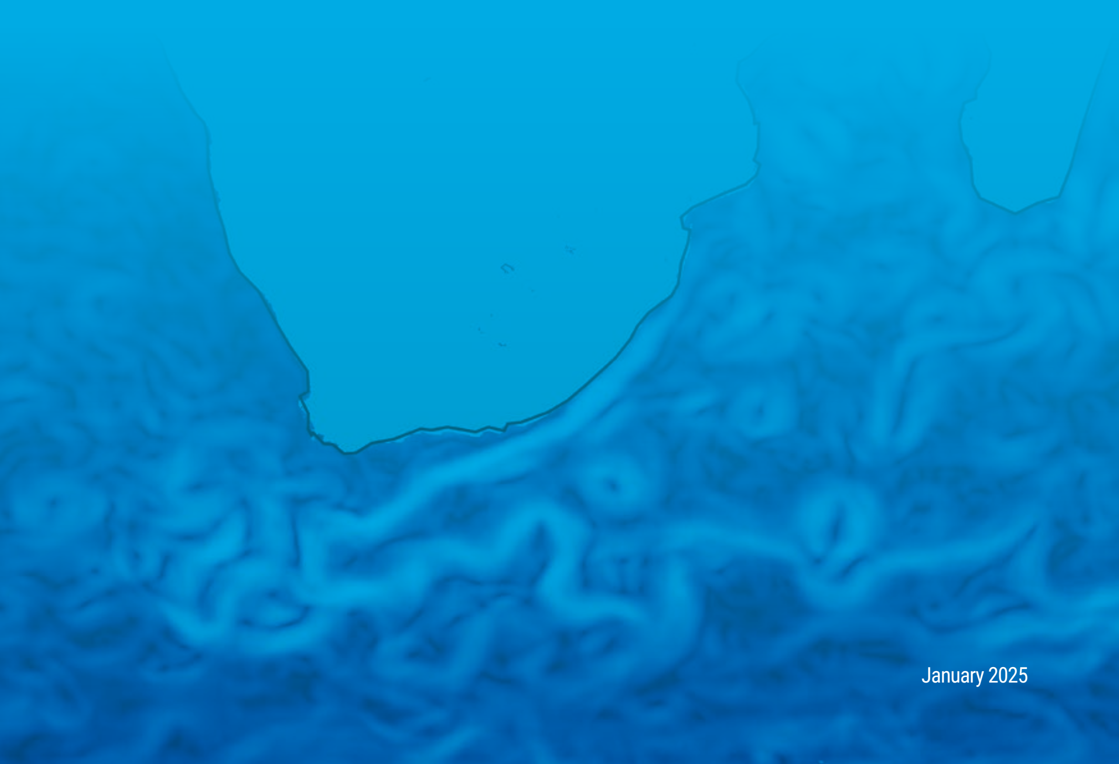
HIGH-RESOLUTION OCEAN CURRENTS FOR OPTIMAL ROUTING

From short-sea shipping to trans-oceanic voyages



January 2025

OCEANIC CURRENTS IMPACT ALL VESSELS

Throughout history, great explorers harnessed ocean currents for navigation. However, with the rise of increasingly powerful engines, the role of currents in navigation and routing plans has diminished. Despite this, forecasting ocean currents remains a challenge for numerical ocean models, and many captains find themselves slowed down by currents which were not predicted by their routing system.

Surface currents affect all ships across the globe. Adverse currents slow ships down, increasing fuel consumption as vessels compensate to maintain their Estimated Time of Arrival (ETA). Conversely, favourable currents enhance a ship's speed over ground, allowing temporary power reduction while maintaining the ETA.

A year-long in-depth statistical analysis of ocean data along the Suez-Malta-Gibraltar route in the Mediterranean Sea reveals that coastal currents and intense eddy formations can significantly extend transit times by several hours. The slower the vessel's speed, the more pronounced the delay to the ETA (Figure 1).

To maintain arrival time (ETA), ships increase speed, leading to excessive fuel consumption. For instance, a container feeder of 2750 TEU, sailing at 18 knots with a fuel oil consumption of approximately 35T/day can induce **20-12 T of additional CO2 emission** and **extra fuel costs** ranging from **2300€ to 3800€[1] for a single trip** between Port-Said (EGPSD) and Tangier-Med (MAPTM).

In the general context of reducing carbon emissions, as well as considering the introduction of the Carbon Intensity Index (CII) by the IMO, the EU ETS regulations or the use of bio-fuels, these additional costs are expected to increase in the next few years. Hence, accurate, high-resolution ocean current forecasts offer a competitive advantage for shipping companies. This solution is readily available today, and is even more profitable in a green-fuel future.

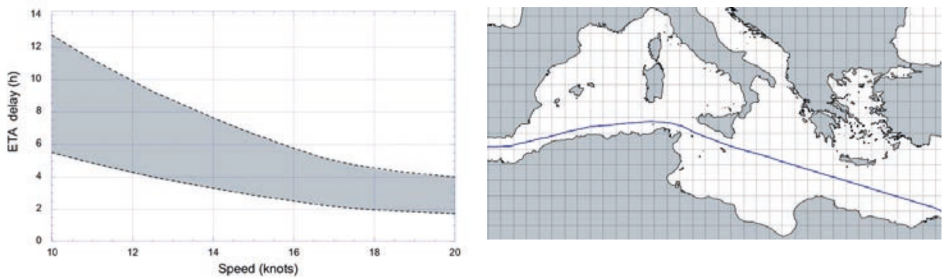


Figure 1 - Average delay in arrival time as a function of the Speed Through Water (STW), induced by surface currents along the Suez-Gibraltar route in the Mediterranean Sea. This statistical analysis was made with one year of ocean data from 2022. The dashed lines correspond to the standard deviation.

1 Assuming an IFO380 price of 550€/T

UNRELIABLE OCEAN DATA LEADS TO SUB-OPTIMAL SHIP ROUTING

Our recent survey of ship captains revealed that, according to their experience at sea, ocean current forecasts are perceived as much less reliable than the wind and wave forecasts. For 70% of captains, the reliability of ocean current forecasts is average or poor (Figure 2).

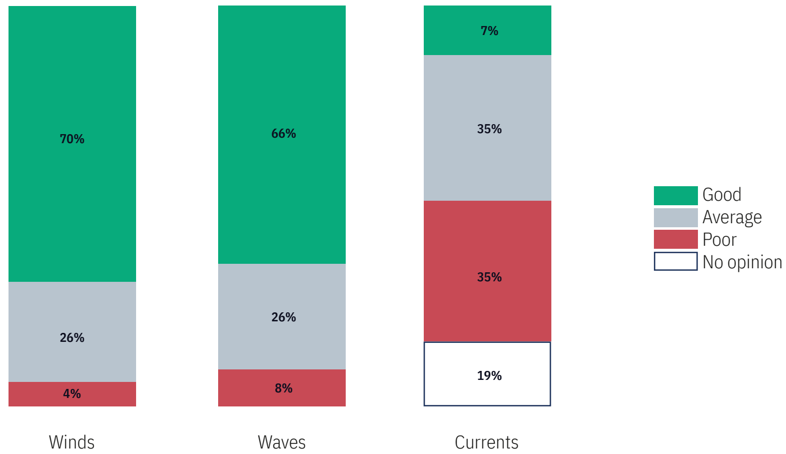


Figure 2 - Captain's perception on the reliability of weather and ocean forecasts.

This is because it is very difficult for numerical models to correctly localize ocean currents or eddies, which are much smaller than anticyclones or atmospheric storms. The typical diameter of a storm is around 1000 km, whereas an oceanic eddy is ten times smaller. In addition, there are far fewer measurements in the ocean than in the atmosphere to correctly initialize numerical models. This leads to an inaccuracy of several tens of nautical miles in the positioning of the main current veins and ocean meanders. This explains the large discrepancies between the predictions of the main operational models and the slowdowns or accelerations induced by real currents on ships.

The example below shows localizations of eddies and meanders around the Gulf Stream, predicted by two different models on the same day (Figure 3). The intensities and the localizations of the eddies and meanders differ significantly between the two models.

Operational oceanic models often disagree on surface currents

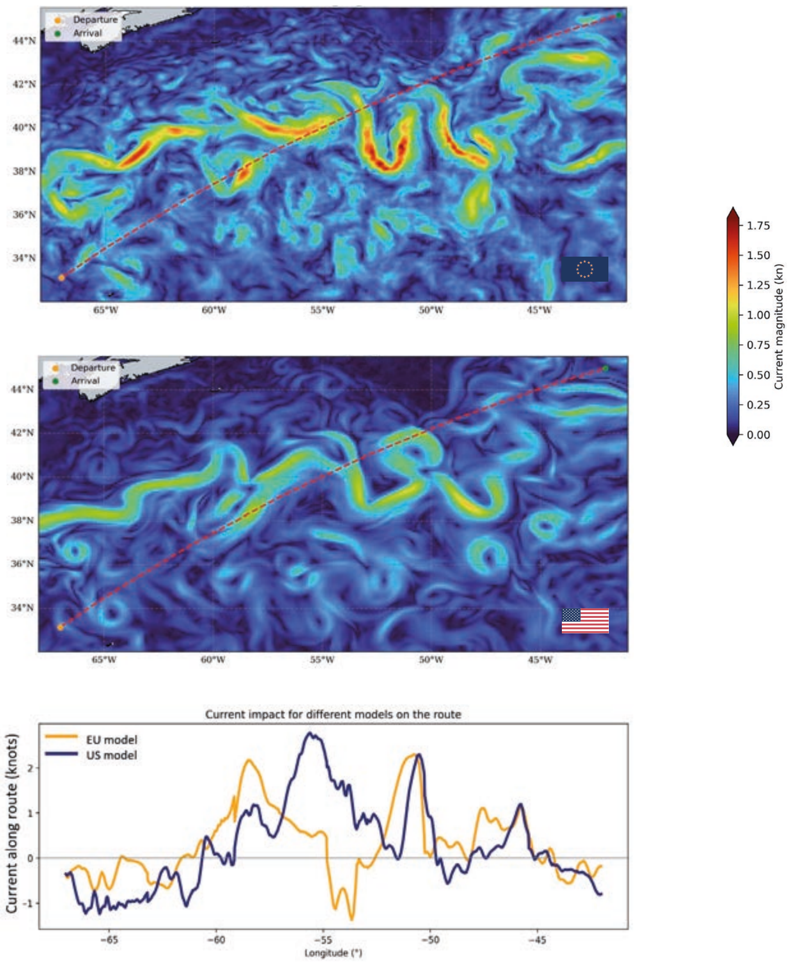
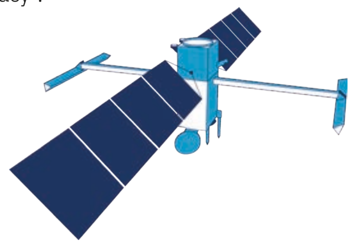


Figure 3 - Nowcast of surface current intensity on July, 1, 2023 according to two global operational oceanic models distributed by the EU's COPERNICUS (Top) and by the US's NOAA (middle). The dashed red line corresponds to the shortest ship route (great circle) from the US to the EU. Significant differences of the current intensity and position can be seen all along the ship trajectory between these two models (bottom).

AI DATA FUSION OF SATELLITE OBSERVATIONS REVOLUTIONIZES OCEAN FORECASTING

Since the early 2020s, research teams at major technology companies have been revolutionizing weather models by developing deep learning systems for operational atmospheric forecasting (Google's GraphCast, Microsoft's Climax, NVIDIA's FourCastNet). The AMPHITRITE R&D team, which comes from France's top AI and oceanography laboratories, develops similar forecasting models for the ocean. Our deep learning systems are specialized models, trained specifically to predict ocean surface currents rather than a complete 3D model of the ocean. This specialization boosts the reliability of our AI models providing high-resolution ocean data[2].

Our AI-based image processing technology integrates data from Sea Surface Temperatures (SST) and chlorophyll (CHL) imagery, along with Sea Surface Height from altimetry satellites and the real-time SWOT-Karin data, available since 2023, to reconstruct surface currents with remarkable accuracy[3].



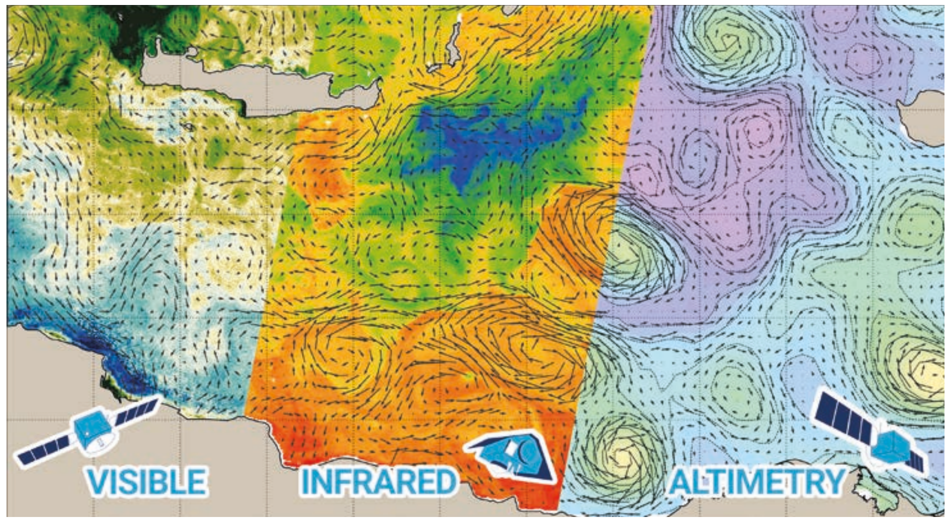


Figure 4 -AI fusion of multiple satellite observations such as Chlorophyll (left), Sea Surface Temperature (middle) and Sea Surface Height (right) allows us to reconstruct surface currents (black arrows). This area corresponds to the eastern Mediterranean Sea near the entrance of the Suez Canal.

2 Kugusheva, A., Bull, H., Moschos, E., Stegner, A., Ioannou, A. & Le Vu, B. (2024). Ocean satellite data fusion for high resolution surface currents maps. Remote Sens. 2024, 16, 1182. https://doi.org/10.3390/ rs16071182

3 Garcia, P., Larroche, I., Pesnec, A., Bull, H., Archambault, T., Charantonis, A. & Béréziat, D. (2024). ORCAst: Operational high-Resolution Current forecasts. Submitted to AIES. 2025.

ONGOING VALIDATION OF OUR MODELS GUARANTEES RELIABILITY

By regularly evaluating the accuracy of our data, we guarantee a very high level of reliability, and also continually improve our data-driven models. Our team of oceanographers and data scientists is dedicated to quality control, and retrieve numerous surface current measurements from drifting buoys, ADCP[4] measurements taken during oceanographic campaigns, as well as high-frequency navigation data supplied by partner shipping companies. This set of reference data, independent of the data used during the learning phases, enables us to test the accuracy of our forecasts and compare them with other operational models used by the shipping industry. Among many evaluation metrics, we first look at the difference between the measured surface current direction and the model's seven-day forecast (Figure 5).

For simplicity, we illustrate our model's performance on two chosen areaswhere maritime traffic crosses many current veins: the Mediterranean Sea and the tip of South Africa (Figure 6).

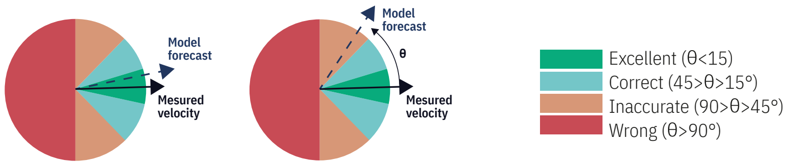


Figure 5 - We compare the direction of measured surface currents (black arrow) with the direction of the model forecast (blue arrow). We then quantify the percentage of misalignment angle amongst all measurements in four categories: excellent (θ<15°), correct (15°<θ<45°), inaccurate (45°<θ<90°) and wrong (90°<θ).

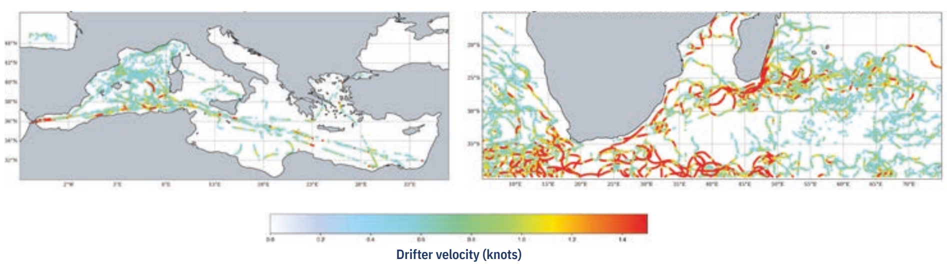


Figure 6 - Trajectories and velocities of the surface drifters used for validation in the Mediterranean Sea and the tip of South-Africa. More than 50 500 and 115 000 in-situ measurements of the surface velocity (at 10m) were collected respectively in these two areas between 2022 and 2024. The color indicates the magnitude of the current intensity.

4 Acoustic Doppler Current Profiler.

In these two areas, the accuracy (good and excellent directions) of several numerical models of the ocean does not exceed 50-60% (Figure 7). This low reliability impedes fine-scale ship routing to avoid adverse currents and to navigate in more favorable regions. Regardless of the optimization algorithm, if the ocean data is poor, ship routing will be unreliable. However, our data-driven models provide a much higher accuracy (Figure 7), the **percentage of excellent forecasts is increased by 60%** while the percentage of **wrong forecasts is divided by two or three !**

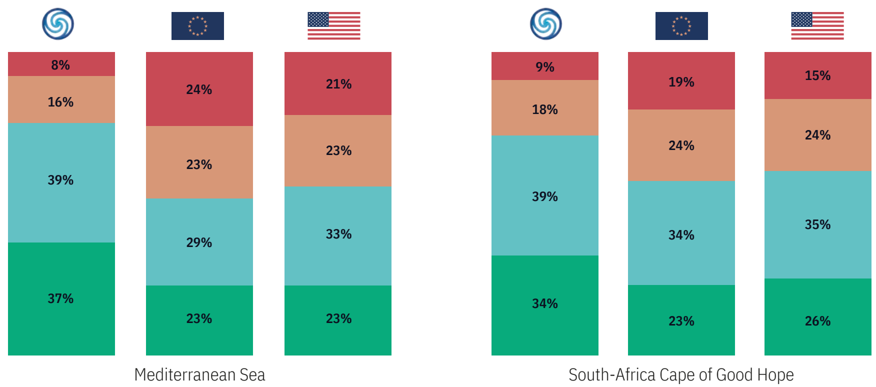


Figure 7 - Comparison of the distribution of the error angles of surface currents between the 7 days forecast of HIRES-CURRENTS (first column) and those of two ocean models of global ocean (second and third columns). These two numerical models represent the state-of-the-art operational ocean forecasting system provided by the EU or US maritime services. The percentage of misalignment angle amongst all measurements are split in four colors-categories: deep green - excellent (θ<15°), light green - correct (15°<θ<45°), orange - inaccurate (45°<θ<90°) and red-wrong (90°<θ).

The accuracy of AI satellite data fusion extends far beyond standard ocean forecasts

Artificial Intelligence has led to breakthroughs in ocean current modelling and its real-word impact in optimizing ship routing lies in its capacity to forecast future states of the ocean. In reponse to the critical need for better ocean forecasts, we have developed an advanced AI module specifically designed to process time-series of satellite observations, propagating complex ocean dynamics into the future.

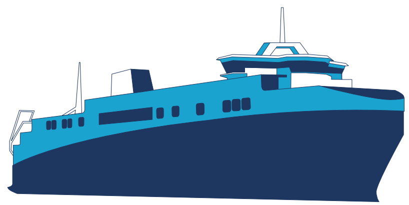
Our HIRES-CURRENTS module forecasts the dynamic evolution of surface currents over the next ten days. This daily ocean current forecast system is capable of generating data all over the globe at a **high-resolution of 3.6 kilometer (1/30°)** at hourly intervals, also taking into account tidal currents. Merging HIRES-CURRENTS data with the state-of-the-art of wind and waves forecasts, provided by institutional weather services, leads to the best quality of oceanic and weather data

We provide reliable and high-resolution ocean data tailored to your needs

EASY FUEL SAVINGS FOR SHORT-SEA SHIPPING IN THE MEDITERRANEAN SEA

Traditional weather routing, primarily employed for trans-oceanic voyages, allows ships to avoid major storms and adverse sea conditions. However, **for short-sea shipping**, especially in enclosed seas, coastal areas, or channels, **more intricate routing is required**. Our goal is to provide the high-resolution data required for fine-scale routing, accurately positioning ships to avoid adverse currents and take advantage of favorable currents.

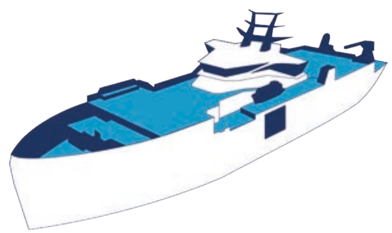
Our latest high-precision data enables a new form of **short-term optimal routing** that fully utilizes the potential of ocean currents. As illustrated in Figure 8, a Ro-Ro ship traveling along the Algerian coast in November 2023 benefitted from this approach.



Initially, its path was hindered by several coastal eddies. With our short-term optimization —provided a day in advance— the vessel altered its course slightly northward, effectively circumventing the eddies. This minor detour, which did not alter the weather conditions along the route, allowed the ship to save over an hour on this journey **and cut fuel consumption by up to 4%** by adjusting its arrival speed. By overlaying the ship's trajectory onto the surface temperature measured by satellite on the same day (Figure 8), we can see that the vessel was optimally positioned to navigate efficiently along the right side of the eddies. Additionally, if the ship had reduced its targeted Speed Through Water (STW) by just 2%, it would have arrived at its destination just one hour later, and reduced its fuel consumption by almost 15% through this optimal routing strategy.

Our new generation of reliable, high-resolution ocean data enables us to provide a new mode of **short-term optimal routing** that harnesses the full potential of ocean currents.

Optimal routing for short-sea shipping is ready to be implemented, starting today, on all ships, without any CAPEX and a high ROI (up to 4-5) for shipowners and charterers.



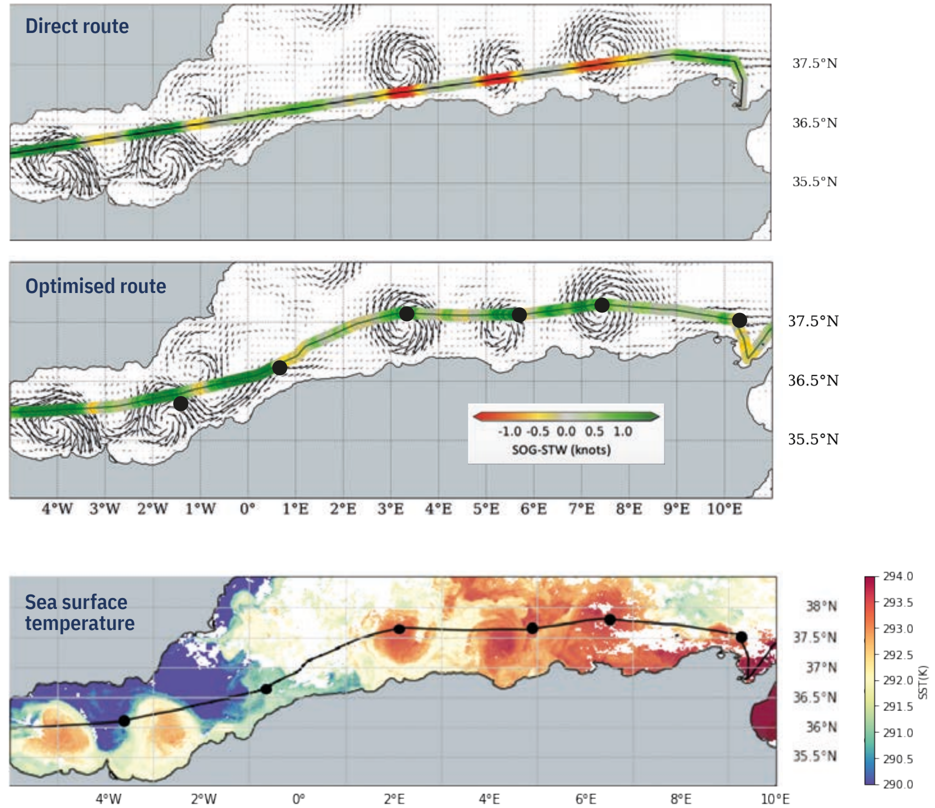
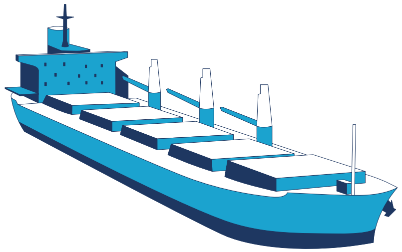


Figure 8 - According to the standard voyage plan, from Tangier to Tunis, the Ro-Ro vessel would have faced several counter-currents induced by coastal eddies (upper panel). The short-term optimal routing (middle panel) provides a small number of extra waypoints (black dots) that lead to an increase of the mean Speed Over Ground (SOG) of 0.6 knots measured by AIS. The impact of the surface currents (SOG-STW) is plotted every 15 minutes, using AIS and navigation data, along the whole voyage. The green (red) dots indicate an increase (decrease) of the SOG by more than 0.5 knots. The optimized route is also plotted on the ultra-high resolution Sea Surface Temperature (lower panel) measured by satellite on the 27 of November 2023.

OPTIMIZING EVERY MILE WITH AI-POWERED OCEAN DATA IN THE NORTHERN-ATLANTIC

Short-term optimal routing is also relevant for trans-oceanic voyages. Even in the middle of the North Atlantic Ocean, veins of currents can be used to speed up a ship's journey. Analysis of the navigation data of a 200m-long bulk carrier, which has chosen a southerly route (dashed line in Figure 9) to avoid storms further north, will encounter several eddies breaking away from the Gulf Stream.



For several hours, this ship will be face against a 0.8-knot current. A slight deviation from the planned voyage can enable the ship to avoid this zone and benefit from favorable currents, accelerating its speed over ground. Then if the ship adjusts its rpm to maintain a constant speed, it can reduce fuel consumption by 4-5%. For this case study, with an average consumption of 26T/day of HFO, the saving will be around €3,600[5] as well as a reduction in CO2 emissions of around 16-19T. The later is not negligible, because if we consider the EU ETS regulation that will be fully applied in 2026, shipowners will be required to pay for allowances on 50% of the CO2 emission from voyages that start or end outside the EU. For this **single voyage**, the **cumulated savings** could then be **around €4,800[5] with just four additional waypoints!** Moreover, the CII will also be reduced by 5%, on this route section, thanks to this simple route adjustment that reduces the fuel consumption and slightly increases the distance covered.

As the difference between the planned and optimized routes is small, the meteorological conditions (wind and waves) are almost identical on both routes. Consequently, this example illustrates the additional gain that is due solely to ocean currents. However, to achieve these gains, we need very precise and reliable ocean current data at high resolution. Today, HIRES-CURRENT data are the only data available for this type of fine-scale routing. Hence, combined with a standard weather routing mainly accounting for large-scale storms (i.e. strong winds and waves), an optimal routing, which takes into accounts the **highest quality of Met-Ocean forecasts**, can then **leads to 10-15% of easy fuel savings** for a trans-Atlantic voyage.

Cutting 4-5% of fuel consumption and CO2 emissions can be achieved with just four additional waypoints over a five-day period.

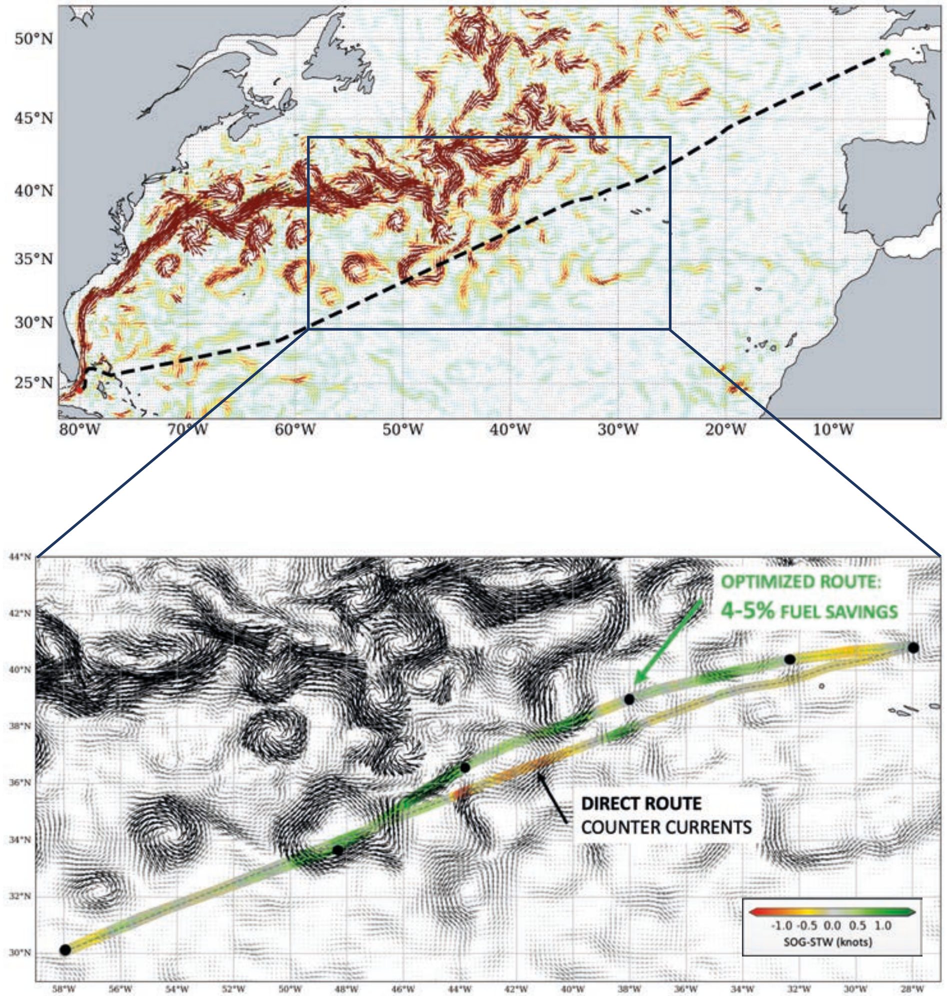
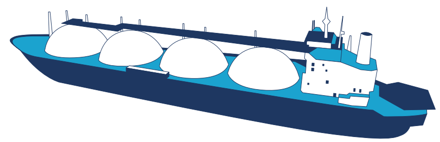


Figure 9 - Upper panel: route taken in December 2022 by a bulk carrier crossing the North Atlantic and following a southerly route. Lower panel: impact of ocean currents between the direct route (voyage plan) and the optimized route, in an area with strong current veins



5 Assuming an IFO380 price of 550€/T and EU-ETS allowance of 70€/T(CO2)

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