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REVIEW OF WEATHER FORECAST SERVICES FOR SHIP ROUTING PURPOSES

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ABSTRACT

Weather data is nowadays used in a variety of navigational and ocean engineering research problems: from the obvious ones like voyage planning and routing of sea-going vessels, through the analysis of stability-related phenomena, to detailed modelling of ships' manoeuvrability for collision avoidance purposes. Apart from that, weather forecasts are essential for passenger cruises and fishing vessels that want to avoid the risk associated with severe hydro-meteorological conditions. Currently, there is a wide array of services that offer weather predictions. These services include the original sources – services that make use of their own infrastructure and research models – as well as those that further post-process the data obtained from the original sources. The existing services also differ in their update frequency, area coverage, geographical resolution, natural phenomena taken into account and finally – output file formats. In the course of the ROUTING project, primarily addressing ship weather routing accounting for changeable weather conditions, the necessity arose to prepare a report on the state-of-the-art in numerical weather prediction (NWP) modelling. Based on the report, this paper offers a thorough review of the existing weather services and detailed information on how to access the data offered by these services. While this review has been done with transoceanic ship routing in mind, hopefully it will also be useful for a number of other applications, including the already mentioned collision avoidance solutions.

Keywords: marine gas turbine, inlet air fogging, applicability

INTRODUCTION

Weather conditions have been taken into account in route planning since the very beginning of marine navigation. Already in the mid-XIXth century, for the first time in history a large compilation of climatology data in the form of weather and currents of the world was made public to the marine community. The data was combined from ships' log books into the "Wind and Current Chart of the North Atlantic" by Matthew F. Maury in 1847. At that time, in many cases seasonally recommended routes from Maury's charts allowed for significant passage reductions. His achievement has been further continued by other researchers and more recently, in the XXth century, taken over by the British Admiralty, US Navy and some meteorological groups. Publications such as Admiralty Ocean Passages for the World or the Navy's Pilot Charts accompanied by historical weather data were the first and basic resources for route planning in the last century. Since the mid-XXth century, route planning taking into account weather conditions, nowadays also known as weather routing (especially for long-distance such as trans-Atlantic routes), has been additionally supported by numerical weather predictions. These days such predictions are made available via the internet in the form of special file formats (GRIB1, GRIB2 or netCDF). Meanwhile, special tools and methods have been created to support route optimisation (originally single-objective ones in terms of passage time or fuel consumption minimisation) by using numerical predictions.

The first methodological approach to weather routing, initially proposed for manual use, was the isochrone method [9]. It was based on geometrically determined and recursively defined time fronts (isochrones) to find time-optimal routes.

In the next decades, computer implementations of the method were developed, as in [7]. There are also other approaches to weather routing: dynamic programming for a grid of points has been proposed in [14,29] and in a 3D version in [5,28]. As presented in [2], solving a specified optimal control problem allows for finding the time-optimal path. Another approach using the extended single-objective Dijkstra algorithm was presented in [11,12]. A multi-objective approach brings new qualities to weather routing by making it possible to optimise more than one criterion at a time. A simplified multi-objective approach to route planning with aggregation to a single criterion has been proposed in [24]. However, a purely mathematical approach to such optimisation with Pareto-optimal sets has been proposed so far by [8,13,20,21,25,30,31].

The importance of numerical weather predictions is increasing lately due to significant changes in seasonal weather trends on the one hand and the improved ability to predict weather dynamics on the other. Modelling of ship and environment interaction is becoming more realistic due to the use of sophisticated numerical tools. Dealing with severe weather conditions has been addressed by many authors. More accurate weather forecasts for marine purposes have been described in [15, 17], among others. Research on the wave climate along the North Atlantic routes has been provided in [27]. A related work on weather conditions for the European coast has been done in [26]. Harsh weather and its impact on ship routing and navigation has been discussed in [3, 4, 6, 16]. Similarly, the impact on ships' behaviour and safety was researched in [1, 10, 19], the application to collision avoidance in [22] and routing of sailing vessels in [23, 30, 31]. In general, it might be safely stated that weather data is nowadays used in a majority of navigational and ocean engineering research problems.

Apart from that, weather forecasts are essential for passenger cruises and fishing vessels that want to avoid the risk associated with severe hydro-meteorological conditions. Currently, there is a wide array of services that offer weather forecasts. They include the original sources – which make use of their own infrastructure and research models – as well as those that further post-process the data obtained from the original sources. The existing services also differ in their update frequency, area coverage, geographical resolution, natural phenomena taken into account and finally – output file formats. The paper offers a thorough review of the existing weather services and detailed information on how to access the data offered by those services.

The rest of the paper is organised as follows. The background of the research, including a brief description of a current weather routing project, has been provided in Section 2. A classification of weather services is presented in Section 3, followed by a discussion on the optimal choice of weather data for ship routing in Section 4. The details of the selected data sources and data formats are given in Section 5 and finally the summary and conclusions are presented in Section 6.

RESEARCH BACKGROUND – SHIP WEATHER ROUTING ACCOUNTING FOR CHANGEABLE WEATHER CONDITIONS

The project entitled "Ship Routing Accounting for Changeable Sea Conditions" (acronym ROUTING, funding schema: ERA-NET Cofund MarTERA-1, call 2017) [32] aims at developing a new type of ship weather routing, based on the research presented in [21]. In this project state-of-the-art robust route optimisation methods are to be applied, and selected sources of uncertainty related to weather predictions are also taken into account. What is more, live ship and weather parameter measurements provided by on-board installed instruments are to be utilised to improve both ship modelling and weather predictions (by means of data assimilation). The primary goal of the ROUTING project is to design, develop and test on-board a prototype of such weather routing system during a 6-month voyage.

The system is to comprise of three key elements:

- Ship handling DSS (decision support system),
- Weather routing DSS,Transmission module supporting ship–shore–ship data transmission (via cost-optimised Wi-Fi/GSM/satellite connection, where applicable).

The ship handling DSS is to be responsible for continuous on-board measurements and generating alerts in case of dangerous operations. The DSS will include devices for:

registering the motions in the six-degrees of freedom (6 DoF),

- estimating fuel consumption,
- monitoring hull stresses,
- monitoring current weather conditions,
- associating the measurements with a specific ship position and speed.

The DSS will introduce also its own, separate GPS measurements in order to improve the position accuracy [18] of stored information.

The weather routing DSS will in turn optimise the routes while taking into account the previous DSS data and weather predictions. The DSS will allow the exploitation of the information provided by the ship handling DSS in terms of improved ship modelling and accuracy of the weather forecast. The DSS will implement a state-of-the-art evolutionary multi-objective method (EMO) for robust route optimisation. Three optimisation criteria (passage delay, fuel consumption and safety of passage) will be constrained by eight optimisation constraints addressing ship stability and the safety of crew and cargo, among others.

It has been decided that, among various sources of uncertainties in the process of ship route optimisation, the key weather forecasted wave parameter, namely significant wave height, will be considered during optimisation as an ensemble forecast (i.e. a vector of forecasts). Such ensemble is a vector of the forecasted values of the same weather parameter created by a stochastic approach with the adoption of random model perturbation. The ensemble forecast approach means that the predicted weather conditions are described, instead of a single predicted value, by a vector of such values, usually equally

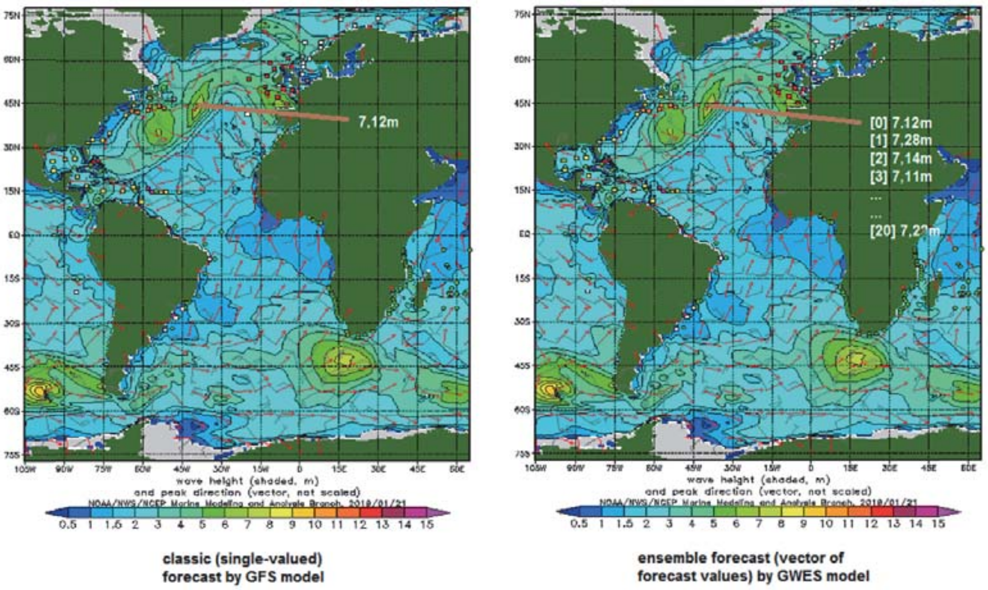

Fig. 1. Illustrative comparison of a single forecast (source: NOAA GFS model data) and ensemble forecast (source: NOAA GWES model data) for significant wave height Hs

probable. It is worth noting that so far there is no robust method available for incorporating ensemble forecasts into the ship weather routing process. Designing and developing such a method will be one of the key challenges in the course of this project.

During the initial phase of the ROUTING project, research on the available weather forecast services, providing forecasts of the assumed weather parameters, accuracy and covering the area of the expected sea trial of the prototype (North Atlantic) was conducted. The following weather parameters are expected to be gathered on the project's weather server:

- wave forecasts:
  - significant wave height (as ensemble forecast),
  - peak wave period,
  - mean wave direction;
- wind forecasts: U- and V- speed components;
- ocean currents: U- and V- speed components.

The next sections provide details on the available weather services and their suitability for the needs of the ROUTING project.

OVERVIEW OF WEATHER SERVICES

Meteorological services deal with archiving, but also the analysis of received meteorological measurements. The services can provide various hydro-meteorological data and forecasts, with wind, sea waves and sea currents, among others. The main task of the services includes creating and disseminating forecasts or reports on the current state of the meteorological situation in a commercial or non-profit way. Some meteorological services use their own data sourced from measuring buoys and stations or from satellite images, while others use external data sources. The weather forecasting process nowadays is realised based on numerical weather prediction (NWP) models. With this approach, the weather situation can be described using a mathematical description provided with a digital file. NWP models are constantly being developed by significant weather services. This mathematical description of the weather situation can be saved in various digital formats (GRiB1, GRiB2 or netCDF), provided they are acceptable to WMO (the World Meteorological Organisation). The metadata of this digital file contains information on the originating centre defined in accordance with WMO standards.

Some of the meteorological services are originating centres, meaning that they use their own measurement sources to broadcast weather forecasts. There are also services that modify existing numerical models, increasing their accuracy and resolution. Another important factor is the range of meteorological services: global (covering the entire world) and local ones. It is worth emphasising that local description usually presents the weather situation using numerical models with a denser description grid, thus offering higher accuracy. Some of the weather services specialise in offering various meteorological and hydrological products. These products can be extracted as forecasts, archive data and current data. Forecasts can be of varying duration, with different transmission and updating frequencies. They are usually created in a deterministic fashion (one forecast value to describe the meteorological situation at a given point in space and time), although ensemble forecasts are becoming increasingly popular. As an illustration between the classic and ensemble approach, a comparison of a single-valued (classic) forecast by the NOAA GFS model and an ensemble approach by the NOAA GWES model for significant wave height (Hs) forecasts is provided in Fig. 1.

WEATHER FORECASTS FOR SHIP ROUTING

The meteorological services disseminate the necessary weather information for many sectors of the economy to carry out specialised tasks. In this paper we will discuss weather services that disseminate information about current and forecasted meteorological conditions needed in shipping, with a focus on ship routing. Ship routing and monitoring is carried out on the basis of ships' manoeuvring data and sea conditions. In this case, it is assumed that the sea conditions are determined by the parameters of wind (speed and direction given directly or via U- and V- components of speed), wave (period, height and direction) and sea currents (speed and direction given directly or via U- and V- components of speed). What is more, the wave parameters such as significant wave height can be determined based on the ensemble approach. The research area covered here (for the purpose of the ROUTING project) is limited to the North Atlantic.

The factors taken into account when selecting a particular weather service include:

- geographical coverage,
- availability of particular hydro-meteorological data (wind, waves, sea currents) for the considered basin (North Atlantic),
- data access costs (where applicable),
- resolution of data occurrence,
- length and frequency of issuing forecasts,
- data formats,
- origin of the provided data, and,
- the experience and overall esteem of a meteorological service.

The aforementioned factors were noted on the basis of available information on the websites and metadata of the forecast description files (GRiB2) of selected weather services. Below we list the characteristics of a few selected weather services, including the organisation, its structure experience, the role it plays in the World Meteorological Organisation and what type of meteorological data is available.

THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA), *HTTP://POLAR.NCEP.NOAA.GOV/*

NOAA is an agency, under the US Department of Commerce, involved in daily weather forecasts, severe storm warnings, and climate monitoring for fisheries management, coastal restoration and supporting marine commerce. The National Centers for Environmental Prediction (NCEP) within NOAA are responsible for providing weather, hydrologic and climate forecasts. This service belongs to WMO, officially identified there under the number 7. NCEP contains nine distinct centres, which are characterised by a large variety of services and products. There are special sub-centres specialising in predicting meteorological conditions for the sea (Ocean Prediction Center and the Aviation Weather Center), but also in space (Space Weather Prediction Center). The Storm Prediction Center (SPS) and Tropical Hurricane Resort in Miami, Florida (NHPC) predict meteorological threats such as tornadoes, strong storms, lightning and fires. The Environmental Modeling Center (EMC) develops and improves numerical weather, climate, hydrological and ocean prediction. This centre operates and maintains more than 20 numerical prediction systems, including GFS, GEFS, SREF and CFS. The Central Operations NCEP manages the flow of data and meteorological products in the organisation. This centre is responsible for preparing NCEP products for dissemination. Products include traditional deterministic forecasts, as well as ensemble forecasts. The models of particular interest in this service include: GFS, Multi-grid Wave, GWES and RTFOS model. All data sources are produced by NOAA. The file format is GRiB2 except for the currents data, which is stored in netCDF format.

Tab. 1. The National Oceanic and Atmospheric Adminsitration (NOAA), http://polar.ncep.noaa.gov/

Model	Data type	Resolution	Forecast runs	Forecast time step / interval	Forecast length	Area
GFS	wind	0.25° x 0.25	4 times a day: 0000, 0600, 1200, 1800 UTC	1h / <120h, 3h / 120h-180h 12h / 180h-384h	384 h	Latitude max: 90° Latitude min: -90° Longitude min:-180° Longitude max:180°
Multi-grid Wave	waves	0.5° x 0.5°	4 times a day: 0000, 0600, 1200, 1800 UTC	1h / <120h, 3h / 120h-180h	240 h	Latitude max: 90° Latitude min: -77.5° Longitude min:-180° Longitude max:180°
GWES	waves (ensemble)	0.5° x 0.5°	4 times a day: 0000, 0600, 1200, 1800 UTC	240h ensemble forecast: 1 control + 20 perturbed members	240 h	Latitude max: 90° Latitude min: -77.5° Longitude min:-180° Longitude max:180
RTFOS	currents	(1/12)° x (1/12)°	once a day		72h	Global

THE EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS (ECMWF), *HTTPS://WWW.ECMWF.INT/EN/FORECASTS*

ECMWF is an organisation that coordinates two services from the EU's Copernicus Earth observation programme: the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S). ECMWF belongs to WMO, where it is identified with the number 98. ECMWF is based in Reading, UK, has 22 Member States and 12 Co-operating States (Poland is not included). It is one of six members of the Co-ordinated Organisations (NATO, CoE, ESA, OECD, EUMETSAT). Primarily, this is a research institute and an operational service, producing and disseminating global numerical weather predictions and other data. The tasks also include the archiving of meteorological data and carrying out scientific and technical research to improve forecasting skills. When considering global forecasts, ECMWF takes into account ensemble-based analyses and predictions. There is free access to all services provided and output data is stored in GRiB2 format.

Tab. 2. The European Centre for Medium-Range Weather Forecasts (ECMWF), https://www.ecmwf.int/en/forecasts

Model	Data type	Resolution	Forecast runs	Forecast time step / interval	Forecast length	Area
HRES	wind	0.125° x 0.125°	4 times a day 0000, 0600, 1200, 1800 UTC	1h / <90h 3h / 90h - 144h 6h / 144h - 240h	240h	Global
HRES-WAM	waves	0.125° x 0.125°	4 times a day 0000, 0600, 1200, 1800 UTC	1h / <90h 3h / 90h - 144h 6h / 144h - 240h	240h	Global
ENS-WAM	waves (ensemble)	0.25° x 0.25°	2 times a day 0000, 1200 UTC	3h / <144h 6h / 144h - 360h	360h	Global

EU COPERNICUS, *HTTP://MARINE.COPERNICUS.EU/SERVICES-PORTFOLIO/ACCESS-TO-PRODUCTS/*

Copernicus is the European Union's Earth Observation Programme based on satellite Earth observation (6 satellites). The organisation includes, among others, a marine service that provides its own archive and prediction of marine data. The marine service includes two different types of centres. The first one – Thematic Data Assembly Centres, collect marine data using satellite and in situ observations in real time. The second one – Monitoring and Forecasting Centres (MFC), generate reanalyses (20 years back), analyses (current) and 10-day forecasts of the ocean. The Copernicus Programme receives data, products and support services from EUMETSAT. EUMETSAT manages the EU space segment and belongs to the originating centre WMO list, where it is listed as number 254. There is free access to all services using own source data. Data is stored in netCDF format.

Tab. 3. EU Copernicus, http://marine.copernicus.eu/services-portfolio/access-to-products/

Model	Data type	Resolution	Forecast runs	Forecast time step / interval	Forecast length	Area
NEMO	waves, currents	.083° x .083°	daily 1200 UTC	1h / <120h	120h	89°S-90°N
NEMO	waves, currents	.25° x .25°	daily 1200 UTC	1h / <120h	120h	83oS-89.75oN

THE GERMAN WEATHER SERVICE (DWD), *HTTPS://WWW.DWD.DE/EN*

Germany's National Meteorological Service, with headquarters located in Offenbach, belongs to the WMO originating centre list as number 78. The numerical weather prediction (NWP) model developed by this organisation is

Tab. 4. The German Weather Service (DWD), https://www.dwd.de/en

Model	Data type	Resolution	Forecast runs	Forecast time step / interval	Forecast length	Area
ICON	wind	7km x 7km	2 times a day 0000, 1200 UTC	1h / <78h 3h / 78h-120 h	120h	Local: Europe
WAM	waves	7km x 7km	2 times a day 0000, 1200 UTC	1h / <78h 3h / 78h-120 h	120h	Local: North Europe
Cosmo	wind	2.8km x 2.8km	2 times a day 0000, 1200 UTC	1h / <27h	27h	Local: North Europe

called ICON. DWD is one of only fourteen weather services in the world running a global numerical weather prediction (NWP) model. DWD belongs to COSMO (the Consortium for Small-scale Modelling). Its general goal is to develop, improve and maintain a non-hydrostatic limited-area weather data model, called COSMO. DWD marine services produce both deterministic and probabilistic ocean data predictions. There is free access to all services using its own source data. Data is stored in GRiB2 format.

JAPANESE METEOROLOGICAL AGENCY, *HTTPS://WWW.JMA.GO.JP*

The Japanese Meteorological Agency is the national weather service of Japan. It includes the Meteorological Research Institute, Meteorological Satellite Center, Aerological Observatory, Kakioka Magnetic Observatory, and Meteorological College. It belongs to WMO under number 34. This service produces and disseminates meteorological deterministic and ensemble forecast data. It develops its own numerical weather prediction models, as follows: GSM, MSM, LFM and GEPS. This service mainly distributes meteorological products for Asia. There is free access to all services using its own source data. Data is stored in GRiB2 format.

ATMOSPHERIC MODELING AND WEATHER FORECASTING GROUP - AM&WFG (NATIONAL & KAPODISTRIAN UNIVERSITY OF ATHENS), *HTTP://FORECAST.UOA.GR/WAMINFO.PHP*

A group of scientists from the Kapodistrian University of Athens have been operating for 25 years on the development of their own models of weather description. This service mainly provides forecasts for the Mediterranean Sea. The meteorological service participates in the creation of numerical model predictions: SKIRON and RAMS, based on the data received from NCEP. There is free access to all services using NOAA source data. Data is stored in GRiB2 format.

THEYR PRECISION WEATHER PLANNER, *HTTPS://WWW.THEYR.COM/INDEX.ASP*

This company is responsible for the commercial delivery of high-precision weather and ocean forecasts. It produces its forecasts using the WRF system model using NOAA data. There is payable access to all services using NOAA source data. Data is stored in GRiB2 format.

Tab. 5. Japanese Meteorological Agency, https://www.jma.go.jp

Model	Data type	Resolution	Forecast runs	Forecast time step / intrval	Forecast length	Area
GSM	wind, waves	0.1875 x 0.1875	3 times a day 0000, 0600, 1800 UTC	-	134h	Global
GEPS	waves (ensemble: 13 members)	0.5625 x 0.5625	2 times a day 0000, 1200 UTC	Twice a week / <34 days	34 days	Global

Tab. 6. Atmospheric Modeling and Weather Forecasting Group - AM&WFG (National & Kapodistrian University of Athens), http://forecast.uoa.gr/waminfo.php

Model	Data type	Resolution	Forecast runs	Forecast time step/ interval	Forecast length	Area
SKIRON	wind, waves	0.1° x 0.1°	-	3h / <120h	120h	Local: Europe

Tab. 7. Theyr Precision weather planner, https://www.theyr.com/index.asp

Model	Data type	Resolution	Forecast runs	Forecast time step	Forecast length	Area
NOAA-WRF	wind, waves	0.01° x 0.01°	-	1, 3 or 6 hours	6 days	Local

METEO CONSULT, *HTTPS://MARINE.METEOCONSULT.CO.UK/*

The METEO CONSULT service disseminates meteorological data using NOAA data sources. It is a private company providing services in forecasting the weather for the maritime sector. There is mostly free access to all services using NOAA source data. Data is stored in GRiB2 format.

EXPEDITION 10, *HTTP://WWW.EXPEDITIONMARINE.COM/EGRIB.HTML*

This organisation offers tactical and navigation software, which is dedicated to well-known regattas. Expedition has been in development since the mid-1990s by veteran Volvo Ocean Race navigator and Whitbread winner Nick White. It offers WRF weather models mainly for the Australian coast. There is free access to all services using NOAA source data. Data is stored in GRiB2 format.

THE TIDETECH GROUP, *HTTPS://TIDETECHMARINEDATA.COM/*

This is a private weather service, which disseminates data from NOAA and Copernicus, but also disseminates sources of the Sri Lankan meteorological centre (http://www.meteo.slt.lk), centre 131 of WMO. This service provides free access in a demo version and full functionality as commercial services. All of its services use NOAA source data. Data is stored in GRiB2 format.

When selecting the appropriate weather service for the purposes of the ROUTING project, the content of the abovementioned tables was verified in the context of the credibility of the organisation and the usefulness of specific data sources. In addition, the ease of access to individual data sources was verified. After the analysis, the following choices have been made.

- Wind: GFS model from NOAA,
- Waves: from NOAA sources
  - mean wave direction and wave period between peaks from the Multi-grid Wave model,
  - ensemble forecast significant wave height from the GWES model,
- Sea currents: Real Time Ocean Forecast System from NOAA.

It must be mentioned here that, when it comes to data sources on ocean currents, some services offer historical archive data instead of forecasts. One such archive-based source is Ocean Surface Current Analysis Real-time (OSCAR), developed by NASA. In practice, such data is useful for estimating seasonal changes of sea currents, but it might not be sufficient as a source for weather routing (where accurate long-term forecasts are needed) or for collision avoidance (where up-to-date data or short-term forecasts are necessary).

SELECTED WEATHER DATA MODELS

The selected weather data models (GFS, Multi-grid Wave and GWES from NOAA) are presented in detail in the following sub-sections.

Tab. 8. Meteo Consult, https://marine.meteoconsult.co.uk/

Model	Data type	Resolution	Forecast runs	Forecast time step / intrval	Forecast length	Area
GFS	wind	4km x 4km	-	-	-	Local: Europe

Tab. 9. Expedition 10, http://www.expeditionmarine.com/egrib.html

Model	Data type	Resolution	Forecast runs	Forecast time step / intrval	Forecast length	Area
NOAA-WRF	wind, waves	0.1° x 0.1° 0.03° x 0.03°	-	1h / <72h 0.5h / <36h	72h 36h	Local: coast of Australia, Europe, China

Tab. 10. The Tidetech Group, https://tidetechmarinedata.com/

Model	Data type	Resolution	Forecast runs	Forecast time step / intrval	Forecast length	Area
NOAA-WRF	wind, waves, currents	0.1-0.02°	2 times a day	3h / <120h	120h	Global

THE GFS MODEL FROM NOAA

The GFS model provides wind data and is available on the Nomads server (administrated by NOAA), under the access link:
http://nomads.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/. The data provided there are organised as follows:

- In the above location, there are folders named according to the rule: gfs.YYYYMMDDHH, where YYYY is the year, MM is the month, DD day, HH hour of the forecast issue.
- In the selected folder, the GFS model files for the given date and time are named according to the following rule: Gfs.tHHz.pgrb2.0p25.FFF, where HH is the time of the weather forecast issue, and FFF is the forecast for the FFF's forecast hour counted from the HH release forecast.
- In the selected file, wind parameters are defined by U- and V- components. The U- component is defined by the ugrd10m variable, and the V- component by the vgrd10m variable.

THE GWES MODEL FROM NOAA

The GWES model provides the significant wave height as one main control forecast and 20 equally probable accompanying forecasts – various variants of the control forecast.

The model is available on the Nomads server, under the access link: http://nomads.ncep.noaa.gov:9090/pub/data/nccf/com/wave/prod/. The data provided there are organised as follows:

- GWES is located in folders named according to the rule: gwes.RRRRMMDD, where YYYY is the year, MM is the month, DD is the day of issue of the GWES model forecast set.
- There are 84 GRiB2 files in the GWES model folder, as well as other files in different formats. The GWES GRiB2 files are marked as follows: gwesPP.glo_30m.tHHz.grib2, where PP is the sequence number in the given set of projections (00 to 20), HH the time of the edition of the forecast data set.
- In the selected files, the significant wave height is defined by the HTSGW variable.

MULTI-GRID WAVE MODEL FROM NOAA

The Multi-grid Wave model provides the data on:

- significant wave height,
- wave period between the peaks,
- mean wave direction.

The model is available on the Nomads server, under the access link: http://nomads.ncep.noaa.gov:9090/pub/data/nccf/com/wave/prod/. The data provided there are organised as follows:

- The Multi-grid Wave model is located in folders named according to the rule: multi_1.RRRRMMDD, where RRRR is the year, MM is the month, DD is the day of the forecast issue.
- There are many GRiB2 files in the folder of this model, including files for local areas.
- GRiB2 files of the Multi-grid Wave model for global coverage are marked as *Multi_1.glo_30m.tHHz.FFF.grib2*, where *HH* is the time of the weather forecast issue, and *FFF* is the forecast for *FFF* - the hour of the forecast calculated from the *HH* release forecast.
- The height of the significant wave in the above GRiB2 file is marked in the full version (long name) as "Significant height of combined wind waves and swell& Ground or water surface", and in the abbreviation "HTSGW". The given HTSGW is expressed in meters [m].
- The wave period between the peaks is named in the full version (long name) "Primary wave mean period & Ground or water surface", with the abbreviation "PERPW". The value of the data is expressed in seconds [s].
- The mean wave direction is named in the full version (long name "Primary wave direction" or "abbreviation"), the value of the data is expressed in degrees, where 0° means the movement towards the real north, 90° towards the east, and 180° towards the south (according to oceanographic convention).

REAL TIME OCEAN FORECAST SYSTEM FROM NOAA

The model is offered by NOAA / NCEP and provides, among others, forecasts of sea currents. Forecasts are available in netCDF and GRiB2 file formats, though the latter covers only selected areas, mainly the Pacific (Fig. 2), so the netCDF files are recommended for worldwide applications, including transatlantic weather routing.

RTOFS data (including global netCDF files) are available under the link:
http://nomads.ncep.noaa.gov:9090/pub/data/nccf/com/rtofs/prod/.

The above location contains folders named according to the rtofs.YYYYMMDD convention, where YYYY is the year, MM is the month and DD is the day of the forecast issue. netCDF (*.nc) files in those folders are named according to the rule: rtofs_glo_2ds_XNNN_PERIOD_MODE.nc, where X equals 'f' (forecast) or 'n' (nowcast – a short-term forecast), NNN is the time in hours that the forecast covers, UPDATE indicates how often the forecast is issued: ("daily", "3hrly" or "1hrly"), MODE means a forecast done for either diagnostic ("diag") or prognostic ("prog") variables.

In the case of weather routing, the recommended files are:
rtofs_glo_2ds_fNNN_daily_prog.nc (NNN: 000, 024, 048 and 072).

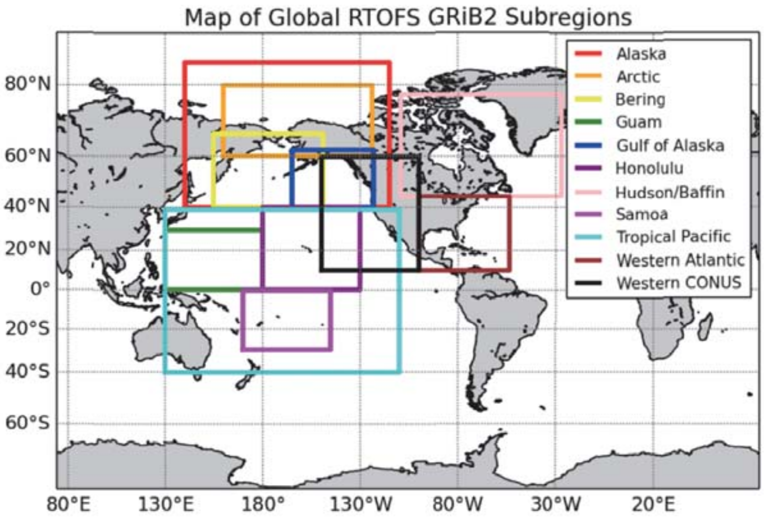

Fig. 2. Geographical regions covered by GRiB2 files of Real Time Ocean Forecast System (image taken from: https://polar.ncep.noaa.gov/global/about/grib_description.shtml).

The files contain, among others, the velocity of a sea current given by the parameters "u_velocity" (velocity towards east) and "v_velocity" (velocity towards north).

It is worth noting that the grid (4500 x 3298 points) in the RTOFS global model files has an Arctic bi-polar patch (above 47°N) and a Mercator projection between 47°N and 78.6°S, as presented in Fig. 3.

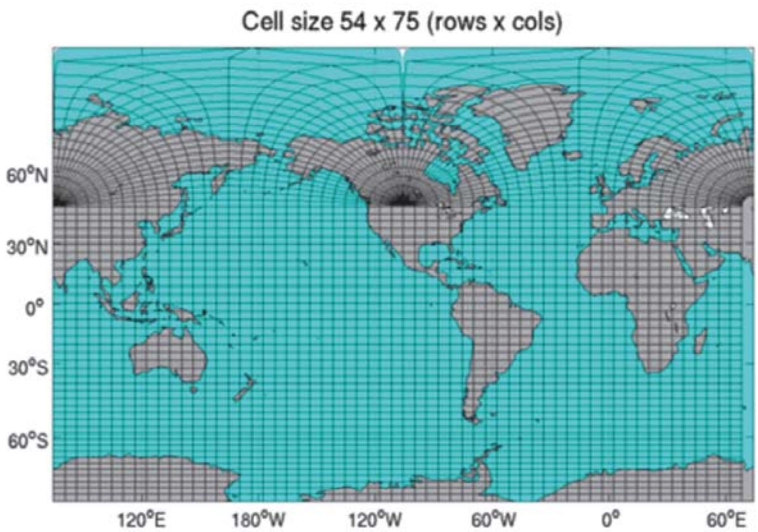

Fig. 3. Grid of the global Real Time Ocean Forecast System (image taken from: https://polar.ncep.noaa.gov/global/about/images/large/pic1.png).

SUMMARY AND CONCLUSIONS

As has been shown in the paper, the multitude of weather data services might actually be misleading. When it comes to the detailed needs (here: for the purpose of weather routing in the North Atlantic), it turns out that the majority of available sources are lacking area coverage, update frequency, resolution or completeness. In the paper a number of weather data services have been presented and the ones that are optimal for the specified needs have been chosen. Following this, their functionality, as well as data access and data formats, has been researched and the results are provided in the current paper. While this review has been prepared with oceanic ship routing in mind, hopefully it will also be useful for a number of other applications, including collision avoidance.

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