Optimization-Based Weather Routing for Sailboats

Article · January 2013

DOI: 10.1007/978-3-642-33084-1_3

5 authors, including:

Jorge Cabrera
Universidad de Las Palmas de Gran Canaria

Josep Isern
Universidad de Las Palmas de Gran Canaria

Daniel Hernández-Sosa
Universidad de Las Palmas de Gran Canaria

Antonio Carlos Domínguez Brito
Universidad de Las Palmas de Gran Canaria

"Optimization-Based Weather Routing for Sailboats"

J. Cabrera-Gámez, José Isern-González, J.D. Hernández-Sosa, A. C. Domínguez-Brito, E. Fernández Perdomo

Instituto Universitario SIANI (www.roc.siani.es),
Universidad de Las Palmas de Gran Canaria (www.ulpgc.es), Spain

In: Sauzé C., Finnis J. (eds) Robotic Sailing 2012. Springer, Berlin, Heidelberg.
10.1007/978-3-642-33084-1_3

BibTeX:

```
@inproceedings{10.1007/978-3-642-33084-1_3,
author="Cabrera-G{\'a}mez, Jorge
and Isern-Gonz{\'a}lez, Jos{\'e}
and Hern{\'a}ndez-Sosa, Daniel
and Dom{\'i}nguez-Brito, Antonio Carlos
and Fern{\'a}ndez-Perdomo, Enrique",
editor="Sauz{\'e}, Colin
and Finnis, James",
title="Optimization-Based Weather Routing for Sailboats",
booktitle="Robotic Sailing 2012",
year="2013",
publisher="Springer Berlin Heidelberg",
address="Berlin, Heidelberg",
pages="23--33",
isbn="978-3-642-33084-1"
}
```

Optimization-Based Weather Routing for Sailboats

J. Cabrera-Gámez, J. Isern-González, D. Hernández-Sosa, A.C. Domínguez-Brito, E. Fernández-Perdomo[1]

Abstract In this paper we propose a deterministic route planner for a sailboat suitable for areas where high quality wind and currents forecasts are available. An optimization based approach is used with the objective of minimizing the time required to arrive at a destination. Several simulations have been performed using high resolution regional forecasts from HIRLAM and MyOcean models in order to test the validity of this method.

1 Introduction

Long term or weather routing deals with the problem of finding a sequence of waypoints connecting given pairs of starting and ending coordinates taking into account weather forecasts and other possible constraints. The solution to this problem has a number of interesting applications in marine navigation for ships, e.g. minimization of fuel consumption or improvement of passenger comfort; or, in sailboats, safe routing and the planning of long distance regattas.

Route planners can be classified into deterministic route planners [1], these are not suitable if the uncertainty of the weather forecast is very high, and non-deterministic route planners, where an ensemble of weather forecasts is used to perform the planning [5].

In this paper, we will focus on a deterministic route planner for areas where high quality wind and currents forecasts are available. We will discuss its application to the problem of optimizing the route of a sailboat with the objective of minimizing the time required to arrive to a destination.

The article is organized into four sections devoted, respectively, to describing the route planner and the wind and current forecast data sources, presenting some simulation results and finally summarizing the main conclusions and future work.

---

[1] J. Cabrera-Gámez, J. Isern-González, D. Hernández-Sosa, A.C. Domínguez-Brito, E. Fernández-Perdomo

Instituto Universitario de Sistemas Inteligentes y Aplicaciones Numéricas en Ingeniería, SIANI. Universidad de Las Palmas de Gran Canaria, Canary Islands, SPAIN. jcabrera@iusiani.ulpgc.es

2 The Route Planner

The architecture of the route planner consists of two levels. At the inner level it uses the approach described by Stelzer and Pröll in [2] to select the best bearing, given the wind direction, sailboat position and bearing, and destination coordinates. At a second level, the router tries to find an optimal route that minimizes time to destination. At this level the influence of currents may also be taken into consideration.

The selection of the best route between two points, given winds and currents forecasts, is performed by an unconstrained nonlinear optimization of the time needed to reach the destination. The procedure is based on the Nelder-Mead simplex algorithm [6] and is known as the *fminsearch* function in Matlab. In this paper the constant goal has been to minimize the duration of the navigation, but it can be easily adapted, for example, to reach a predetermined rendezvous point with a minimal time delay.

Routes are defined by a set of a few intermediate waypoints. The optimization explores the possible routes found by displacing these waypoints from their initial positions. The number of waypoints used is a parameter of the algorithm and it depends basically on the duration of the regatta. In this paper we have used two basic approaches for defining the initial localization of waypoints. If the algorithm is capable of finding a route without introducing any intermediate waypoint, then the set n of waypoints is obtained from this initial route by taking n points along the trajectory separated by a regular time lapse. Note that this is equivalent to using the original algorithm of Stelzer and Pröll [2] to define the full route. This approach is not viable in cases where the algorithm fails due to the presence of obstacles. In those cases the initial set of intermediate waypoints is spread uniformly over the line defined by the departure and destination points.

The route is only approximately defined by the final position of the waypoints. There is a second parameter that controls how far from a given waypoint the route is allowed to vary. As the waypoints are only used to explore the space of possible routes, this parameter, called radius of precision, is normally set to a large distance, typically several kilometers.

Algorithm

1. Define how many intermediate waypoints are to be used and the precision radius (maximum allowed distance for passing a waypoint).

2. Set up the size of the searching area around the initial route. This parameter defines how far the route waypoints can be displaced from their initial localization.

3. Choose the time step for simulating the sailboat motion. In this paper we have chosen 60 seconds.

4. Obtain an initial approximation for the route and set up the initial set of waypoints. An initial approximation for the route can be obtained in different ways: maximum circle, direct rhumb, etc.

5. Run an unconstrained nonlinear search over possible localizations for intermediate waypoints with the objective of minimizing the route's time.

The planner may or may not include the effect of currents in the definition of the route, as will be shown later. Surface currents are obtained from high resolution ROMs models and the values corresponding to the instantaneous position and time of the sailboat are defined by linear interpolation of the grid values.

3 Winds and Currents

The route planner uses numerical, high resolution (0.05º resolution in latitude/longitude) weather forecasts produced by the Spanish Meteorological Agency (AEMET). These forecasts [4] are produced using a HIRLAM model that provides one analysis and 12 forecasts (+3h) in GRIB1 format files, covering a period of 36 hours. A new update is produced every 6 hours. The planner uses the wind field computed at a 10 meters interval over ground.

The planner can also be fed with ocean currents provided in NetCDF format. In this paper, current maps are obtained from MyOcean (IBI domain) or ESEOCAN ROMs provided by Puertos del Estado (Spanish Harbor Authority).

The planner uses a simple kinematic model of a sailboat where the physical modeling of the vessel is summarized in its polar diagram. As a byproduct of the ROM model, the planner is capable of dealing with routes along coastlines.

4 Results and Discussion

Some of the results obtained in simulation are summarized in the following figures. To avoid repetition in each simulation, we first summarize the elements of the presentation that are common to all figures.

Simulations are sketched as a series of snapshots running left to right, and then downwards. Note that every snapshot is time stamped (hours and minutes of simulated time) along the top edge. To make reading the figures easier, normally only the wind field is displayed. When the wind speed is over 6 m/s, wind arrows are colored in green. The same style of presentation is used with current fields. In this case, current arrows are colored deep blue when currents are equal or over 0.3 m/s. When displaying both current and wind fields, the wind field is shown at a lower resolution to aid visualization. All simulations have been run using the highest resolution data available.

Two routes are depicted in most figures. Routes in magenta are the routes obtained by the application of the algorithm presented in [2]. In this case, the algorithm tries to set bearings that maximize the Velocity Made Good (VMG) to destination at each simulation step. We term this approach as "direct to goal" or DtG. Green curves denote trajectories obtained by the route planner through optimization. In all cases, trajectories are simulated with a temporal resolution of 60 seconds and the same polar diagram used in [2]. The precision radius used at intermediate waypoints was 2 km and 300 m for destination.

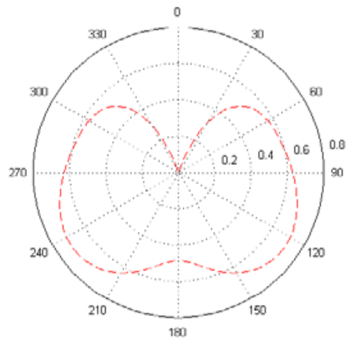

Fig. 1 Polar diagram used in the simulations at wind speed of 1 m/s [2].

The route planner is programmed in Matlab. Even though it is unoptimized Matlab code (using only one processor core), it takes 348 seconds on an Intel Core i7 -2630QM 2GHz/ 8GB of RAM laptop to solve the route depicted in Figure 3.

We have not considered leeway effect nor do we model any velocity decrement when tacking. These two aspects are seen as future enhancements to the simulation.

Figures 2 and 3 show simulation results in a scenario located on the western part of the Canary Islands archipelago. Both series of figures depict the routes obtained, respectively, with a DtG approach or with the route planner. Figure 2 does not include the effect of the currents, which, as Figure 3 demonstrates, are an important factor in this specific case. Wind field is depicted at a lower resolution in Figure 3, but it is the same shown in Figure 2. In these simulations, the number of intermediate waypoints was set to four.

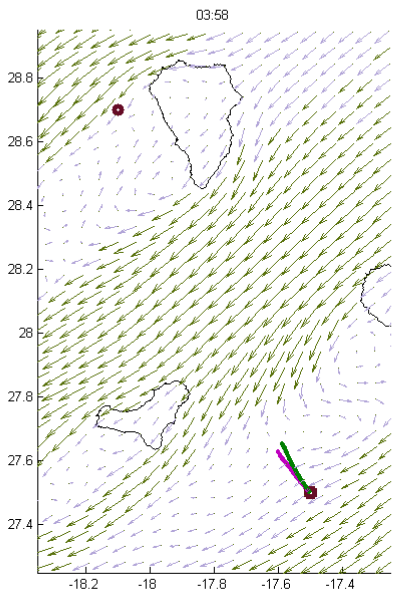

Fig. 2-1

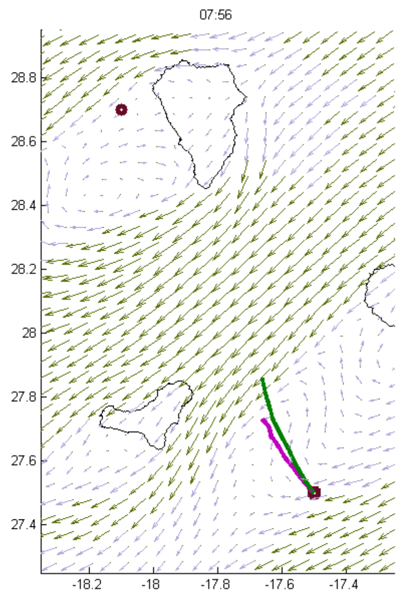

Fig. 2-2

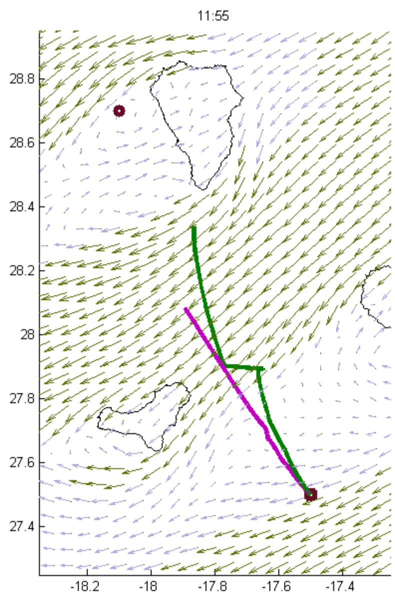

Fig. 2-3

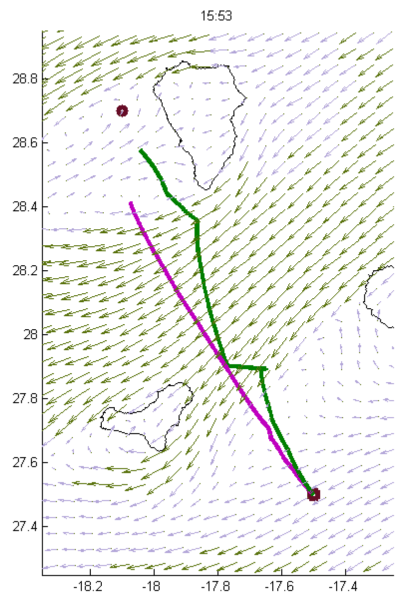

Fig. 2-4

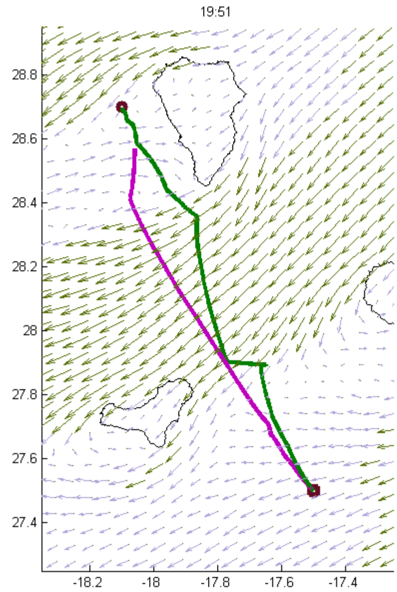

Fig. 2-5

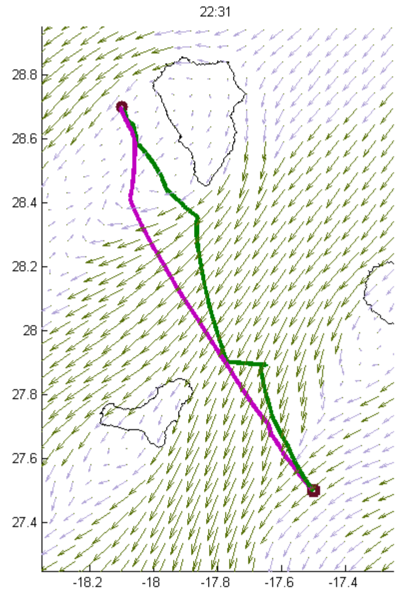

Fig. 2-6

Fig. 2 Simulation snapshots including only the effect of winds in a scenario located on the western islands of the Canary archipelago. In these figures only the wind field is shown. In this case, the optimized route arrives to destination nearly 4 hours before than the DtG route.

Trade winds, blowing in the Canaries from northeast in summer and autumn, are clearly appreciable in these figures. This wind regime, combined with the islands' high relief (La Palma, max. height is 2426 m), is responsible for the appearance of strong eddies at the southwest of the islands that alter the current patterns in those zones. Wind vortices are also clearly appreciable leeward of the islands, especially to the west of La Palma (the most northern island).

The results arising from the simulation included in Figure 2 show that the optimized route takes advantage of knowledge of the spatial distribution of the wind in advance. The resulting route is about 3 hours and 30 minutes shorter than the DtG route.

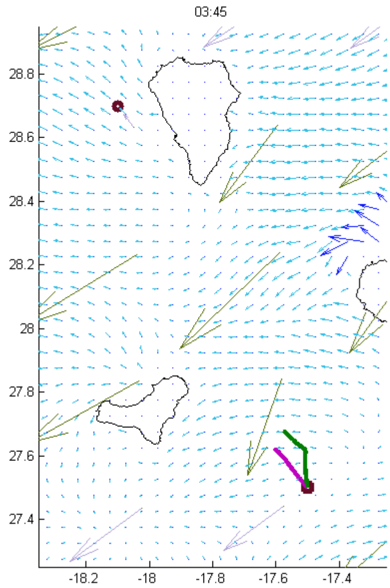

Fig. 3-1

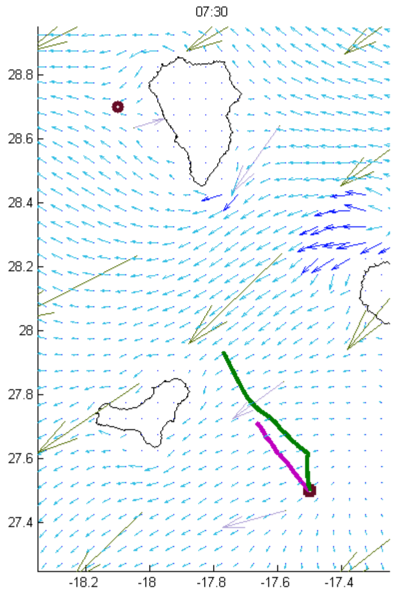

Fig. 3-2

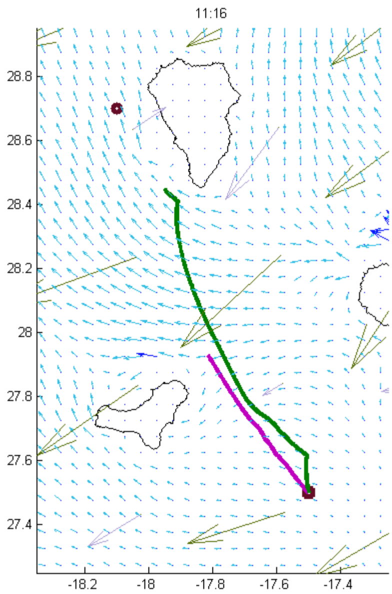

Fig. 3-3

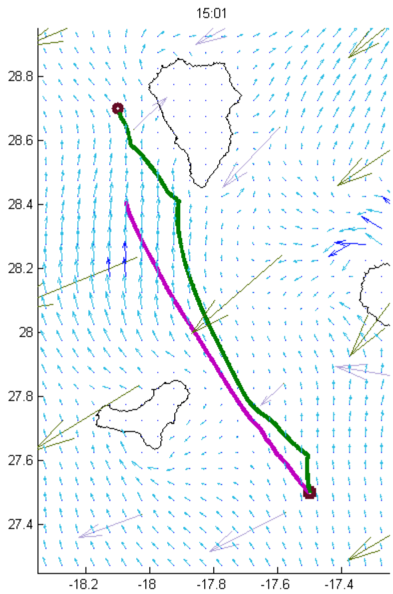

Fig. 3-4

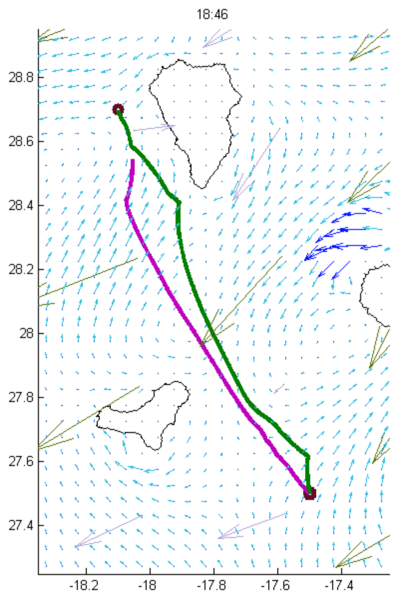

Fig. 3-5

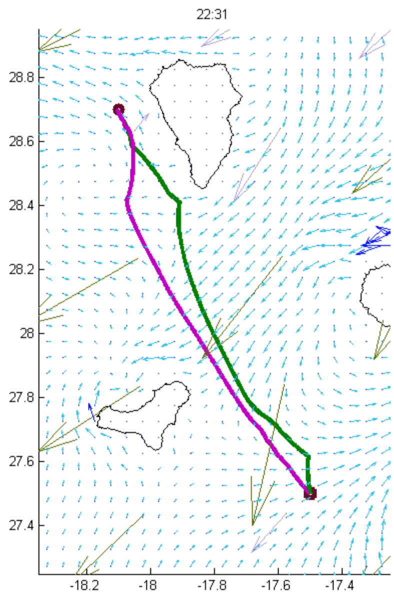

Fig. 3-6

Fig. 3 Simulation snapshots including the effect of winds and currents in the same scenario (and data) used in Figure 2. These figures show the current and the wind (at lower resolution) fields.

Figure 3 shows the routes resulting from taking into account the effect of currents over the same scenario. In this specific case the effect of the currents is very important and in fact the optimized trip time is reduced by 6h 30m. Note that the routes produced by the DtG in figures 2 and 3 are identical.

Finally, the series of snapshots included in Figure 4 depicts the planning of a route from Las Palmas de Gran Canaria (Gran Canaria) to Arrecife (Lanzarote), a classic regatta in the Canaries. The simulation shown takes into consideration the effect of adverse currents, which occur over the entire route. In fact, in this case if the effect of currents is ignored the simulation gives a total time that is shorter by 54 minutes.

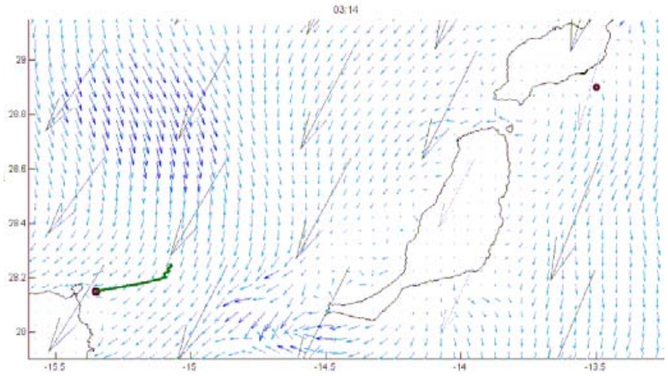

Fig. 4-1

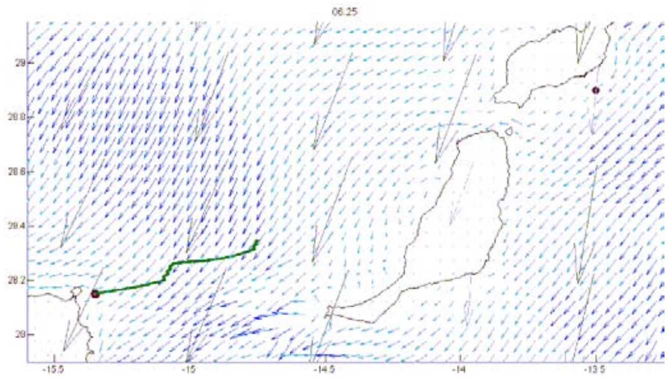

Fig. 4-2

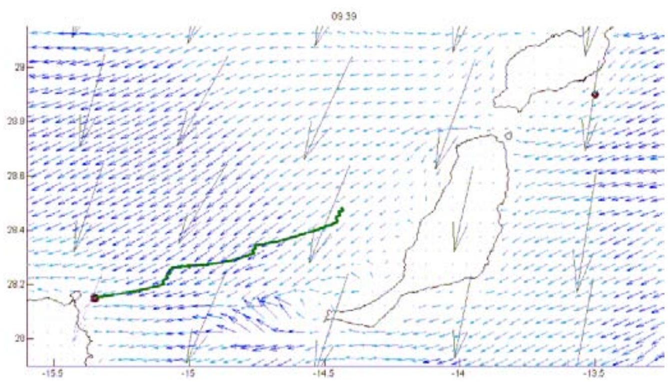

Fig. 4-3

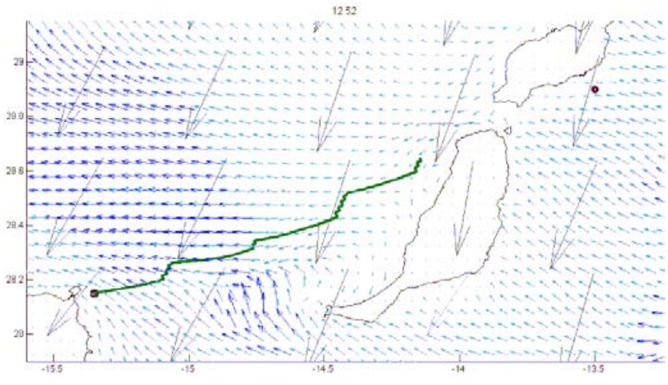

Fig. 4-4

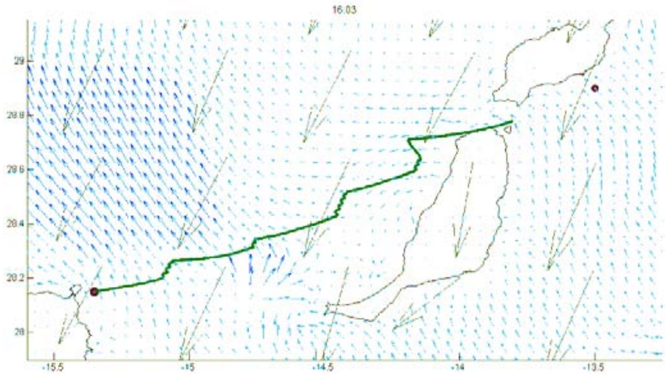

Fig. 4-5

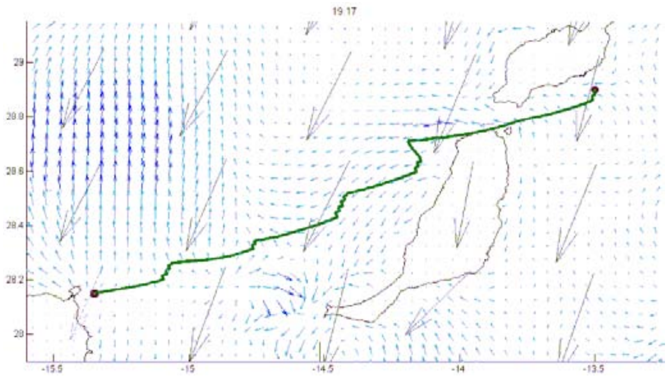

Fig. 4-6

Fig. 4: A route for a classical regatta in the Canary Islands.

The results achieved in this paper should be considered preliminary. In simulation and with a number of simplifications, it has been demonstrated that high resolution wind and current forecasts can play a significant role in optimizing sailboat routes. However, simulations are quite different from using an actual boat, as a number of factors ranging from unmodeled aspects (e.g. leeway or wave influences) to forecast credibility have not been studied in this preliminary work.

Future work will address the effect of leeway and waves over the planned route. The extension of the route planner to operate with forecast ensembles or - in general - take into consideration the credibility of wind and current forecasts is also foreseen.

Acknowledgments

This work has been partially supported by the project ProID20100062 funded by the Autonomous Government of Canary Islands (Agencia Canaria de Investigación, Innovación y Sociedad de la Información), FEDER funds and the Departamento de Informática y Sistemas at ULPGC. The authors thank Puertos del Estado and AEMET (Agencia Estatal de Meteorología) for granting access to their numerical products and data repositories.

References

1. Langbein J, Stelzer R, Frühwirth T (2011) A Rule-Based Approach to Long-Term Routing for Autonomous Sailboats. In Robotic Sailing, Springer-Verlag.
2. Stelzer R, Pröll T (2008) Autonomous sailboat navigation for short course racing. Robotics and Autonomous Systems, 56:604-614.
3. AEMET (2012) AEMET's High Resolution Limited Area Model. Accessed May 2012. ftp://ftpdatos.aemet.es/modelos_numericos/..
4. Puertos del Estado (2012) Forecast & Measurement networks. Accessed May 2012. http://www.puertos.es/en/oceanografia_y_meteorologia/redes_de_medida/index.html.
5. Kristensen NM (2010) Sensitivity to ensemble wind and current input. Master thesis in Geosciences Meteorology and Oceanography, University of Oslo.
6. Lagarias JC, Reeds JA, Wright MH, Wright PE (1998) Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions. SIAM Journal of Optimization, Vol. 9, Number 1, pp. 112–147.