PRELIMINARY

Deltares

TKI Ocean Race and Oceans Sustainability research project 2022-24

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Contents

1 Introduction

This report provides a summary of the TKI Ocean Race research project and evaluates the project activities, project deliverables and project experiences. This project is conducted in the period 2022 – 2024 under the TKI Maritime program[1], with the following consortium partners:

- DutchSail B.V. (referred to as *DutchSail*. Representing *Team JAJO*)
- Stichting Deltares (referred to as *Deltares*)
- Allseas Engineering B.V. (referred to as *Allseas*)
- Poortman Sailing Services/Rotterdam Offshore Sailing Team (referred to as *ROST*)
- Stichting New-York – Rotterdam (referred to as *NYR rowing team*)
- Provincie Zuid-Holland

The project objective is: *Through sailing, collecting relevant data and analysing the results to develop our models and better understand the hydrodynamics of the world's oceans, ultimately optimising offshore navigation and reducing carbon emissions.*

Figure 1.1: Project objective

Chapter two summarizes the workplan and project deliverables. Chapter three describes the hydrodynamic models used under this project and chapter four the operational framework for making forecasts using these hydrodynamic models. Next, chapter five elaborates on the sailing competitions and concludes with a validation of the delivered forecasts with the measurements from the field campaigns. Chapter six elaborates on the pilot carried out with Allseas with a heavy lift operation in the East Irish Sea. Chapter seven describes the last field campaign executed under this research project, a trans-Atlantic rowing challenge. Highlights from the Ocean Summit in The Hague are discussed in chapter eight. And finally, a summary and conclusion can be found in chapter nine.

[1] Top consortium Knowledge & Innovation (in Dutch: *Topconsortia voor Kennis en Innovatie*). See https://tkimaritiem.nl/

2 Work plan

As part of a scientific program, various field campaigns were carried out by the consortium partners:

i) The European Championships for Sailing in Breskens, participated by ROST
ii) The Ocean Race 2022-23, participated by Team JAJO
iii) The Fastnet Race, participated by ROST and Team JAJO
iv) An offshore heavy lift operation called 'project Morecambe', executed by Allseas
v) A trans-Atlantic rowing challenge, executed by the NYR rowing team.

Measurements and relevant field experiences acquired during these field campaigns, helped to better understand the hydrodynamics at unique locations of the world's seas and oceans, leading to improved numerical models. In close collaboration with modelling teams and software development teams, contributions are established to successors[2,3,4,5] of various software packages. These are incorporated into products for, amongst others, governments, the maritime sector, the offshore wind industry and scientific communities.

The data collected during the field campaigns also allowed for a data-model-comparison, to verify model results using field measurements in remote and unknown areas. In addition, feedback received based on these field campaigns helped to co-design and co-create an operational web interface to better distribute relevant data and information. This can support the maritime industry to optimize offshore navigation, to i) ensure safety at sea, ii) save cost and time, and iii) to reduce CO2-emissions (see Figure 2.1). Results are presented during the Ocean & North Sea Summit in The Hague on the 14th of June 2023, associated with The Ocean Race.

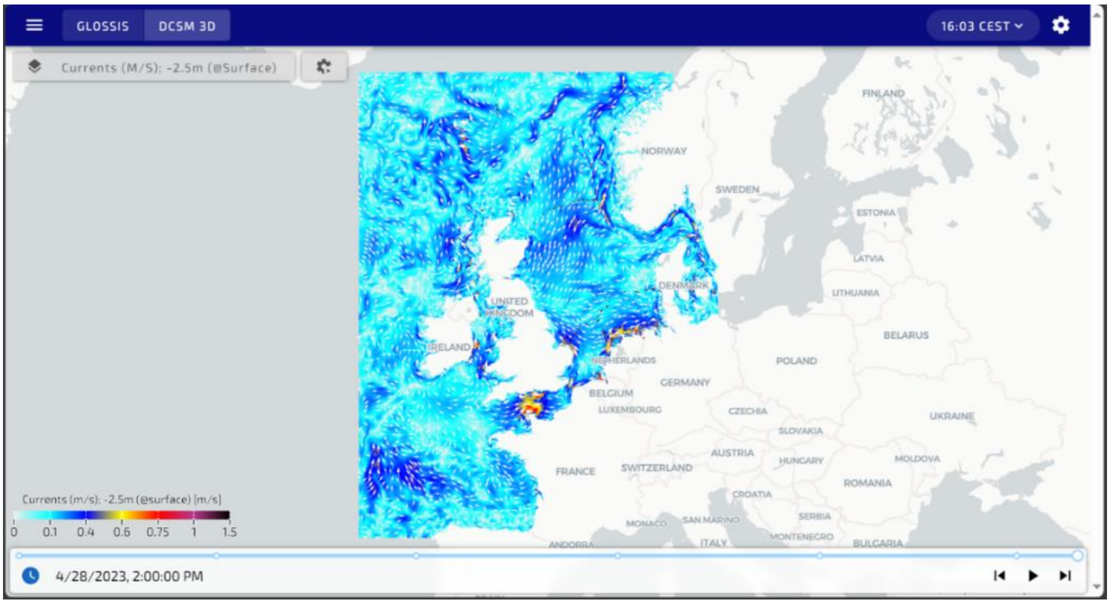

Figure 2.1: Impression of the operational web interface to better distribute data- and information needs to (potentially) support the maritime industry to optimize offshore navigation and to reduce CO2-emmssion.

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[2] See link to 'GTSM model description and development'
[3] See link to 'Development of 3D DCSM-FM'
[4] See link to 'Delft3D FM: the successor of the Delft3D 4 Suite'
[5] See link to 'Delft-FEWS supported release versions'

3 Models

Under the TKI Ocean Race project, the Delft3D Flexible Mesh hydrodynamic modelling software (Delft3D FM)[6] was used, the successor of the Delft3D 4 Suite. Like Delft3D 4, the Delft3D FM is capable of modelling water level and current variations under the forcing of tide, wind, air pressure and density gradients, but now on an unstructured grid which allows flexible model refinement to increase resolution for particular regions of interest.

The field campaigns helped to better understand the hydrodynamics at unique regions of interest, leading to improved numerical models. For example to better model baroclinic effects at the model boundaries of Deltares' three-dimensional model of the North Sea (*3D DCSM-FM*), and to better understand model partitioning for fast parallel computing and complex 3D geometries with combined z,sigma-model layering.

Numerous model schematisations are built, using the Open-Source Software[7] of Delft3D FM. Model schematisations and data products used in the TKI Ocean Race project are described in detail below.

3.1 GLOSSIS product

The Global Tide and Surge Model (GTSM) is a depth-averaged hydrodynamic (Delft3D FM) model, developed by Deltares, with global coverage. GTSM has a spatially varying resolution which increases towards the coast and can be used to simulate water levels and currents, that arise from tides and storm surges. There is a broad range of applications and (research) projects which make use of GTSM[8].

The global model can be applied in areas of low data availability, which are difficult to access, and with complex dynamics. It can be used in areas vulnerable to storms and cyclones where fast and accurate local information is required for emergency decision-making and disaster risk reduction. Due to its global nature, the GTSM is an ideal platform to study large-scale oceanic changes due to Climate Change. Examples of (commercial) application of GTSM are Smartcom navigation systems, Google, Made Smart Group and The Ocean Race.

The GTSM also runs operationally at Deltares on a daily basis in GLOSSIS[9] (GLobal Storm Surge Information System), producing 10-day water-level and storm surge forecasts on a global scale every 6 hours. It therefore provides the possibility of easily providing forecasting services anywhere in the world. Such forecasting services are used not only for early warning of extreme water levels, but also for navigation purposes (including a unique combination of tidal and deep-sea currents).

GLOSSIS can accurately predict tidal currents along the coast and can be coupled to operational ocean models (e.g. HYCOM, CMEMS[10]) to incorporate a proper representation of currents in deep oceans. This is how the GLOSSIS product under this TKI Ocean Race project is setup, combining ocean currents from the Deltares Global Tide Model with the CMEMS product.

[6] https://www.deltares.nl/en/software-and-data/products/delft3d-flexible-mesh-suite
[7] https://oss.deltares.nl/web/delft3dfm
[8] https://www.deltares.nl/en/expertise/projects/global-modelling-of-tides-and-storm-surges
[9] https://www.deltares.nl/en/expertise/projects/global-storm-surge-information-system-glossis
[10] https://data.marine.copernicus.eu/viewer/expert

3.2 2D DCSM-FM product

Deltares also developed a Delft3D FM hydrodynamic model of the Northwest European Shelf: the Dutch Continental Shelf Model – Flexible Mesh[11] (DCSM-FM). This model covers the North Sea and adjacent shallow seas and estuaries in the Netherlands, such as the Wadden Sea, the Ems-Dollard estuary, the Western Scheldt and the Eastern Scheldt. There are several versions of DCSM-FM available: a 3D-model (3D DCSM-FM) and two 2D-models (DCSM-FM 0.5nm and DCSM-FM 100m). The resolution of the DCSM-FM 0.5 nm varies with the local water depth from about 4 nautical miles at the location of the open boundaries in the oceanic waters to ~ 0.5 nautical miles in the shallow, coastal waters. DCSM-FM 100m, also a 2Dh depth-averaged model, includes additional refinements in Dutch coastal waters and has a grid resolution of about 100 m along the Dutch coast.

3.3 3D DCSM-FM product

The 3D DCSM-FM[12] sets a new standard for the 3D modelling of regional hydrodynamics. It is used for, amongst others, operational water and coastal management, and research. The model simulates water levels (tide and storm surge), currents, water temperature and salinity. Both short-term and long-term developments can be assessed, at both local and regional scales. The model provides insights into the fate and interactions of complex natural phenomena in coastal waters and the open sea. It covers the Northwest European Continental Shelf, which includes the entire North Sea from the Irish Sea to the Baltic Sea and from the coast of Northern Spain to the coast of Scandinavia.

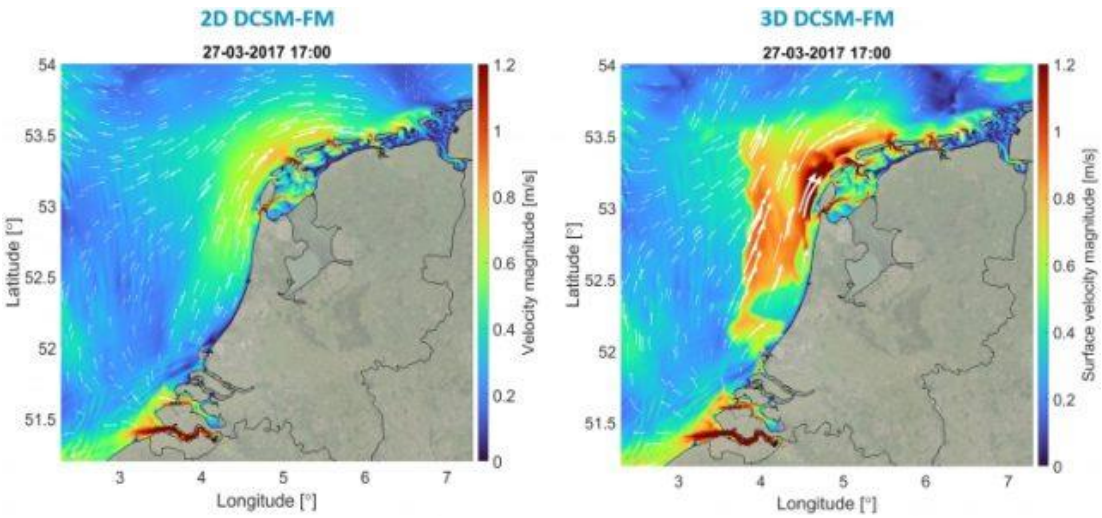

Figure 3.1: Impression of the depth-averaged flow velocities from a 2D model (left) and surface flow velocities from 3D DCSM-FM (right)

The TKI Ocean Race project helped to operationalize the 3D DCSM-FM model. It is now run operationally at Deltares on a daily basis, both in hindcast mode and forecast mode. The hindcast is based on latest available (external) data sources aiming for high accuracy and making it suitable for analysing historical events. In forecast mode, the model runs a two-day forecast every 6 hours, outputting several parameters such as water levels, storm surges, current velocities, salinity, and temperature. Such forecasting services are not only useful for navigation purposes, but also for early warning of extreme water levels, Search and Rescue applications, water quality and ecological purposes (like environmental disasters, oil spills and salvage operations).

[11] https://iplo.nl/publish/pages/132741/factsheet-noordzee-dflowfm2d-v2022_v3.pdf
[12] https://www.deltares.nl/en/expertise/projects/3d-dutch-continental-shelf-model-flexible-mesh

3.4 Copernicus (CMEMS data)

The Copernicus Marine Environment Monitoring Service (CMEMS[13]) is part of the EU's Earth observation program, delivering high-quality information on ocean conditions. CMEMS excels in using advanced models and data assimilation techniques to convert vast observational data into practical data products.

Key offerings include reanalyses and forecasts of ocean currents. Reanalyses provide detailed historical reconstructions of ocean states, crucial for climate research and long-term environmental monitoring. Forecasts offer up-to-date predictions of oceanic conditions, aiding in marine navigation, fisheries management, and disaster preparedness.

CMEMS products and services enhance our understanding and management of marine environments, supporting research, operational activities, and informed decision-making in ocean and coastal stewardship.

In the TKI Ocean Sustainability project, the ocean currents from CMEMS have been used to complement the tidal flows simulated by Deltares' GTSM. This combined data product of tidal (barotropic) and oceanic (baroclinic) flows has been shared with the navigators of Team JAJO during the Ocean Race and with the NYR rowing team during their Trans-Atlantic challenge.

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[13] https://www.copernicus.eu/en

4 Operational framework

The operational forecasting system is based on Delft-FEWS[14], an open data handling platform specifically designed for forecasting and warning systems. Delft-FEWS[15] consists of a sophisticated collection of modules designed for building and customizing an operational framework to the specific requirements of an individual organisation.

Because of its unique characteristics concerning data importing, processing, and model connections, Delft-FEWS has been applied in a wide range of operational situations and is considered a world standard in early warning systems (applied in +100 countries)[16]. Users include, among others, the Bureau of Meteorology (BoM) in Australia, the Environment Agency in the UK, the Mauritius Meteorological Service (MMS), The National Institute of Meteorology in Mozambique (INAM), Rijkswaterstaat (RWS) in the Netherlands and the National Weather Service (NWS) in the USA.

By using Delft-FEWS under the TKI Ocean Race project, developments and experiences are shared with a global user community[17] such that other forecasting agencies around the world benefit from our developments.

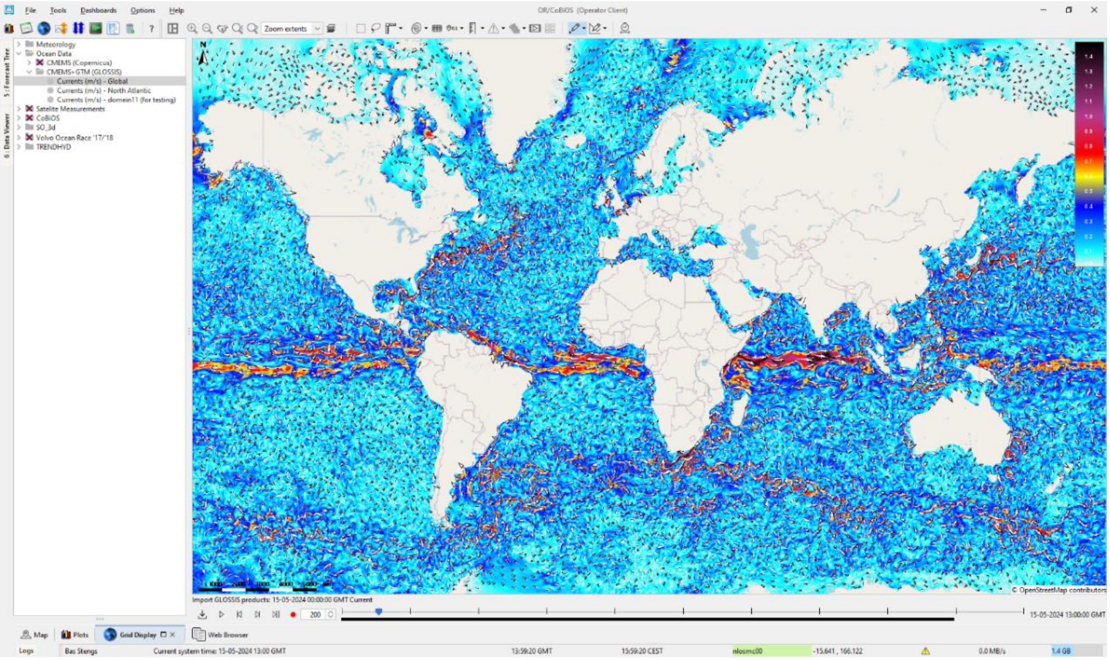

Figure 4.1: Impression of Delft-FEWS, visualizing a 10-day ocean forecast of sea surface velocities

[14] See Introduction to Delft-FEWS (youtube.com)
[15] Delft-FEWS can be used free of charge with a signed license agreement.
[16] See highlights of Delft-FEWS show cases
[17] See Home - Delft-FEWS - oss.deltares.nl

Delft-FEWS system provides several options: from a prototype/pilot Stand Alone system to a robust client-server system. Models and workflows are full-automatically run in client-server mode. Global models run in the operational framework called GLOSSIS. Data from this system is ingested in another system called FEWS-Offshore, which runs various processing workflows and regional models to serve marine forecasting purposes. This application is linked to an interactive web viewer (called the WebOC[18]) for data visualization and data dissemination. This allows users to inspect ocean currents without losing model accuracy, and downloading datasets for specific regions of interest in GRIB-format.

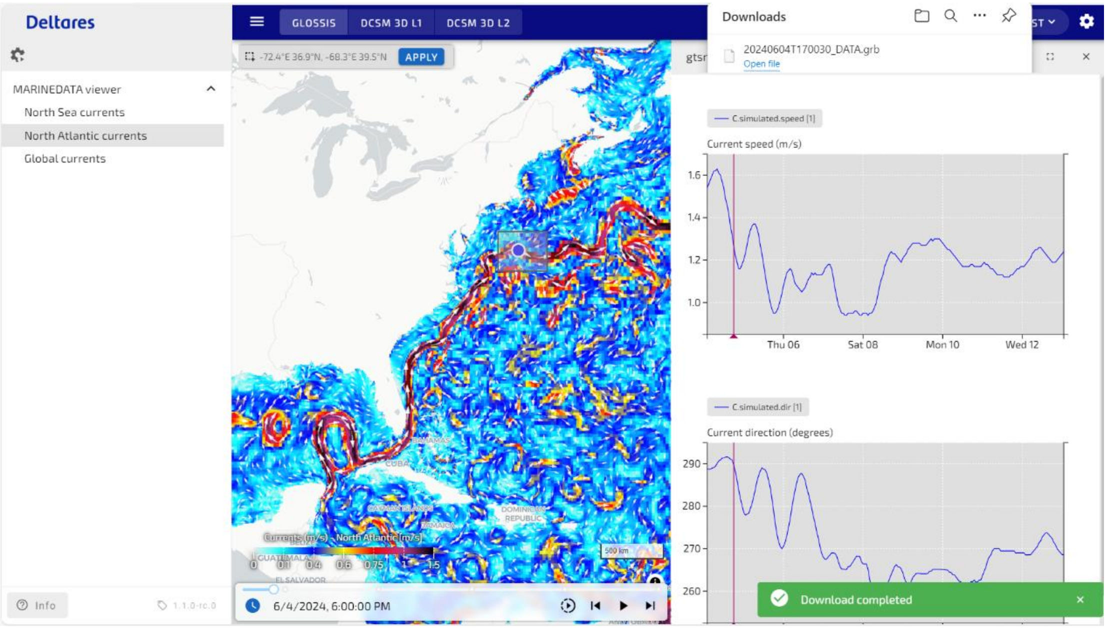

Figure 4.2: *Impression of the Marine Data Viewer; visualizing and downloading ocean currents. Both for gridded datasets (defined by a specific region of interest) and scalar datasets (for a point location with specific coordinates).*

[18] See 11 Web Operator Client - DELFT-FEWS Documentation - Deltares Public Wiki

5 Sailing competitions

5.1 Assisted ROST during EK championships in Breskens

In August 2022, ROST participated in the European Championships ‘Breskens Sailing’, a sailing competition which took place in the Western Scheldt (South-West in the Netherlands). Deltares shared plots, similar to a tidal atlas, of the simulated flow velocities (using DCSM-FM 100m) with ROST. The flow pattern figures were fine-tuned with ROST and included features such as the locations of buoys for visual reference during the race, as well as bathymetry contours (see Figure 5.2).

With the help of a flow model from Deltares and clever sailing, ROST managed to achieve 2nd place during the European Sea Sailing Championship on the Western Scheldt near Breskens[19]. Besides the young talent in the boat and good coaching of the sailing team, a decisive asset was knowledge about the currents in the dynamic area in the estuary of the Western Scheldt.

Figure 5.1: ROST competing during the European Sea Sailing Championship on the Western Scheldt near Breskens

The Western Scheldt is a very challenging sailing area with its tidal currents, sandbanks, and deep shipping channels. To make strategic choices based on the prevailing currents, an accurate numerical model can be used, which includes the weather patterns that affect the local currents. Deltares provided a new forecast every 6 hours, based on the latest meteorological forecast, of the flow velocities in the Western Scheldt. According to ROST the quality of the data was accurate enough to make tactical choices and seek for the fastest route. Thorough preparation is ‘key’ within the sport and the collaboration with Deltares made this possible. Feedback coach ROST: “*The result was astonishing. A second position during the*

[19] https://www.deltares.nl/en/news/rost-takes-silver-at-european-sea-sailing-championship-with-help-from-deltares/

European Championship with a young talent team among proven pro-sailors is truly a major achievement."

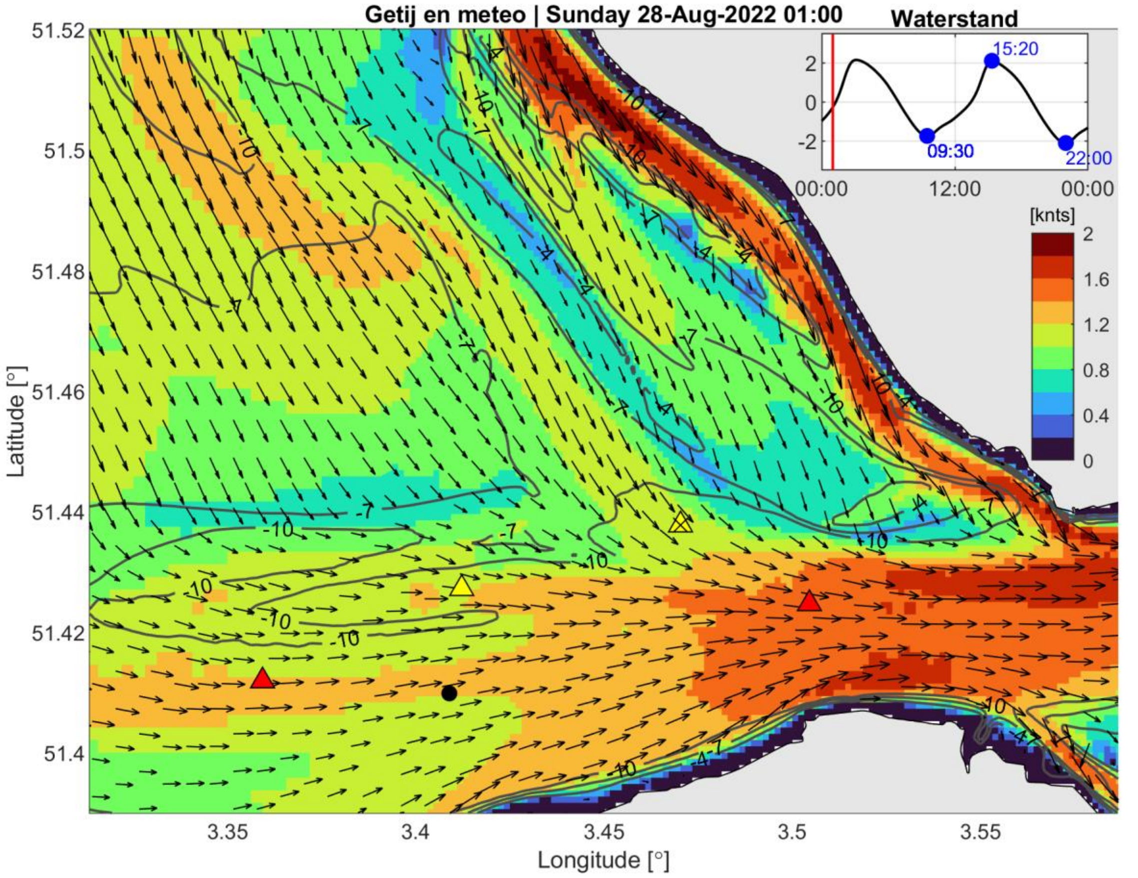

Figure 5.2: Example of data share. Ocean currents shown in knots, tidal water level shown in meters. For georeferencing various buoys are plotted on the map and contour lines are drawn to help detect shallow regions.

5.2 Ocean Race 2022-23

The Ocean Race 2022-23 had two disciplines; the foiling IMOCA fleet racing around the world and the VO65 fleet which participated in three stages of the race:

- Alicante to Cabo Verde (leg 1)
- Aarhus to The Hague (leg 6)
- The Hague to Genova (leg 7)

Team JAJO was one of the six VO65 teams competing for the Ocean Race VO65 Sprint Cup. This new trophy is specially created for VO65 teams and awarded to the team that accumulated the best score across three different legs of the race.

Figure 5.3: Route of the Ocean Race VO65 Sprint

5.2.1 Leg Alicante – Cabo Verde

The first leg of the Ocean Race 2022-23 started on Sunday 15th of January 2023. Six VO65 teams were on the starting line in Alicante (Spain) competing for the Ocean Race VO65 Sprint Cup. The teams sailed from the Mediterranean Sea through the challenging Strait of Gibraltar, with strong tide- and density driven ocean currents, combined with strong winds. Team JAJO used the Deltares GLOSSIS product for the routing. Due to the strong winds, they tore one of their sails, but continued to set sail passed the Canary Islands to Cabo Verde. Team JAJO finished in second place[20].

Feedback navigator Team JAJO: *"The models from Deltares helped us very well in the Strait of Gibraltar. There we gained many miles compared to the competitors by staying close to the coast (less head current). Furthermore, we also experienced less current at the entrance and exit of the street by staying north of the stronger current. See also the image below – our 'track' is the green one."*

Figure 5.4: Screenshot how the VO65 teams sailed through the Strait of Gibraltar (from East to West), with Team JAJO shown in green, choosing a unique route by sailing close to the coast where they experienced less head current.

[20] https://www.jajo.com/the-ocean-race/team-jajo-tweede-in-eerste-leg-the-ocean-race-vo65-sprint-cup/

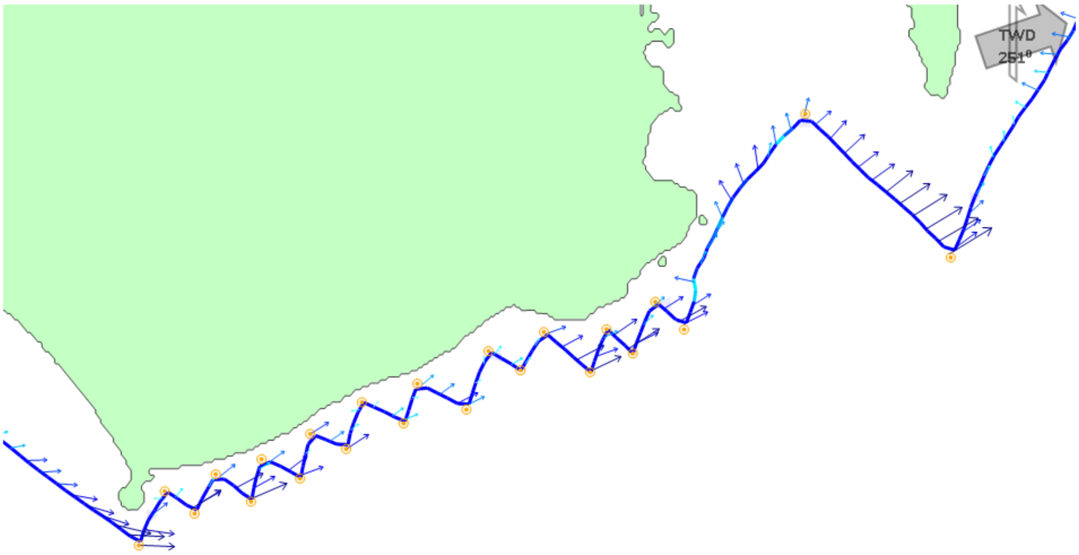

Figure 5.5: *Screenshot indicates how team JAJO sailed through the Strait of Gibraltar (from East to West), experiencing head current shown by the coloured arrows.*

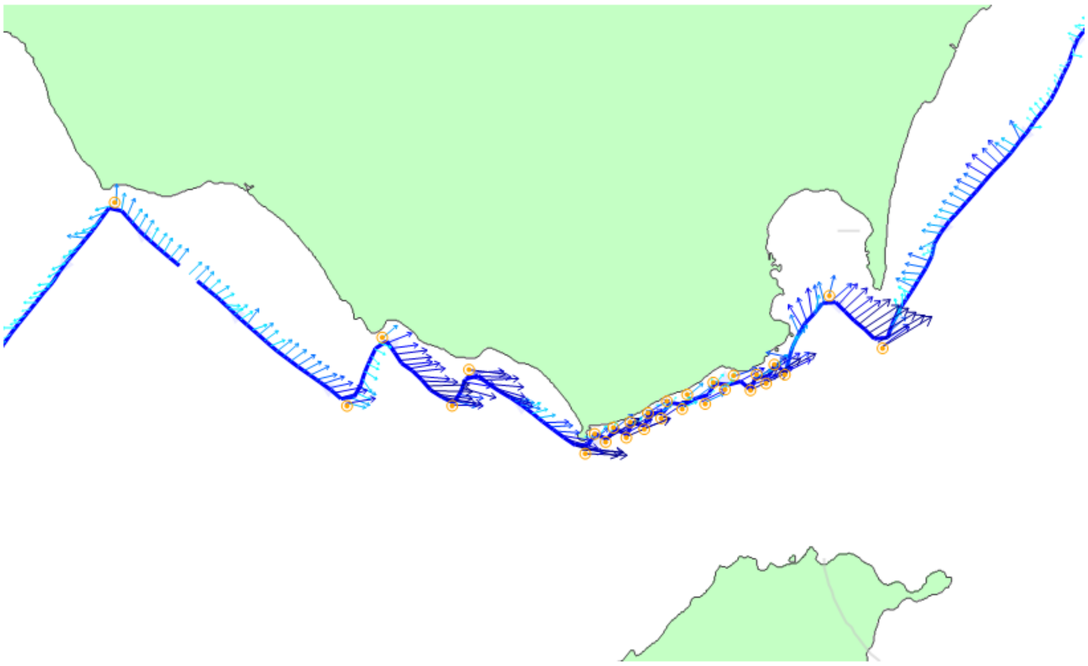

Figure 5.6: *Impression how Team JAJO sailed through the Strait of Gibraltar (from East to West), experiencing head current shown by the coloured arrows.*

5.2.2 Leg Aarhus – The Hague

The second leg of the Ocean Race sprint started on Thursday the 8th of June 2023. The teams headed from Aarhus (Denmark) to The Hague (The Netherlands). Deltares shared currents from the 2D DCSM-FM model with Team JAJO. In a relative calm sea state, Team JAJO finished in third place.

Team JAJO experienced difficulties navigating out of the Baltic Sea: "*In the Baltic Sea / near the Norwegian coast, the 2D DCSM-FM model seemed less accurate and deviated more* *compared to TideTech. For example, the current in the Deltares model was almost zero, although there was sometimes a current of 1.5 knots".*

The first part of this leg went through the Kattegat and Skagerrak. The hydrodynamics in these areas are quite complex, influenced by stratification and water exchange with the less saline Baltic Sea. These complex, three-dimensional hydrodynamic processes are not represented in the 2D model. Modelling surface currents in basins like the Kattegat, Skagerrak, and along the Norwegian coast requires a more sophisticated approach, such as using the 3D DCSM model. Unfortunately, operationalizing this model within the forecasting framework of Delft-FEWS was still under development during this leg.

5.2.3 Leg The Hague – Genova

The final leg started on 15th of June 2023 when all teams headed to the finish in Genova (Italy). The teams sailed through the challenging English Channel and Strait of Gibraltar again, before finishing in Genova. Team JAJO used the 2D DCSM-FM data in the North Sea and English Channel, and the GLOSSIS product in the second part of the leg. After an intensive battle, Team JAJO crossed the finishing line in second place and secured the second place on the overall leaderboard[21].

Feedback navigator Team JAJO: "*We benefited from the Deltares models during this leg, especially around Gibraltar and in the UK channel. Our speedometer had some problems, so the measurement data may not be reliable. Nevertheless, we noticed that the Deltares models accurately predicted the ocean currents both in time and space. We used both the Deltares model and the TideTech model such that we could compare and get a feel for uncertainties."*

Figure 5.7: Team JAJO at the finish in Genova

5.3 Fastnet Race

5.3.1 Introduction

In July 2023 both Team JAJO and ROST participated in the Fastnet Race. This is an offshore yacht race which takes place every two year between Cowes (South of the UK) and Cherbourg (France) rounding the iconic Fastnet Rock (South of Ireland). An epic race of 700 nm. Over 350 teams participated. This edition, heavy weather made it tough competition, which caused ROST to retire after approximately 8 hours of sailing due to structural damage the boat sustained. Team JAJO finished in 2nd place[22]. Deltares shared their 2D DCSM-FM product with both teams.

[21] https://www.teamjajo.nl/sailor-quotes-after-leg-7
[22] See race results

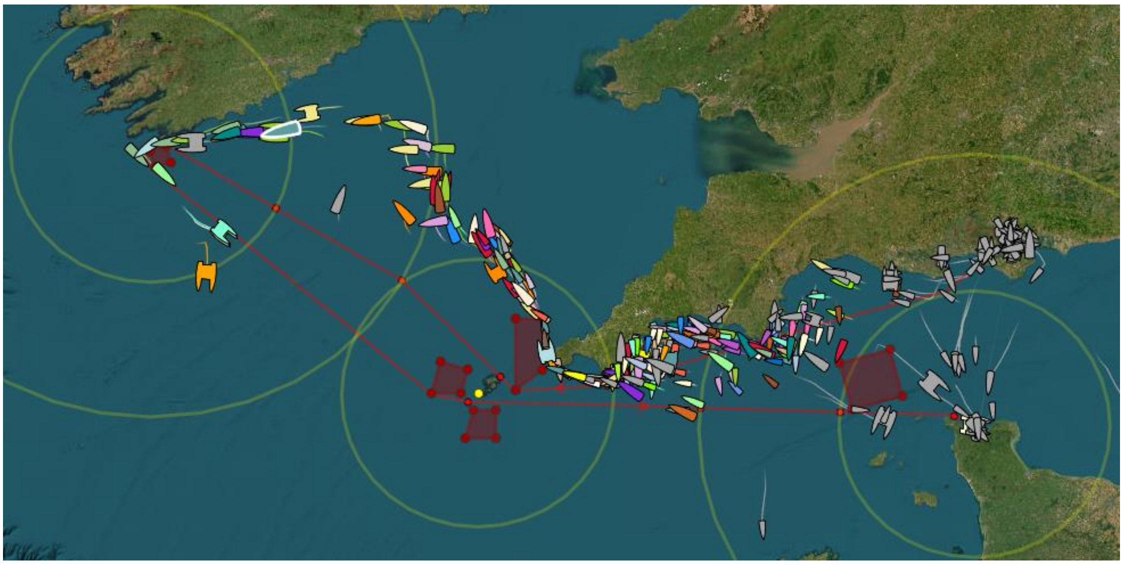

Figure 5.8: Fastnet Race 2023, with over 350 teams competing.

5.3.2 ROST

Feedback ROST:

"Thanks for a great cooperation and some very useful files again; they gave us a lot of confidence.

Here's an update that comes earlier than expected: sending this email from Cowes, because as you might have seen on the tracker we had to retire from the race and return to the starting port.

The conditions were quite brutal during the first 24 hours, heavy weather upwind with wind against current (makes terrible sea state). Even though we sailed as conservative as we could we suffered some damage inside the boat and had to retire from the race after +/- 8 hours.
All onboard are fine and by turning around and slowing down we stopped the damage from spreading and kept it repairable, which we are looking into now.

All in all, a bit of a disappointment, but we're trying to find comfort in the fact that we made the only right decision in a situation beyond our control. The attached gif gives an impression of the sea state; this was still in sheltered waters 😊.

We'll send you the logfiles and our findings for the few hours we could use your models, but as said, it was definitely an asset during preparation."

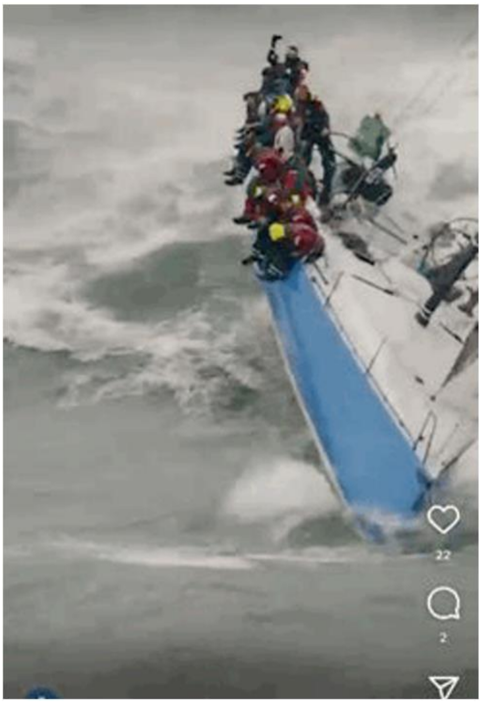

Figure 5.9: ROST battling a heavy sea state during the Fastnet Race.

5.3.3 Team JAJO

Feedback navigator Team JAJO:

"During the iconic Rolex Fastnet Race there are several important land points where currents have a major effect. The more than 350 teams participating all try to capture the most favourable currents. The VO65 Team JAJO received flow data from Deltares and thus received very detailed information that made a significant contribution to achieving a 2nd place in the general classification."

Total results for IRC Overall: 358

IRC Course Record

Pos	Yacht	Skipper/s	Owner	TCC	Finished	Elapsed	Corrected	Boat Type	Source	Points	Status
1	CARO CAY52	MAX KLINK	MAX KLINK	1.413	25 Jul 2023 06:25:02	02d 16:40:02	03d 19:22:29	Botin 52	Committee	115.7	Finished
2	TEAM JAJO NED1	CLARKE MURPHY	CLARKE MURPHY	1.654	24 Jul 2023 22:18:42	02d 08:33:42	03d 21:33:11	VOLVO OCEAN 65 4.7	Committee	113.5	Finished
3	WARRIOR WON USA60564	CHRIS SHEEHAN	CHRIS SHEEHAN	1.409	25 Jul 2023 08:26:38	02d 18:41:38	03d 21:58:18	PAC 52	Committee	111.8	Finished

Figure 5.10: Results of the Fastnet Race 2023, with Team JAJO in 2nd place.

"For us, the ocean current was mainly important for the section between Southampton and Lands End. This is where the landscape has many features that influence ocean current. The biggest difference between the data provided by Deltares compared to the commercial data that we obtained, was that the Deltares ocean current seemed to be much more accurate around these different landscape features. We try and aim for most favourable currents, even if that means differences of 0.1nm. This determines how close we sail to the coast, aiming for favourable currents near specific landscape features. Here we saw that the difference between the current at sea vs. close to the coast in the Deltares model is much larger, and in

reality more precise, than in commercial models. This gave us an advantage over the other teams."

5.4 Validation of ocean current predictions with measured boat data

For most events where team JAJO and ROST received current forecasts, Deltares received logdata from the onboard navigational systems of the teams. Based on the logdata of the boats, Deltares performed analysis to validate the forecasts that were prepared for the teams.

5.4.1 Measuring currents from moving boats

A moving boat cannot measure currents directly because the boats itself move through the water. The closest estimate available are called **Set** and **Drift** (see Figure 5.11). **Set** (an angle) and **Drift** (a magnitude) describe the differences between:

1. the course (**COG)** and speed **(SOG)** over the globe measured with GPS.
2. the heading (**HDG)** and speed **(BSP)** of the boat through the water.

Set and **drift** give a perfect current measurement if two conditions hold:

- **COG, SOG, HDG** and **BSP** are measured without errors.
- A boat does not move sideways at all.

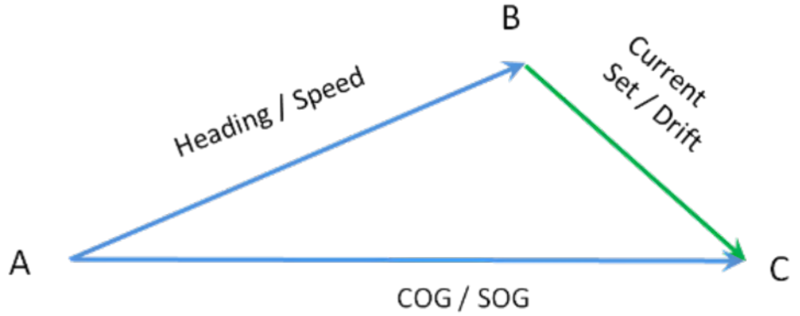

Figure 5.11: Illustration of calculation of Set and Drift from the boat's heading and speed relative to the water and the boat's course and speed relative to the globe.

In practice, both conditions are not always met. Especially small calibration errors in the boat's compass heading and speed through the water (measured by a spinning wheel underwater) can cause erroneous set and drift measurements. Furthermore, especially when sailing through waves and close-hauled course, sailing boats always experience some sideways drift (Leeway) that impacts Set and Drift, which is not induced by hydrodynamic currents.

This effect can for example be seen in the logdata from ROST during the Fastnet race (see Figure 5.13) just before and after a tack (course change) of the boat, the measured current vector changes significantly in direction. This is likely due to sideways movement of the boat while sailing upwind in extremely heavy weather.

While measurements are not always perfect, they still provide useful information for the scientists at Deltares. The next section describes how the information obtained during the sailing competitions improved our model understanding.

5.4.2 Results of the validation

Figure 5.12 shows the comparison of current measurements and forecast during the European Championship in the Western Scheldt. On August 23rd ROST sailed races just outside of the Western Scheldt. In the early morning, the team experienced incoming tidal currents that turned to outgoing tide around 12:00 UTC. The timeseries of current magnitudes indicate that it is underestimated, up to half a knot. This can partly be explained by the fact that a 2D (depth-averaged) model was used, surface currents are usually stronger that the current averaged over the total water column. Accounting for this effect in a 3D model, or assuming a certain correction factor on the current magnitude would likely improve the forecast. However, it is not a full explanation of the difference. The direction of the current seems to be in good agreement with the measurements at the moment where there are relatively strong currents. The oscillations of measured current direction around 11:00 UTC are suspicious and indicate some measurement issues.

Figure 5.13 and Figure 5.14 show the results of the validation during the Fastnet race by both Team JAJO and Team ROST. Due to the particularly heavy seas during this race, the boats likely experienced significant leeway that distorts the current measurements. Nonetheless, the data from the boats are in generally good agreement with the measurement offshore in the English Channel. However, there are clear points where the model likely falls short. Just like in the Western Scheldt, the current magnitude is often underestimated in the model. Furthermore, close to shore the model does not seem to capture all local characteristics. This concerns the start in the Solent, around the Isle of Wight and other landscape features along the British South Coast where Team JAJO measured peak currents over 4 knots that were not forecasted.

Although team JAJO indicated that the forecasts by Deltares did pick up more of these local features than commercial models, there is room for improvement here. In the future, it would be beneficial to study whether more detailed models with higher resolution can capture the local features even better. Also, other ocean parameters like sea surface temperature and salinity are good indicators to assess the reliability of the overall model performance. Adding these 3D ocean parameters to the forecasts and being able to compare them to site conditions, helps to optimize offshore navigation.

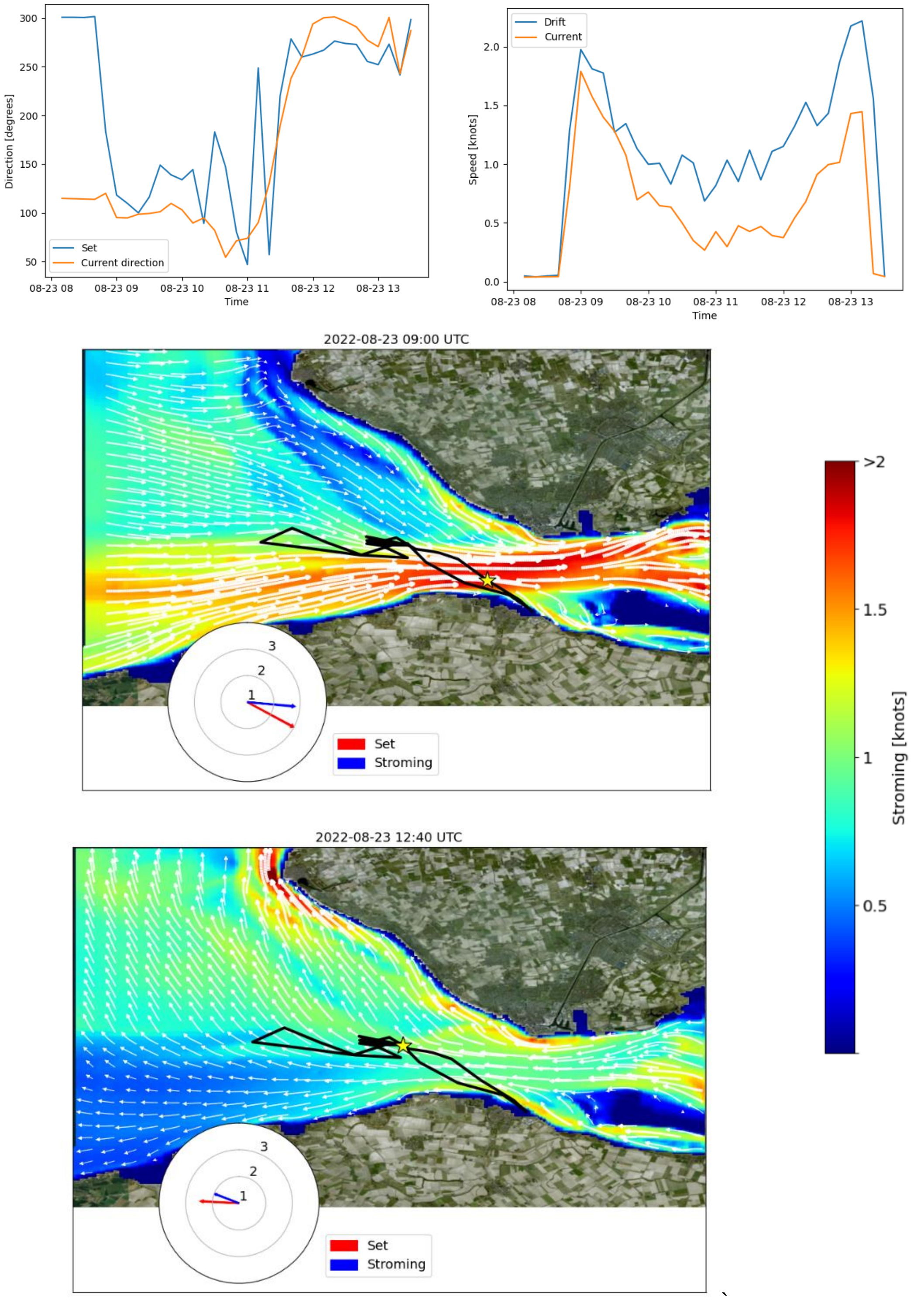

Figure 5.12 Plots showing timeseries (current direction and current magnitude) and a snapshot of a top view of the data-model-comparison, during the European championships in Breskens obtained by ROST on 23rd of August 2022. 'Set' and 'Drift' represent the measurements.

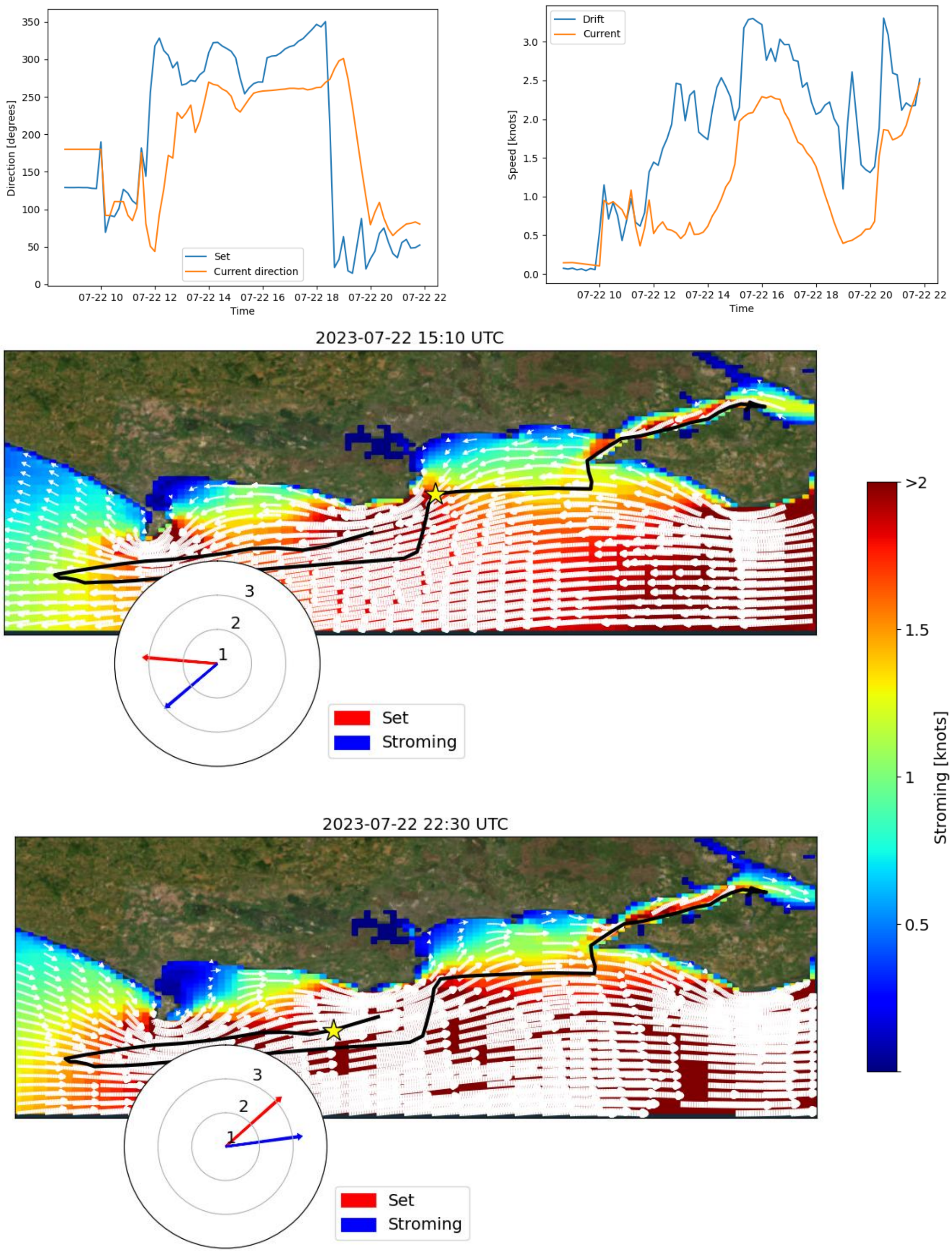

Figure 5.13: Plots showing timeseries (current direction and current magnitude) and a snapshot of a top view of the data-model-comparison, during Fastnet Race by ROST on 22nd of July 2023. 'Set' and 'Drift' represent the measurements.

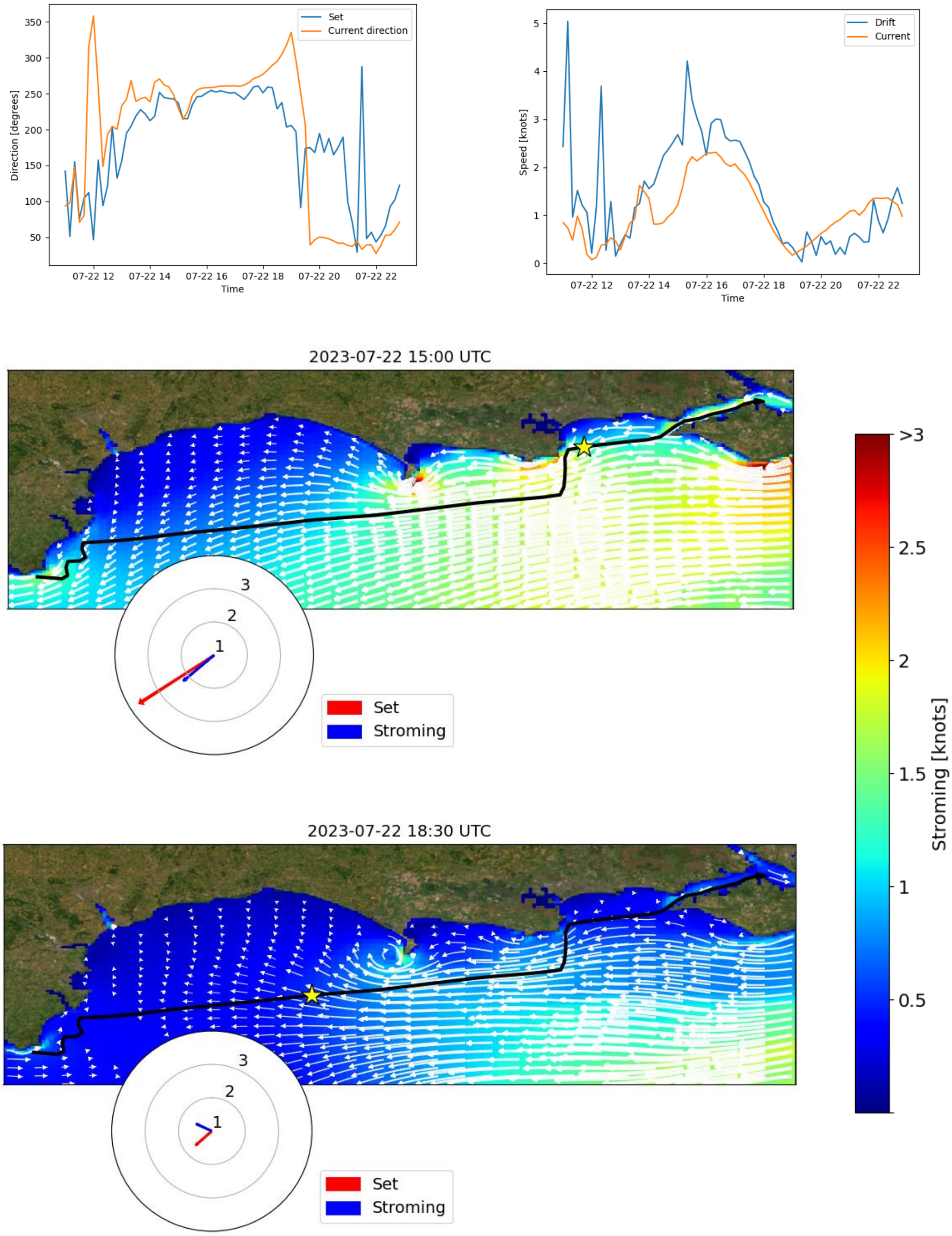

Figure 5.14 Plots showing timeseries (current direction and current magnitude) and a snapshot of a top view of the data-model-comparison, during the Fastnet Race by Team JAJO on 22nd of July 2023. 'Set' and 'Drift' represent the measurements.

6 Pilot Allseas

6.1 Introduction

As part of the TKI Ocean Race and Oceans Sustainability research project[23], Deltares carried out a pilot with Allseas for an offshore operation in the Morecambe Bay. It was tested whether Deltares ocean forecasts can have an added value for this offshore operation carried out by Allseas, for planning and executing a safe and efficient (in terms of CO2-emmisions) operation.

The Morecambe project took place in July 2023, when the Pioneering Spirit removed 2 Jackets in just two days. The 4,500-tonne structure was transferred offshore to the cargo barge Iron Lady (Figure 6.1), for transfer to the recycling yard.

Figure 6.1 Allseas Morecambe project. The Pioneering Spirit lifting the second offshore jacket with Iron Lady moored next to it. Operations are timed favourably (during slack water) by means of the TKI Ocean Race Pilot.

The numerical model that is used to simulate the tidal and wind-induced currents is named 2D DCSM-FM. At locations DP3 (53.815850° N, 3.561767° W) and DP4 (53.875261° N, 3.561011° W), the resolution is approximately 1 nautical mile. These locations, together with the computational grid and tide gauges stations in the Morecambe Bay area, are depicted in Figure 6.2. The tidal range in the Morecambe Bay is approximately 9meters, which induces strong tidal currents.

[23] https://tkimaritiem.nl/del002-ocean-race-and-oceans-sustainability-research-project/

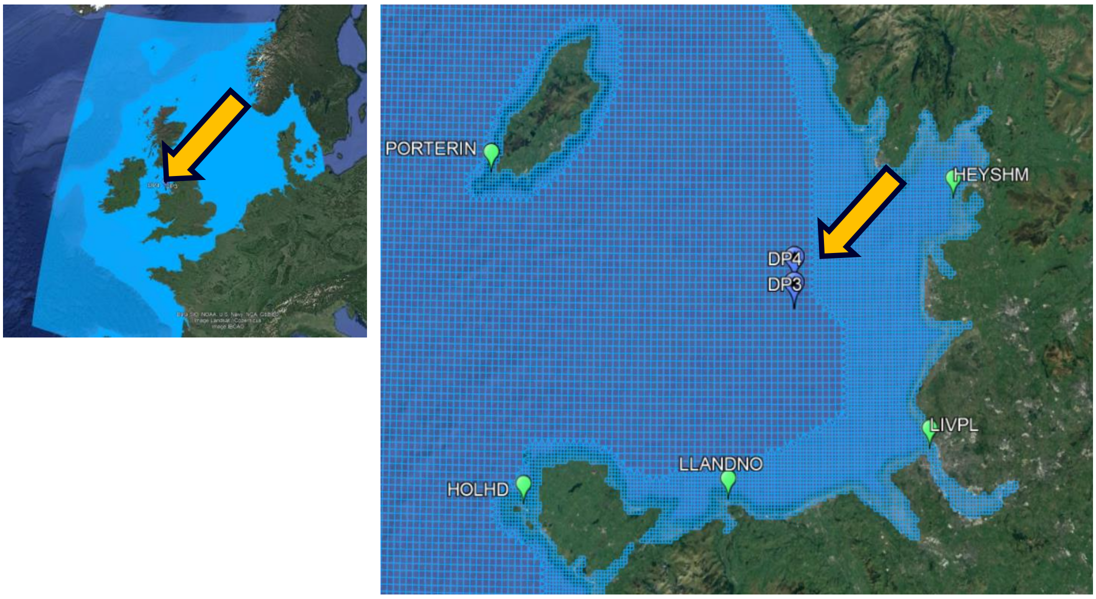

Figure 6.2 *Computational grid (blue), locations DP3 and DP4 (blue markers), and tide gauge station (green markers) in the Morecambe Bay*

6.2 Forecasts for the pre-project phase

A tide-only simulation (without meteorological forcing) was performed with the 2D DCSM-FM product to predict the tidal flow in the Morecambe Bay. Figure 6.3 shows the forecasted depth-averaged tidal currents on an arbitrary moment in time. These map-plots are provided with an hourly interval for the period 23 May – 6 July 2023. The timeseries shows the water level at DP3 to indicate the phase of the tides. All data is in time zone UTC+0.

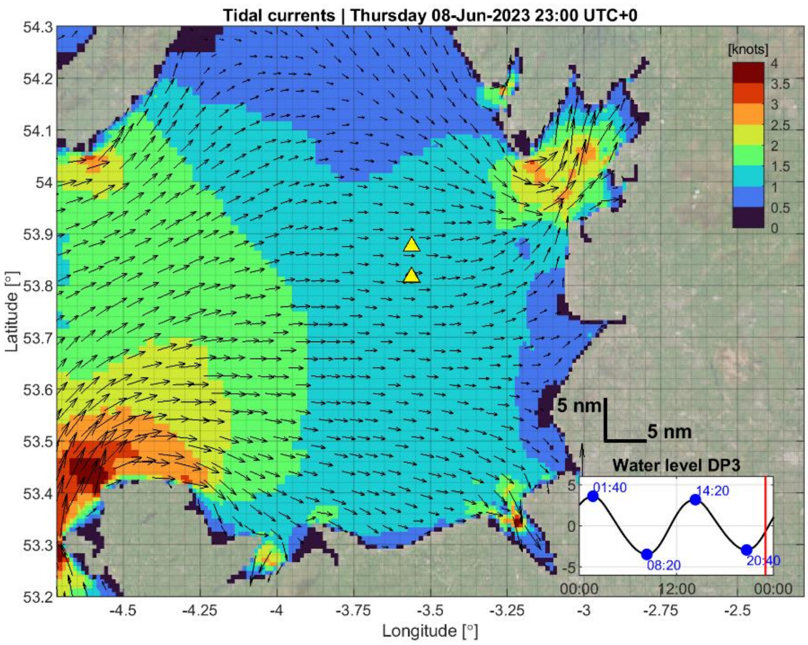

Figure 6.3 *Tidal currents (magnitude in colours, direction indicated with vectors) in the Morecambe Bay. The yellow triangles indicate locations DP3 and DP4.*

Next to the spatial overview, timeseries of the flow direction and magnitude at locations DP3 and DP4 are provided in .csv format. As an example, the first few lines for location DP3 are copied below:

```
# Flow "go-to" direction, considered clockwise from geographic North
# DP3: Lat/Lon [deg] = 53.815850, -3.561767
# Date [yyyy-mm-dd HH:MM (UTC+0)]; DP3 flow magnitude (m/s); DP3 flow
direction (degrees from N)
2023-05-23 00:00;0.35;63
2023-05-23 00:10;0.31;59
2023-05-23 00:20;0.26;54
...
```

6.3 Forecasts during the offshore operational phase

During the offshore operation, Allseas provided twice a day current predictions (in the same .csv format as illustrated above) at locations DP3 and DP4. The 10-day forecast contains the simulated depth-averaged tidal and wind-induced flow at an hourly interval. In the hydrodynamic model, the meteorological forcing is based on ECMWF's IFS[24]. This data was included in the weather reports from the naval department of Allseas.

6.4 Evaluation

Two of Allseas naval architects were on-board using the ocean forecasts from Deltares to advise the crew on the operations. The data provided was mainly used to support the captain and vessel team in the operation (therewith reducing fuel/energy/emissions). The ocean currents were especially useful for timing tug- and mooring operations during slack water (moving the barge "Iron Lady"). The high time resolution gave the crew better understanding of the ocean currents, and gave them an advantage compared to existing products. Also, peak velocities were captured rather well and helped tug operators to better anticipate their operations.

Curiously, during the operation the crew experienced relatively high waves (Hs > 2.5 m), statically this should happen only once a year. That made the engineering team quite busy on-board checking the weather forecast for a fast and safe operation.

Figure 6.4 Allseas Morecambe project. The Pioneering Spirit lifting the first offshore jacket. Operations are timed favourably (during slack water) by means of the TKI Ocean Race Pilot.

[24] https://www.ecmwf.int/en/forecasts/documentation-and-support/changes-ecmwf-model

7 Trans-Atlantic rowing challenge

During the TKI Ocean Race project, the NYR rowing team joined the consortium as an extra partner. Their ambition to safely cross the Atlantic in a rowing boat (for charity) links very well to the project scope of the consortium. Originally, this challenge was planned to take place in May/June 2023, but got postponed due to logical challenges to May/June 2024. At the same time, a new technology became available (called the WebOC) with the potential to support the project objective: easy sharing of data and information to better understand the hydrodynamics of the world's seas and oceans to optimize offshore navigation and reduce CO2-emissions. With this opportunity, it was decided to extend the TKI Ocean Race project with another six more months, until June 2024.

The NYR rowing team is supported by two professional offshore navigators with tens of years of experience in the field of offshore sailing and offshore rowing. The route optimization for the Trans-Atlantic rowing challenge is different compared to offshore sailing because there is no element of competition and ocean currents are even more important. Current speeds of less than 0.1 kts affect the routing.

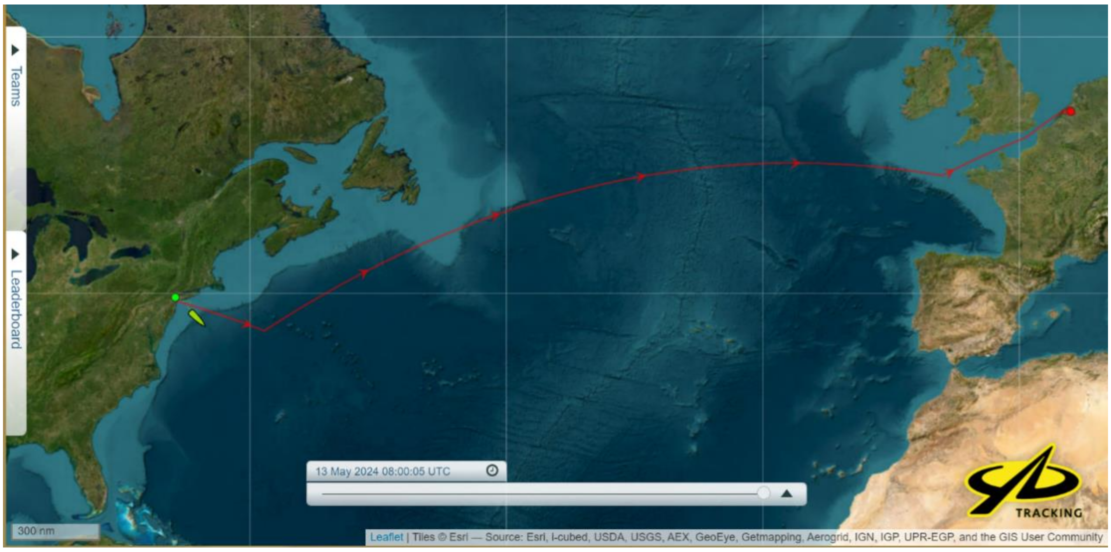

Figure 7.1 Location tracker of Trans-Atlantic crossing, with the rowing team heading off to the Gulf Stream on the 13^{th} of May 2024.

After a major logistical operation, the NYR rowing team started their challenge on 8^{th} of May 2024. Departing from New York and leaving the Hudson River at a favourable tidal moment. In the river mouth they reached speeds up to 6 knots, with the push of the tide and unfavourable wind conditions. Once out in the ocean, their speed reduces to approximately 2 to 4 knots. The team is aiming for the Gulf Stream, a warm and swift Atlantic current which flows eastwards. They reached that current after 12 days. The team reports that the water here is notably warmer and water vapor makes the scene rather mysterious. The navigators confirm that the position of the Gulf Stream is forecasted by the GLOSSIS product with an accuracy of approximately 15 nautical miles, similar to their experiences with other rowing challenges.

Often underestimated, is the effect of waves particularly on small vessels. Under specific circumstances, resonance-like-behaviour can occur. Depending on the vessel and the crew, this effects the transit both in terms of conveniences and efficiency.

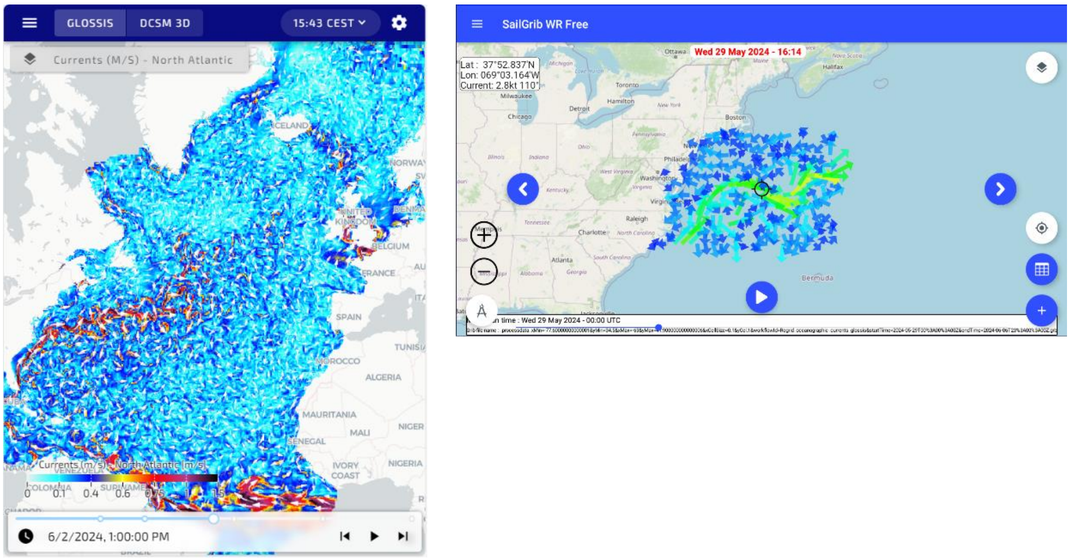

Figure 7.2: Impression of the data distribution for the Trans-Atlantic crossing on a mobile device; The Marine Data Viewer (on the left) for visualizing and downloading a 10-day forecast for the North Atlantic, and the routing software SailGrib WR (on the right) with the imported GLOSSIS product.

Unfortunately, the NYR rowing team had to withdraw from their challenge to cross the Atlantic because of health conditions of one of the team members. A detailed update of their challenge including the rescue operation can be found on their blog[25]. After the rescue operation, the team reached the East Coast safe again, but a salvage operation of their rowing boat Alexia was not possible.

Figure 7.3 The team departing the Hudson River (New York), and the rescue after 12 days at sea.

[25] https://www.newyorkrotterdam.nl/nieuwsberichten/

In the current forecasts that Deltares provided within this project, the focus was mainly on tidal, wind-driven, and ocean currents. The effect of waves was not considered. The importance of wave information became evident during the trans-Atlantic rowing challenge and the pilot with Allseas. With Allseas, wave heights were observed during the operation that statistically should occur only once a year. Accurate predictions of wave heights, directions and periods help in planning and safely executing the operation. The NYR rowing team, having a very different type of vessel compared to the Allseas pilot, also had to account for the height and direction of the waves. Even though the rowing boat can handle a lot, one of the team's blogs[26] mentions that at a certain moment the team had to keep the boat perpendicular to the waves to avoid capsizing.

In the future, we could extend the predictions to include wave information, for example based on Deltares' North Sea Wave model. This could be done either by adding the wave-driven currents to current predictions or by providing the wave height, direction, and period as separate variables to the navigator. Recently, a paper was published showing how hybrid modeling (combining process-based and machine learning models) can improve operational wave forecasts[27]. For the open ocean, we could use global datasets of ocean currents, tides, and wave-driven currents, similar to the approach of CMEMS' SMOC product[28].

[26] https://www.newyorkrotterdam.nl/nieuws/dag-12-zondag-19-mei-deel-1/

[27] https://www.deltares.nl/en/expertise/projects/wave-movements-in-north-sea-better-predicted-by-machine-learning

[28] https://marine.copernicus.eu/sites/default/files/wp-content/uploads/2019/04/Poster_SMOC_EGU2018APRIL.pdf

8 North Sea and Ocean Summit

The Ocean & North Sea Summit 2023[29] was held in The Hague on the 14th of June 2023, during the stop-over of the Ocean Race 2022-23. The summit attracted over 300 participants from various private companies, governments, knowledge institutes and the sport sector.

During the plenary opening, the audience was taken on a journey through enthusiastic stories from sailors of the Ocean Race to better understand how sailing athletes operate at sea and make decisions under high pressure. Furthermore, there were interesting keynote speeches from prominent speakers from both the business sector and the government. During the breakout sessions, various topics were addressed (see full program in Appendix A). In the breakout session for ‘Optimizing Offshore Navigation’, intermediate results of the TKI Ocean Race project were presented, demonstrating how to leverage hydrodynamic models to optimize navigational routes.

Figure 8.1 The Ocean Race stop-over in The Hague.

It was concluded that The Netherlands has a long history in the Ocean Race and sailing. Teams are increasingly supported by research centers and companies. Sailing also brings more answers and solutions ashore. A sailing competition ship acts as a 'wet laboratory' where global dilemmas can be tested, screened and improved. Dilemmas like CO2 emissions, biodiversity, circular building materials and health at work under high stress. The trend of using sports as a test case is being increasingly adopted.

[29] See https://oceannorthsea.nl/

9 Summary and conclusions

During the 2022-23 edition of the Ocean Race, a scientific program is carried out to collect relevant data, evaluate the performance of flow predictions and analyse measurements, to ultimately optimise offshore navigation and reduce carbon emissions. This is done by means of the following field campaigns carried out by the consortium partners:

i) The European Championships for Sailing in Breskens, participated by ROST
ii) The Ocean Race 2022-23, participated by Team JAJO
iii) The Fastnet Race, participated by ROST and Team JAJO
iv) An offshore heavy lift operation called 'project Morecambe', executed by Allseas
v) A trans-Atlantic rowing challenge, executed by the NYR rowing team.

Measurements and relevant field experiences acquired under these field campaigns have enhanced our understanding of the hydrodynamics at unique locations of the world's seas and oceans. However, obtaining highly accurate current data from a sailing boat, especially in high seas, is hard. Nonetheless, an assessment of model accuracy has been conducted based on a data-model-comparison (chapter 5.4) and experiences from the crew (chapter 5.1 - 5.3).

Based on the assessment, it is concluded that the forecasted ocean current provided by Deltares generally align well with the observed ocean currents, a finding supported by the pilot carried out with Allseas (chapter 6) and the Trans-Atlantic rowing challenge (chapter 7).

Based on the experience of the sailors, the forecasts can be improved by:

- Including wave effects as a measure of the sea state. Often underestimated, but important for sailors and the offshore industry, is the effect of waves on offshore vessels. For the offshore industry, under specific circumstances and depending on the type of vessel and its crew, resonance-like-behaviour can occur which affects transits and offshore operations, both in terms of conveniences and efficiency. Sailors take waves into account as a safety concern in their routing. Especially for the foiling IMOCA's in the next ocean race, accurate information on wave conditions will be crucial as these boats are much more sensitive to the sea state than the older generation VO65 boats.
- Offering higher time-resolution in hydrodynamic forecasts. Accurate information on timing of the slack water moments significantly improves offshore operations, in terms of competition, workability and efficiency (reducing carbon emissions).
- Improving surface current estimates by moving to a 3D model approach. Ocean currents are generally underestimated with depth average models.
- During field campaigns, other ocean parameters like sea surface temperature and salinity are good indicators to assess the reliability of the overall model performance. Adding these 3D ocean parameters to the forecasts and being able to compare them to site conditions, helps to optimize offshore navigation and reduce emissions.
- Allow generation of even higher resolution, nested models for areas with complex geometries and local features such as the British south coast and the Baltic Sea.
- Keep coupling science with sports. Innovative measurement techniques to obtain accurate and reliable ocean measurements, benefit sport teams during trainings and competitions for optimizing their performances and enables Deltares to validate their models.

The web portal designed and tested proved its concept to improve the ease to share data and information with stakeholders, without the loss of resolution (i.e. Δt, Δx, Δy, Δz). This technology supported the scope of the project and helped to exchange data and information for better understanding the world's oceans. Maintaining the portal and its services is a continuous process and requires a follow-up project to be sustained to serve future opportunities.

The TKI Ocean Race project, including several field campaigns, has highlighted the potential for enhanced oceanic understanding to significantly benefit the maritime industry. Improved understanding of ocean hydrodynamics not only cuts cost and time but also enhances sea safety and reduces CO2 emissions.

Appendix A – Program North Sea and Ocean Summit

Ontvangst & Registratie	**9:30 - 10:00**
Opening Plenair Met Minister Mark Harbers (Infrastructuur & Waterstaat), Tim van Hattum (WUR - NL2120), Ivo van der Mark (JAJO) en Mark van Koningsveld (Van Oord/ TUDelft) ingeleid met verhalen vanaf zee door Simeon Tienpont en Jelmer van Beek.	**10:00 - 11:30** Grote zaal
Breakout Sessies Ochtend 1. Energieparken 2. Veiligheid op Zee 3. Optimalisatie vaarroutes (in English) 4. Herindeling Noordzee	**11:30 - 13:00** verschillende zalen
Lunch Bon appétit	**13:00 - 13:50** Souterrain
Breakoutsessies Middag 5. That Foiling Feeling (in English) 6. Voedsel uit Zee 7. The future is Water / Learning Communities 8. Herindeling Noordzee	**14:00 - 15:30** verschillende zalen
Plenair Terugkoppeling Met Martijn Ollefers (Allianz), Saskia Jaarsma (TenneT), Suzan Vellekoop (Dutch Wavemakers) en Ton Jonker (provincie Zuid Holland) ingeleid met verhalen vanaf zee door Annemieke Bes en Rosalin Kuiper.	**15:45 - 16:45** Grote zaal
Nabespreking Onder het genot van een hapje en een drankje.	**16:45 - 18:00** Souterrain
Einde	**18:00**

Figure A.1: Program North Sea and Ocean Summit

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