Progress Report for:

Tools for Optimizing Performance of VOYages at Sea

(Project number: 284382)

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1. Introduction

The MarTERA ERA-Net Cofund project TOPVOYS is supported by the Research Council of Norway (RCN), the French Ministry of Environment, Energy and the Sea (MEEM), and the South African Department of Science and Technology (DST). The international partnership includes the Nansen Center (project coordinator) and Grieg Star (Norway), OceanDataLab, Actimar and CMA-CGM (France) and CSIR and SAIMI (South Africa).

The aim of the TOPVOYS project is to advance and implement analyses tools and decision support system for voyage optimization. Based on marine weather analyses and forecasts including wind, wave and surface current conditions, sea surface temperature fields, ship characteristics and cargo requirements, the best shipping route will be determined. The proposed approach aims to identify the optimum balance between minimization of transit time and fuel consumption and reduction of emissions without placing the vessel at risk to damage or crew injury. The tools will be tested both in post-voyage analyses and real time operations for North Atlantic Ocean crossings, voyages from Europe through the Mediterranean Sea and the Suez Channel to the Far East (e.g. China, South Korea) and voyages around Southern Africa including porting in Cape Town. The work is broken down into the following 8 work packages and respective lead partner.

WP1: Review of best practices and identification of deficiencies. **Lead:** NERSC
WP2: Review of shipping company´s routing requirements. **Lead:** CMA-CGM'
WP3: Identification and procurement of routing information sources. **Lead:** OceanDataLab
WP4: Design of advanced tools for voyage optimizations. **Lead:** OceanDataLab
WP5: Testing of tool performances. **Lead:** Actimar
WP6: Integration and implementation of the tools into a decision support system. **Lead:** Actimar
WP7: Synthesis, Dissemination and Communication. **Lead:** NERSC
WP8: Training courses and training material. **Lead:** NERSC

2. Progress

This progress report presents the status of the TOPVOYS project achievements during 2021. The progress has unfortunately been influenced by the Corona virus pandemic, notably regarding the interaction with the shipping companies that was planned during visits to the CMA-CMG Headquarter in Marseille (France) as well as regarding participation on selected ship voyage legs. An extension to the end of March 2022 has been granted. This will, in particular, secure better handling of the work in WP4, WP5, WP6 and WP8.

The project partners have interacted via emails, telephone calls and virtual meetings. Two progress meetings have been held in 2021. The 1st took place on 10 February 2021 as a virtual meeting while the 2nd meeting took place at the premises of Actimar in Brest, France on Monday 22 November 2021.

WP 1: Review of best practices regarding routing (lead NERSC)
Previously completed and reported.

WP 2: Review of the requirements from shipping companies (lead CMA-CMG)
Previously completed and reported.

WP3: Identification and procurement of routing information sources. Lead: OceanDataLab

The types of data and information products considered necessary for provision of reliable and optimized ship routing can be grouped into marine weather data, model forecast fields, near real time satellite data and in-situ measurements. Regarding the satellite data there is a wide range of oceanic variables that will be used to retrieve and validate the surface currents and frontal structures as indicated in Table 1, including sea surface temperature (SST), chlorophyll (Chl) observations, surface geostrophic current, significant wave height and wavelength and propagation direction.

Table 1. *Key satellite sensor data (level, resolution, provider). Note that radar altimeter data (wave height) are available in the CMEMS multi-observation data set.*

Sensor	Product	Level	Resolution	Data Provider
Sentinel-3 SLSTR SST and SEVIRI	Sea surface temperature/fronts	L2	~ 1 km	EUMETSAT
Sentinel-3 OLCI Chl	Chlorophyll/fronts	L2	~ 300 m	EUMETSAT
Sentinel-3 and Jason altimeters	Surface geostrophic current/fronts	L3	~ 10 km	CLS/Salto Duacs
Sentinel-3 and Jason altimeters	Significant wave height	L3	~ 10 km	CLS/Salto Duacs
Sentinel-2 spectral imager	Wave length - direction/glitter	L2	~ 1 km	ODL
Sentinel-1 A/B SAR	Wave length - direction	L2	~ 1 km	Scihub/ESA
Sentinel-1 SAR Doppler shift	Radial surface current	L3	~ 2 km	Scihub/ESA
CMEMS-Multi-Obs (Global)	All above from Sentinel-3	L3/L4	~ 10 km	CMEMS

Importantly, these satellite data can often be complemented and collocated with in-situ data allowing comparison of the surface current and frontal structures derived from the satellite data to the Argo floats, surface drifter data, HF-radars and on-board estimates of surface currents as shown in Table 2.

Table 2: In-situ sensor data and providers

Sensor	**Key products/resolution**	**Coverage**	**Data providers**
HF radars	Surface current/ order km	surface	EMODNET PHYSICS
Loch (ship-based)	Surface current/ tens of meters	surface	CMA CGM (Watch Report)
Argo	Surface current/ ~100 m	surface	CMEMS, Coriolis
Surface drifting buoys	Current/~100m	15m depth	CMEMS, Coriolis

Finally, the satellite and in-situ based observation data are combined and extended with surface current and wave field forecast products offering global and regional coverages at spatial resolutions ranging from 25 km to 2km as shown in Table 3.

Table 3: *Complementary model-based surface current fields. *The GlobCurrent fields is an interpolated regular global surface current product derived from satellite data. Geostrophic balance and Ekman current estimation applied.*

Product	Coverage	Resolution	Model	Provider
CMEMS-GLOBAL	global	~ 8 km	NEMO	CMEMS
RTOFS	global	~ 8 km	HYCOM	NOAA
GOFS	global	~ 8 km	HYCOM	NRL
MED-CMEMS	Mediterranean Sea	~4 km	NEMO	CMEMS
IBI	Iberian Peninsula & Bay of Biscay	~2 km	NEMO	CMEMS
GlobCurrent*	global	~ 25 km	Geo/Ekman	CMEMS
Wave Model	global	~ 10 km	MFWAM	MeteoFrance

A major innovation in this project is the systematic use of satellite observations of the marine environment in near real time to generate information products tailored to ship locations and their planned course for the next 24 hours. Presently, the joint EU-ESA Copernicus program (https://marine.copernicus.eu) ensures routine access to the sea surface current, significant wave height, wave spectra and sea surface temperature derived from the Sentinel satellite missions (see Table 1). These variables, in turn, allows the identification and location of meandering surface current frontal boundaries and eddies, evidence of wave-current interactions and presence of crossing seas.

WP 4: Development of the routing optimization tool (lead OceanDataLab)

An innovative tool (combining GeoSPaaS, SEAScope and Actiroute) aiming at providing value-added surface current products currently tailored to the Mediterranean Sea, North Indian Ocean, East Asia seas, North Atlantic, South Atlantic and seas around Southern Africa has been developed and is now undergoing regular testing (see Figure 1). The products are provided both from available forecasts and from satellite-based and in-situ observations. A series of post-processing routines are implemented to provide the optimized surface current product using a metrics defined to qualify the surface current forecast performances at each in-situ measurement and collocated satellite-based location. In so doing, the comparison of models with satellite derived sea surface temperature and surface geostrophic current is used to assess the ability of the ocean models to locate the mesoscale structures (e.g. eddies, meanders fronts).

The architecture and components of GeoSPaaS used in this project as well as their interaction with the SEAScope processing chain are shown in Figure 2. GeoSPaaS has two primary functions in the TOPVOYS project, including:

- Searching for relevant data from various sources by type, date and location;

- Automatic downloading and converting of data to IDF which is the format used by SEAScope.

The key components include the harvesters to gather metadata from the data providers and repositories, a REST API to manage communication with the SEAScope processing chain, and processing software which takes care of downloading the data and converting it to IDF. For the harvesting, each data provider (Copernicus, PO.DAAC, etc.) typically has their own way of making the data available. As such, it becomes necessary to write specific code for each of them. GeoSPaaS are also used to index and collect the data required for the production of the optimized products, for the detection of oceanic structures and for the validation.

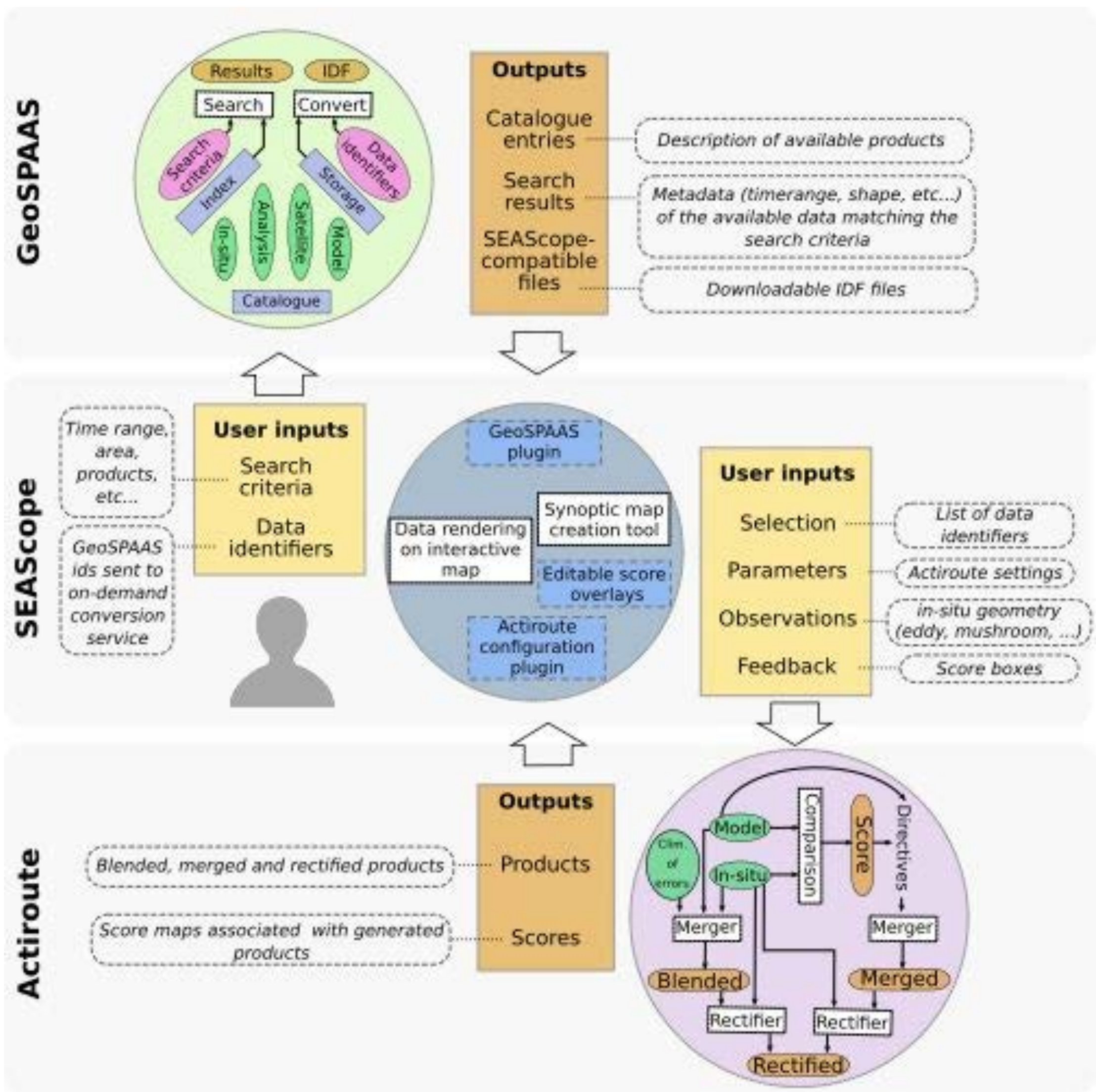


Figure 1. *Schematic illustration of the key TOPVOYS tools (GeoSPaaS, SEAScope and Actiroute) and their integration for ship routing optimization*

A client application, implemented as a Python package, has been developed to translate user requirements (area, time frame and products list) into GeoSPaaS requests. It leverages GeoSPaaS ability to process requests in parallel to reduce the time it takes to get the data and stores the results in a local cache to minimize the amount of data transferred over the network when the same data are required in multiple scenarios. The application also reorganizes the downloaded data to match the file layout expected by the visualization tool (named SEAScope) and provides configuration files that set the default rendering options for each product.

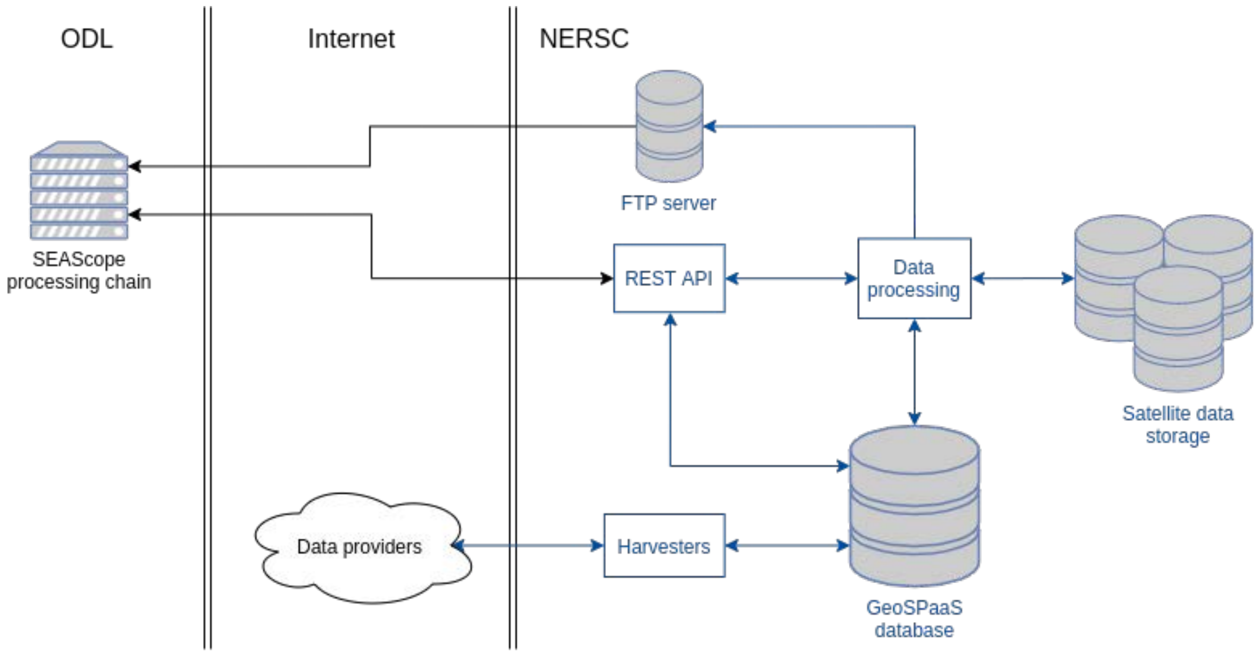


***Figure 2**. GeoSPaaS architecture and interconnection with SEAScope*

Support for the new products has been added in the software components that bring data from the provider to the user: GeoSPaaS, the Python client application and SEAScope. Each addition of a new product has been followed by tests in these three components.

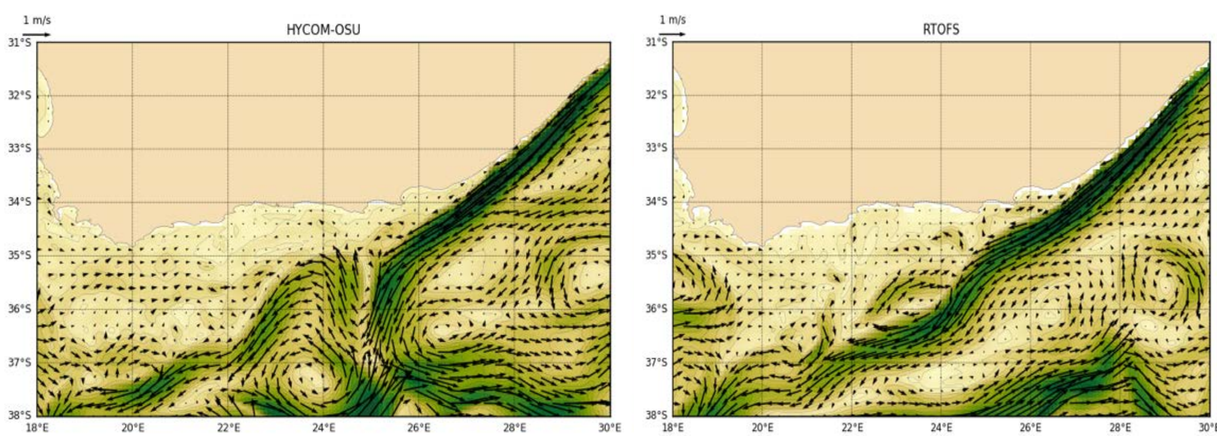
SEAScope has the ability to render vector fields as animated streamlines, a useful feature that simplifies the comparison of several surface current products. SEAScope also had a very limited support for annotations: it was possible to draw lines and polygons on the map to emphasize oceanic structures detected on satellite observations and modelized data, but no extra information could be attached to these shapes and the map became difficult to read when too many annotations were rendered on the screen, notably because it was not possible to have different colors for shapes of the same type (i.e. all line-type shapes had to be of the same color). These limitations have been lifted after a major overhaul of the code responsible for annotations. It is now possible to attach user-defined properties to each shape, allowing annotations generated automatically by front detection algorithms to include metrics and other information that users can see in SEAScope when the associated shape is selected. Users can also define new collections of annotations and apply a different rendering style for each collection, thus allowing annotations that share the same shape type to be rendered with different colors as long as they are defined in different collections.

WP 5: Evaluation of the tool performance (lead Actimar)

The testing and evaluation of the tool have consisted in validating the new metric (based on identification of surface currents that are crossing SST fronts) performance in a hindcast mode for different areas (Agulhas Current and the Arabian Sea). The first step was to identify periods for which models represented significantly different current fields and where available in-situ observations (drifters or WatchReport) enabled model assessments and discrimination. The second step was to verify if the choice of the best product would have been the same using only satellite-based SST observations of mesoscale features and meandering fronts.

For example, considering the Agulhas Current region in June 2021, the HYCOM-OSU and RTOFS models (with different parametrizations and atmospheric forcing) represent two realistic but different surface current fields (Figure 3, top). In the east of the area, both models simulate the same general southwestward current along the coast. However, between 22°E and 26°E, the current fields are different. Whereas HYCOM-OSU simulates large meanders in the Agulhas Current, RTOFS simulate a clockwise circulation. In comparison with in-situ data (not shown) it is clearly evident that the most reliable surface current is the one simulated by RTOFS.

The front detection algorithm applied to the SEVIRI observations enables to highlight the main frontal structures in the area (Figure 3, middle). The new metric assumes that if the current fields are consistent with the SST observation, flux values should equal 0 implying that frontal structures are transport barriers whereby the surface current cannot cross. For increasing flux values, on the other hand, the consistency between the surface current flow direction and the SST frontal orientation deteriorates. The application of the new metric to HYCOM-OSU and RTOFS (Figure 3, bottom) provides significantly higher flux values (red) for HYCOM-OSU compared to RTOFS (blue), suggesting that the RTOFS surface current fields are more consistent and reliable.



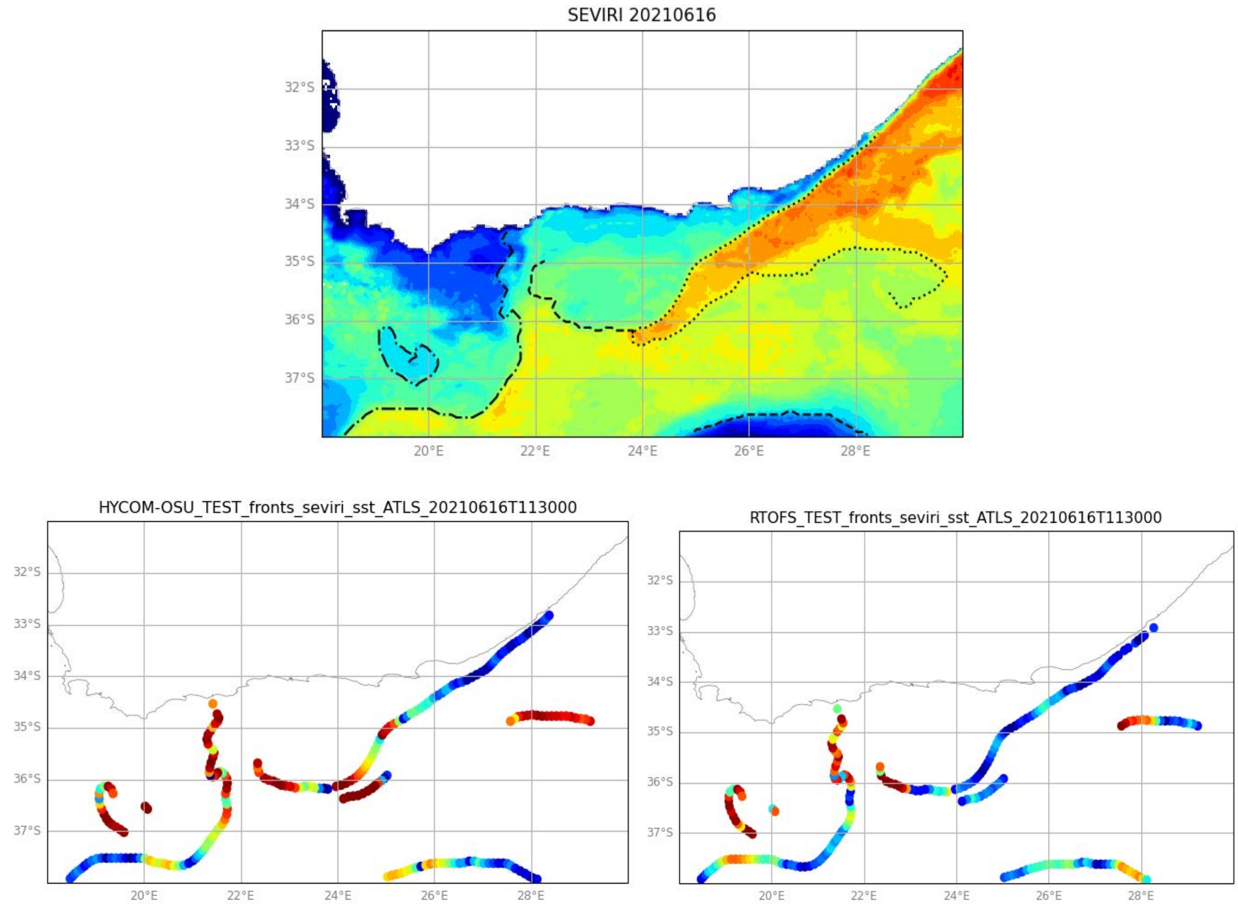


Figure 3. *Daily mean of surface current (top) in the Agulhas region area extracted from the HYCOM model (left) and the RTOFS model (right) the 16/06/2021. Daily mean of SEVIRI SST fields and derived the same day (middle). Flux through SST fronts computed from daily fields from HYCOM and RTOFS (bottom).*

surface drifter trajectories are overlaid. The new metric assumes that when the current fields are consistent with SST observations, there are no current flow across the SST fronts (e.g. metric value equal 0). For larger metric values, the consistency between the current flow direction and the satellite-based SST fronts deteriorates. Applied to HYCOM and MERCATOR (Figure 2), the metric computes significantly higher values (yellow) for MERCATOR whereas values computed for HYCOM are consistently lower (blue/green color), suggesting more reliable current fields derived from HYCOM.

Another test case is presented for the Gulf of Aden and Socotra Island region (Figure 4). This area encompasses meandering currents, frontal boundaries and mesoscale eddies and the challenge is to precisely locate the position of these features for optimizing the ship routing. The HYCOM and MERCATOR ocean model simulations reveal the presence of an anticyclonic eddy (white lines in the red boxes) to the northeast, slightly more westward for MERCATOR. A larger bell-shaped meandering structure (orange boxes) is also depicted in both simulations. In this case it is shifted eastward in the MERCATOR model while the inflection of the current towards Somalia is too far north. These discrepancies are further confirmed when the satellite-based SEVIRI SST field and

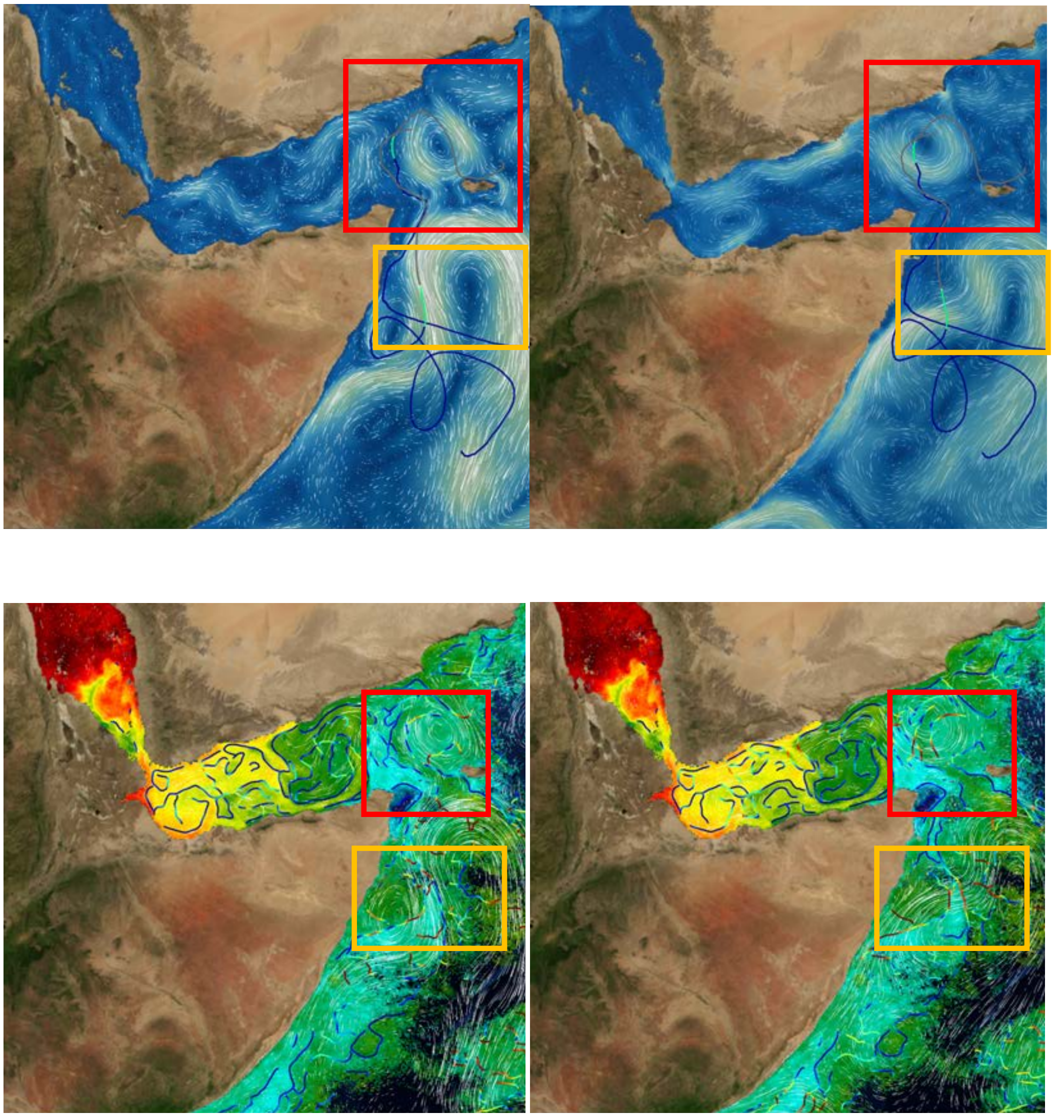


Figure 4. *Maps of daily mean surface current (upper) in the Gulf of Aden/Socotra Island area extracted from the HYCOM model (left) and the MERCATOR model (right) on 21/10/2019. Drifter trajectories are displayed in blue/green/grey prior to/on/after 21 October Corresponding daily mean SEVIRI SST fields (lower) from 21 October. The white lines mark the daily velocity field from HYCOM (left) and MERCATOR (right).*

The comparison of the different products in terms of quality and reliability (metric values, scores) forms the basis for the selection of the best optimized route. The routing will account for the metric values retrieved from the comparison between model-based velocity fields, satellite-based SST frontal locations and surface drifter data (when available). In this paper we have used near real time satellite data and in-situ data of the surface current and sea surface temperature fields for assessment of the model-based surface current field for ship routing. It has been demonstrated that synoptic satellite-based SST maps of surface frontal structures provide highly important evidence of meandering currents and eddies which are proxy for the surface currents dynamics. As such they allow assessment and validation of the quality of the model-based surface current products. Moreover, regular use of a wave ray-tracing model with different surface currents are run for simulations of possibly occurrences of extreme waves invoked by wave-current interaction. In so doing a reliable traffic-light system will be provided by which the metric values for the pre-selected ship routes build on regular near real time updates of: (i) rapidly changing currents associated with meandering ocean fronts and eddies; and (2) likelihood of crossing seas leading to wave energy focusing and presence of dangerous waves. The work is still in progress for testing in the Agulhas Current and the Gulf Stream regions.

WP 6: Integration of the tool in a decision support system (lead Actimar)

The implementation of the new metric in Actiroute is in progress and currently being tested. It will be available in early 2022. The comparison plots (comparable to those presented Figure 3) will be automatically generated on daily basis and become an additional support for the definition of the merged product. The tool performance including the full interactions between GeoSPaaS, SEAScope and Actiroute will be tested on selected voyages through the Arabian Sea and the Agulhas Current from 5-20 January 2022.

WP 7: Synthesis, Dissemination and Communication (lead NERSC)

The TOPVOYS project has been presented at the MarTERA Brokerage events in August 2018, the Mid-term meeting in Spring 2019 and the meeting in November 2021. In addition, the project results have been disseminated via scientific papers and training material, workshops, conferences and direct intervention towards end users. The TOPVOYS project also host a website (http://topvoys.nersc.no/). In addition, information about the TOPVOYS project is also obtained from the MARTERA ERA - NET COFUND program website https://www.martera.eu/projects/topvoys.

The TOPVOYS project findings and results were presented at the 14th International Conference on "Marine Navigation and Safety of Sea Transportation" TransNav 2021 organized jointly by the Faculty of Navigation, Gdynia Maritime University and The Nautical Institute from 16 to 18 June 2021 (*http://transnav2021.umg.edu.pl*). The Conference, jointly organized by the Faculty of Navigation of the Gdynia Maritime University and The Nautical Institute, was originally planned as a physical meeting in Gdynia, Poland. However, due to the Covid-19 pandemic it was hosted as a virtual conference. The focus of the conference was high-quality, scholarly research that addresses development, application and implications, in the field of maritime education and training (MET), nautical science, maritime safety management, maritime policy sciences, maritime industries, marine environment and energy technology. The conference therefore provided a forum for transportation experts, scientists, engineers, navigators, ergonomists, and policy-makers with an interest in maritime research.

In the TOPVOYS paper [11] and the MarTERA Newsletter [12] it is demonstrated how use of near real time satellite data and in-situ data of the surface current and sea surface temperature fields allows assessment and optimization of the model-based surface current field for ship routing. It is demonstrated that synoptic satellite-based SST maps of surface frontal structures provide highly important evidence of the meandering flow direction of the surface currents along SST fronts and eddies which are proxy for the surface currents dynamics. As such they allow assessment and validation of the quality of the model-based surface current products. Moreover, regular use of a wave ray-tracing model with different surface currents are run for simulations of rapidly changing and possibly occurrences of extreme waves invoked by wave-current interaction.

WP 8: Training courses and training material (lead NERSC)
In order to secure efficient and rapid take-up of new advances in tool development for ship routing optimization and decision support system training courses and training material will be an essential work task. This will be developed in collaborations with the participating shipping companies and service provider.

3. Financial Status

An overview of the budgeted expenses (NERSC + Grieg Star) versus the real costs for 2021 is provided in Table 4. The exact figures for 2021 will be known when the financial report is delivered in January 2022.

Cost Plan	Budget 2021	Actual 2021
Personal cost	1992	1992
Purchase of R&D support		
Equipment	72	72
Publication costs		3
Other expenses (travel, etc)	124	50
Total	**2188**	**2117**

Table 4. *Budgeted versus actual costs form 2020. All numbers are in 1000 NOK.*

References

[1] Johannessen, J.A. et al (2021a), Tools for Optimizing Performance of VOYages at Sea, TransNAV International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 15, No. 1, March 2021.

[2] Johannessen, J.A. et al (2021b), TOPVOYS: Tools for Optimizing Performance of VOYages at Sea, MarTERA News Letter, November 2021.