Progress Report for:

Tools for Optimizing Performance of VOYages at Sea

(Project number: 284382)

Table of Contents

1. Introduction

The three year (June 2018 – May 2021) funded 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-CMG (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 distinct work packages with the respective lead partner.

WP1: Review of best practices and identification of deficiencies. **Lead:** NERSC

- At the onset of the project a review of the best practices for ship routing will be carried out in consultation with the participating partners and by accessing other open available information. Based on this information an analyses will be carried out and the major weaknesses and deficiencies of routing information and decision support system identified.

WP2: Review of shipping company´s routing requirements. **Lead:** CMA-CGM'

- An overview of the requirements will be collected and assessed according to requirements implemented by national and international regulations (e.g. Coastal Directorates, IMO, EU) as well as by individual shipping companies. The latter will include a review of how the analyses of the quality of the routing are done versus the forecasting accuracy and skill. The regional aspects of routing requirements with respect to different ocean basin will also be reviewed.

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

- Based on routine requirements, identification of relevant information sources will be performed. This will include, in particular, the Copernicus Core Marine Service information such as surface current and sea state models output, in addition to remote sensing based sea surface temperature (SST), chlorophyll a (Chla), surface current, sea state and in-situ based observations from surface drifters and ships (including examination signals from AIS). Additional sources of information such as high-resolution satellite-based observation snapshots in particular from the ESA Sentinel 1-2-3 satellite series (not available in the Copernicus Marine Service) will first be processed and examined with respect to retrievals of surface current and wave-current interactions. In so doing their relevance for the analyses tools and decision support will be judged.

WP4: Design of advanced tools for voyage optimizations. **Lead:** OceanDataLab

- Based on SEAScope, an existing open source interactive visualization platform at OceanDataLab, dedicated processing plugins will be developed to enable timely assessment of the different surface current and wave model forecast, based on NRT satellite observations, in-situ observation network and near real time assessment of the ship performance including integration of signals from AIS. The advanced tools will provide a semi-automated way to give a quantitative score to each model. Based on these scores, the tool will facilitate the NRT production and validation of a merged optimized model forecast, with associated error estimates, to be subsequently used for ship routing. The advanced tool design and integration will be conducted in close collaboration with the ocean analysts that will perform the semi-automated forecast optimization.

WP5: Testing of tool performances. **Lead:** Actimar

- Tool testing will first be performed in hindcast mode and then in forecast mode. In the hindcast mode, testing will be performed by comparing a fully supervised forecast optimization such as already operated by Actimar for CMA-CGM to the semi automated output of the developed system, based on a posteriori analysis of ship measurements along past experiments. This hindcast mode testing will also serve as a training for ocean analysts. In forecast mode, the performance analysis based on production time and accuracy evaluation will be undertaken by the ocean analysts using the semi-automated forecast optimization process. Optimized forecast will then be used by the shipping company partners to optimize their routing. After the experimental voyage, a cost/benefit analysis will be performed to evaluate the gain of using the advanced tools, based on subsequent fully supervised optimization process. The benefit analysis will include the relative contribution assessment of each information source.

WP6: Integration and implementation of the tools into a decision support system. **Lead:** Actimar

- The present version of decision support system for optimizing ship routing will be upgraded to incorporate the new qualified tools developed in WP4 and tested in WP5.

WP7: Synthesis, Dissemination and Communication. **Lead:** NERSC

- The TOPVOYS project will be present at all the MarTERA organised common events for those projects funded in the frame of this call. This includes:- the Brokerage events in August 2018; the Mid-term meeting in Spring 2019; - and the Final meeting in November 2021. At these events relevant stakeholders will be invited. The TOPVOYS project has therefore dedicated appropriate resources for such dissemination activities including participation to these activities organised by MarTERA. In addition dissemination of project results will be based on several communication routes such as scientific papers, posters, courses and training material, web based tools, workshops or direct intervention towards end users. In particular, dissemination to national end users in all partner countries will be emphasized. A complete dissemination plan will be provided for the full proposal and will specify how the planned activities will contribute to the impact of the project.

WP8: 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 and is foreseen to take place both in the second and third year of the project.

2. Progress

This progress report presents the status of the TOPVOYS project achievements during 2020. The progress has been somewhat hampered by the Corona virus pandemic, notably regarding the execution of the planned physical meetings and some of the interaction with the shipping companies. This is further addressed in the respective work package reports.

WP 1: Review of best practices regarding routing (lead NERSC)
This review of the existing tools and techniques available for ship routing has enabled us to better understand the shortcomings of existing systems and to identify improvements that will be implemented and tested in the TOPVOYS project. Normally the shipping companies requires routing services for all voyages of 5 days duration or longer (shorter voyages may be considered on a case-by-case basis). Factors that are considered include:

- optimal passage planning, weather routing and avoidance of bad weather, excessive wind / waves affecting fuel consumption due to added resistance and reduced propulsive efficiency
- using positive currents and avoidance of adverse currents,
- cargo planning maximizing gains through trim & adjusting trim when appropriate and possible
- avoiding excessive / unnecessary deadweight
- monitoring the fuel performance systems, once fitted, and making adjustments to further improve the efficiency of the vessel.

The communication with the vessels must be regular to secure:

- Pre-departure routing advice once the departure date is known (initial voyage plan). The input is used by the Master for the voyage planning.
- Updating frequency depends on the weather development or can be requested from the vessel ranging from 4 times/ day to 2-4 days between reports. This method is quite static / historic; - no dynamic forecast and automated schedule advice is provided.
- Main parameters presented in tabular form for 0000 and 1200 hrs are:
    - Wind; direction/speed
    - Waves; direction, height (H1/3), period
    - Current factors
- These reports are transmitted on board on e-mail as a PCF attachment, so the information must be interpreted by the Master. If any changes to the voyage plan is recommended, this is discussed with the vessel's operator. The voyage plan which is pre-defined in the ECDIS is then updated.
- The information received is seen as helpful by the Masters; It helps them to plan the voyage. However, particularly in bad weather, the information is not sufficiently accurate. This might well be due to data update frequency.
- In adverse weather, the Master always has the overruling authority.
- The Operator/Voyage Officer is in regular contact with the vessel during the transit to discuss the speed settings etc, but we feel that the post evaluation / learning could be improved by
    - implementing online voyage forecasting capabilities
    - organizing operational and technical support functions ashore
    - enhanced system integration on board
    - empowerment of the shore staff and officers

WP 2: Review of the requirements from shipping companies (lead CMA-CMG)
In this review we have been made aware of the need for tool development in order to make routing services more aligned with the expectations and requirements of the shipping companies. The role of the fleet center is to route the vessels with the objective of safe arrival in time jointly with fuel consumption optimization and emission reduction.

Table 1 provides and overview of required surface current and sea state products and information. Today the sea state information in strong surface current regions is most often inaccurate and impose large safety margins, causing exaggerated impact on the routing and sometimes even dangerous situations.

	Improved Surface Currents	**Combined Risk-index for dangerous sailing conditions (considering traffic light system)**
Coverage	global	global
Spatial resolution	10km (or better)	10km (or better)
Temporal resolution/revisit	daily or better	daily or better
Variables of interest	Surface current and assisting in finding following current	Freak waves, Crossing Sea, Wave current interactions, Iceberg areas
Accuracy threshold	Highly important to know the confidence level and uncertainties of the surface current and sea state products	
Length of data record	Near real time and off-line data for assessment of difficult encountered situations	Near real time and off-line data for assessment of difficult encountered situations
Format	GRIB2/NetCDF	GRIB2/NetCDF
Product delivery	FTP	FTP
Documentation	Product User Manual with specification of format, variables, etc. and with information on product quality.	

Table 1: *Overview of required surface current and sea state products and information.*

WP 3: Identification of the data sources necessary to routing (lead OceanDataLab)

The types of data and information products necessary for reliable and optimized ship routing can be grouped into marine weather data, forecast model fields, satellite (see Table 2) and in-situ data. Regarding the latter there are a wide range of oceanic variables that are and will be used to validate the surface currents, including sea surface temperature (SST) and chlorophyll (Chl) observations. The signature of currents is also observed qualitatively in the SAR images (roughness fronts) like Sentinel 1, as well as in the Sentinel 3 OLCI Glitter product. The quality of the surface currents and the relevance of the algorithms are validated qualitatively by visually comparing the position of the structures.

Sensor	Level	Resolution	Provider
Sentinel-3 SLSTR SST	L2	~ 500m	EUMETSAT
Sentinel-3 OLCI Chl	L2	~300m	EUMETSAT
Sentinel-1 A/B SAR	L2	~100m	Scihub/ESA
Sentinel-1 A/B Doppler shift	L3	~ 2 km	Scihub/ESA
CMEMS-Multi-Obs (Global)	L3/L4	Varying (~10 km)	CMEMS
MODIS SST	L2	1 km	PODAAC
MODIS Chl	L2	1 km	PODAAC
VIIRS SST	L2	~1 km	PODAAC
VIIRS Chl	L2	1 km	PODAAC
SEVIRI SST	L3	~5 km	PODAAC
GMI	L3	~11 km	JAXA
AMSR2 SST	L3	~11 km	JAXA

Table 2: *Satellite sensor data (level, resolution, provider) used in the TOPVOYS project. Note that radar altimeter data (wave height) are available in the CMEMS multi-observation data set.*

Moreover, further quantitative validation is conducted using Eulerian- and Lagrangian-based comparison of the surface current derived from ARGO profiling floats, surface drifter (SVP) data HF-radars and on-board estimates of surface currents as indicated in Table 3.

Instrument	Depth	Provider
HF radars	surface	EMODNET PHYSICS
Loch	surface	CMA CGM (Watch Report)
ARGO	surface	CMEMS, Coriolis
Surface drifting buoys	15m	CMEMS, Coriolis

Table 3: *In-situ sensor data and providers*

The observation data are combined and extended with surface current forecast products offering global and regional coverages at spatial resolutions ranging from 25 km to 2km as shown in Table 4.

Product	Coverage	Resolution	Model	Provider
CMEMS-GLOBAL	global	~ 8 km	NEMO	CMEMS
HYCOM	global	~ 8 km	HYCOM	NOAA
RTOFS	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		CMEMS

Table 4: *Complementary model-based surface current fields. The GlobCurrent fields is an interpolated regular global surface current product derived from satellite data.*

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

The tool development and testing has been two-fold. Firstly, proper interaction between the SEAScope 3D visualization tool (developed by OceanDataLab) and the ACTIROUTE tool (developed by Actimar) for provision of surface current products optimized for a routing software, based on the analysis of the performance of the forecast products and available observations is now ensured. Secondly, to ensure that the search, collection and provision of in-situ and satellite data together with model fields undertaken by GeoSPaaS (development by NERSC) can be exploited by SEAScope a mechanism enabling the conversion of GeoSPaaS data to the IDF (Intermediary Data Format) format and conventions expected by SEAScope. A REST Application Programming Interface (API), that enables programs to communicate over a network using a widespread protocol (HTTP) is therefore implemented. Hence a search program running alongside SEAScope sends HTTP requests to the REST API, which responds the same way with a list of datasets matching the criteria. A dedicated webservice is set-up to which SEAScope can send requests that, in turn, trigger the conversion of data in the proper IDF format directly on the GeoSPaaS platform. The resulting files are exposed on an FTP server, where SEAScope can download them. ODL provided the conversion tool and developed software components which enable to read and apply the specific filters for each data type. The respective tools and their interactions are shown on Figure 1 below.

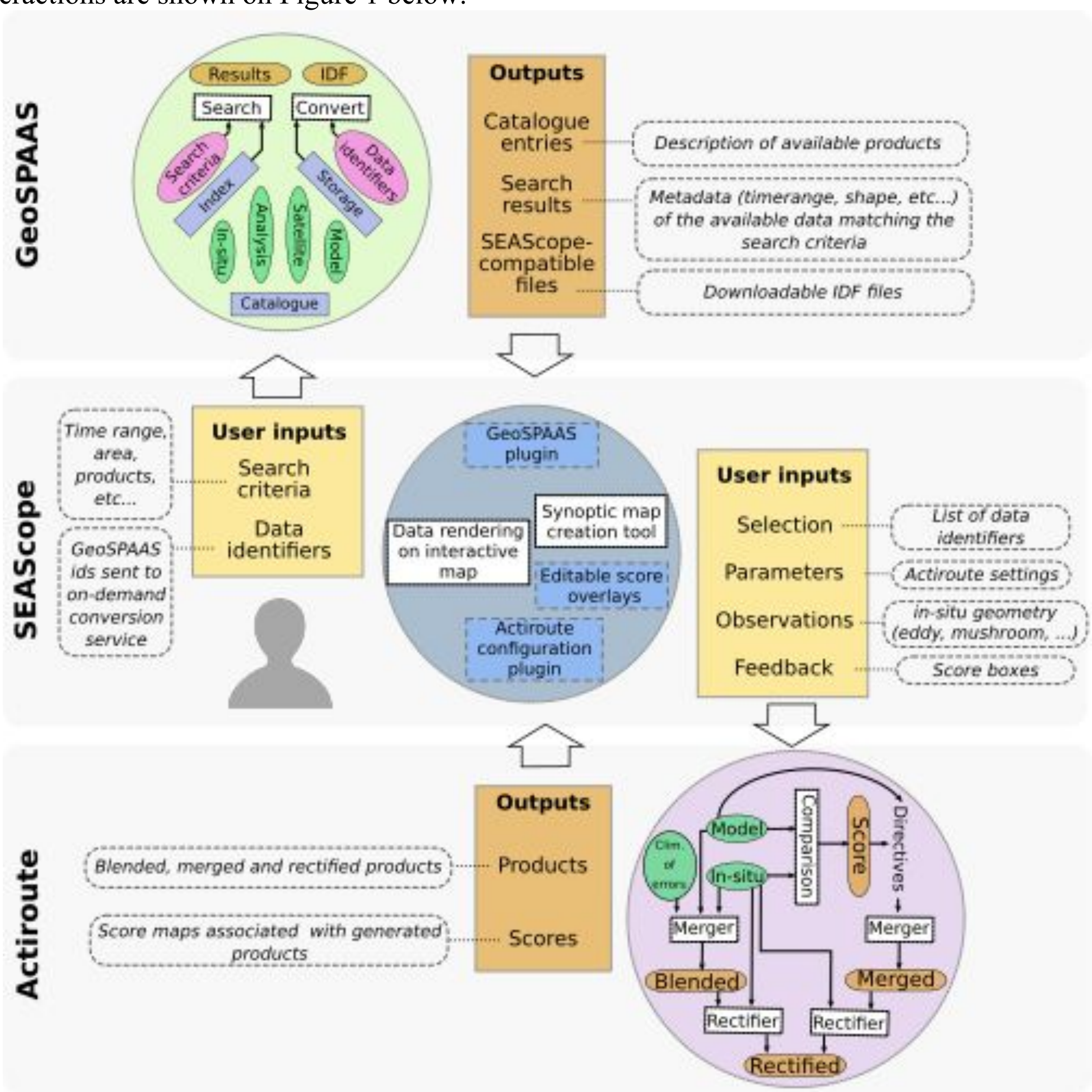

Figure 1. *Schematic illustration of the key TOPVOYS tools and their integration for ship routing optimization*

In short, the GeoSPaaS functionalities and interaction with SEAScope is schematically illustrated in Figure 2 and include:

- Search engine to enable searching capabilities of relevant datasets and to expose it in a search interface;
- Gathering metadata information about a dataset (a description of its contents, its spatial and temporal coverage, the URL(s) where it can be downloaded, etc...) and writing it to a database;
- Enable user to find and access data via an API (Application Programming Interface);
- Ensure retrievals in the IDF format (at the API) usable by the SEAScope application;
- Downloading of datasets referenced in the database via HTTP and FTP.

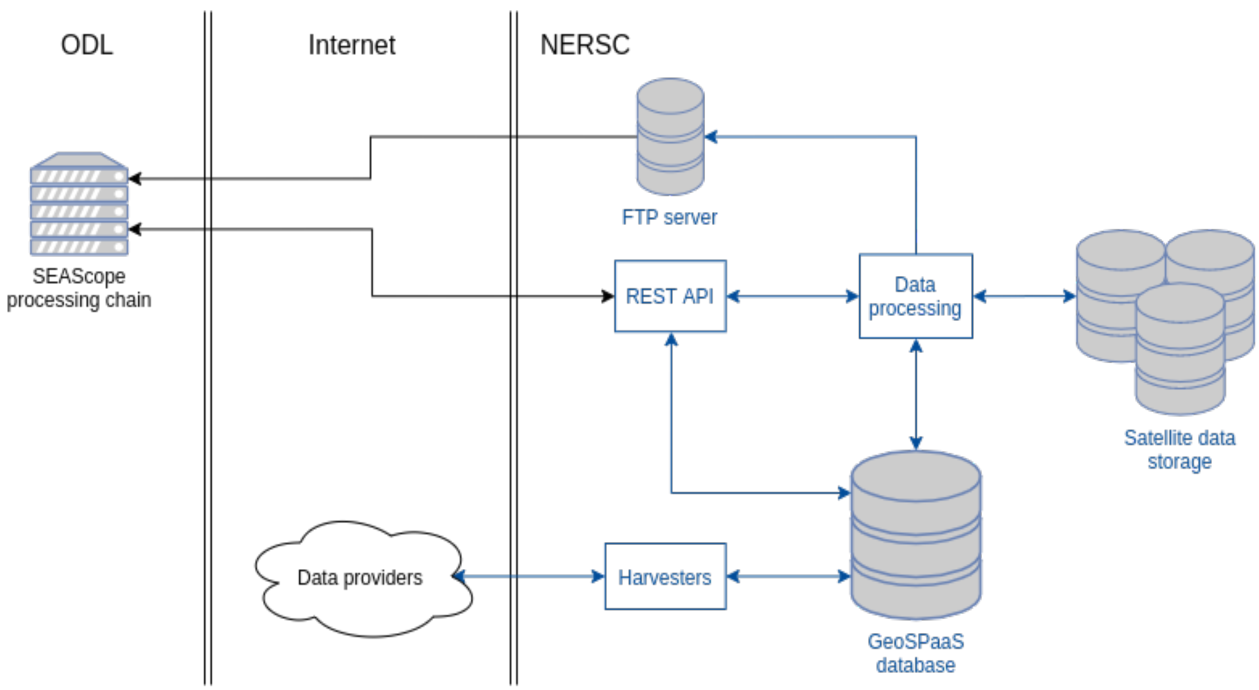

Figure 2. *Overview of the GeoSPaaS components, functionalities and and interaction with SEAScope*

The harvesting mechanism in GeoSPaaS feeds metadata from the data providers into the GeoSPaaS database, while the search program running on ODL's infrastructure send requests to the REST API to search for interesting datasets. Once a relevant dataset is found, a request can be forwarded which triggers the download of the dataset file(s) on the Nansen Center's infrastructure and the conversion (Data processing) of these files IDF.

ODL has regularly tested the webservice set up by NERSC during its implementation in order to make sure that both tools are compatible with each other and to allow for updates and improvements. A functional prototype is now up and running for a subset of the required data (see Figure 3). It is expected to be further extended, tested and validated in the coming months.

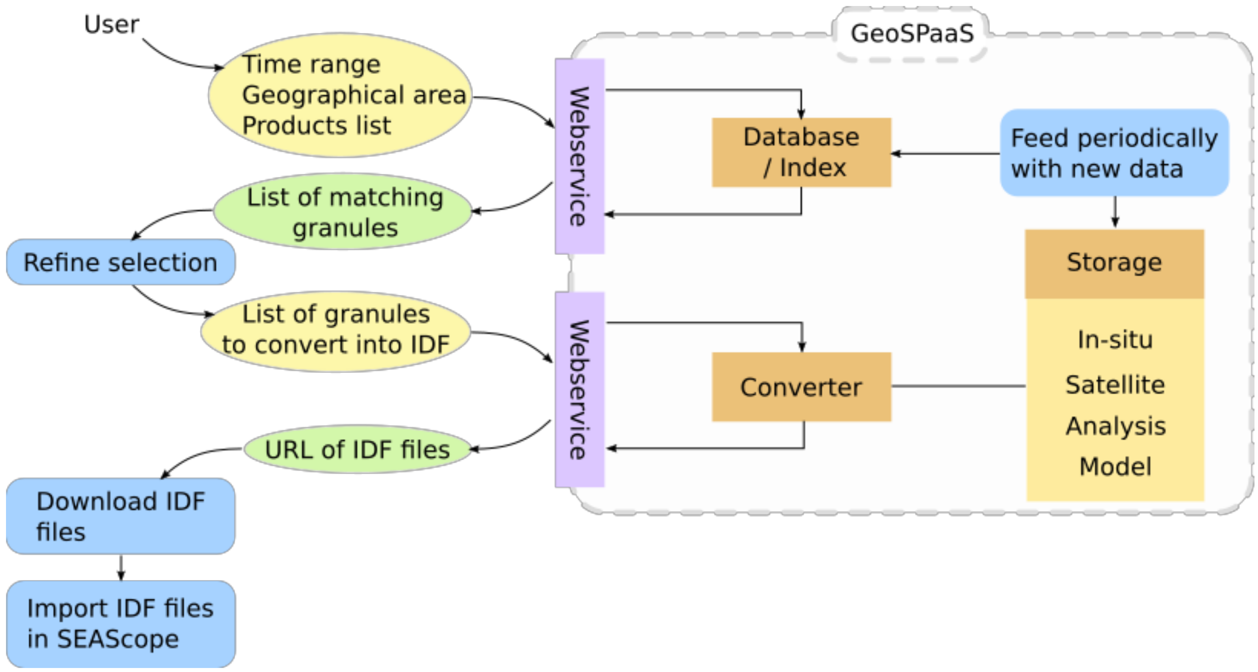

Figure 3. *Schematic illustration of the interaction between SEAScope and GeoSPaaS*

SEAScope contains a set of scripts that can automatically detect oceanic fronts based on satellite observations of the surface temperature and Chlorophyll. The front detection algorithms are based on a histogram analysis in order to detect the separations between the different water masses as detected in the SST field and or Chlorophyll distribution. The technique is robust in the face of noisy observations and makes it possible to compute the probability of the presence of a front on each pixel of the image. A ridge-following algorithm is then applied on the probability of the presence of a front. This enables constructions of continuous fronts with a confidence flag associated with each frontal structure.

Synoptic maps of these frontal structures provide information about the ocean surface frontal meandering patterns and motions which are proxy for the surface currents dynamics. Moreover, the scripts also ensure comparison and validation of the frontal maps with independent observed and/or modelled surface current products as shown in Figure 4. This is based on reconstruction of a surface current field from the satellite-based SST frontal maps (derived from SEVIRI) followed by an interpolation onto the grid of the surface current products derived from GlobCurrent. The two surface current maps are then compared and assessed for consistency and accuracy. Only points containing frontal information are used for this validation. All in all, the comparison demonstrates that the mesoscale anticyclonic eddy is satisfactorily positioned in both fields. This clearly suggest that the method is promising although there are slight differences in both surface current magnitudes and directions.

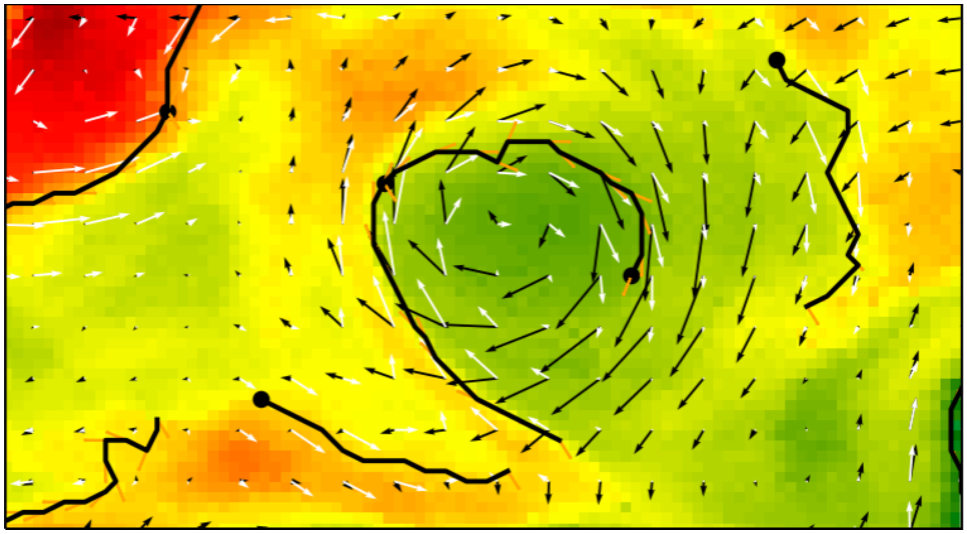

Figure 4. *Comparison of independent surface current fields. The white arrows represent the surface current field derived from the SST frontal map and re-interpolated on the grid to validate against the black arrows independently derived from the GlobCurrent products.*

ACTIROUTE (see Figure 1) deliver a current product optimized for a routing software, based on the comparison of the quality of the different model forecast products in relation to the available independent observations. This analysis provides comparison scores ranging from 1 (poor) to 5 (excellent) and is tailored to both current direction and current magnitude as indicated below.

- Current direction scores:
  - Between 4 and 5: direction difference less than 25°
  - Between 3 and 4: direction difference between 25° and 60°
  - Between 2 and 3: direction difference between 60° and 120°
  - Between 1 and 2: direction difference between 120° and 180°
- Current magnitude scores:
  - Between 4 and 5: magnitude difference < 0.2 knt
  - Between 3 and 4: magnitude difference between 0.2 - 0.5knt
  - Between 2 and 3: magnitude difference between 0.5 - 1 knt
  - Between 1 and 2: magnitude difference > 1 knt

The scores are established automatically through comparison with direct current estimation made on the bridge (e.g. WatchReports -WR), with surface drifters and visually by comparison with SST field. Three approaches are currently offered:

- The merged product consists in creating a current product which is a "patchwork" of the various analyzed products. This product indicates, in each sub region of an oceanic basin, which forecast product is the best in regard to the comparison with available observations. It associates a confidence index used by the routing software. This procedure requires the intervention of an operator in order to determine the confidence index, which is not calculated but based on an "expert opinion".

- The blended product consists in setting up an automated procedure to merge and combine the forecast models. Its principle is to average the products, weighting them according to their error in regard to the observations.

- The corrected product consists in updating the simulated current locally using the available observations (estimations made from the ships and /or from surface drifting buoys). This procedure is based on the reconstruction of an "observed" current field. The method consists in a variational interpolation depending on several parameters which can vary according to which oceanic basin is considered.

The interaction between SEAScope and ACTIROUTE furthermore strengthen this analysis, in particular, the blended and corrected products, by automatically taking into account satellite-based surface current products such as illustrated in Figure 4 which further reinforce the confidence index given to the optimized product.

The mesoscale and sub-mesoscale features such as shown in Figure 4 can have large influence on the sea state, and in particular the wave heights can change due to the refraction by the spatially varying surface current (Marechal and Ardhuin, 2020). As such it seems like the satellite altimeter observations of wave height gradients reveal a magnitude that is constrained by the surface current gradients as shown in the Agulhas Current (Figure 5). This satellite-based wave height gradient detection (derived from data made available in GeoSPaaS) will become part of the traffic light system that shall be included in WP5.

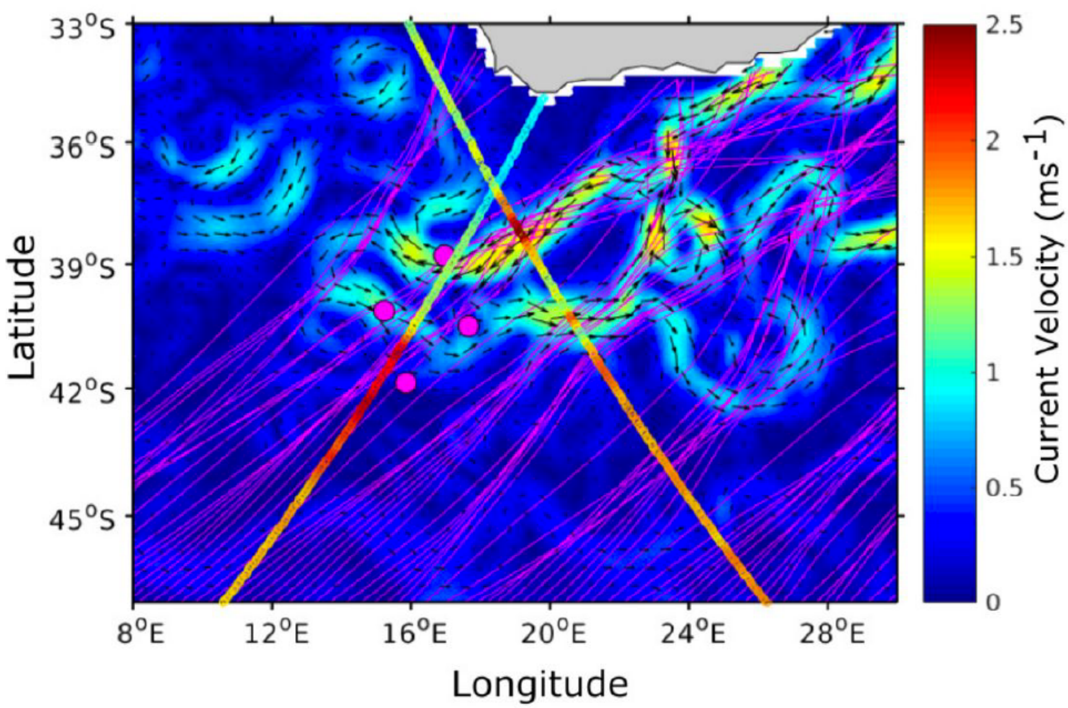

Figure 5. *Daily surface geostrophic currents on 2016.02.28 (velocity as black arrows). The magenta lines map the swell propagation rays. The magenta circles give the Sentinel-1 wave-mode images location the same day. Two Jason-2 altimeter tracks are shown, whose Hs values are normalized to fit the current scale (Quilfen et al., 2018).*

WP 5: Evaluation of the tool performance (lead Actimar)
This will consist in testing the tools on different routes and with different types of data, on real and simulated journeys. It will allow to make sure that the developed tools are relevant and reliable before its operational use.

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

WP 7: Synthesis, Dissemination and Communication (lead NERSC)
This task consists of all communication actions, in particular the publications and participation to symposiums. It also includes writing synthesis reports for the various sponsors of the project.

WP 8: Training courses and training material (lead NERSC)
Training sessions and training material destined to shipping companies

3. Communication and Outlook

The TOPVOYS project host a dedicated website (http://topvoys.nersc.no/) where provision of open information are obtained. In addition, information about the TOPVOYS project is also obtained from the dedicated MARTERA ERA - NET COFUND program website https://www.martera.eu/projects/topvoys. The corona virus pandemic has impacted the TOPVOYS project resulting in cancellation of planned physical project meetings, hindered visits to the participating shipping companies, and partly delayed the project progress. As such the French partners in the project has been given an extension of the project to the end of 2021. A similar request has been placed by the South African partners. In view of this it is also the intention of NERSC with Grieg Star to submit a request for a no-cost extension (via a change notification) from May 2021 to the end of the year, in order to avoid the consequences of the delay with the lack of ability to incorporate all findings and achievements expected between June and December 2021. This will, in particular, enable proper handling of the planned outstanding work in WP4 led by OceanDataLab, WP5 and WP6, both led by Actimar, and WP8 led by NERSC.

A project progress meeting was also held at Actimar in Brest (France) from 2-3 December 2019. At this meeting the plans for 2020 where addressed and agreed and including the 3-days workshop at the CMA-CMG Fleet Center in Marseille (France) in May 2020. This workshop, however, was cancelled due to the corona virus pandemic and is now postponed to May 2021.

A 1-day meeting took place in Cape Town, South Africa during the Nansen-Tutu Center 10 years anniversary symposium from 10-13 March 2020. It was attended by Marjolaine Krug, Fabrice Collard and Johnny A. Johannessen. Moreover, Marjolaine Krug (now Department of Environment, Forestry and Fishery – DEFF, Oceans and Coast Directorate, South Africa) addressed the relationship between the national Oceans and Coast Information Management System (OCIMS) and the TOPVOYS project at the approval of the 10-year strategic plan for OCIMS by the South African government for the period 2020-2030 in March 2020. OCIMS brings together expertise in marine data management, ocean modelling and Earth observation to provide value added products or Decision Support Tools including Integrated Vessel Tracking (IVT) to stakeholders.

Since 15 March 2020 the project partner interactions have been through emails, telephone calls and virtual meetings, mostly with OceanDataLab and Actimar. A reschedule of planned meetings and workshops will be forwarded with the change notification and request for the extension of the project to the end of 2021.

By obtaining acceptance for the requested extension of the project we also plan to disseminate the TOPVOYS project findings and results at the 14thInternational 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 in Gdynia, Poland (*http://transnav2021.umg.edu.pl*). The Conference is jointly organized by the Faculty of Navigation of the Gdynia Maritime University and The Nautical Institute. The focus of the conference is 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. Subjects of papers include telecommunications, electronics, robotics, computer engineering, astronomy, mathematics, GNSS, geodesy, GIS, cartography, hydrography, meteorology, command and control, psychology, operational research, maritime traffic engineering, risk analysis, theoretical physics, operation in hostile environments, instrumentation, mechanical engineering, ergonomics, port and ocean engineering, financial planning and law. Also of interest are logistics, transport and mobility. The conference provides a forum for transportation researchers, scientists, engineers, navigators, ergonomists, and policy-makers with an interest in maritime researches. The registration and submission deadline for abstract is 31 December 2020.

4. Financial Status

An overview of the budgeted expenses (NERSC + Grieg Star) versus the real costs for 2020 is provided in Table 4. The work situation (at the Nansen Center) for the reporting period has seen a good progress on the GeoSPaaS functionalities and interaction with SEAScope within WP4. This is largely thanks to the full-time employment of the scientific software developer Adrien Perrin.

Cost Plan	Budget 2020	Actual 2020
Personal cost	2638	1824
Purchase of R&D support		
Equipment	229	152
Other expenses (travel, etc)	125	132
Total	**2992**	**2008**

Table 5. *Budgeted versus actual costs form 2020. All numbers are in 1000 NOK.*

However, as noted there is an underspending of around 630 kNOK regarding personal cost and 144 kNOK in equipment and other expenses. The former is related to a slightly delayed progress in WP4 (work hours for NERSC), while the latter is due to cancellation of the planned progress meetings as well as the workshop planned at the Fleet Center of CMA-CMG. Further details of the financial situation with the proposed budget plan for 2021 will be forwarded with the economic report in January 2021. We will also accordingly forward a change notification.