OE-591 Introduction to Dynamic Meteorology

Weather routing for sailing vessels

A comparison of sailed routes during regatta EST105 and programmed least time routes by weather routing program VISIR

Karine Jansen

5-11-2017

Introduction

Whether onboard a supertanker or a 12-foot yacht, every sailor is extremely dependent on weather. It was, it is and it will always be a determining factor in every ocean passage. Back in the days, the famous clipper ships could make their successful passages with their very precious cargo of tea thanks to the first steps in drawing up charts where the winds and ocean currents were depicted.

Matthew Maury (1806 – 1873), nicknamed 'pathfinder of the seas', could not fulfill his duties as midshipman on US navy frigates any longer after a leg injury. The navy did not know what to do with him so he studied navigation, meteorology wind and currents. He went through old ship logbooks and charts and found interesting patterns in winds and currents, which he illustrated in month by month charts. This drastically reduced the length of ocean voyages. Especially the area without winds, the so-called doldrums were extremely important to know in order to avoid getting becalmed in the middle of the ocean.

Nowadays ship owners and captains are using state-of-the-art routing services in order to shorten passages and reduce fuel costs. For sailing regatta's these programs are used to optimize the use of the wind and minimize sailing time.

The project

CMCC, the Euro-Mediterranean Center on Climate Change, has developed a new numerical model for the on-demand computation of optimal ship routes based on wind and sea-state forecasts, VISIR. The present version is capable of determining least-time ship routes for small displacement motor vessels and sailboats in the Mediterranean. The bathymetry is included in order to address topological issues of coastal navigation. VISIR is an operational system available at http://visir-nav.com/. Their code is open source and accessible at http://visir-model.net/.

In this paper several VISIR sailboat routes are computed through the operational service and compared to the routes sailed during the regatta EST 105 from Italy to Montenegro.

The Regatta - EST 105

EST 105 is an annual offshore race of 105 NM. It started in Bari (Italy) at 12:00 CEST on April 28th and sailed to the Bay of Kotor (Montenegro). There are two different classes, the more competitive ORC class with 39 participating yachts and the LIBERA class with 25 yacht. The ORC class sailed all the way into the bay of

Kotor to Tivat and a time-on-distance rating system is used to get the final results. The LIBERA yachts only had to go as far as Herceg Novi to finish and the results are based on the real sailed time.

The yachts used for this weather routing comparison are listed in the following table and slide 5. These yacht types where chosen because their polar plots are supported within VISIR.

Table 1: The yacht types

Yacht Type	Name	Class
Dufour 385	Oltremare	ORC
Grand Soleil 40	Indigo	ORC
	Jolly Roger	ORC
	Grande Cesare	ORC
First 40.7	Ol-Tirsenoi	LIBERA
	Polyann	ORC

VISIR

Routing algorithm

To compute a least-time optimized route within VISIR the position of a departure and an arrival mark are assigned. In this case the arrival mark is set to be just outside of the Bay of Kotor in order to avoid complex coastline, bathymetry and currents effects within the bay. The departure time is also set, with the attention to using the proper time, VISIR uses local time for this. The bounding box is the area in which a search for the optimal route is carried out. Proper selection of this box is necessary to actually find the optimal route instead of a suboptimal one. The time for computation of the route is displayed and increases with a larger box. The bounding box used for this project is depicted in slide 6.

Graphs

VISIR uses a graph-search algorithm. Space is divided into nodes whereby some nodes are linked to each other. The links define possible paths for the sailboat to travel from one node to another. The time elapsed for this displacement is called edge weight or edge delay. Due to the nature of a sailboat the edge weight also depends on the traveling direction, therefore a directed graph is used.

The nodes are placed on a regular grid in latitude and longitude coordinates with spacing 1/60°. This corresponds with a spacing of about 1 NM along the meridional direction. Links are possible between each node and its first and second neighbors, which leads to an angular resolution of $\tan^{-1}(1/2) = 27°$, see slide 6. The optimal path minimizes the sum of the edge weights along the path. There are both exact and heuristic-based methods that determine the optimal paths. VISIR uses Dijkstra's algorithm, an exact method, to determine the optimal route [2].

Dynamic fields

As the wind forecast is dynamic the edge weights explicitly depend on time. The edge delay is evaluated at the earliest time the edge is considered by the algorithm.

Topological constraints

Several commercial software's for sailboat routing employ the isochrones method [5] & [6], this method is based on a recursive branching calculation of the distance traveled over each segment's course at varying angles. They use a fixed time interval and find the route with the maximum distance traveled. However, this method poses limitations in how they deal with landmasses. VISIR uses a graph-search algorithm, where the edges intersecting or being tangent to the coastline are preliminary removed from the graph. This way the bathymetry of the Mediterranean is included and only the edges that are safe for navigation are considered in the search. The depth of the selected sailboat class is also considered so that there will always be enough water under the keel.

Sailboat modelling

The dynamical response of sailboats to the environmental conditions are described in terms of their polar plots. It shows the theoretical attainable speed for a specific sailboat at various wind speeds and directions. These polar plots combine the hydrodynamic hull-water interaction together with the sail aerodynamics and stability constraints. In VISIR the information for the polar plots comes from the ORC international certificates for the various yacht types. Slide 7 shows the polar plots for the yachts used in this project.

Wind forecast

The 10m height wind forecast from the IFS model operated by the European Centre for Medium-Range Weather Forecast (ECMWF) is employed in VISIR. By using the 10m height wind forecast any effects of shear are neglected. Shear or twist is the variation in wind direction and speed between the deck and the masthead.

The wind forecast use the original ECMWF resolutions. A 3-hourly resolution for the first 30 hours since the analysis and 6-hourly after that. The horizontal resolution is 1/8°, which corresponds to approximately

7.5 NM in the meridional direction. The 12:00 UTC analysis is used so that the forecast time is at least 7 hours, see table 2.

Table 2: ECMWF analysis

day	**time (UTC)**	
j-1	12	analysis is carried out (at ECMWF)
j	t<01	still employing forecast from analysis of j-2
j	t>01	now employing forecast from analysis of j-1

The wind map images within the VISIR interface are updated daily between 4 and 8 CEST. However, the computations employ the most updated forecast available.

Forecast verification

An evaluation of ECMWF forecast is published every year [4]. The scatter index is the standard deviation of error normalized by the mean observed value. According to the paper published in December 2016 the scatter index is between 13% and 28% during the first 3 days after analysis. Compared to other models they show very good results on scatter index, see slide 10.

Results

Calculated routes

The computed routes for the different yacht types are shown on slide 8. As stated before the arrival point was chosen to be outside of the bay of Kotor to avoid complex coastline, bathymetry and current effects. During the whole regatta there is a steady breeze over the race course ranging from 15 to 20 knots from the ESE to SSE. That means the yachts could sail a comfortable beam to broad reach across the Adriatic Sea. As shown in the polar plots these conditions are especially favorable for the Grand Soleil 40's and First 40.7's. Their expected route duration is 12 hours and 10 minutes. For the Dufour 385 the expected duration is slightly longer, 13h02m.

Both the geodetic and optimal route show specific kinks, see slide 12. The geodetic route is only provided for topological information without any reference to its kinematical aspect [1]. The plot on slide 12 shows the COG (course over ground) of the optimal route over the cumulative time. The COG jumps from 63° to 45°. This is because of the limited angular resolution of the graph. It corresponds exactly with the links between nodes O - C and O - B'. However, it can be concluded that the optimal route is a relatively straight line across, possibly with a very slight SE deviation.

Sailed routes

The sailed routes of both the ORC and LIBERA classes are displayed on slide 13. Especially the ORC class shows some variations in the sailed routes. In order to determine the optimal route, the sailed routes were divided into four options: straight, little SE, medium SE and extreme SE. The table on slide 13 lists the results of the ORC class and the sailed route they took. These results are already compensated for their ORC rating. It is clear that a more direct route showed better results, the winning yacht Indigo (Grand Soleil 40) sailed a very straight line across. The yachts that took an extreme SE deviation ended pretty low in the overall score.

Discussion

The following table lists the calculated and actual sailed route durations for the different yachts, together with the difference between the two. The sailed duration is in all cases longer than the calculated one.

Table 3: Comparison sailed and calculated duration

			duration		
Yacht Type	**Name**	**Class**	**calculated**	**actual**	**difference**
Dufour 385	Oltremare	ORC	13h02m	14h34m	1h32m
Grand Soleil 40	Indigo	ORC	12h09m	13h05m	0h56m
	Jolly Roger	ORC	12h09m	13h48m	1h39m
	Grande Cesare	ORC	12h09m	13h13m	1h04m
First 40.7	Ol-Tirsenoi	LIBERA	12h10m	13h00m	0h50m
	Polyann	ORC	12h10m	15h07m	2h53m

Furthermore, slides 15 to 18 compare the actual data received from the GPS tracker with the calculated data from VISIR at different time slots. For reference a weather forecast from PredictWind [10] is also included. This 10m wind forecast shows ECMWF on the right and a PredictWind model PWE, based on ECMWF, on the left. The GPS speed is slightly less in all cases.

There are different possible reasons that could cause this difference in speed and with that the overall duration. The actual wind conditions the yachts experienced are unknown. Therefore, the used wind forecast cannot be verified and we do not know if the yacht sailed up to their full potential according to their polar plots. The polar plots are said to address both the hydrodynamic and aerodynamic aspects of a sailboat. Extreme wavy conditions, for example when the wave direction does nog match the wind direction, are not taken into account. Therefore, it might be interesting the combine the wind and wave forecasts in the weather routing program. This will be complex as there will be different polar plots needed for that. Furthermore, neglecting the wind shear by using the 10m height wind forecast could cause the difference in sailed and calculated speeds. A compensation depending on the height of the center of effort of sail area would reduce the calculated wind speeds and therefore boat speeds.

Additionally, as the operational version of VISIR does not take current into account yet this could be the cause for difference in calculated and sailed speeds. The modelled current at the surface for April 28 is pictured in figure 1 [9] and they seem to be predominantly to the northeast over the sailed course. Hence, the current is not expected to have slowed the yachts down.

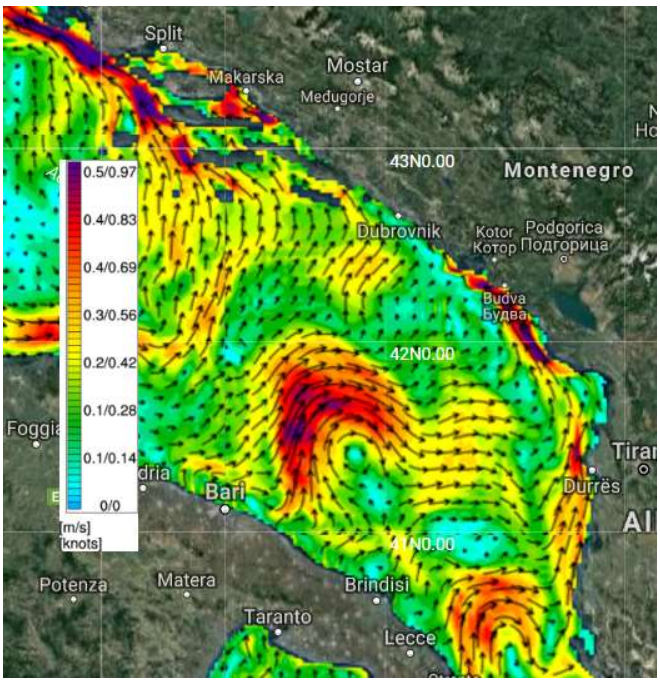

Figure 1: Current Adriatic Sea, 04/28/2017, [9]

Conclusions and recommendations

The optimal routes sailed during the regatta EST 105 agree very well with the least-time optimized route calculated with VISIR. The fastest way across the Adriatic from Bari to the Bay of Kotor showed to be a very straight line. However, the calculated routes showed some kinks that can be assigned to the limited angular resolution of the graph in the current operational version of VISIR. This issue has been addressed in the research version already.

Even though the differences in the calculated and the actual sailed route durations are not extremely large, the yachts were underway approximately 1 to 1.5 hours longer than calculated. The speed over ground (SOG) was lower in general, for all yachts at all time slots. In order to find the reason for this discrepancy it is necessary to receive the actual wind data (speed and direction) from onboard. This way the wind forecast can be verified and we could determine if the yacht sailed at the full potential according to their polar plots.

For a future comparison of sailed and calculated routes it would be interesting to look at a longer regatta. This would limit the issues related to the resolutions of the wind field and of the VISIR graph. Unfortunately, none of the longer races in the Mediterranean took place during the time span in which this project needed to be finished. Additionally, more 'interesting' routes could be computed, where the wind directions and speeds show more variance. During EST 105 the optimal route was just a very straight line across the Adriatic Sea, with a very steady breeze concerning direction and speed. Hence the functionality of tacking, jibing and the bathymetry within VISIR were not tested.

References

1. G. Mannarini, N. Pinardi, G. Coppini, P. Oddo and A. Iafrati, "VISIR-I: small vessels – least-time nautical routes using wave forecasts", Geoscientific model development, 2016
2. G. Mannarini, G. Turrisi, A. D'Anca, M. Scalas, N. Pinardi, G. Coppini, F. Palermo, I. Carluccio, M. Scuro, S. Cretì, R. Lecci, P. Nassisi and L. Tedesco, "VISIR: technological infrastructure on an operational service for safe and efficient navigation in the Mediterranean Sea", Natural hazards and earth systems sciences, 2016
3. G. Mannarini, R. Lecci, G. Coppini, "Introducing sailboats into ship routing system VISIR", 6th International conference on information, intelligence, systems and applications (IISA), 2015
4. T. Haiden, M. Janousek, J. Bidlot, L. Ferranti, F. Prates, F. Vitart, P. Bauer and D.S. Richardson, "Evaluation of ECMWF forecasts, including the 2016 resolution upgrade", ECMWF, Tech. Rep., 2016
5. Y. Lin, M. Fang, R. Yeung, "The optimization of ship weather-routing algorithm based on the composite influence of multi-dynamic elements", Applied ocean research, 2013
6. [online] http://www.bwsailing.com/bw/columns-blogs/weather-routing-software/
7. [online] http://visir-nav.com/
8. [online] http://visir-model.net/
9. [online] http://oceanlab.cmcc.it/afs/
10. [online] https://www.predictwind.com/