Micro-Gauges

For the installations, we worked with local rope access technicians. 2 technicians are mandatory by regulations to perform the installation. In this frame, vorteX-io has compiled a directory of rope access technicians.
We select the rope access technicians according to their location, availability, and the price. We also consider their professionalism, their motivation and enthusiasm for our system, and their human behaviour.
For the installations in the Rhône delta sites we worked with the company “Midi Cordes” based in Lamanon in the Département des Bouches-du-Rhône.

Figure 11: Logo of the company "Midi Cordes"

For the installations in the United-Kingdom, we worked with the local company “Highline Access” based in Bristol.

Figure 12: Logo of the company "Highline Access"

2.6.2 For piloting drones

The drone operations have been performed by our partners I-TECHDRONE, a French company specialized in professional drone operations. The I-TECHDRONE team has managed the regulation points and the field operations. They are trained to use the vorteX-io VTX-1 lightweight LiDAR altimeter and have a strong experience in drone flights with more than 10,000 hours of flight. For the Severn deployment, a boat was rented to take off an land from the boat to guarantee that the drone stay at less than 1 km from the pilot, accordingly to the regulations. The boat pilot is named David Bobbett.

Figure 13: Logo of the I-TECHDRONE company

3 Campaigns logs

3.1 Installation of the Micro-Gauges

The campaign lasted 2 days: the 27/07/2022 for the installation in France and the 06/09/2022 for the installation in the United Kingdom. Here are the logs of the installations for both days.

3.1.1 Installation in France (July 27th, 2022)

08:30 The technicians arrived in Port-Saint-Louis-du-Rhône.

09:00 Beginning of the base GNSS measurement. The base is installed on the bridge above the place where the station is going to be installed.

09:15 Installation of the micro-station and the solar panel under the bridge. A steel plate is fixed under the bridge and the micro-station is fixed to it with a magnet. The solar panel is fixed to the bridge cornice with stainless steel screws. Once the micro-station is installed, 3 consecutive measurements are performed. A validation is remotely done by the vorteX-io team to confirm that the micro-station is working properly and is well installed. All health parameters of the station are checked remotely. Then the rope access technicians precisely measured the distance between the reference point of the micro-station and the GNSS base.

Figure 14 shows the micro-station and the solar panel installed on the bridge.

Figure 14: Micro-station and solar panel installed in Port-Saint-Louis-du-Rhône

10:00 End of GNSS measurements. End of the installation in Port-Saint-Louis-du-Rhône.

11:30 The technicians arrived in Fos-sur-Mer.

11:45 Beginning of the base GNSS measurement. The base is installed on the bridge above the place where the station is going to be installed.

12:00 Installation of the micro-station and the solar panel under the bridge. The micro-station is fixed to the bridge with a magnet. The solar panel is fixed to the bridge cornice with 4 neodymium magnets. Once the micro-station is installed, 3 consecutive measurements are performed. A check is remotely done by the vorteX-io team to confirm that the micro-station is working properly and is well installed. All vital parameters of the station are verified remotely. Then the rope access technicians measured the distance between the reference point of the micro-station and the GNSS base.

Figure 15: Micro-station and solar panel installed in Fos-sur-Mer

12:30 End of GNSS measurements. End of the installation in Fos-sur-Mer. End of the campaign on the Rhône delta site.

3.1.2 Installations in the Severn estuary (September 6th, 2023)

09:30 The technicians arrived in Newport.

10:00 Installation of the micro-station and the solar panel under the bridge. The micro-station is fixed to the bridge with a magnet. The solar panel is fixed to the bridge cornice with 4 neodymium magnets. Once the micro-station is installed, 3 consecutive measurements are performed. A check is remotely done by the vorteX-io team to confirm that the micro-station is working properly and is well installed. All vital parameters of the station are verified remotely. Then the rope access technicians measured the distance between the reference point of the micro-station and a reference point on the bridge that they mark (cf Figure 17). During the GNSS campaign measurements, they will only have to measure the distance between the GNSS base and the mark to get the complete distance between the GNSS base and the micro-station.

Figure 16 shows the micro-station and the solar panel installed on the bridge.

Figure 16: Micro-station and solar panel installed in Newport

Figure 17: Reference point for vertical alignment - Black circle on white lip to concrete footing to pedestrian pathway barrier

11:30 End of the installation in Newport.

13:00 The technicians arrived in Weston-Super-Mare.

13:15 Installation of the micro-station and the solar panel under the deck structure. The micro-station is fixed to the structure with a magnet. The solar panel is fixed to the structure with 4 neodymium magnets. Once the micro-station is installed, 3 consecutive measurements are performed. A check is remotely done by the vorteX-io team to confirm that the micro-station is working properly and is well installed. All vital parameters of the station are verified remotely. Then the rope access technicians measured the distance between the reference point of the micro-station and a reference point on the structure that they mark (cf Figure 19). During the GNSS campaign measurements, they will only have to measure the distance between the GNSS base and the mark to get the complete distance between the GNSS base and the micro-station.

Figure 18 shows the micro-station and the solar panel installed on the bridge.

Figure 18: Micro-station and solar panel installed in Weston-Super-Mare

Figure 19: Reference point for vertical alignment – cross marked on wooden beam behind and below pedestrian barrier

15:00 End of the installation in Weston-Super-Mare. End of the campaign in the United Kingdom.

3.2 Drone deployments

3.2.1 The Severn estuary (February 24th, 2023)

The drone campaign was carried out on February 24th, 2023.
The first step consists in installing the GNSS base in Penarth, in a zone quite in the centre of the deployment area to optimise the base length between the 2 extrema points on the drone flights. The base location is shown in Figure 20.

Figure 20: Location of the GNSS base during the drone campaign of the Severn Esturay

Then the first flight started at 8:04 and the last flight started at 10:46 (local time). The departure of the boat from the harbour was driven by the tide timing. The different flights and timing are detailed in Figure 21. All flights were performed at an altitude of ~20m above the water surface and at a speed of 6 m/s. All flights were performed in automatic mode, the drone following the programmed flight plans to guarantee that the measurements are following the Sentinel-3B track, then the centreline of the tributary. The sky was clear, but the wind speed was about 6 m/s with gusts reaching up to 11 m/s. Wave height was bout 1 m during the whole campaign.

The campaign was stopped for safety reason at the end of the flight n°7 (on the comeback) due to too important wind gusts.
A total distance of 50.8 km was measured by the LiDAR altimeter during drone flight.

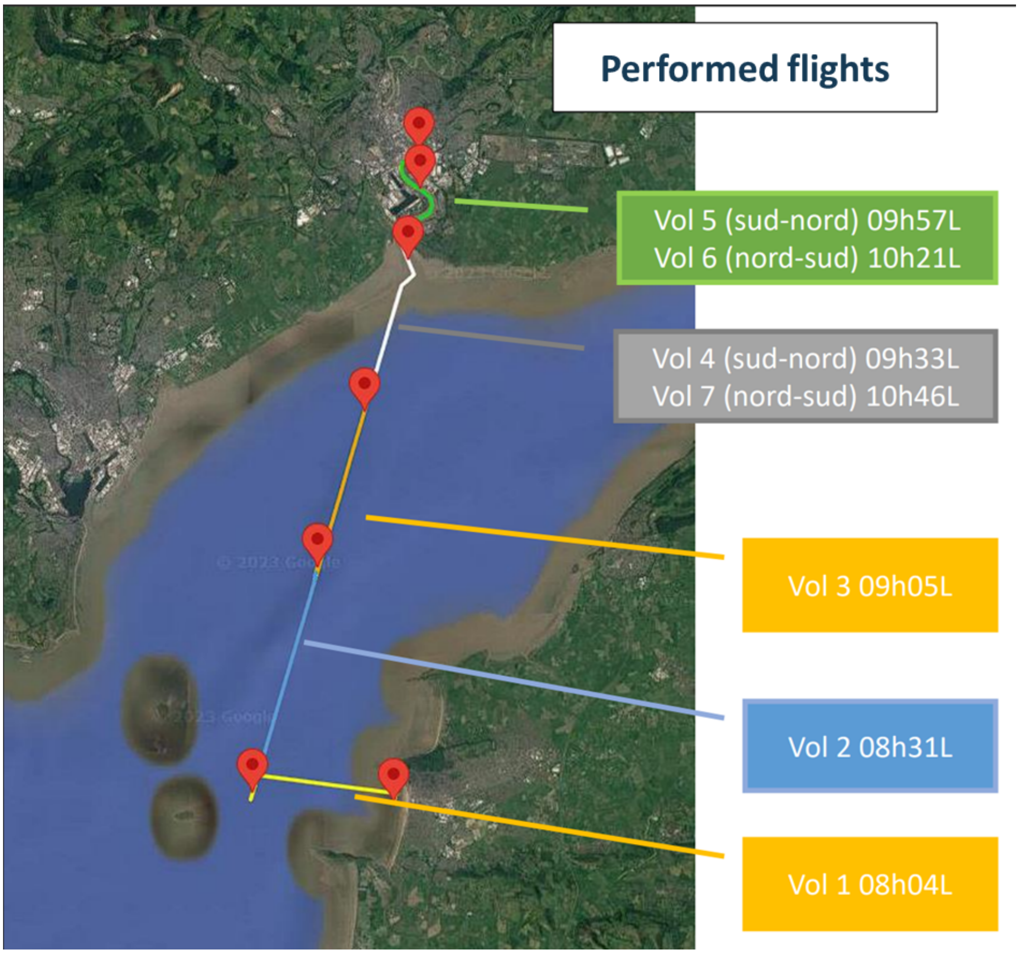

Figure 21: Flights performed during the drone campaign in the Severn estuary

Two events must be noted during the Severn campaign (illustrated in Figure 22):

- a collision with a tanker has been avoided during flight #3 (left map in Figure 22)
- a static flight has been performed in the vicinity of the tide gauge installed in the entrance of the harbour of Newport.

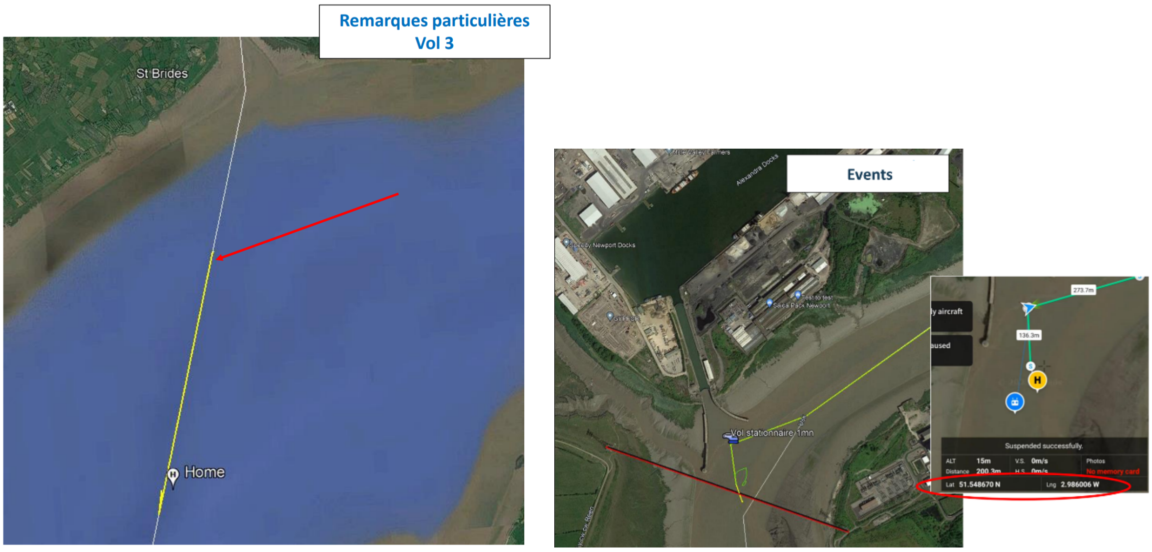

Figure 22: Events occurred during the drone campaign in the Severn estuary (left: collision avoidance, right: static flight in the vicinity of a tide gauge)

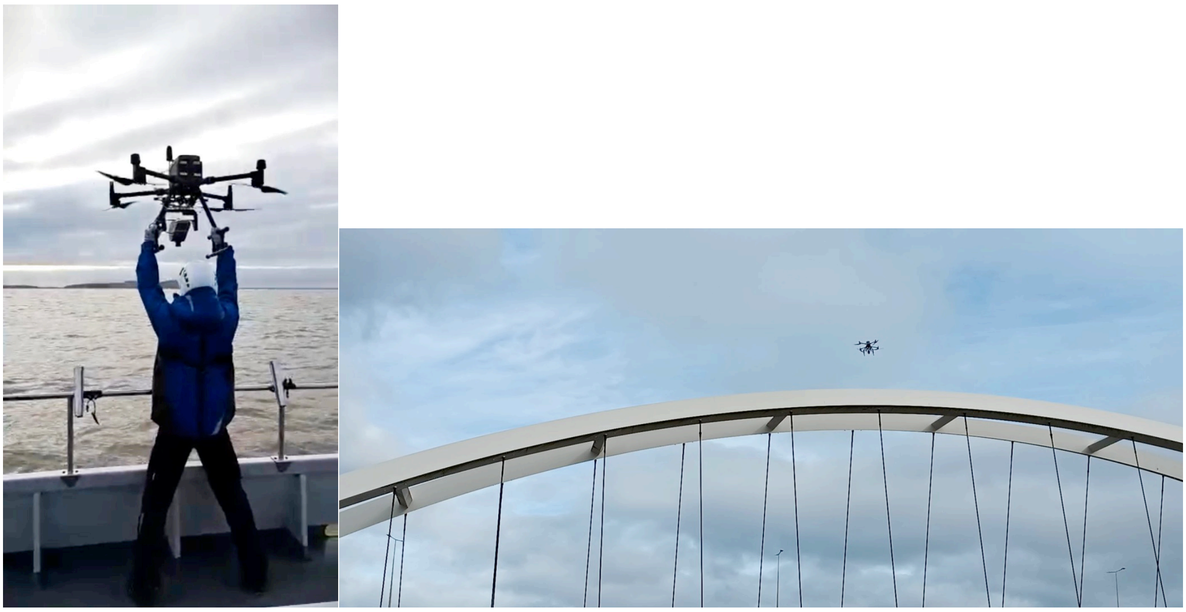

Figure 23: Pictures taken during the drone campaign in the Severn estuary. Left: Take-off from the boat. Right: Drone flying in the vicinity of the Newport bridge

3.2.2 The Rhône delta (April 13th, 2023)

The drone campaign was carried out on April 13th, 2023.
The first step consists in installing the GNSS base in Port-Saint-Louis-Du-Rhône, at 7:40 (local time). A picture of the GNSS base installation is shown in Figure 24.

Figure 24: Picture of the GNSS base installed in Port-Saint-Louis-Du-Rhône.

The maps of the performed flights are shown in Figure 25. All flights were performed at an altitude of 25 m above the water surface at a speed of 6 m/s.
Here is the campaign log:

- **7:40:** Installation of the GNSS base in Port-Saint-Louis-Du-Rhône
- **8:17:** Take-off of the first flight above the canal where the micro-gauge is installed.
- **9:29:** Take-off of the first flight above the Rhône River close to the canal.
- **9:44:** Take-off of the second flight above the Rhône River (in the downstream direction).
- **10:17:** Take-off of the third flight above the Rhône River (in the downstream direction).
- **11:03:** Take-off of the fourth flight above the Rhône River (in the downstream direction).
- **11:26:** 3 attempts to perform measurements at the south extrema, but loss of the radio link with the drone each time (the drone automatically come back to the location of the remote control). End of the flights above the Rhône River.
- **13:58:** check of the GNSS base.
- **14:37:** Take-off of the first flight in Fos-Sur-Mer (above the canal).
- **15:15:** Take-off of the second flight in Fos-Sur-Mer (in the bay). Presence of tanker in the area (cf Figure 26)
- **18:10:** Switch off the GNSS base. End of the campaign.

A total of 35.3 km has been measured during this campaign for a total flight duration of 1 hour and 50 minutes.

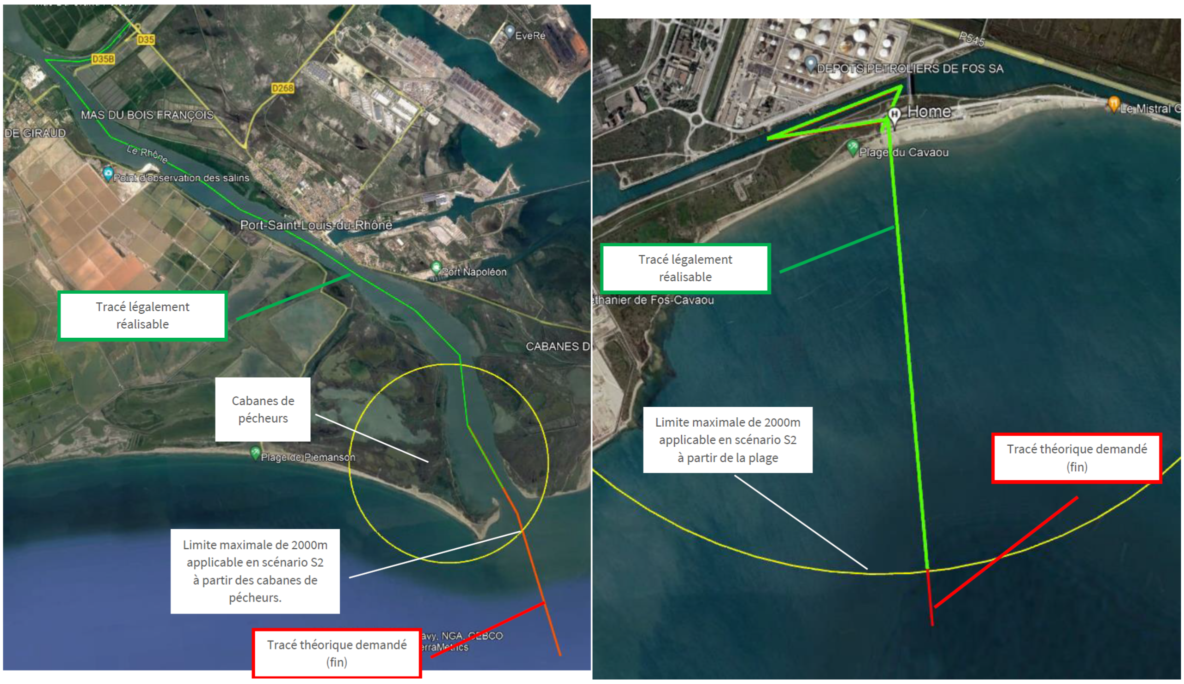

Figure 25: Maps of the flights performed during the Rhone delta campaign. The green lines represent the performed flights. The red lines represent the flights (or parts of flights) that could not be performed.

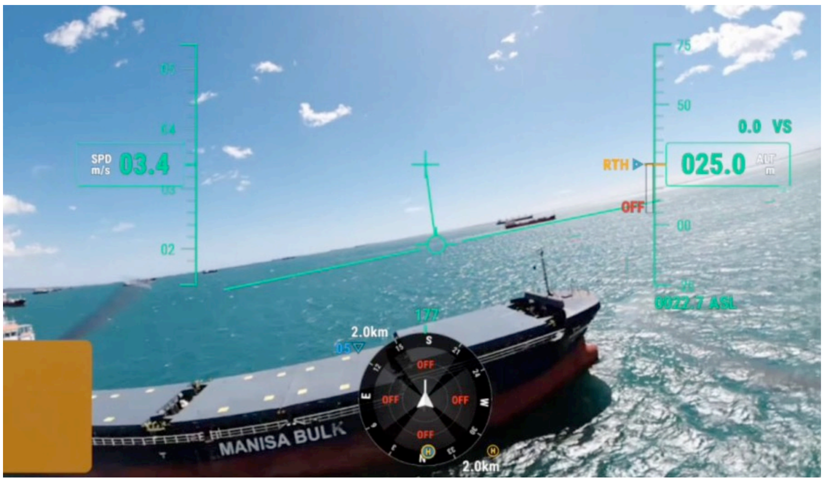

Figure 26: Picture of a tanker taken from the drone camera.

4 First analysis of collected data

4.1.1 Micro-Gauges data

The first step of the data analysis is the computation of the reference height of the micro-stations from the GNSS measurements recorded by the Septentrio base. There are 4 GNSS data processing for this campaign, one for each micro-station. The processing for the installations in the United-Kingdom have not been done yet because there was no GNSS measurements during the installation (GNSS base not available for this installation). Those measurements will be performed later. This processing consists in a Precise Point Positioning (PPP) to compute the precise reference altitude of the base. During the installation, the technicians has measured the distance between the reference point of the micro-station and the centre of phase of the GNSS antenna. With a precise positioning of the base and this distance, we can then compute the height of the micro-station and get the precise height of the water level measured by the LiDAR.

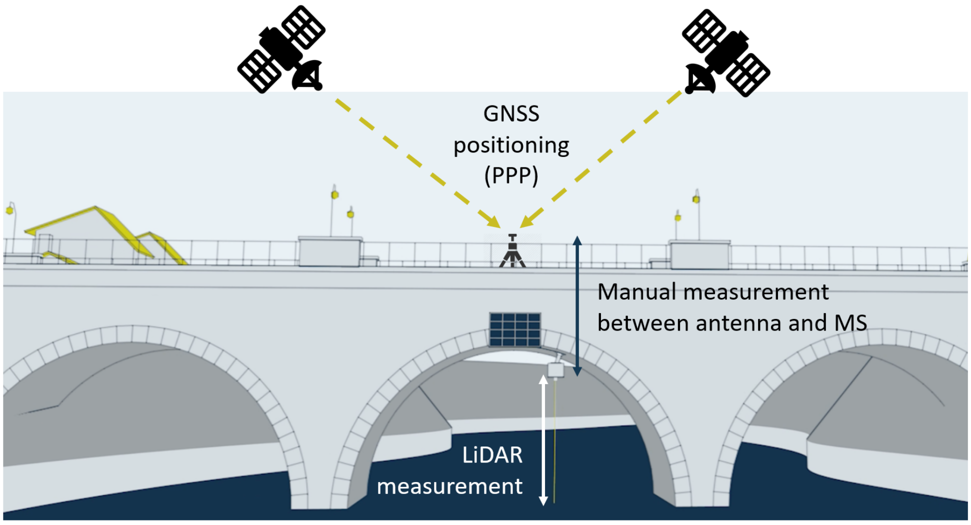

Figure 27: Description of the vorteX-io measurement

To perform the PPP processing we use the GNSS products from the GRGS ("Groupe de Recherche de Géodésie Spatiale") such as the precise ephemeris of the GNSS satellites, the clock corrections, etc.… With these products and the RINEX recorded by the base we can compute the precise altitude of the base. We then compute the median of the base height. The result is an altitude in the WGS84 system. Then we correct this altitude with the French geoid to obtain the orthometric height.

Figure 28 corresponds to the histogram of the position of the base for the installation in Port-Saint-Louis-du-Rhône:

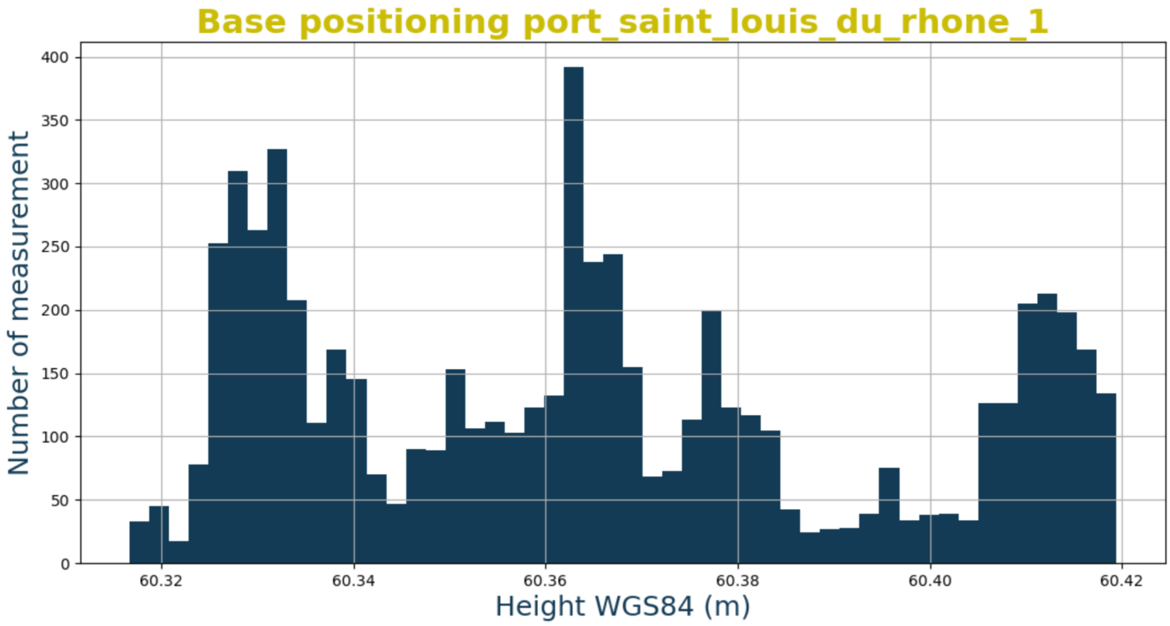

Figure 28: Histogram of the altitude of the bases computed by PPP during the installation

In Fos-sur-Mer the quality of the GNSS positioning is low because the bridge is metallic and generates a lot of perturbations. An altimetric reference has been computed but another GNSS measurement campaign is planned to compute a better altimetric reference. The water surface altitude will be measured in this campaign as reference. Thus, the GNSS base will not be positioned on the bridge avoiding any potential perturbations due to the metallic structure.

Once the positions have been computed, we correct them with the distances measured by the technicians to obtain the precise altitude of the micro-stations. This gives us the precise altitude of the water measured by the micro-station. We obtain the time series measured by the 2 micro-stations named: “port-saint-louis-du-rhone_1” and “fos-sur-mer_1”. These time-series are displayed in Maelstrom platform where a project team FFSAR-Coastal has been created (Maelstrom - Portail d'accès (vortex-io.fr)). All the project team can directly access in real time to the Micro-Station measurements thanks to this web platform. All the information about the station can be found on this platform with the pictures taken by the station. Other information as rainfall rate and local temperatures are also displayed. Other hydrological parameters computed from the water height are displayed on the platform as the water surface elevation speed.

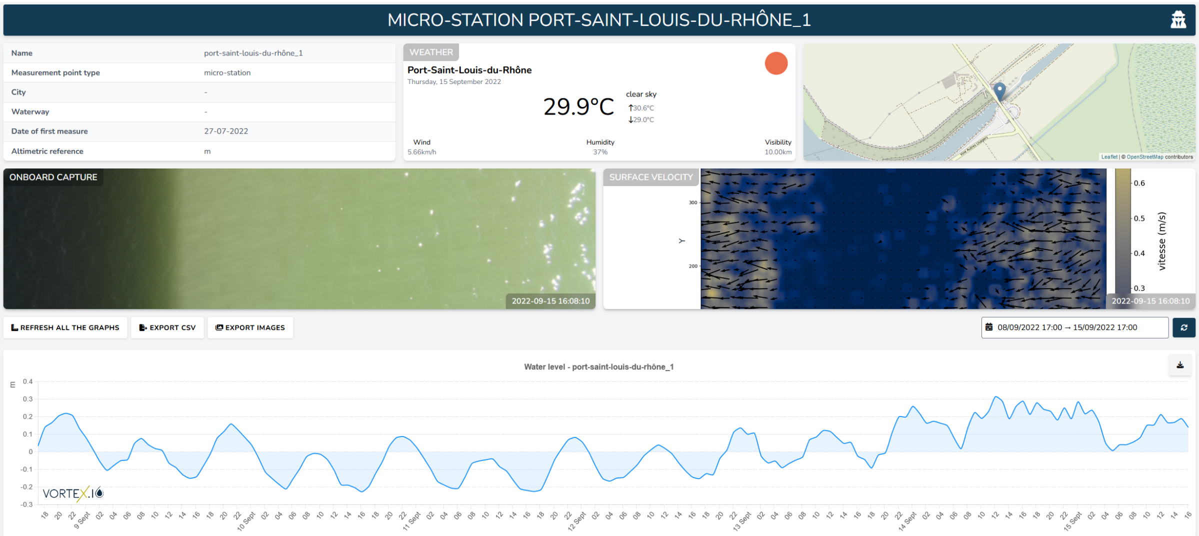

Figure 29: Time series of water surface height measured by the station named "port-saint-louis-du-rhone_1" displayed on Maelstrom, the vorteX-io data visualization platform

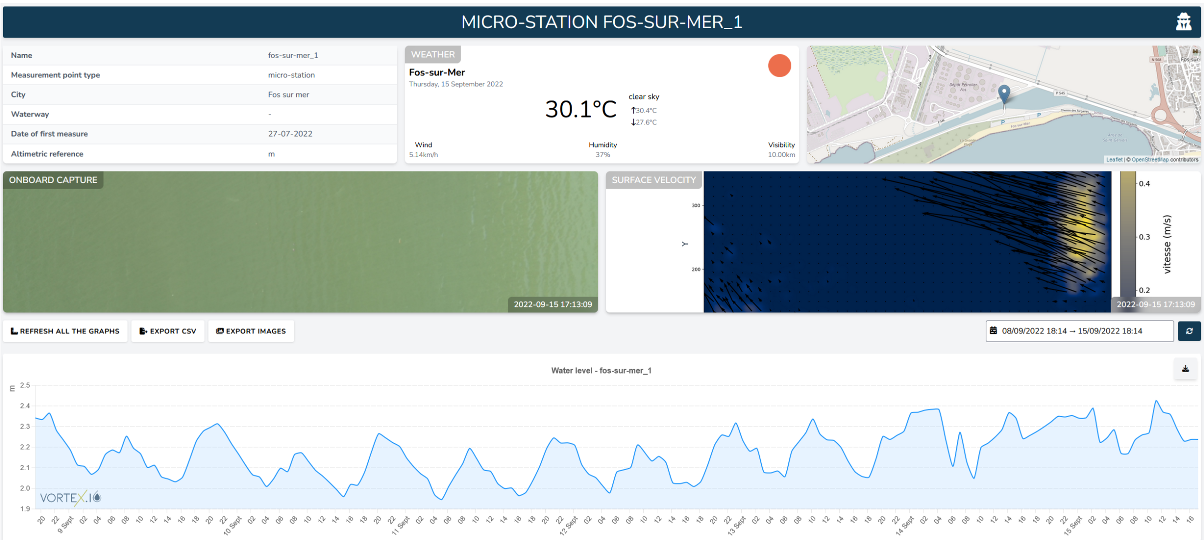

Figure 30: Time series of water surface height measured by the station named "fos-sur-mer_1" displayed on Maelstrom, the vorteX-io data visualization platform

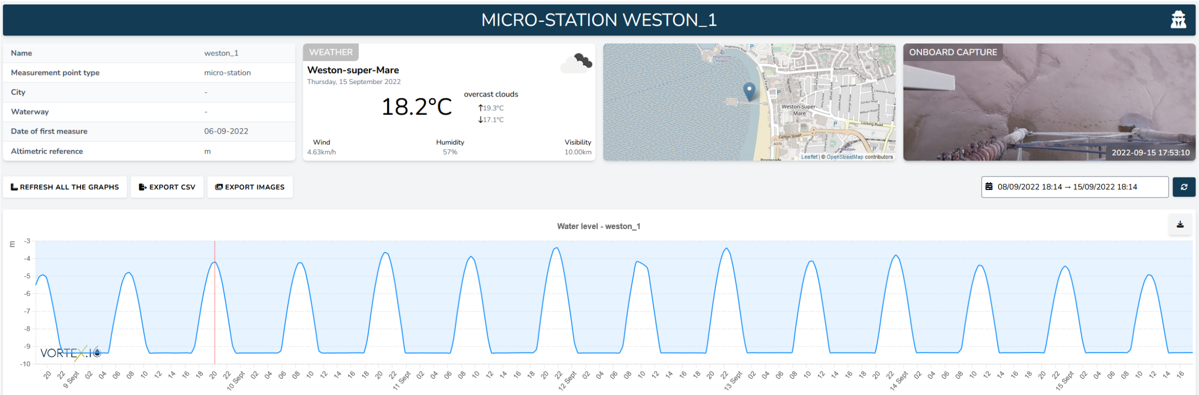

Figure 31: Time series of water surface height measured by the station labelled "weston_1" displayed on Maelstrom, the vorteX-io data visualization platform.

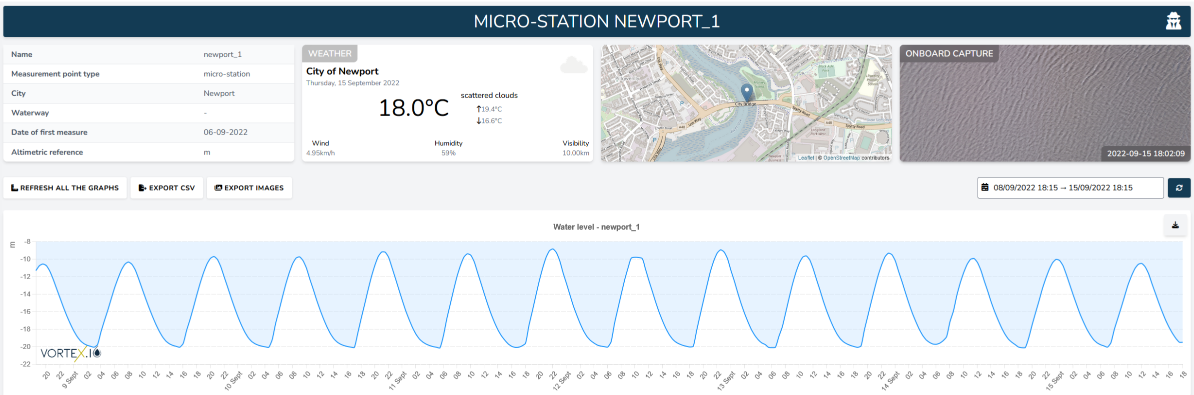

Figure 32: Time series of water surface height measured by the station labelled "newport_1" displayed on Maelstrom, the vorteX-io data visualization platform.

The data measured by the 4 stations are coherent. We clearly observe the tidal signal in the Severn estuary. It is important to note that the site is dry at low tide at the Weston Super-Mare site (weston_1).

4.1.2 Drone data

4.1.2.1 Severn estuary

As explained earlier in this document we need to first compute the precise position of the base to then compute the precise altitude of the altimeter embedded on the drone. The position of the base is obtained by performing a PPP (Precise Point Positioning) processing. The obtained position of the base is very precise, with a standard deviation lower than 3 mm, as shown in Figure 33. The number of satellites tracked by the GNSS base during the acquisition time is around 19 in average. The satellites of the GALILEO, GPS and

GLONASS constellations are used to perform the positioning. The quality of the positioning is very good. The base position is 60.601 m (WGS84).

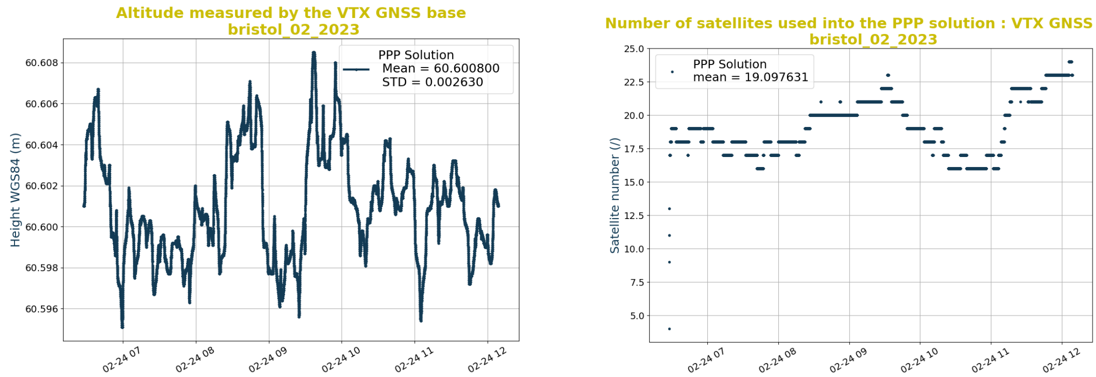

Figure 33: PPP positioning of the base on the left and the number of satellites tracked by the base on the right.

Once the precise position of the base is computed, we can perform the PPK positioning of the altimeter. Almost all the ambiguities are fixed when the altimeter is flying and thus the positioning is of good quality. We can see in Figure 34 the evolution of the altimeter altitude during different flights of the campaign. This precise positioning allows to get a precise water surface height measurement. We can see that 2 flights present a positioning with floating ambiguity solution. For these flights, the positioning quality is not optimal but is still useable to compute the water surface height. No reason has been found to explain this issue, the number of tracked GNSS satellites has simply dropped suddenly.

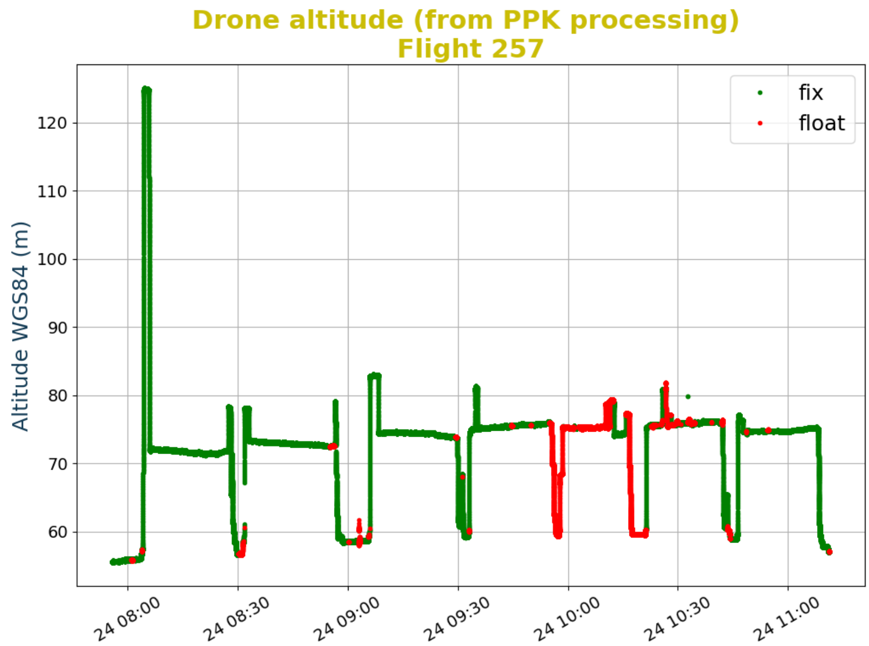

Figure 34: Altitude of the altimeter during several flights of the drone campaign in the Severn estuary. The colors represent the positioning quality (green: ambiguities are fixed, red: float ambiguities)

Once the precise positioning computed, we can compute the water surface height from LiDAR measurements. We have applied a running average (window of 15 seconds) on the WSH measured by the altimeter to decrease the measurement noise. The LiDAR measurements are performed at 7 Hz, and we finally resampled to 0.5 Hz for the data dissemination.

The raw water surface height measurements (before the 15 seconds filtering) from flights from Weston to Newport (South to North) are shown in Figure 35. The observed slope on the measurements is due to the tide evolution during the flights (flights are not instantaneous, each flight lasts between 20 to 30 minutes). Before the filtering, we can clearly see the wave signal on the water surface height measured by the LiDAR altimeter.

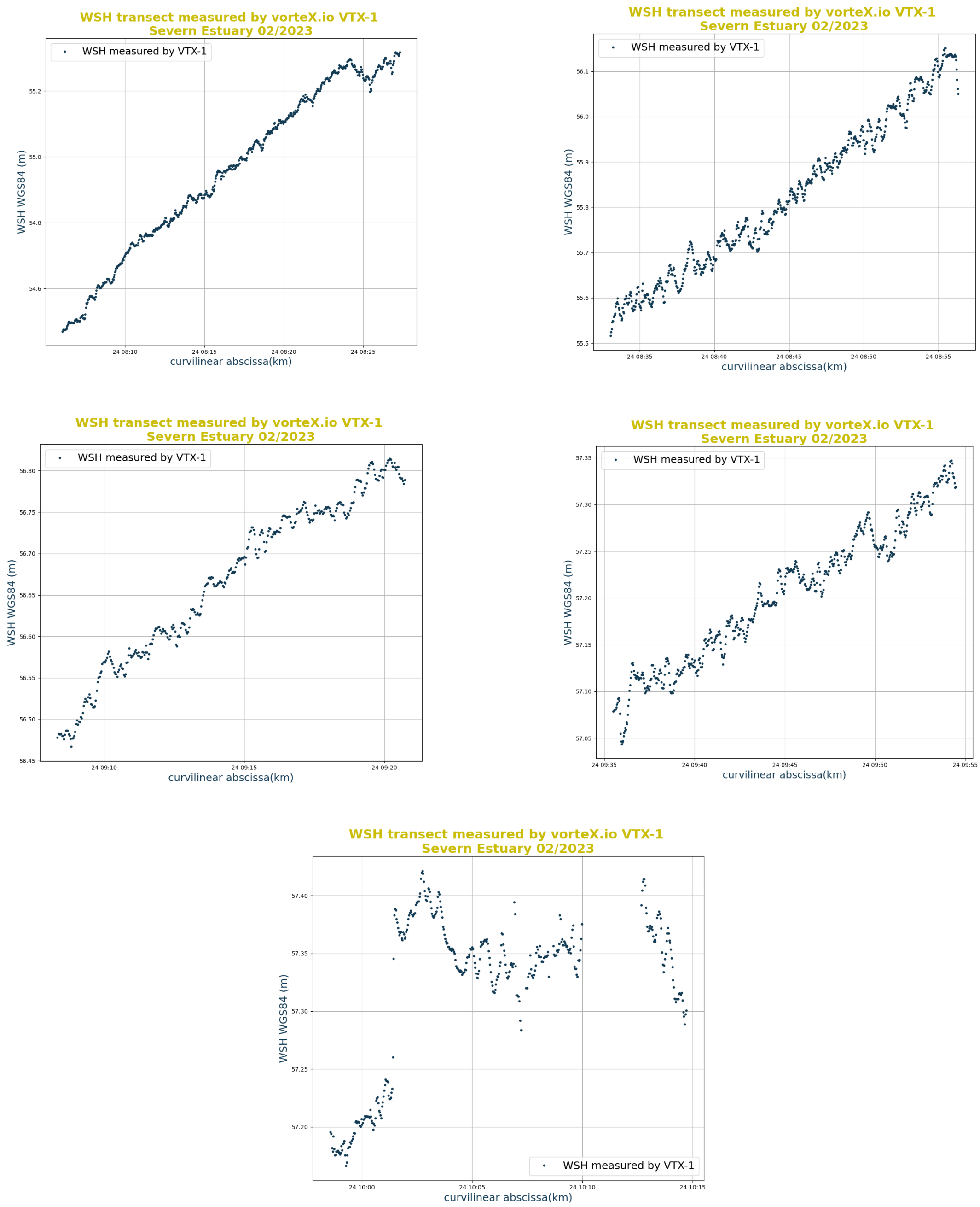

Figure 35: Raw water surface height (before the 15 seconds filtering) measured by the vorteX-io VTX-1 LiDAR altimeter embedded on the drone during the Severn estuary campaign. Each figure corresponds to a flight performed from the South to the North.

The filtered water surface height measurements are given in Figure 36. The objective of this filter is to remove the wave signal.

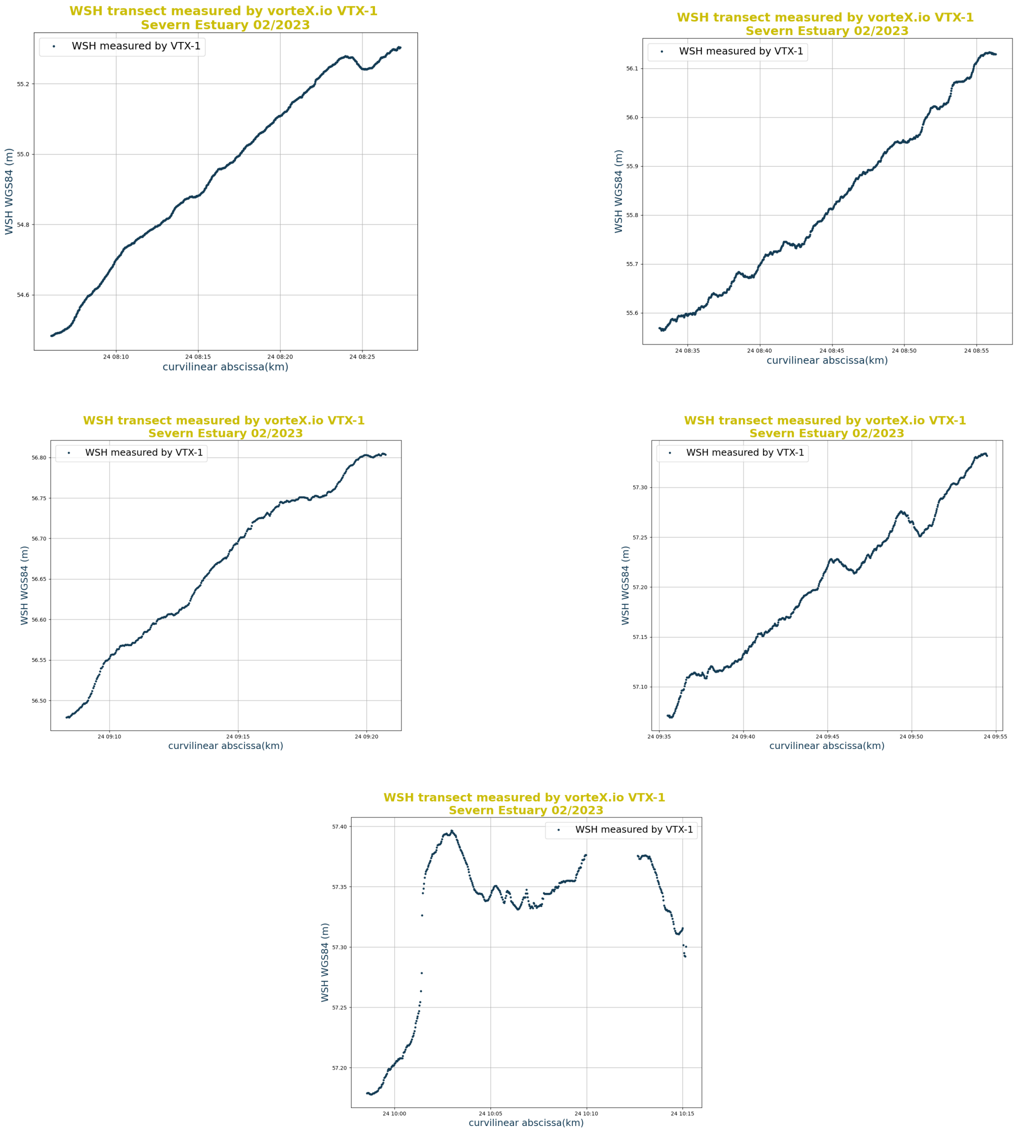

Figure 36: Filtered water surface height (after the 15 seconds filtering) measured by the vorteX-io VTX-1 LiDAR altimeter embedded on the drone during the Severn estuary campaign. Each figure corresponds to a flight performed from the South to the North.

The water surface height measurements performed during the flights from the North to the South (only 2 due to strong winds) are given in Figure 37 before filtering and in Figure 38 after filtering.

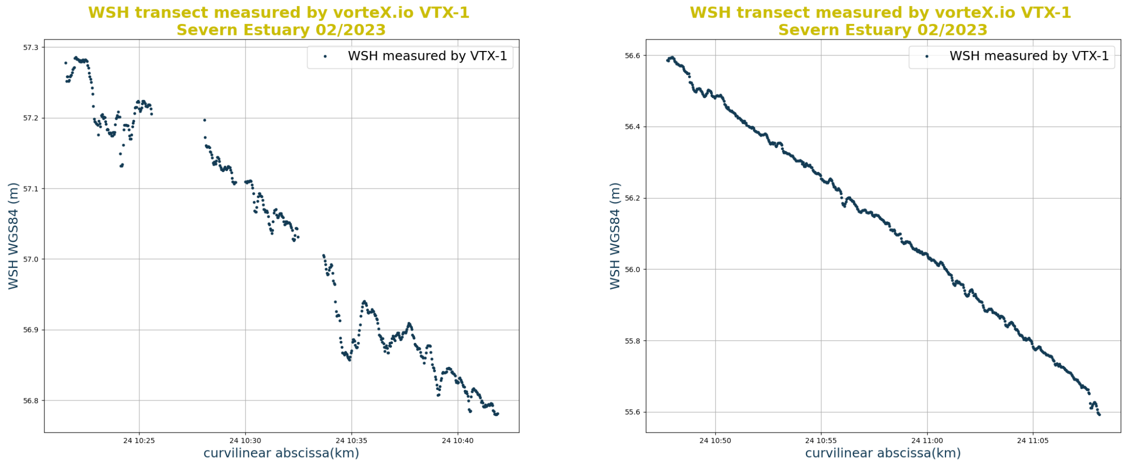

Figure 37: Raw water surface height (before the 15 seconds filtering) measured by the vorteX-io VTX-1 LiDAR altimeter embedded on the drone during the Severn estuary campaign. Each figure corresponds to a flight performed from the North to the South.

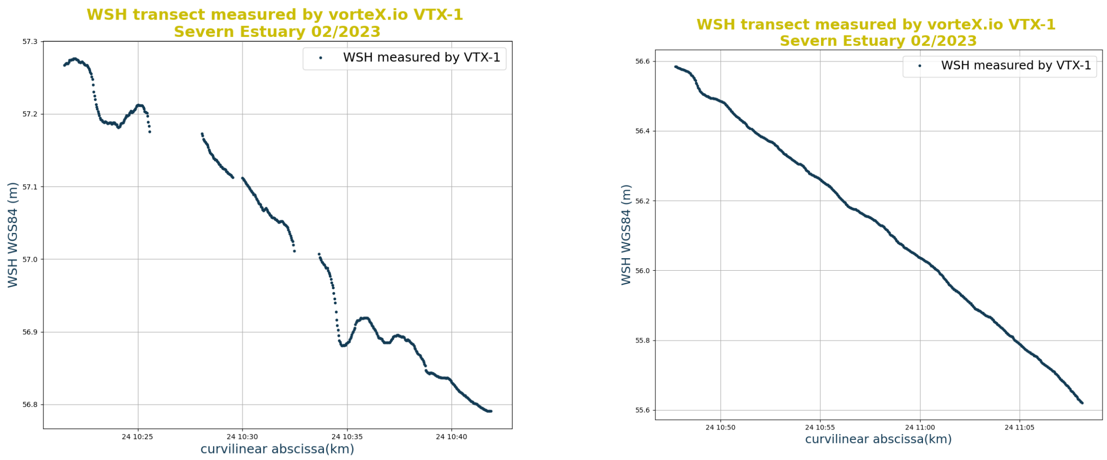

Figure 38: Filtered water surface height (after the 15 seconds filtering) measured by the vorteX-io VTX-1 LiDAR altimeter embedded on the drone during the Severn estuary campaign. Each figure corresponds to a flight performed from the North to the South.

4.1.2.2 Rhône delta

The position of the base is obtained by performing a PPP (Precise Point Positioning) processing. The obtained position of the base is very precise, with a standard deviation close to 1.2 mm, as shown in Figure 39. The number of satellites tracked by the GNSS base during the acquisition time is around 18 in average. The satellites of the GALILEO, GPS and GLONASS constellations are used to perform the positioning. The quality of the positioning is very good. The base position is 51.256 m (WGS84).

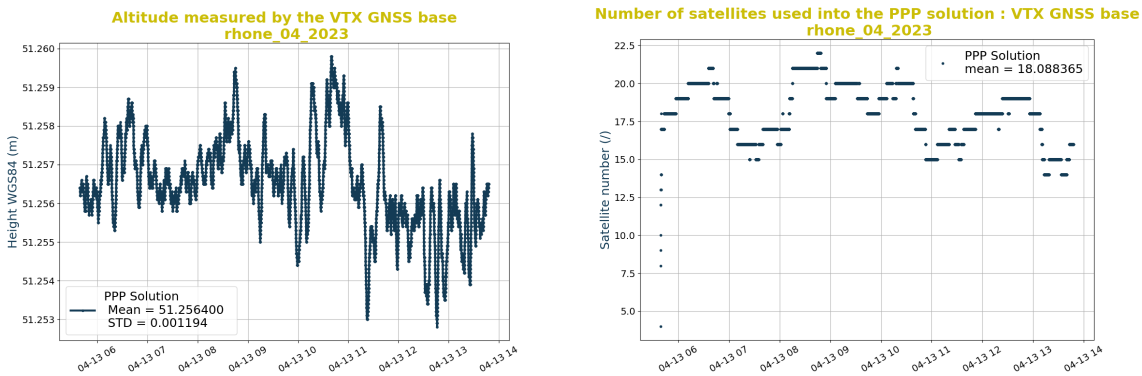

Figure 39: PPP positioning of the base on the left and the number of satellites tracked by the base on the right.

Once the precise position of the base is computed, we can perform the PPK positioning of the altimeter. Almost all the ambiguities are fixed when the altimeter is flying and thus the positioning is of good quality. We can see in Figure 40 the evolution of the altimeter altitude during 1 flight of the campaign. This precise positioning allows to get a precise water surface height measurement. Some floating ambiguities (red points) are visible in this example but are mainly located at the end of the flight, when the altitude of the drone is strongly decreasing during the landing phase. Those points correspond to measurements above land and are thus not considered for computing the water surface height. These floating ambiguities do not impact the quality of the retrieved water surface height.

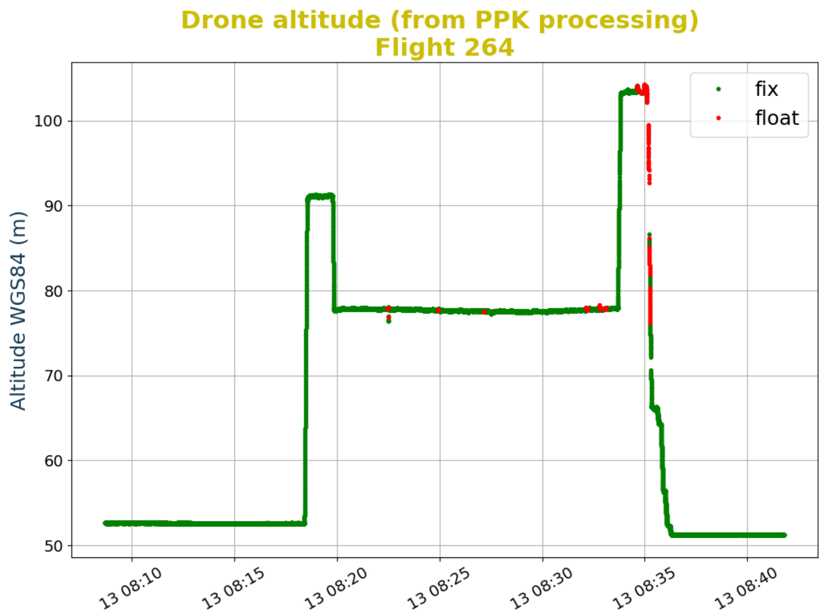

Figure 40: Altitude of the altimeter during several flights of the drone campaign in the Rhône delta. The colors represent the positioning quality (green: ambiguities are fixed, red: float ambiguities)

Once the precise positioning computed, we can compute the water surface height from LiDAR measurements. We have applied a running average (window of 15 seconds) on the

WSH measured by the altimeter to decrease the measurement noise. The LiDAR measurements are performed at 7 Hz, and we finally resampled to 0.5 Hz for the data dissemination. The water surface height measured over the Rhône River (and the canal in Port-Saint-Louis-Du-Rhône where the Micro-Gauge is installed) is given in Figure 41. A curvilinear abscissa has been computed all along the drone flight from the micro-gauge installed on the canal to the mouth of the Rhône River. We can clearly see the slope of the Rhône River (from abscissa 2000 to 14300) until the Mediterranean Sea.

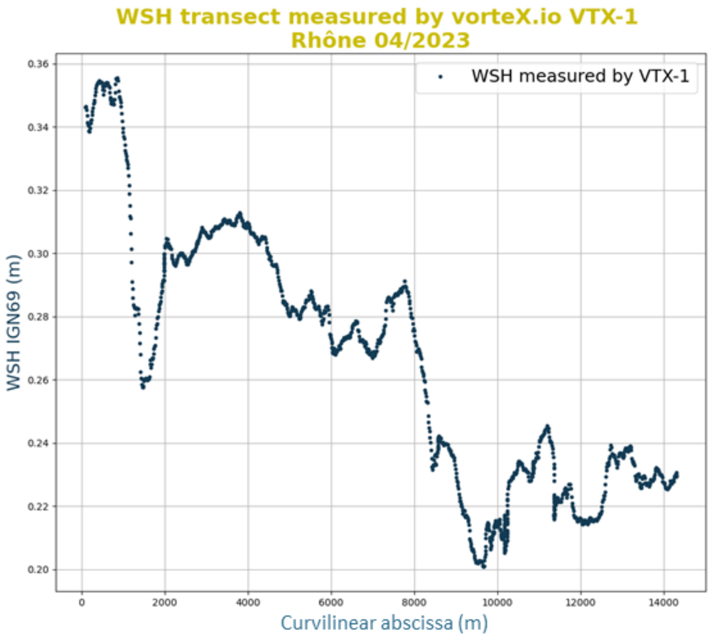

Figure 41: Filtered water surface height measured on the canal in Port-Sain-Louis-Du-Rhône and the Rhône River. The water surface height is plotted as a function of the curvilinear abscissa computed along the drone flight (given in meters), from the micro-gauge in the canal, until the mouth of the Rhône River.

The measured water surface height in Fos-Sur-Mer is shown in Figure 42. The left figure represents the whole campaign in Fos-Sur-Mer as a function of time. It contains several back and forth which explain the height variations. The right figure is a zoom on a one-way flight above the canal where the micro-gauge is installed.

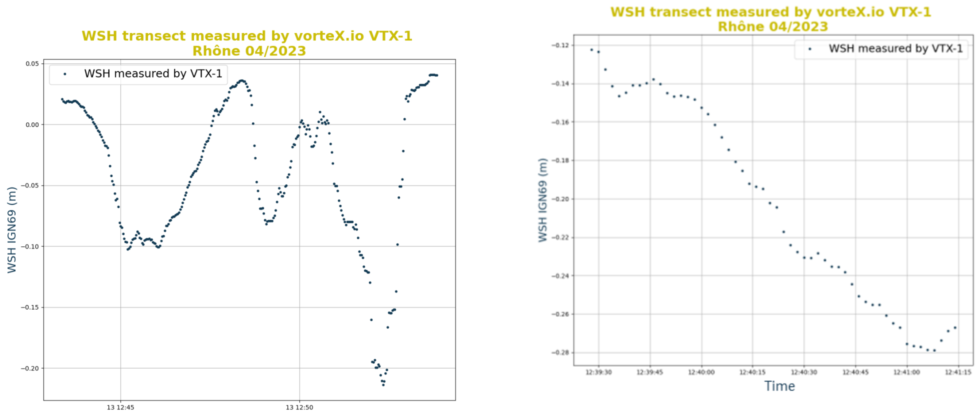

Figure 42: Filtered water surface height measured on the canal in Fos-Sur-Mer and in the bay. Left: the entire flights performed as a fucntion of time. Right: zoom on the part over the canal.

5 Campaigns synthesis

- 4 micro-stations have been installed in the Rhône delta and in the Severn estuary close to, or bellow Sentinel-3 tracks.

- The GNSS PPP processing has provided excellent results on 1 site. The precise positioning of the micro-gauge in Weston and Newport has been performed using the drone measurements (the closest measurements in space and time has been considered). The positioning the micro-gauges installed in Port-Saint-Louis-Du-Rhône and Fos-Sur-Mer have been confirmed by the drone measurements.

- The measurements in all the sites are nominal and all micro-stations are working properly. All stations have been synchronized with their respective Sentinel-3 passes.

- A micro-gauge failure occurred in March on the device installed in Weston. The micro-gauge has been replaced on April 6th. The gauge is working properly since then.

- Drone flights have been performed successfully over the Severn and Rhône estuaries. The resulted measurements present very good quality. Measurements are given in NetCDF format in raw and filtered version on the Severn estuary to see or remove the wave signal. No specific wave signal has been observed in the Rhône campaign, then only the filtered version is given.

- Drone flights have been carried out nearby the micro-stations to measure the topography between the micro-stations and the satellite ground tracks. These drone campaign confirmed the altimetric references of the stations.

List of Acronyms

AD	Applicable Documents
CCO	Channel Coastal Observatory
DTU	Danmarks Tekniske Universitet (Technical University of Denmark)
EO	Earth Observation
ESA	European Space Agency
MTR	Mid Term Review
NOC	National Oceanography Centre
RD	Reference Document
SAR	Synthetic Aperture Radar
SatOC	Satellite Oceanographic Consultants Ltd
SMAP	Stand Alone Multi-Mission Processor
SRAL	SAR Radar Altimeter
S3A, S3B	Sentinel 3A, and Sentinel 3B