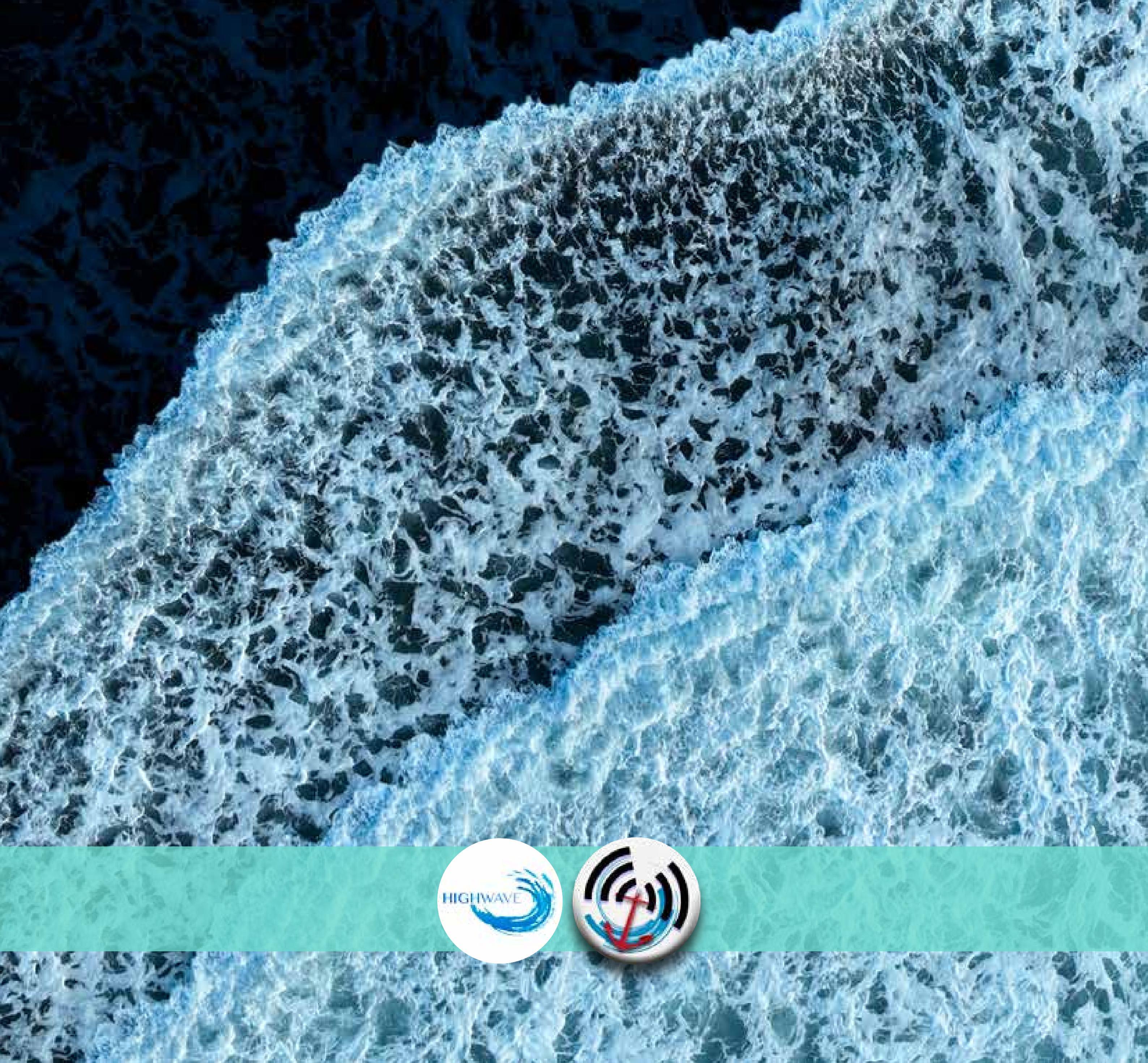
2019
2025

An interdisciplinary project
to better understand ocean waves

HIGHWAVE AND THE AIRS STATION

Modelling the energy dissipated by breaking waves



HIGHWAVE

Firmly anchored at two separate points on a cliff on Inishmaan Island, the PODs (Portable Observation Devices) provide a stereovision image of the sea in real time.

The Highwave researchers

FRÉDÉRIC DIAS

A renowned mathematician and researcher specialising in fluid dynamics, Frédéric Dias has been working on wave hydrodynamics and mathematical modelling for almost 40 years. Between 2012 and 2016, he launched a research project on the formation and impact of rogue waves. This project has already received funding from the European Research Council (ERC). In 2018, he launched the Highwave project together with Arnaud Disant. This is an interdisciplinary project that aims to better understand and model wave breaking under real conditions. Frédéric Dias is also a professor at ENS Paris-Saclay and at UCD (University College Dublin).

frederic.dias@ens-paris-saclay.fr

ARNAUD DISANT

Arnaud Disant is a marine research engineer, a former lecturer at the Irish Naval Academy and an expert in telecommunications. He is actively involved in the Highwave project as technical director of the AIRS research station. Based in Ireland, he regularly helps in setting up experiment protocols on Inishmaan Island. In 2012, Arnaud created SeaFi™: a wireless maritime network enabling very long-distance connections. He integrated this technology into the Highwave project to help in the construction of a unique system for real-time data retrieval and instant transmission to the research station's servers.

arnaud.disant@ucd.ie

An observation site unique in the world

Located at the heart of the Aran Islands, about twenty kilometres west of the Irish coast, the island of Inishmaan literally means "the middle one" in Irish. Measuring less than 10 km², it is the perfect place to observe waves: the waves that arrive here are very energetic and the way they break is not perturbed by any obstacles.
The Atlantic stretches as far as the eye can see, and the nearest land mass is the east coast of Canada. Another advantage is that there are not many people on the island. This reduces the risk of the connected instruments, which are often left unattended, being vandalised.

Designing connected tools that can withstand the harsh conditions at sea and the power of breaking waves was one of the major challenges of the project.

Moving forward!

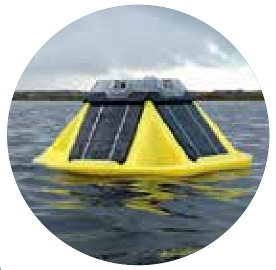
Highwave is a ground-breaking interdisciplinary project aimed at gaining a better understanding of breaking waves. Why do waves break? What energy do they dissipate? What gaseous exchanges take place at the water/air interface? What movements do rocks undergo as a result of their interactions with breaking waves? These are just some of the questions that Highwave wants to answer, with one main objective: to design a new mathematical model of this phenomenon that will ultimately allow for a better understanding of climate evolution.

We were able to create the station thanks to the support of the European Research Council. We now want to make it a cutting-edge tool for the international community, at the service of the planet.

Our ambition is that the station remains active for a long time to come.

Frédéric Dias and Arnaud Disant

On the west coast of Inishmaan Island, the breaking waves have a lot of energy and are not hampered by any natural obstacles.



2018 First record, validated by the Guinness Book of Records, for the longest wifi connection at sea achieved using SeaFi™ technology: 35.92 km.

1st semester 2019 Launch of the Highwave project and funding of €2.5 million received from the European Research Council (ERC Advanced Grant).

2nd semester 2019 The Aran Island Research Station (AIRS) is set up and the first measurement tools installed.

2020 First experiments carried out *in situ* on Inishmaan Island.

May 2023 New world record for the longest wifi connection at sea of 36.83 km, achieved using SeaFi™.

2025 End of the Highwave project's first cycle of experiments and analysis of the results obtained.

2018 2019 2020 2021 2022 2023 2024 2025

Getting to the heart of waves

The Highwave project is particularly ambitious and aims to better understand breaking waves and put forward a new mathematical model for this phenomenon. The findings from the project could be of interest for many maritime sectors.

Frédéric Dias, a mathematician who has always been fascinated by waves, moved to Ireland nearly 15 years ago to work on a research project on wave energy converters – that is, machines that recover the energy produced by waves. His love of Ireland meant that it was only natural that he chose the Aran Islands a few years later when he decided to study wave breaking as part of the Highwave project, a research project for which he was awarded €2.5 million in funding from the European Research Council (ERC Advanced Grant) in 2019.

Supported by both the Ecole Normale Supérieure Paris-Saclay and UCD (University College Dublin), Highwave is an ambitious interdisciplinary research project combining ocean engineering, statistics, mathematical modeling and fluid mechanics. Its aim is to understand why waves break, to find out how much energy is dissipated when they break and, ultimately, to create a new mathematical model to describe breaking waves at sea.

"Numerically simulating the breaking of waves over a large area of the ocean is one of the greatest scientific challenges there is," says Frédéric Dias. "As I am above all a mathematician, my main objective with Highwave is to invent a new system of equations that will allow us to model wave breaking over a large sea domain in three dimensions."

By breaking, we mean the breaking point, that is, the moment at which the wave breaks and foam forms. This phenomenon can be studied using the famous Navier-Stokes equations, which are among the most complex in fluid mechanics. Developed in the 19th century, these equations are unique and perfectly suited to studying single breaking waves. There is a problem, however, in that they require a lot of computational resources when applied to analysing a wider area of the ocean with thousands of breaking waves.

There is therefore a need to develop new mathematical models if we want to model wave breaking over an entire sea domain. To this end, Frédéric and his team (a dozen post-docs and PhD students) have identified four areas of study (see box page 7). Preliminary results have already been obtained and the project will run until the end of 2025. The mathematician hopes that significant progress will have been made in modelling these breaking waves by that time. ❖

ERC Advanced Grant of
€2.5 million

Four study areas

– 1 –

Understanding why waves break on the open sea and how much energy they dissipate when they do. This is the most fundamental research-oriented objective. The results obtained from this study will allow for better sea-state forecasts, for example, in the medium term and for improved insights into the gaseous exchanges that take place when a wave breaks and foam forms.

– 2 –

Understanding and modelling the motion of medium-sized rocks (weighing a few kilograms) under breaking waves. Frédéric and his team record their movements thanks to a system of coloured rocks, analysed by drone. In the near future, some of the rocks will even be fitted with an accelerometer so that their precise trajectory beneath the waves can be mapped. In the long term, these results could be of particular interest to manufacturers installing wave or tidal power machines.

– 3 –

To find out how much energy is dissipated when waves break, not just at sea, but also when they encounter obstacles or structures such as cliffs, harbours or boat hulls. In this context, Frédéric and his team will be studying how large boulders weighing several hundred tonnes situated on top of the Inishmaan cliffs move when hit by waves. This applied research may well help determine new standards for better designing ship hulls, for example, or port infrastructures.

– 4 –

Setting up all the connected instruments required for the experiments in the three areas outlined above.
This meant constructing the AIRS station on Inishmaan Island and connecting the instruments via SeaFi™ technology (see pages 10-11). This phase of the work, led by Arnaud Disant, began in 2019 with the invaluable help of the island's inhabitants. Today the AIRS station is fully operational and collecting data useful for the three main objectives of the Highwave project.

Arnaud Disant, members of the scientific team and residents carry the POD (Portable Observation Device), which will be anchored to the cliff.

A rich collaboration with the islanders

Inishmaan Island was chosen above all because of its geographical location, which makes it a particularly interesting place to study waves. But also thanks to the warm welcome of the local population. "When we toured the Aran Islands to talk about the project, we immediately sensed that the residents would support us," Frédéric points out. "We were welcomed with open arms, so we very quickly decided to set up the project here," adds Arnaud. From the outset, the island's inhabitants offered to lend land to the two scientists on which they could install the different containers for the future AIRS research station. Local fishermen also helped Arnaud to set up the connected buoy by boat. Other residents help out whenever there is equipment to be transported, a container to be repainted or minor repairs to be carried out. This is indeed a real collaboration between scientists and the general public. "The local people were keen to see that the research station would provide them with a form of scientific tourism that would be more environmentally friendly than the mass tourism that can develop on some of Ireland's islands," states Arnaud. And the collaboration has developed even further today, as a real partnership has been set up between the local school and the project. Schoolchildren are regularly invited to the station to follow its progress. Some of them have even worked on projects based on the station's activities in a national science competition and won a prize for their work.

How does the AIRS research station work ?

The AIRS station allows for a wide range of parameters to be studied using custom-designed, connected instruments.

Highwave initially started as an interdisciplinary project to study wave breaking *in vivo*. Without a research station in the field, however, it was impossible to obtain all the relevant data. This is why the Aran Island Research Station (AIRS) came to life. Designed to collect an impressive amount of data, this research station is the brainchild of Frédéric Dias, Arnaud Disant and their colleagues. As soon as they were awarded the €2.5 million grant from the European Research Council, they began putting the various modules in place - under the supervision of Arnaud, the technical director.

"Today, the AIRS station consists of two containers on the island: a research module and a workshop module. A third container on the mainland serves as a base camp: it is here that new instruments are designed and data is retrieved from the island," explains Arnaud.

The research station liaises daily with a multitude of connected objects positioned both in the sea and on cliffs, sending data in real time using SeaFi™ technology, a unique wireless maritime network invented by Arnaud Disant (see pages 10-11). Autonomous in terms of energy thanks to a mix of wind turbines, solar panels and a diesel generator, the AIRS station can therefore collect data without interruption, whatever the weather conditions, particularly during storms, which are of particular interest to the researchers working on the Highwave project.

And the future ?

When the Highwave project ends, normally at the end of 2025, it would be a shame not to continue exploiting this multi-purpose research station. "Dismantling it is not an option we are considering at the moment," emphasises Frédéric Dias. "The idea would be that scientists continue to benefit from it beyond the Highwave project," adds Arnaud Disant.

Indeed, the variety of sensors at the AIRS station means that the data collected will be of interest not only to meteorologists but also to astronomers and climatologists.

As the station will be fully operational by that date, scientists wishing to use it will also gain precious time in setting up their research protocols. Arnaud insists: "It took us between 18 and 24 months to obtain the right to install buoys at sea in a fairly wide area around the island. Future researchers who want to collect such data will not have to expend that time and energy." Being able to use the station's sensors and having access to real-time data feedback should be of great benefit to the research community, whose budgets are often tight and deadlines sometimes too short to set up such an advanced system.

As well as the Highwave team, the station has already hosted the first team of researchers from the United States, whose research area was similar to that studied by Highwave: studying how boulders perched on cliffs shift as a result of repeated wave impacts.

Another reason to continue with the AIRS station after 2025 is that it is of benefit to the local community, both economically and socially. Local residents work on the regular maintenance of the station and others, especially young people, can do their work placements there. The scientific tourism that this research station opens up should also enable Inishmaan Island to sustain its economic vitality in the years to come. ❖

The main AIRS station connected instruments

1 CONNECTED BUOY

Measuring almost three metres in diameter, this buoy is central to the system and collects a large amount of particularly interesting data. Located 10 kilometres off the west coast of Inishmaan Island and firmly anchored to the seabed, it is equipped with a battery, solar panels and a SeaFi™ antenna to transmit the data collected in real time. These various sensors record parameters as diverse as air and water temperature, wind speed and direction, wave height, direction and period. Equipped with an accelerometer, the buoy also records its movements in three dimensions. This particularly innovative buoy has received an additional "Proof of concept" grant from the European Research Council (ERC).

2 WEATHER STATION

Placed next to the research module, this weather station comprises a few very simple tools, including an anemometer and a rain gauge. It records wind strength and direction, as well as rainfall. This data will allow the researchers to correlate the breaking of the waves with these external parameters.

3 PODS

Designed specifically by Arnaud for the Highwave project, the two PODS (Portable Observation Devices) are large plastic tubes designed to be robust to the strongest storms. Fitted with a battery, solar panels and a camera, they are firmly anchored to the cliff at two separate points. Their aim: to record images of the same area of the sea from two different angles and therefore obtain a real-time view of the sea in stereo vision.

4 SMALL CONNECTED BUOYS

Two small buoys with solar panels complete the arsenal of connected instruments. Too small to be equipped with a SeaFi™ antenna, they transmit their data via a conventional satellite connection. They can be used in two different ways: either in anchored mode, or in drift mode. The latter mode is particularly interesting for studying surface currents by letting the buoy drift for one to two months and recording its various positions over time.

5 ADCP MODULE (Acoustic doppler current profiler)

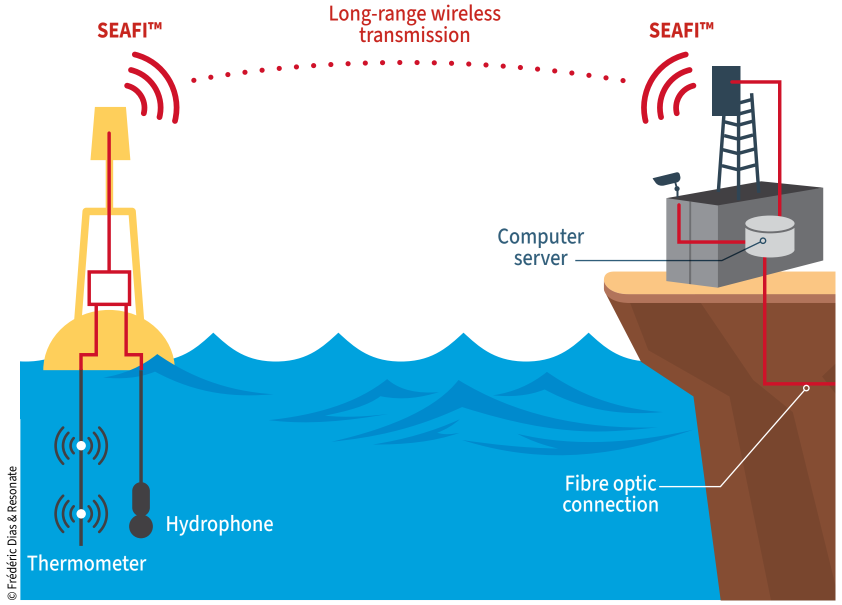
Also known as a current meter, this device provides information on the height of water and the speed and direction of marine currents at any given instant. This module works by emitting and then receiving acoustic signals in different directions. Although not connected in real time, its data are stored in the device and read out frequently.

6 ADDITIONAL TOOLS

The AIRS station also has a large number of small additional pieces of equipment, such as a seismometer, radar, drone and hydrophone. These are not connected in real time, but can be used to widen the range of data recorded.

SeaFi™: a long-range maritime wireless network for the Highwave project

Thanks to this unique, high-performance wireless data transmission technology, the Highwave project retrieves data recorded by the constellation of instruments orbiting the station in real time.




The SeaFi™ antenna on the roof of the research station in Inishmaan

"One of the major challenges of the Highwave project was to set up secure, real-time retrieval of the large amount of data collected," insists Frédéric Dias. And to achieve this, it seemed obvious to use SeaFi™, a technology invented by... Arnaud Disant, himself, several years before the Highwave project began.

In 2012, Arnaud, who was already a marine research engineer, was surprised to discover that there was a gap in maritime communications and that it was complicated to exchange large volumes of data at reasonable speeds. At the time, there were only three solutions: satellite communications, but these are very expensive, especially when the data volumes are large; the mobile phone network, which is sometimes available at sea, but which was not designed for unpopulated areas; and the last solution, which involves leaving a USB key containing the information you want to exchange on dry land. This solution is too restrictive.

To address this problem, Arnaud began to think about a wifi-based solution that could encompass all the issues relevant to the marine world. SeaFi™ was thus born.

A giant wifi

What is SeaFi™? In practice, it works like a classic home wireless network, but with a greatly increased distance range. On the land side, SeaFi™ antennas are installed on lighthouses or specially designed coastal stations to extend the internet network well beyond the coastline. On the seaward side, an antenna is installed on each of the connected equipment, buoys or boats, which can then transmit the recorded data in real time.

The results are impressive and SeaFi™ recently set a series of new records. Speeds don't lag behind either: the main connected buoy in the Highwave project can communicate at around 30Mbits/s despite being located 10 kilometres offshore.

The main challenge was to build antennas perfectly resistant to the difficult conditions at sea.
Arnaud Disant

It has not all been plain sailing however. To develop such high-performance technology, Arnaud and his teams had to overcome a number of challenges. "The main one was to build antennas that would perfectly withstand the harsh conditions at sea," he insists. Since connected objects are intended to remain at sea for many months, this means that the SeaFi™ antennas they carry have to be robust to phenomena like storms, salt water and impacts with floating debris. Such a hostile universe had to be taken into account when designing the antennas.

The second major challenge was to successfully create a long-distance wifi link between devices located several kilometres apart. SeaFi™ uses the international 802.11 standard specific to wireless local area networks and a brand new Wireless Maritime Area Network (WMAN) concept, the range of which is far greater than domestic wireless networks.

While he says he can't unveil the secret behind the long-distance technology, Arnaud admits that a great deal of work has gone into the antennas. Larger than domestic antennas, they were tested in the harshest conditions at sea by the Irish Navy before being deployed in scientific projects. What is more, the Wireless Maritime Area Network concept invented by Arnaud allows for large ocean areas to be secured and it could become part of the connected ports landscape (Smartport).

The final major challenge to be addressed is security. The data in the SeaFi™ system is extremely important and very valuable. For maximum security, Arnaud developed a 100% in-house solution. "We use a closed network. The network identifier and transmission protocols are non-standard, which gives this technology added security," he insists.

Over its 12-year life, SeaFi™ has been deployed in the port of Cork to connect tugboats and in the port of Rosslare to connect the MV Stena Horizon ferry to its home port. But above all, since 2019, it has become one of the essential building blocks of the Highwave project by enabling data to be recorded in real time: transmission takes place twice a second for all the parameters studied by the main buoy. Once transmitted to land, the data is immediately stored on a dedicated server, ready to be used by Frédéric Dias and the team of researchers he works with.

"Without SeaFi™, we would have had to go out by boat at regular intervals to pick up the buoy and copy the data stored locally," explains Frédéric. There was a major risk of the buoy disappearing in a storm, and with it all the data it was carrying. Now, even if the buoy were to become loose, all the data recorded right up to the very second before it starts drifting are stored on the project server. This is a considerable advantage and is one of the reasons that makes Highwave so unique.

In the future, SeaFi™, which has been independent from Highwave since 2013 and has already been successfully deployed in commercial ports and on board offshore vessels, could interest more customers thanks to its secure connection, high speeds and low use cost. Opening up the SeaFi™ project to investors will see the creation of a new telecommunications operator dedicated to coastal services that offers not only scientists but also the maritime world a high value-added alternative to conventional telecommunications means. ❖

Promising preliminary results

Most of the advances from mathematical modelling should come at the end of the project, but the extensive data collected by the AIRS station have already produced some exciting results.

IMPROVING MARINE FORECASTS

Frédéric and his colleagues have already succeeded in improving sea-state forecasts using Bayesian statistics. To achieve this, they made use of the four public-domain weather forecasts issued by Météo France and its American, German and Irish equivalents. After weighting the wave forecasts from each of the organisations and comparing them with the data on the waves at Inishmaan, the Highwave project teams were able to identify a potential improvement of between 1% and 8% in the forecasts. And the reduction in error can reach 48%. "Today, we can confirm that our predictive model, which is based on public-domain data, is one of the most accurate sea-state forecasting systems in the world," says Frédéric.

UNDERSTANDING HOW THE ROCKS AT THE TOP OF THE CLIFFS MOVE

One of the aims of the Highwave project is to analyse how breaking waves dislodge the gigantic several-tonne-weight boulders located at the top of the cliffs on Inishmaan Island. Before moving on to in situ analysis, an initial experiment with smaller “smart” rocks was carried out in a laboratory in Marseille. As things stand, many questions remain unanswered, but the researchers have already observed that the rocks shifted the most when high pressures and long impact durations were present at the same time. The experiment will be extended on Inishmaan Island by placing accelerometers on several boulders. This will allow the researchers to make a connection between the trajectory of the rocks’ motions and the sea and wave conditions observed by the AIRS station.

DEFINING GAS EXCHANGE IN BREAKING WAVES

When a wave breaks, foam appears on the surface of the water as air bubbles mix with salt water. This phenomenon, about which very little is known at present, is of fundamental interest to the Highwave project researchers. "The order of magnitude of CO_2 fluxes at the water/air interface remains very imprecise today," explains Frédéric. "A better understanding of gas exchange in breaking waves could be of major importance for issues linked to climate change".

A RANGE OF INDUSTRIAL APPLICATIONS

The SATT *(Société d'accélération de transfert technologique)* of the University of Paris-Saclay, responsible for transferring research results to the market, has begun talks with a number of economic players concerning the Highwave project. To date, several industrial companies have shown a keen interest in the project's various areas of study. Improving predictive models of sea-states and better understanding the currents under breaking waves could be very useful to manufacturers managing offshore structures such as floating wind turbines, for example, by enabling them to optimise equipment maintenance costs or productivity. Other emerging industrial applications include reducing ship energy consumption, optimising shipping routes, monitoring coastal erosion and improving the design of coastal infrastructures.

For more information:

About the Highwave project
https://www.highwave-project.eu/

On SeaFi™ technology
https://www.SeaFi.eu/index.php/concept

Contacts:

Jean-Michel Ghidaglia
Scientific Director, Agence Ody.C
University Professor
ghidaglia@free.fr

Stéphanie Jullien
Managing Director, Agence Ody.C
sjullien@lagenceodyc.com

Mathilde Salomon
Development Director, Agence Ody.C
msalomon@lagenceodyc.com

Scan this QR code to go directly to the Highwave project website

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www.lagenceodyc.com
Director: Stéphanie Jullien
Project manager: Mathilde Salomon
Editor: Nathaël Rusch
Artistic director: Céline Lapert