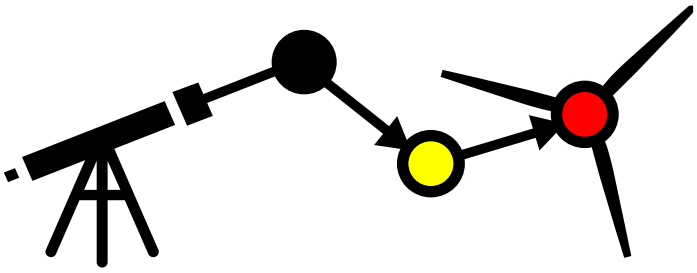
BeFORECAST



Deliverable: Offshore drone campaigns results

Deliverable No.: D1.3

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DOCUMENT SUMMARY

This report details the successful execution and analysis of drone-based meteorological measurement campaigns conducted by SABCA for the BeFORECAST project. The initiative aimed to enhance offshore wind power forecasting by integrating novel drone-collected data. Across 41 flights (29 onshore, 12 offshore), the project validated a comprehensive system that includes sensor integration, operational procedures, and data analysis. Key achievements include the selection and integration of an on-board ultrasonic anemometer on a multicopter platform, utilizing extension mounts (up to 1.0 m) to mitigate rotor-wash effects. A ZX300M lidar served as a crucial reference, deployed on both ground and on a vessel for offshore trials. Comparative analysis demonstrated consistent performance between onshore and offshore lidar references, with a mean offset of ~1.0 m/s between the onboard sensor and lidar. The campaigns successfully de-risked offshore UAS operations, validated measurement methodologies, and delivered datasets, advancing BeFORECAST's capability to incorporate drone-derived wind data into improved offshore wind forecasting models.

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1 Introduction

1.1 Definitions and abbreviations

Within the scope of this document, following abbreviations are applicable.

AMSL	Above Mean Sea Level
ATC	Air Traffic Control
ATO	Above Take-off Level
BU	Business Unit
BVLOS	Beyond Visual Line of Sight
ConOps	Concept of Operations
CTV	Crew Transfer Vehicle
EASA	European Union Aviation Safety Agency
EFS	Emergency Floatation System
ERP	Emergency Response Plan
FTS	Flight Termination System
GCS	Ground Control Station
GND	Ground
GNSS	Global Navigation Satellite System
GWO	Global Wind Organization
Hs	Significant Wave Height
IP	Ingress Protection
LDG	Landing
LiPo	Lithium Polymer Battery
LMRA	Last Minute Risk Assessment
LUC	Light UAS Operator Certificate
MTOW	Maximum Take-Off Weight
NOTAM	Notice to Airmen
NOGEPA	Netherlands Oil and Gas Exploration and Production Association
OHVS	Offshore High Voltage Substation
QRH	Quick Reference Handbook
PDRA	Pre-defined Risk Assessment
PPE	Personal Protective Equipment
PPM	Pre-Post Mission Checklist
RTH	Return To Home
SOP	Standard Operating Procedure
SORA	Specific Operations Risk Assessment
T/O	Take-off
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
VLOS	Visual Line of Sight

1.2 Purpose of the deliverable (D1.3): offshore drone campaign results and readiness

In this deliverable, offshore drone measurement campaigns that are initiated by SABCA are introduced including the preparations done for offshore campaigns.

The purpose is to compare drones' wind speed and direction measurement quality compared to a reference system. For this deliverable, existing and new Belgian wind farm zones were investigated for their relevance of efficiently characterizing wind conditions in offshore wind farms. The Belgian wind farms are located both in Belgian and Dutch airspace, therefore cross-border operations were also taken into account.

In a first stage, all necessary approvals with the relevant authorities were obtained including airspace and windpark owners. Both Belgian and Dutch aviation authorities were involved for the cross-border operations where necessary. The mission requirements and hardware capabilities are transposed into actual missions, both for the flying platforms and the payloads. This enabled the finalization of the SORA and ConOps, which were the basis of the requests for the approvals. These studies and documentations were already shared within the deliverable, D1.2 of this project.

In a second stage, several flight campaigns were organized during the course of the project, testing the developments and integrations of tasks T1.4 and T1.5, in a real-life environment.

1.2.1 Achieved milestones:

1.2.1.1 Mission specification for first offshore drone measurement campaign

Mission specification for first offshore drone measurement campaign milestone was successfully achieved within Beforecast project. This involved the comprehensive definition of the first offshore drone operations, later completed in Norther wind parks. This includes detailed flight plan, crew training and logistics plans for Norther wind park. The specific sensor payload, comprising solutions from FT technologies and SABCA datalogger, was integrated and validated for these missions. The SORA (Specific Operations Risk Assessment) and ConOps (Concept of Operations) documents were finalized and approved by the relevant authorities, ensuring full regulatory compliance for cross-border operations. This milestone provided the essential blueprint for the safe and effective execution of the subsequent offshore measurement campaigns.

1.2.1.2 First offshore drone measurement campaign completed

The first offshore drone measurement campaign was completed on 25.03.2025 at Norther wind park in Belgium. SABCA has executed airborne measurement campaigns at several altitudes. The integrated payload (FT technologies) operated nominally. However, due to technical issues, the reference lidar measurements at Norther could not be taken. Operations were conducted without incident under safe wind conditions, validating the SOPs and risk mitigations defined in risk assessments.

1.2.1.3 Second offshore drone measurement campaign conducted near Princess Elisabeth zone (partial due to logistics)

The second offshore campaign, planned for the Princess Elisabeth zone, was partially achieved. Due to logistical limitations to access Westhinder platform and conduct flights, on-station operations within PEZ were not feasible within the available time window. Activating the contingency plan, SABCA conducted several flights taking off from a rental boat in a coastal offshore area on 22.04.2025. The Alta X payload collected several datalogs from various flight altitude to compare with ZX 300M lidar. The collected datasets supported validation of the wind-profile benchmarks relevant to BeFORECAST project goals.

2 Utilized Drone and Measurement Instruments

2.1 Freefly AltaX Drone Platform Description and Technical Features

The Freefly Alta X is a high-performance professional drone designed for heavy payloads and versatile applications. With an unfolded diameter of 2273 mm (including propellers) and a folded diameter of 877 mm, it offers a compact design for transport while maintaining a robust operational footprint. Standing 387 mm tall (434 mm in Skyview configuration), the Alta X is powered by four high-efficiency motors, each capable of delivering a continuous power output. Its 33x9-inch folding propellers, made from carbon fiber-filled nylon, ensure durability and optimal performance, with two clockwise and two counter-clockwise props for stability.

The drone supports a maximum takeoff weight of 34.86 kg (76.85 lbs) and can carry payloads up to 15.06 kg (33.20 lbs), making it ideal for demanding aerial operations. It is powered by a 44.4V battery system with XT-90 connectors. The Alta X features a custom PX4 flight control stack with multiple flight modes, including manual, position, mission, and return-to-home. It supports various GNSS systems (GPS, Glonass, Baidoo, Galileo) and offers FPV capabilities, along with customizable boom-tip orientation lights. This drone is a versatile and powerful tool for professionals in industries such as cinematography, surveying, and logistics.

For SABCA UAS operations, certain customizations are initiated by the SABCA technical team.

Figure 1: AltaX platform customized for offshore operations.

2.2 On-board Drone Anemometer

The selection of appropriate wind measurement instrumentation was a critical early step in preparing for the demanding offshore drone campaigns. Following several months of rigorous technical benchmarking, a comprehensive evaluation of various anemometer products was conducted. This process focused on identifying sensors that not only met the requirements for offshore deployment but also offered optimal performance when integrated onto a drone platform. Key selection criteria included a simplistic and robust design for reliability in harsh marine environments, high measurement accuracy across a wide range of wind speeds, and crucially, a low weight profile to maximize drone endurance and payload capacity. Based on these factors and their proven performance in similar applications, ultrasonic anemometers emerged as the preferred technology.

Further in-depth research, including detailed supplier meetings and a thorough review of relevant scientific articles and industry case studies on drone-based wind measurement campaigns (particularly those conducted by reputable universities and leading industrial entities), solidified this decision. This extensive study led to the selection of FT Technologies' FT743 model ultrasonic anemometer for offshore operations. The FT743 was chosen for its exceptional combination of compact size, minimal power consumption, rapid response time, and its ability to provide precise wind speed and direction data without moving parts, making it ideally suited for the dynamic and challenging conditions anticipated during the offshore drone campaigns.

Figure 2: FT743-D-SM model acoustic anemometer is used during drone campaigns.

2.3 Reference Measurement Device

To ensure the highest quality and validate the accuracy of the drone-collected data, a robust reference measurement system was essential. For this purpose, the ZX300M lidar was selected and rented for a one-month period. This model was chosen due to its established reputation and proven performance in challenging offshore environments, notably being the same unit deployed by the Norther wind park on its Offshore High Voltage Substation (OHVS) and Westhinder platform.

Figure 3: ZX300M lidar is used during test campaigns as a reference measurement unit.

The ZX300M's capability to provide highly accurate, long-range wind profile measurements made it an ideal candidate for comparative analysis. Its deployment allowed for a direct, independent validation of

the drone-mounted anemometer data, providing a crucial benchmark against a trusted, industry-standard offshore measurement system. This comparative approach was important for building confidence in the drone's measurement capabilities and ensuring the reliability of the data delivered to the BeFORECAST project.

Figure 4: ZX300M lidar is used during test campaigns as a reference measurement unit. This image is retrieved from Droneport tests conducted by SABCA.

3 Mission Preparations

3.1 Site Surveys

A site survey is a critical step in planning and executing drone servicing and maintenance operations. It involves a comprehensive assessment of the operational site to identify potential risks, logistical challenges, and environmental factors that could impact drone performance and safety. The survey ensures that the site is suitable for drone operations and helps operators make informed decisions about equipment, personnel, and procedures. By conducting a thorough site survey, operators can minimize risks, optimize operations, and ensure compliance with regulatory requirements.

3.1.1 Environmental Assessment

Environmental assessment focuses on evaluating the natural conditions of the site, such as:

Weather Patterns: Identifying wind speeds, temperature variations, and precipitation levels that could affect drone performance.

Terrain Analysis: Assessing the topography, vegetation, and potential obstacles like trees or buildings.

Environmental Responsibility in North Sea Offshore Operations: Offshore operations in the North Sea are governed by strict environmental and safety regulations to minimize ecological impact and ensure accountability. One critical requirement is that all parties involved in these operations must retrieve any equipment, tools, or parts that accidentally fall into the ocean during their activities. This mandate helps prevent marine pollution, protects aquatic ecosystems, and ensures the safety of navigation in the area. Additionally, all such incidents must be promptly reported to the relevant authorities, detailing the nature of the lost items and the measures taken for their recovery. Compliance with these regulations proves the industry's commitment to environmental and operational responsibility.

This assessment helps operators plan for environmental challenges and ensures that drones are equipped to handle site-specific conditions.

3.1.2 Infrastructure Mapping

Infrastructure mapping involves identifying and documenting all relevant infrastructure at the site, such as:

Landing and Take-off Zones: Designating safe areas for drone operations.

Power Sources: Locating nearby power supplies for charging batteries or operating equipment.

Access Points: Mapping roads, pathways, and other access routes for personnel and equipment.

This component ensures that the site is logistically prepared for drone servicing and maintenance activities.

3.1.3 Communication and Navigation Analysis

Communication and navigation analysis evaluates the availability and reliability of systems required for drone operations, including:

GPS Signal Strength: Ensuring accurate navigation and positioning.

Radio Communication: Verifying that operators can maintain clear communication with drones and ground teams.

Connectivity: Assessing the availability of cellular or satellite networks for data transmission and remote monitoring.

This analysis ensures that drones can operate safely and effectively without losing connectivity or navigation capabilities.

3.1.4 Regulatory Compliance

Regulatory compliance involves reviewing the site's adherence to local, national, and international regulations, such as:

Airspace Restrictions: Identifying no-fly zones or restricted airspace.

Permits and Approvals: Ensuring that all necessary permissions for drone operations have been obtained.

Safety Standards: Verifying that the site meets safety requirements for personnel and equipment.

This component ensures that drone operations are legally compliant and reduces the risk of regulatory violations.

3.2 Benefits of Site Survey

Conducting a site survey offers several benefits that enhance the safety, efficiency, and success of drone servicing and maintenance operations:

Risk Mitigation: Identifying and addressing potential hazards before operations begin reduces the likelihood of accidents or equipment failures.

Operational Efficiency: Understanding the site's layout and conditions allows operators to plan more efficient workflows, saving time and resources.

Regulatory Compliance: Ensuring adherence to regulations minimizes legal risks and avoids delays caused by non-compliance.

Improved Decision-Making: A detailed site survey provides operators with the data needed to make informed decisions about equipment, personnel, and procedures.

Enhanced Safety: By addressing environmental, logistical, and regulatory challenges, site surveys create a safer operational environment for both drones and personnel.

3.3 SABCA Site Survey at Norther Wind Parks

3.3.1 Site Survey Description and Activities

On 16.10.2024, SABCA conducted a site survey at Norther wind park. This site survey is done for the preparation of SABCA offshore drone flights at Norther wind park. It mainly focuses on assessing the environment to ensure safe and efficient drone operations. The job includes evaluating factors such as wind patterns, sea state, and visibility conditions that may impact drone flight performance. Surveyors used specialized equipment to gather data on potential obstacles, communication signals, and flight paths. As part of the RF spectrum analysis, recording of the existing wavelengths is done. The role requires coordination with drone operators and offshore engineers to ensure that the survey supports precise and secure flight planning. Strict adherence to safety protocols and regulatory guidelines for both offshore

and airspace operations is essential. The findings are documented clearly to facilitate successful drone missions and project objectives. The work requires use of CTV and accessing to OHVS's top deck where the drone operations take place.

3.3.2 Main Equipment and Preparation

For site survey at Norther, SABCA team prepared various equipment and PPE to have a successful result in the offshore environment. Some of this equipment include, a robust GPS device, a spectrum analyser with its laptop and software (see Figure 5), various size transportation boxes, and offshore grade PPE in-line with Norther induction trainings and requirements to access to CTV and OHVS platforms.

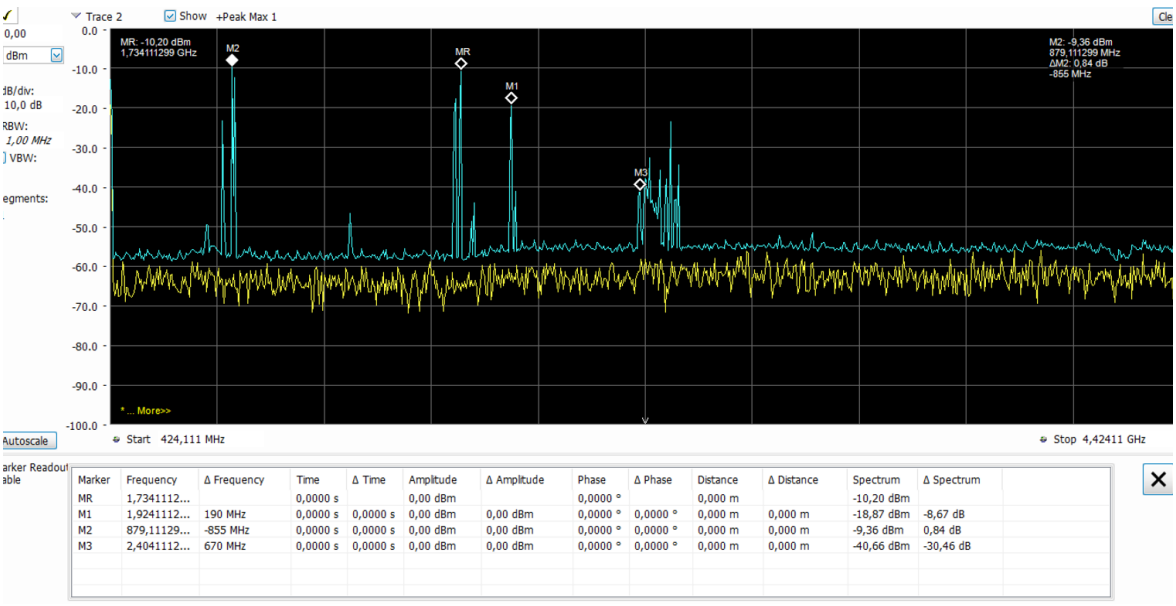

Figure 5: Various signal sources recorded on Norther OHVS using a spectrum analyzer.

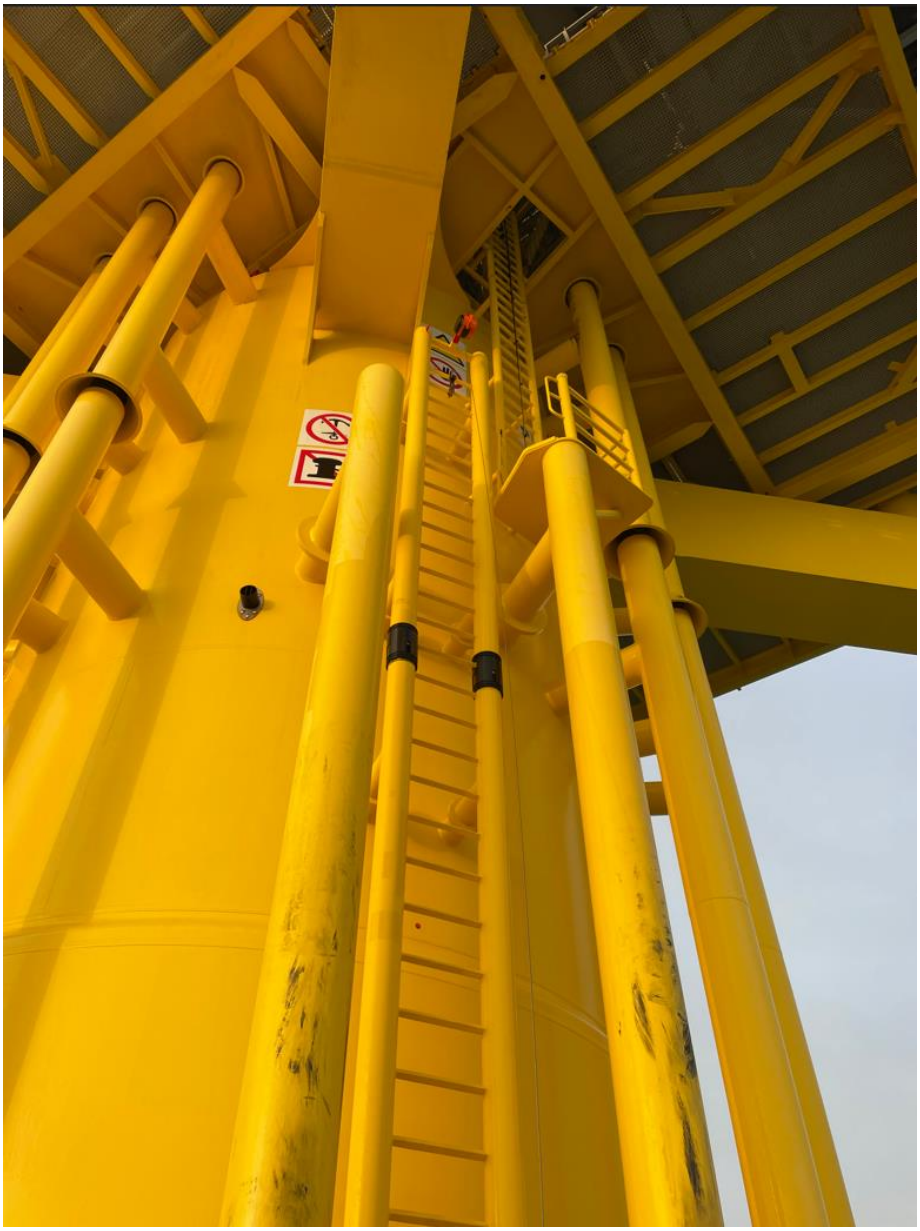

Figure 6: Access to OHVS requires specific GWO trainings and certifications. One of them includes working at heights training to be able to transfer the crew from CTV to OHVS.

3.3.3 Required Certificates and Documents

SABCA personnel kept close contact with Norther officials to make sure all crew members that will take part in offshore missions and site survey get the required training and certifications. Most of the certifications are uploaded on an online platform called Offshare. Here below is the list of some of the certificates and documents that SABCA has prepared and provided where necessary. This list is in-line with Norther training matrix to be fulfilled before accessing offshore vessels and structures:

- ID cards of the personnel

- Nogepa Medical Certificates
- Work Permit
- GWO Trainings
- Picture of the personnel
- Blood Group of the personnel
- BA5 Certification of the personnel
- Norther Induction Trainings
- Pilot certificates
- LMRA

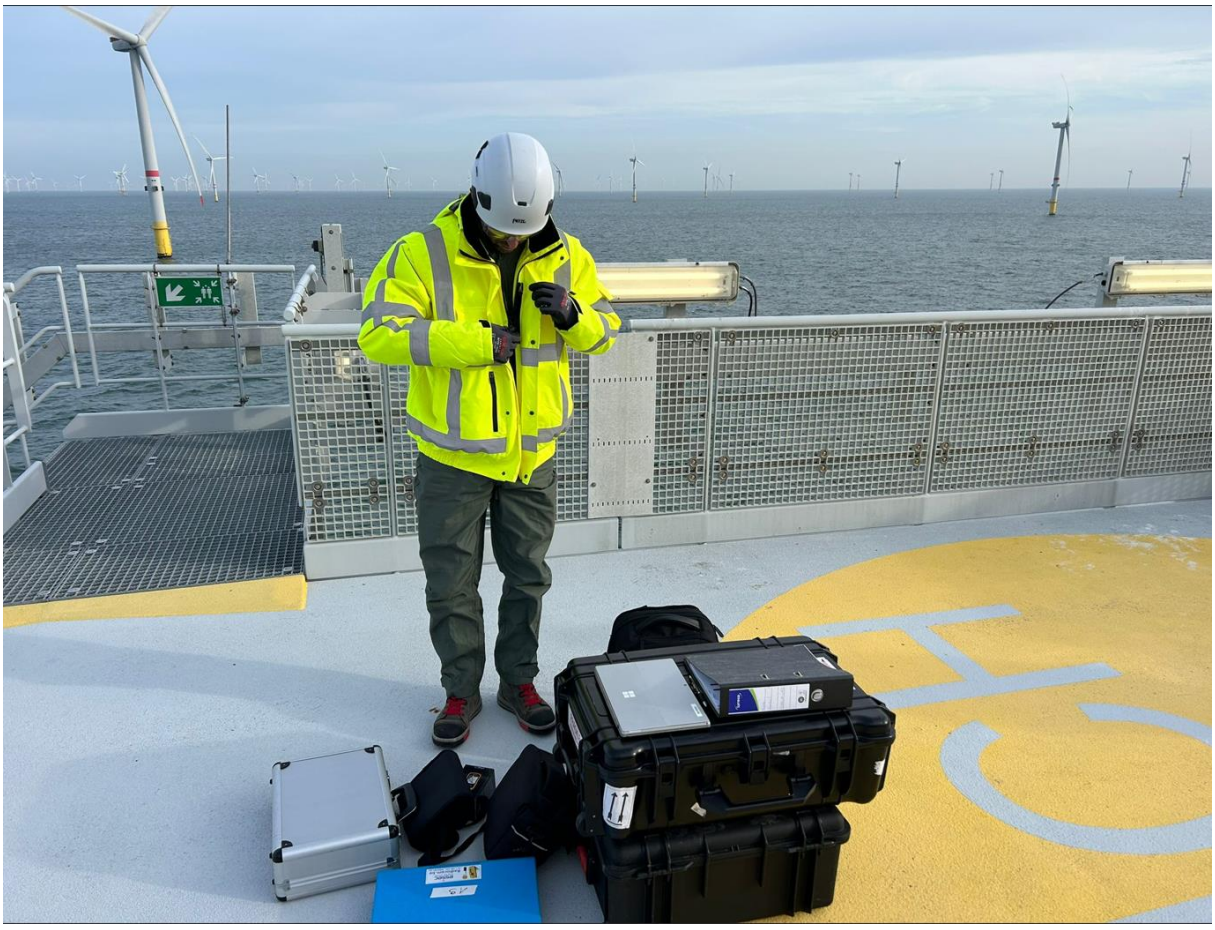

Figure 7: SABCA crew prepared measurement equipment for the site survey while keeping the necessary PPE on all the time during site survey activities on Norther OHVS.

3.3.4 Inspections

The site survey at the Norther Wind Park Offshore High Voltage Station (OHVS) was conducted to ensure the feasibility, safety, and efficiency of offshore drone operations. The inspection of the take-off and landing site (OHVS) involved assessing the dimensions and surface type of the take-off area, verifying its suitability using pre-survey data, and identifying potential changes due to site-specific factors like crane locations or restricted access. The exact coordinates and altitude of the take-off location were recorded, and potential risks such as nearby obstructions (e.g., power lines, cranes, and buildings) were analyzed. The survey also evaluated access to the take-off area, radio line-of-sight between the Ground Control System (GCS) and the take-off location, and transport logistics.

Figure 8: Potential energy sources are defined for the mission equipment.

Connectivity was assessed through internet access tests (4G, 5G, Wi-Fi) and RF spectrum analysis, while flight and approach paths were reviewed for obstructions. Visual documentation of the site, including

wind turbines and potential hazards, was carried out, and practical considerations like crew facilities, safe corridors, and preparation areas were identified.

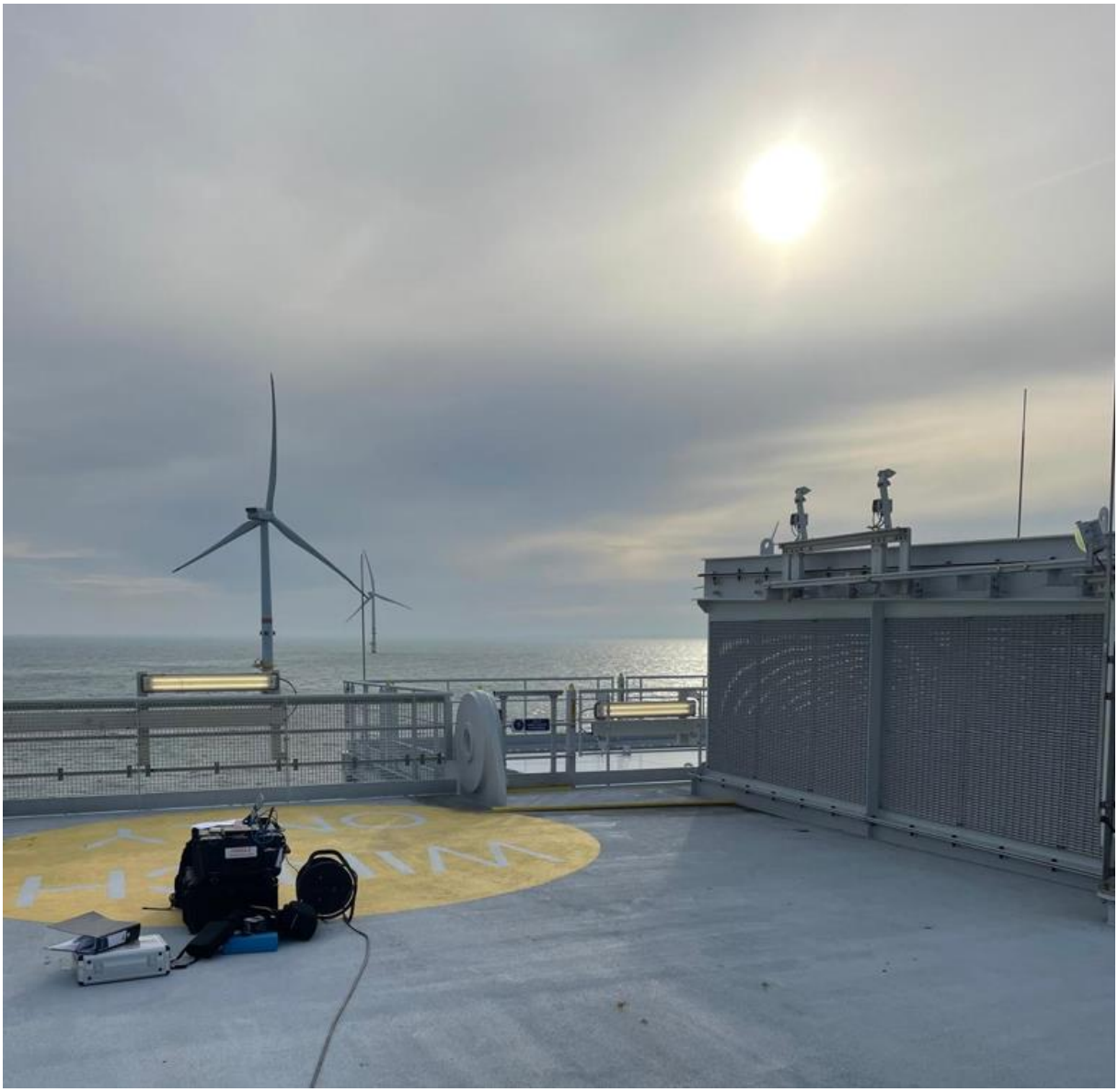

Figure 9: T/O and landing locations are clarified. Potential emergency landing locations are defined.

Figure 10: Obstacles such as nearby antennas are identified.

The Crew Transfer Vehicle (CTV) inspection focused on its operational readiness for transporting equipment and personnel to the OHVS. This included determining the meet-up location, crew positions, and travel time, as well as assessing the CTV's dimensions and procedures for accessing the OHVS. Equipment transfer limitations were identified, and the GCS setup was tested as part of a simulated flight mission. Power supply availability, potential interferences, and obstructions were also evaluated. Visual observers (VOs) were positioned to ensure clear airspace visibility and effective communication with pilots and vessels. Additional assessments included the placement and calibration of antennas, ensuring secure and stable setups, and evaluating workspace and storage facilities for UAV equipment, tools, and power supply. These activities were essential to ensure operational readiness, mitigate risks, and address logistical and safety requirements for offshore drone operations.

4 Missions

Additional to the lab tests, multiple operations are conducted to ensure the drone system is ready for the offshore missions. In total, 41 flights tests are completed. 29/41 were in on-shore conditions, and 12 offshore flights. See below table for the breakdown:

Table 1: Breakdown of mission flights.

Count of Static/Flight	Sensor stick size [m]	Measurement Height [m]		
	0.5	0.75	1	Grand Total
Measurement location				
Albatros		7		7
Droneport	24	3	2	29
Norther	5			5
Grand Total	**29**	**10**	**2**	**41**

4.1 On-shore Missions

On-shore mission campaigns are completed in Droneport (Drone test center)in Belgium. Droneport flights are conducted by SABCA for multiple days to prepare for offshore flights using the development and final payload layout. The intention was to simulate all possible flight campaigns in a rather safe environment while also considering the potential failure modes and determine how to mitigate them.

In the initial stage, all flights are completed with dummy payloads to determine the best flight path for measurement campaigns considering endurance limitations. Once the flight path and the number of flight cycles are clear, rest of the test flights are completed with the final offshore configuration which includes units such as the final anemometer payload layout with different stick length options, floatation devices and communication modules. See the following figures for some of the layouts that are used at Droneport test campaigns.

Figure 11: Droneport flight setup using 50cm stick design.

Figure 12: Droneport flight setup using 75cm stick design.

Figure 13: Droneport flight setup using 100cm stick design.

Figure 14: SABCA drone during its' flights tests with anemometer payload.

Figure 15: SABCA Droneport flights to prepare for offshore missions with anemometer payload.

4.2 Offshore Missions

4.2.1 Offshore Drone Operations at Norther

4.2.1.1 Preparations

On top of test flights at Droneport, SABCA also prepared some key documentations for offshore operations. These documents were developed to ensure the smooth execution of operations, compliance with regulatory standards, and the safety of all stakeholders involved. Some of these documents include a detailed planning presentation outlining the objectives and logistics of the operations, a PPM checklist to ensure all critical steps are addressed before and after each mission, a QRH for immediate guidance for the crew, and an ERP to address potential incidents effectively. Additionally, SABCA conducted comprehensive risk assessments to identify and mitigate potential hazards, developed payload integration procedures and manuals to ensure seamless integration of equipment, and prepared a PDRA to comply with aviation safety requirements. Furthermore, flight cards were created to document mission-specific details, and CONOPS was prepared to provide a high-level overview of the operational framework. Alongside these efforts, SABCA ensured the regular maintenance of all equipment, and protocols to guarantee optimal performance and reliability during operations.

Figure 16: Drone preparations are completed on OHVS before each flight.

4.2.1.2 Weather conditions

Weather conditions are critical for planning and performing the missions offshore. There are multiple layers of information to check. Some are as follows: wind speed, wind gusts, precipitation, visibility, mean sea height level, ambient temperature, lightning risk.

Most of this information is retrieved from StormGeo and compared with various sources. The day of the operations at Norther (25.03.2025), the weather report is as follows:

CET	CONF	WINDS							TOTAL SEA				WIND WAVES			SWELL			WEATHER			CURRENT	
Date Time	Conf	Dir	Ws10m	Wg10m	Ws70m	Wg70m	Ws100m	Wg100m	Hs	Hmax	Tz	Tp	H	T	Dir	H	T	Dir	T2m	Vis	SST	Dir 0m	Cs0m
		(°)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m)	(m)	(s)	(s)	(m)	(s)	(°)	(m)	(s)	(°)	(°C)	(m)	(°C)	(°)	(m/s)
TUE																							
25/03 06		250	5	6	7	8	8	9	0.6	0.9	3.6	5.2	0.3	1.9	260	0.6	4.6	3	7	10,000.0	7	214	0.5
25/03 07		247	5	7	8	9	8	9	0.6	0.9	3.5	5.2	0.3	2.0	257	0.6	4.6	2	7	10,000.0	7	206	0.4
25/03 08		248	6	7	7	9	8	9	0.6	0.9	3.4	5.1	0.3	2.2	256	0.5	4.6	1	8	10,000.0	7	154	0.2
25/03 09		253	6	8	7	8	8	9	0.6	0.9	3.3	5.0	0.4	2.3	258	0.5	4.6	1	8	10,000.0	7	72	0.4
25/03 10		257	7	9	7	8	7	8	0.6	0.9	3.3	4.7	0.3	2.4	260	0.4	4.5	359	8	10,000.0	7	58	0.7
25/03 11		264	6	9	7	8	7	8	0.6	1.0	3.3	4.4	0.4	2.5	266	0.5	4.5	359	8	10,000.0	7	53	0.8
25/03 12		271	6	9	6	7	7	8	0.5	0.8	3.3	4.2	0.3	2.5	270	0.4	4.3	351	8	10,000.0	7	51	0.8
25/03 13		271	5	8	6	7	6	7	0.5	0.8	3.3	4.1	0.3	2.3	269	0.5	4.0	334	8	10,000.0	7	46	0.6
25/03 14		272	5	7	6	7	6	7	0.5	0.8	3.3	4.0	0.3	2.2	270	0.5	4.0	330	8	10,000.0	8	31	0.2
25/03 15		274	4	7	6	7	6	7	0.5	0.8	3.3	4.0	0.2	2.0	272	0.4	3.9	324	8	10,000.0	8	276	0.1
25/03 16		275	4	6	6	7	6	7	0.4	0.7	3.3	4.0	0.2	1.7	276	0.4	3.8	320	8	10,000.0	8	237	0.3
25/03 17		286	4	5	5	6	6	6	0.4	0.7	3.3	4.0	0.1	1.6	286	0.4	3.8	319	8	10,000.0	8	229	0.6
25/03 18		279	4	5	5	6	5	6	0.4	0.6	3.3	4.1	0.1	1.3	275	0.4	3.7	319	8	10,000.0	8	228	0.7
25/03 19		281	4	6	5	6	6	6	0.4	0.6	3.4	4.2	0.1	1.4	282	0.4	3.8	322	8	10,000.0	8	229	0.6
25/03 20		299	5	6	5	6	5	6	0.4	0.6	3.3	4.4	0.1	1.5	301	0.3	3.9	325	9	10,000.0	8	225	0.4
25/03 21		323	5	6	6	7	6	7	0.4	0.6	3.2	4.5	0.1	1.6	324	0.4	4.0	328	9	10,000.0	8	158	0.1
25/03 22		344	6	7	6	7	6	7	0.4	0.6	3.1	4.6	0.2	1.9	338	0.3	4.1	330	9	8,000.0	8	63	0.5
25/03 23		355	6	7	6	7	7	8	0.4	0.6	2.9	4.5	0.2	2.0	348	0.3	4.2	331	8	7,000.0	8	55	0.8

Figure 17: Weather forecast by StormGeo at Norther wind park.

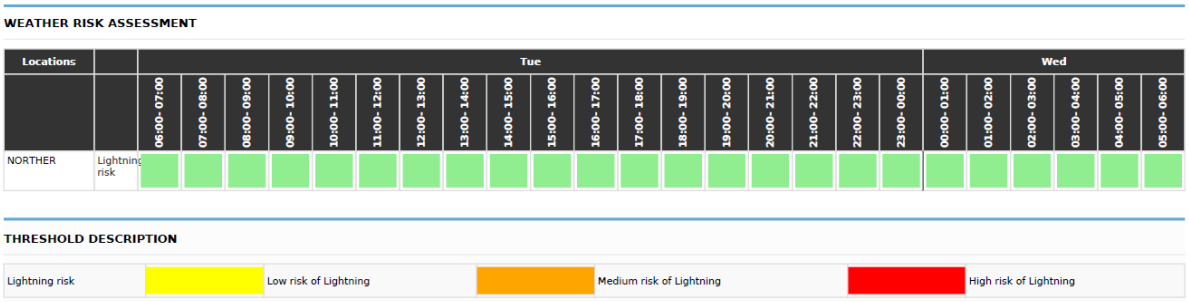

Figure 18: Lightning risk assessment by StormGeo at Norther wind park.

4.2.1.3 Risk Assessment

Before this mission, a risk assessment is conducted and shared with Norther. The work permit is approved once all relevant documentation is completed and confirmed by Norther.

4.2.1.4 Crew

For the offshore operations, SABCA crew consists of 1 pilot, 1 GCS operator and 1 payload operator. For Norther side, there are 2 participants to coordinate the operations on OHVS.

4.2.1.5 CONOPS

During the offshore mission in the Norther wind farms the Freefly Alta X is used to demonstrate wind measurements. To ensure the safety of people and infrastructures, the distance between the wind turbine and the drone, is always kept minimum at 200m. Regarding the wind measurements, the UA is operated on top of OHVS and hovers at specified altitudes to capture wind speed and direction.

The mission is performed in VLOS over sparsely populated and uncontrolled airspace.

Table 2: Specifications for the offshore flights campaign at Norther wind park area.

Type of UAS	Freefly Alta X multicopter (31kg)
Type of operations	VLOS
Type of ground area	Sparsely populated area
Type of airspace	Uncontrolled airspace

The UA is equipped with floatation devices (see image below) that can prevent the drone from sinking in the water in case of an accident.

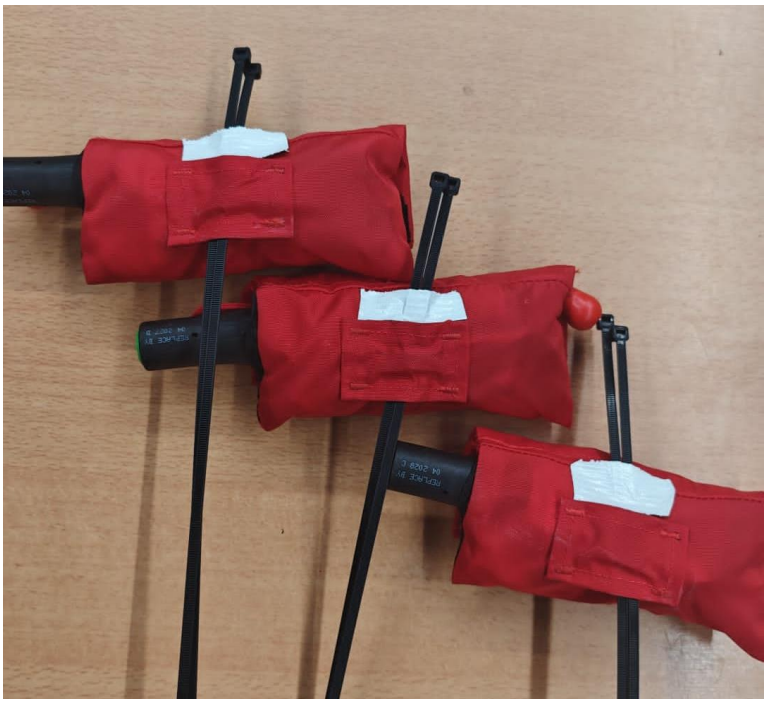

Figure 19: Emergency Floatation System that is mounted on the drone.

Table 3: Flight campaign details at Norther windfarm.

Flight Number	Altitude (AMSL) [m]	Altitude (ATO) [m]
1	70	32
2	76	38
3	85	47
4	100	62
5	107	69
6	50	12

4.2.2 Offshore Flights at Norther Wind Park

On 25.03.2025, the SABCA team successfully carried out offshore drone operations at the Norther wind park. The operation began with the SABCA and Norther crews meeting at the port of Oostende to gather all the necessary equipment. The equipment was carefully prepared and transported to the CTV using specialized lifting bags designed for safe and efficient handling. While this was underway, the Norther personnel ensured that all required preparations for offshore access were completed, including safety checks and logistical arrangements.

After approximately 1.5 hours of sailing from Oostende, the SABCA and Norther teams arrived at the OHVS located within the Norther wind park. Upon arrival, the equipment was lifted onto the OHVS platform using cranes, while the crew ascended the structure, adhering to the safety protocols and techniques learned during their GWO training.

Before commencing the primary measurement campaigns, several critical pre-flight procedures were conducted. These included system sanity checks, magnetometer calibration of the drone, and a preliminary test flight. These steps were essential to ensure that all systems were properly calibrated, functioning as expected, and that the pilot had full confidence in the drone's performance under offshore conditions.

For the wind measurement campaign, six flights were completed at varying altitudes to collect comprehensive data on wind conditions.

Typically, Norther's onboard profiling lidar system, located on the OHVS, is expected to be operational during such campaigns to provide reference data for comparison with the drone's measurements. However, due to unforeseen technical issues, the profiling lidar was not functional on the day of the operations. Despite this setback, the SABCA team successfully completed the planned flights, demonstrating the reliability and adaptability of their drone systems in challenging offshore environments.

This operation highlights the growing role of drone technology in offshore wind park maintenance and monitoring, offering efficient and precise solutions for both inspection and environmental data collection.

Figure 20: SABCA drone with wind sensor during take-off from OHVS.

Figure 21: SABCA drone during measurement campaigns at Norther wind park.

Figure 22: View from Norther OHVS. Operational crew of Norther and SABCA are visualized during drone operations.

4.2.3 Offshore Drone Operations at North Sea

During the Belgian North Sea testing phase, the original plan to operate from the Westhinder platform near Princess Elizabeth region was revised due to logistical complexities (access windows, platform coordination) and the extended vessel transit time required to reach the site. As a pragmatic alternative, the team rented a vessel from Oostende and conducted trials approximately 2–3 hours offshore, preserving representative marine conditions while improving operational flexibility and safety margins.

For reference measurements, a ZX300M lidar was integrated on board. Because the ZX300M is typically deployed at stationary locations (e.g., on an OHVS or fixed mast), the unit is calibrated for its configuration to account for vessel motion and wave-induced dynamics.

Figure 23: ZX300M sensor is located on the boat to compare the drone on-board measurements and on-shore tests.

Mechanically, the lidar was mounted on a reinforced platform with vibration damping elements and oriented to minimize negative effects from vessel structure.

To enable safe UAS operations at sea, a custom safety landing net was designed, and mounted on the vessel deck (see figures). The net geometry and attachment points were selected to:

Provide a forgiving capture area for minor drift during recovery.

Avoid rotor contact with rigid structures.

Allow fast re-launch while securing the aircraft between flights.

Operational SOPs included deck crew locations, coordinated approach patterns, and stabilized hover holds before settling into the net. SABCA established clear go/no-go criteria tied to wind gust thresholds, wave height, deck motion and crew readiness.

The Alta X multicopter executed multiple flights with boat-based launch and recovery. Flight tasks included:

Stepped-altitude hovers at predefined levels, maintaining steady hover to acquire continuous wind measurements at each altitude band.

Hold segments for sensor stabilization and to support synchronized comparisons with the ZX300M averaging periods.

Figure 24: Offshore measurement campaign preparations.

The drone payload consists of the FT743 ultrasonic anemometer (wind speed/direction, temperature), and the onboard avionics for GNSS and attitude data. Data logging captured:

- High-rate raw measurements of wind speed, direction and temperature.
- Aircraft state (position, altitude AGL/MSL, attitude, vibration metrics).
- Health telemetry (battery, link quality) for operational traceability.

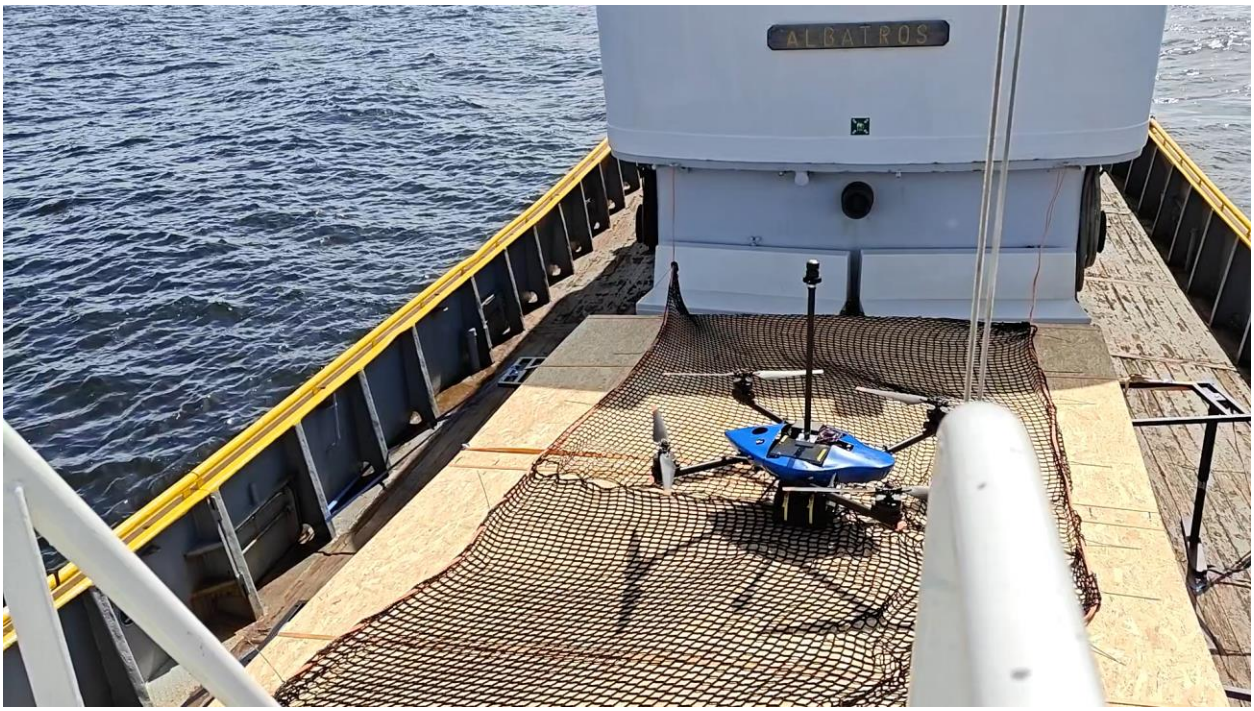

Figure 25: The drone is recovered with a net for landing.

Data quality assurance focused on:

- Time synchronization between the drone and ZX300M (GNSS time alignment; cross-correlation checks on gust events).
- Filtering or avoidance of rotor-wash influence via extended stick geometry and sensor placement offset, plus excluding initial stabilization seconds at each altitude.
- Removal of segments affected by significant deck-induced motion when comparing to lidar returns.

These tests met the primary objectives of:

- Validating measurement procedures and data quality in a marine environment prior to full offshore campaigns.
- Verifying the suitability of the FT743-based payload for wind profiling.
- Demonstrating safe and repeatable boat-based launch and recovery using the custom landing net and refined SOPs.
- Establishing a reference dataset for comparison with prior onshore tests and for calibrating processing parameters (e.g., averaging windows, motion compensation) used in the offshore campaigns.

Lessons learned and improvements implemented:

- This mission was attempted once with the crew to the Westhinder platform. Due to sea conditions, some crew members experienced seasickness and SABCA had to cancel the flights. As lessons learned, SABCA crew will conduct a more detailed sea-state and weather window assessment 48 and 12 hours before deployment, with a final go/no-go checkpoint, provide anti-

motion sickness measures (medication, hydration, light meals) and brief the crew on mitigation techniques in advance.

- Slight relocation of the anemometer on the airframe to further mitigate any residual rotor interference.
- Avoiding ZX300M wind profiling area with the drone waypoints such that the drone's propellers do not cause measurement noise for ZX300M.

Overall, the Belgium North Sea trials provided a robust intermediate step between controlled onshore tests and full-scale offshore wind farm operations, de-risking the campaign logistics and enhancing confidence in both the measurement approach and operational procedures at sea.

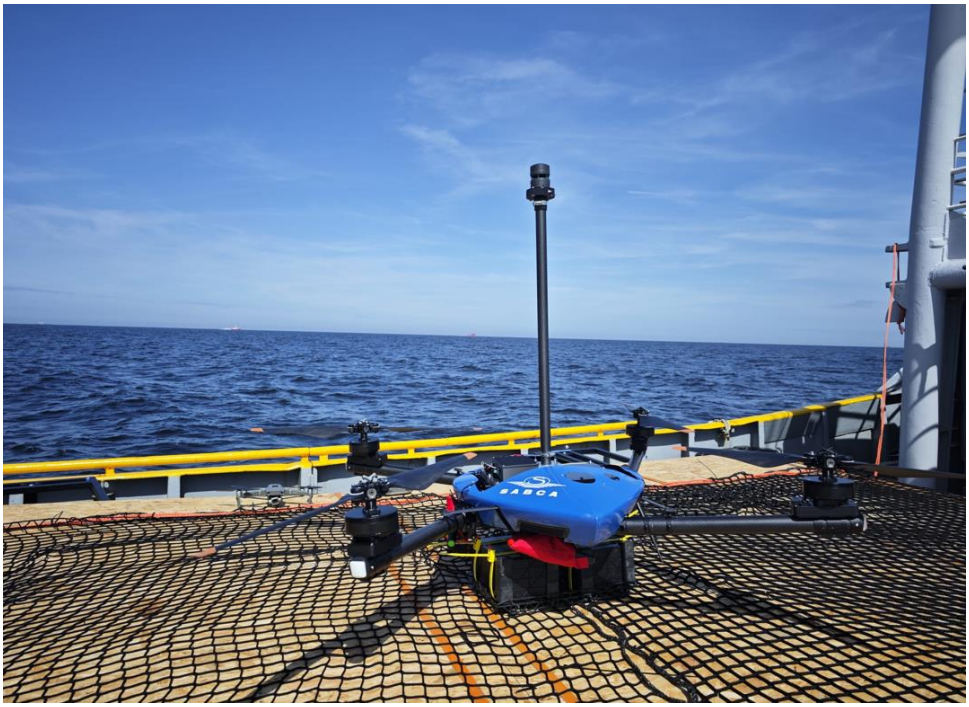

Figure 26: SABCA drone at offshore missions during boat operations.

Figure 27: SABCA drone hovered at various altitudes to collect wind speed, direction and temperature data.

Figure 28: SABCA drone hovered at various altitudes to collect wind speed, direction and temperature data.

5 Data Analysis

A total of 41 flights were executed for this campaign: 29 onshore (DronePort) and 12 offshore. All flights underwent systematic screening to identify valid segments and exclude non-representative intervals. For each flight, SABCA crew verified payload status, GNSS quality, and aircraft attitude limits to ensure that only high-quality data contributed to the analysis set. This process enabled a high quality dataset suitable

for cross-comparison between onshore and offshore conditions and for validation against the reference lidar.

SABCA team applied timestamp correction and synchronization across the wind sensor (FT743), the reference ZX300M lidar, and the drone's onboard avionics (GNSS/IMU) to place all events on a common timeline. Time offsets were estimated using GNSS time references and verified via cross-correlation of identifiable wind gust signatures. This alignment ensured that comparisons represented the same physical air mass and conditions, enabling robust point-to-profile validation.

Targeted filtering and masking were then applied to remove non-representative data. Specifically, following data are removed for better analysis:

- During aircraft stabilization (initial seconds after arriving on target measurement altitude)
- During approach and departure to/from hover positions
- During maneuvers that could induce rotor-wash artifacts or temporarily block the ZX300M beam geometry.

The resulting dataset consists of steady-state hover windows matched to ZX300M averaging periods, providing clean comparisons for wind speed and direction profiles and enabling consistent aggregation of results across the 29 onshore and 12 offshore flights.

5.1 Comparison of Stick Length vs Measurement Quality at Onshore Tests

To mitigate propeller downwash and the cylindrical recirculation zone that can shield the wind sensor from free-stream flow, SABCA designed and tested a series of carbon fiber extension mounts to elevate the anemometer above the rotor plane. Three stick lengths were evaluated—0.5 m, 0.75 m, and 1 m—balancing aerodynamic exposure, structural stiffness, mass, and operational practicality.

The mounts were engineered to minimize vibration transmission and deflection, using lightweight carbon tubes with tailored clamps and damping interfaces at the airframe attachment points. Cable routing and strain relief were incorporated to avoid signal noise and ensure reliable data collection. During hover tests, each configuration was assessed for data quality improvements, mechanical behavior, and impact on flight performance.

Preliminary results indicated a clear reduction in downwash influence with increasing stick height, with the 0.75 m and 1 m sticks providing the most consistent alignment with reference measurements during stable hover. The 0.5 m option offered operational convenience and lower drag but showed occasional sensitivity to rotor-induced flow under higher thrust settings. Final selection for offshore campaigns prioritized the 75–1 m range for critical measurements, while retaining the 0.5 m configuration as a backup for constrained operations.

As seen on Figure 29, the lowest wind speed errors were achieved with the 1.0 m sensor height. Performance degraded progressively as the sensor was brought closer to the rotor plane, with noticeably higher errors at 0.75 m and the largest errors at 0.50 m. This trend is consistent with expectations: increasing stand-off distance reduces exposure to propeller downwash, recirculation, and local turbulence intensities that can bias measurements during hover.

A comparable, statistically robust assessment for wind direction error is not yet possible due to limited sample size across all three configurations. Additional repetitions under varied wind regimes and with longer steady-state times at each altitude should be collected to strengthen direction error statistics.

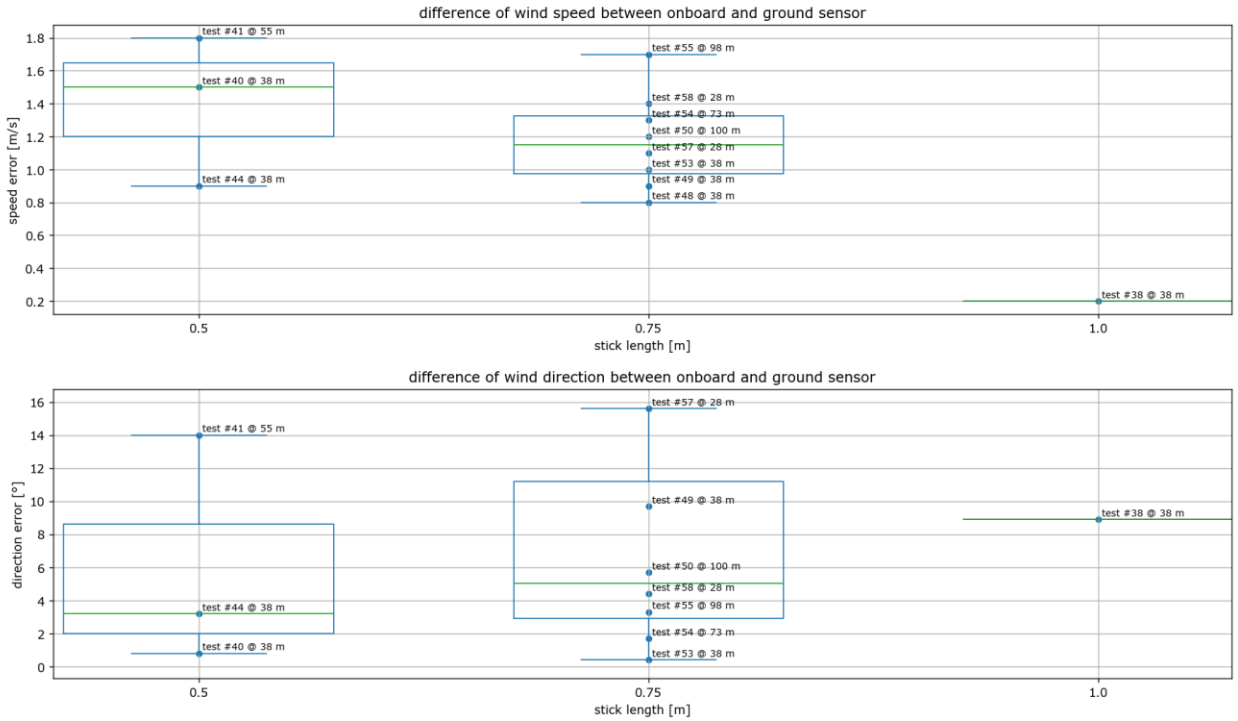

Figure 29: Distribution of stick design height vs measurement error. As expected longer stick design tend to have better accuracy.

Initial cross-checks were conducted using the same sensor height (0.5 m stick) at two hover altitudes, approximately 38 m and 55 m AMSL. The resulting performance relative to the ZX300M lidar was broadly consistent across the two heights, indicating limited sensitivity of the measurement bias to this change in hover altitude under the tested conditions. As shown in Figure 30 and Figure 31, the mean wind speed error at 38 m was 1.5 m/s, while at 55 m it was 1.7 m/s. Corresponding wind direction errors were 6.9° and 3.8°, respectively.

The small differences between these error metrics fall within the platform's acceptable heading uncertainty and operational variability and can therefore be considered statistically similar for the purposes of this analysis. This suggests that, with a 0.5 m height stick design, the residual influence of rotor-wash and local flow distortion on the anemometer signal is comparable at both heights tested.

That said, a more definitive conclusion would benefit from additional repetitions under a broader range of environmental conditions (e.g., varying stability, shear, gustiness), as well as longer steady-state hover times to tighten confidence intervals.

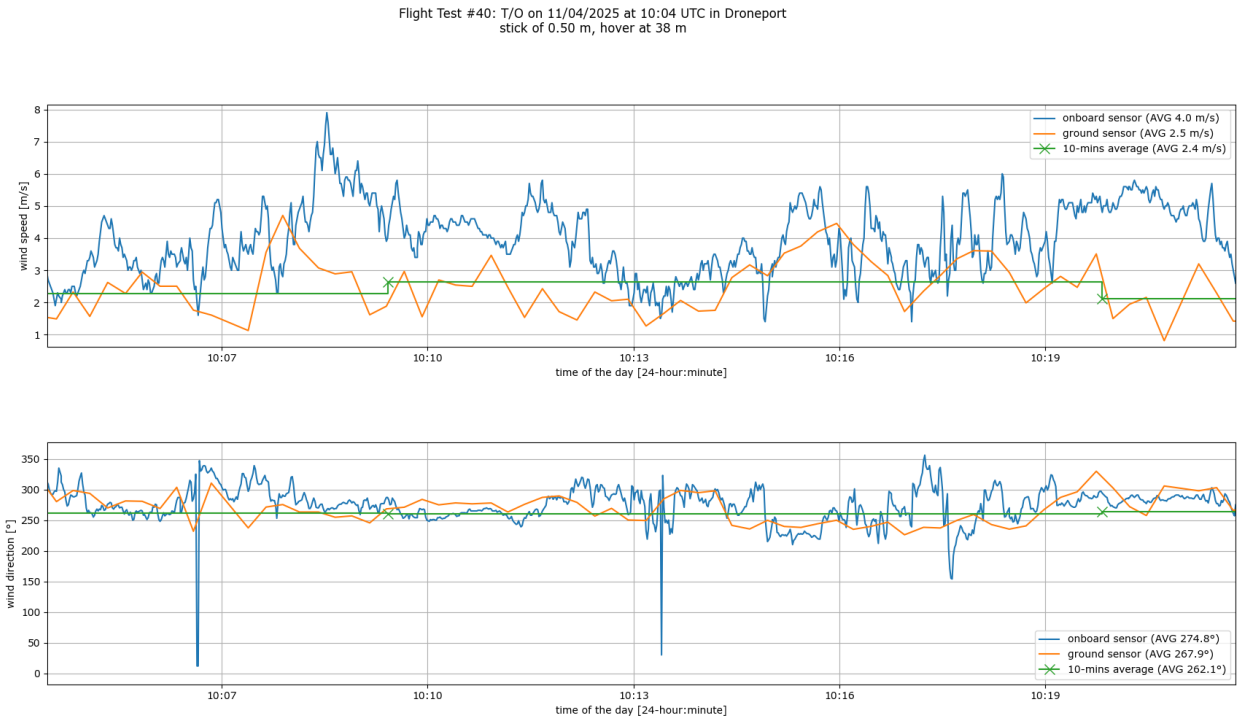

Figure 30: Comparison of 0.5m stick design at onshore environment vs ZXL measurements @38m height

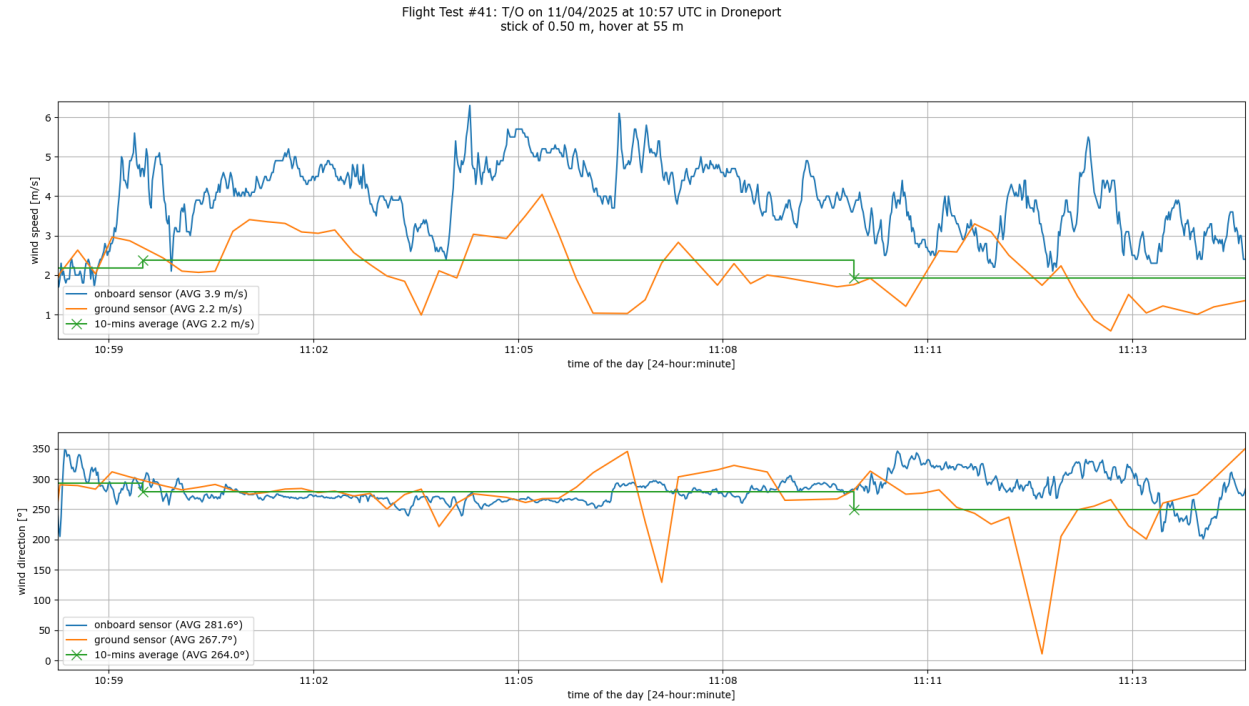

Figure 31: Comparison of 0.5m stick design at onshore environment vs ZXL measurements at 55m height.

Next comparison is done with 75cm stick design as seen in Figure 32. The average error compared to the ground sensor (ZX300M), dropped from 1.5m/s to 0.8m/s. It is a significant improvement for the measurements. After checking several data points this behaviour seemed consistent but to conclude more data measurement is required.

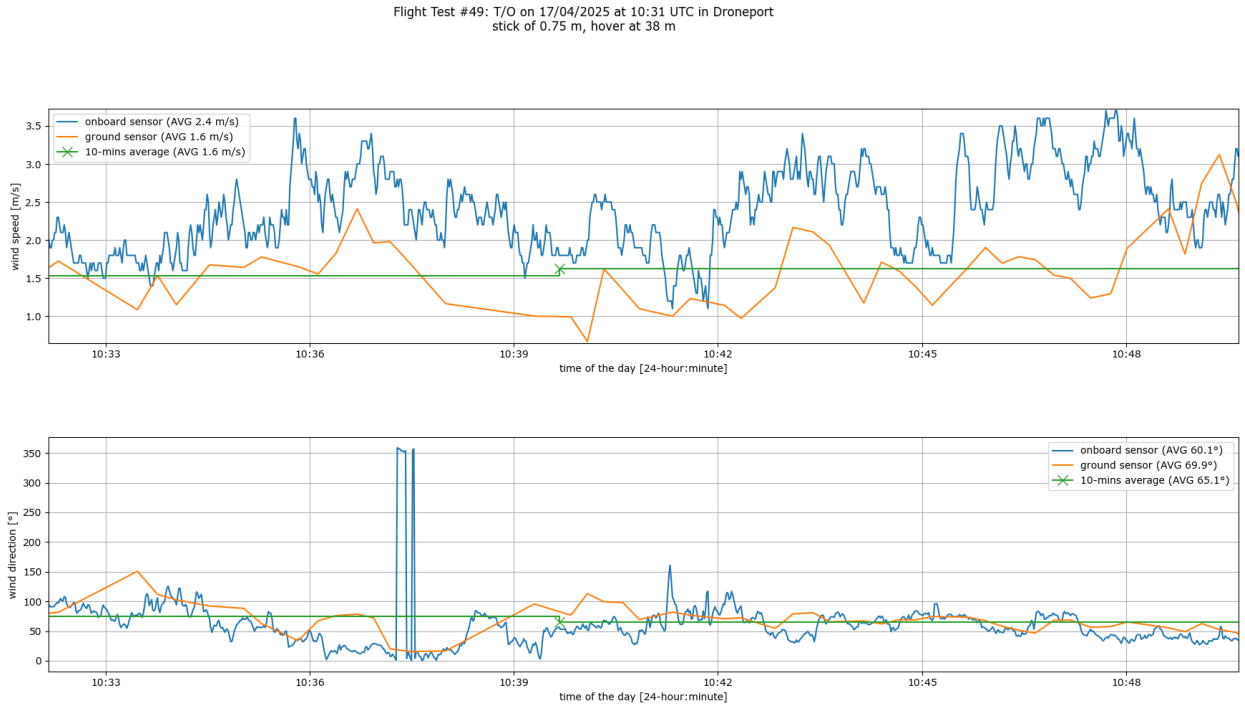

Figure 32: Comparison of 0.75m stick design at onshore environment vs ZXL measurements @38m height.

There were also 2 drone flight tests with 100cm stick design. But due to issues with the effects on flight dynamics, it is decided not to use this version at further tests, including offshore.

5.2 Comparison of Onshore vs Offshore Tests

For the offshore phase, two distinct test campaigns were conducted: operations in the vicinity of the Norther wind park and boat-based takeoff and landing (T/O and LDG) trials in the Belgian North Sea. In both campaigns, SABCA executed multiple hover profiles and recorded wind measurements across several altitudes. However, the fixed reference sensor at the Norther wind park was not operational on the flight day, limiting the ability to perform direct validation there. Consequently, the primary quantitative comparison focuses on the boat-based flights, where a ZX300M lidar was deployed and configured for motion-compensated operation.

The initial objective of the comparison was to verify whether the ZX300M lidar delivers consistent performance when mounted on a vessel compared to ground-based deployments (e.g., the DronePort campaigns). Given that prior onshore analyses identified a mostly consistent offset between the ZX300M and the drone's onboard wind sensor, the analysis explicitly examined whether this offset behavior persists offshore. This approach serves two purposes: it tests the effectiveness of the ZX300M's motion

compensation and filtering on the boat, and it provides a like-for-like benchmark against the known onshore bias patterns.

As shown in Figure 33, the offshore boat campaign displays a mean difference between the ZX300M reference and the onboard anemometer of approximately 1.0 m/s. This value is closely aligned with the offset observed during the DronePort tests (about 0.8 m/s), indicating strong consistency between the boat-mounted and ground-based lidar references within the combined uncertainty bounds. The result provides additional confidence that the ZX300M was correctly calibrated and appropriately configured to mitigate wave- and motion-induced effects during boat operations. In practical terms, the persistence of a similar offset suggests that the residual bias is more likely due to systematic factors in the onboard measurement system (e.g., remaining rotor-wash influence, mounting geometry, or response characteristics) rather than degradation of the ZX300M signal quality at sea.

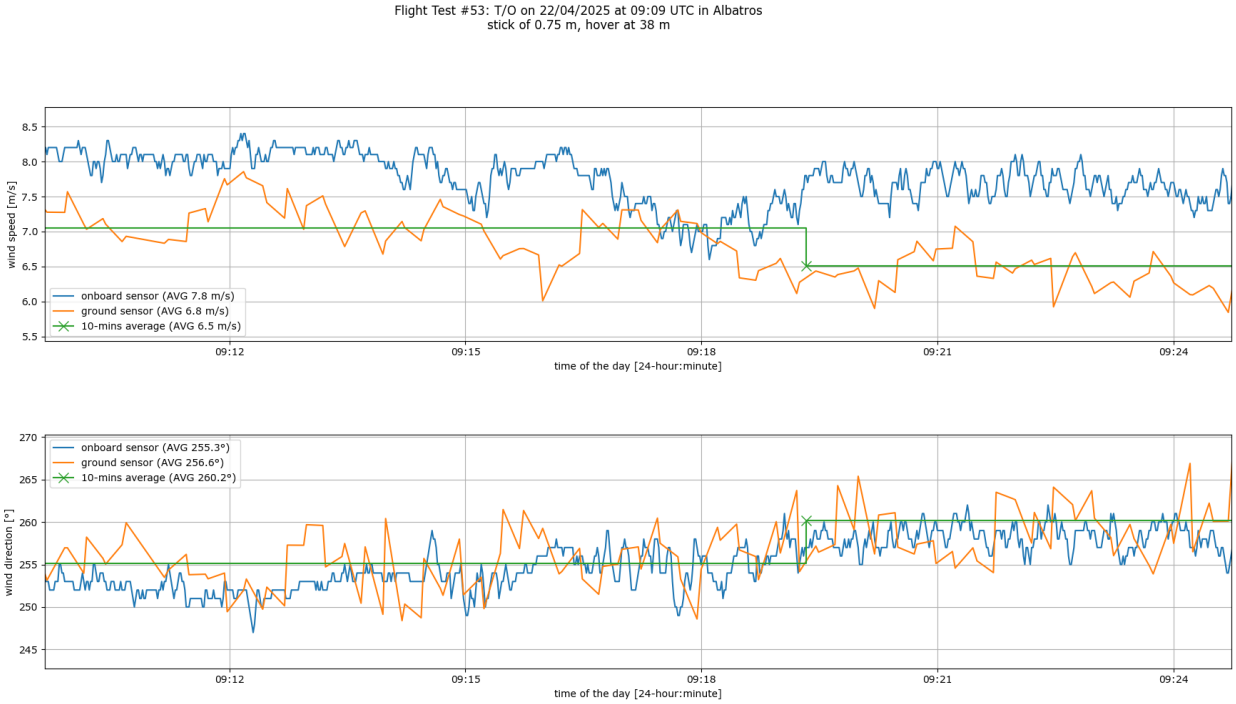

Figure 33: Comparison of 0.75m stick design at offshore environment vs ZXL measurements @38m height

6 Lessons Learned & Recommendations

Budget: To access the offshore environment, the SABCA crew is required to have GWO training, NOGEPA medical certificates, and offshore-certified PPE. However, these costs were neither anticipated nor included in the Beforecast Project budget. As a result, SABCA had to identify solutions to meet these requirements for their crew members. This unexpected deviation from the original budget has been noted as a lesson learned for future offshore operations and projects.

Authorizations: Obtaining the necessary authorizations to fly offshore is a complex process due to the varying regulations imposed by wind park owners, airspace-owning countries (such as the Netherlands and Belgium), and the need to comply with EASA rules and regulations. These overlapping requirements

create significant administrative and logistical challenges. This complexity was not fully anticipated during the planning phase, highlighting the importance of thoroughly addressing regulatory frameworks in future offshore projects.

Weather Limitations: Weather conditions pose significant limitations for offshore operations, with factors such as wind speed, gust speed, precipitation, fog, and sea wave levels all needing to be carefully considered. This challenge is further compounded by the need to align suitable weather windows with authorized flight dates, which can be difficult to secure. Additionally, ensuring the crew remains up-to-date with all required training and certifications adds another layer of complexity. These constraints highlight the importance of meticulous planning and flexibility in scheduling for future offshore projects.

Rough sea conditions and sea-sickness: For maritime missions, to mitigate seasickness, SABCA crew will conduct a more detailed sea-state and weather window assessment 48 and 12 hours before deployment, with a final go/no-go checkpoint, provide anti-motion sickness measures (medication, hydration, light meals) and brief the crew on mitigation techniques in advance.

Invest in Training: Ensure drone operators are skilled in navigating offshore conditions and interpreting inspection data.

Adopt Advanced Technologies: Incorporate autonomous systems, robust sensors, and durable components to enhance safety and efficiency.

Enhance Collaboration: Build strong partnerships between drone service providers, wind park operators, and regulatory bodies.

Focus on Predictive Maintenance: Use drone data to anticipate and address issues proactively, reducing downtime and costs.

Develop Regulatory Frameworks: Work with aviation authorities to streamline drone operations in offshore environments.

7 Conclusion

The BeFORECAST measurement campaigns successfully demonstrated the feasibility, safety, and scientific value of drone-based meteorological observations for offshore wind applications. Across a total of 41 flights—29 onshore at DronePort and 12 offshore in the Belgian North Sea—SABCA validated the following: sensor selection and integration, boat-based launch and recovery procedures, time-synchronized data acquisition, and data analysis aligned with project objectives.

Ultrasonic anemometry was selected after extensive benchmarking for its accuracy, reliability, low mass, and suitability for UAS integration; FT Technologies FT743 met performance expectations under both onshore and offshore conditions. To mitigate rotor-wash and local flow distortion, SABCA engineered carbon-fiber extension mounts (0.5 m, 0.75 m, 1 m), with analysis indicating that greater stick height (notably 1.0 m) performs the lowest wind speed error during hover. Reference measurements were compared by a ZX300M lidar, rented for a month and configured for both ground and boat operations.

The boat integration included motion-compensation strategies and mechanical damping to compensate against wave-induced dynamics.

Operationally, the team adapted effectively to maritime constraints. The initial plan to stage from Westhinder was revised due to logistics and transit time; instead, a rental vessel from Oostende enabled testing offshore. SABCA designed a custom landing net for safe boat-based takeoff and landing with the Alta X platform. During offshore campaigns near the Norther wind park and in coastal waters, multiple hover flights at varying altitudes were completed, capturing continuous wind measurements.

Time alignment across FT743 (on-board wind sensor), ZX300M (reference lidar), and drone avionics was achieved using GNSS references and validated via gust cross-correlation. Comparative results showed consistency between boat-based and ground-based lidar references: the offshore mean offset between ZX300M and the onboard anemometer was ~1.0 m/s, closely matching the ~0.8 m/s observed onshore. This supports the conclusion that boat-mounted ZX300M measurements, with proper configuration, are reliable for reference. Altitude-specific tests at 38 m and 55 m using a 0.5 m stand-off produced similar error levels (1.5 m/s and 1.7 m/s; direction errors 6.9° and 3.8°), within platform heading uncertainty, indicating limited sensitivity to these height changes under the tested conditions.

Overall, the campaigns demonstrated safe, repeatable offshore UAS operations, including boat-based T/O and LDG, with refined SOPs and risk mitigations.

Validated the measurement approach against a trusted lidar reference in both onshore and offshore settings.

Identified optimal sensor mounting practices (favoring 0.75–1 m height) to minimize bias from rotor-wash and local flow disturbance.

Limitations primarily relate to sample size for wind direction error across all mount configurations and the lack of co-located fixed reference data during the Norther campaign day.

In conclusion, SABCA's measurement campaigns achieved their core objectives under T1.4–T1.6: they de-risked offshore operations, delivered validated datasets, and provided actionable insights for sensor integration and mission design. The work materially supports BeFORECAST's ambition to incorporate wake effects and real-time drone measurements into improved offshore wind forecasts for Belgian wind farms and grid operators.