Visualizing Weather Along Ship Routes

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Contents

Chapter 1

Introduction

This seminar paper discusses ways of visualizing weather with a strong focus on maritime applications. It roughly outlines the underlying data and how to get a hand on the weather data. The direction of research on this topic was coordinated together with the Hamburg based company Maritime Data Systems[1] to support them on product development and design of their ship routing application *Seatracks*.
Furthermore a prototype application was developed to experiment with own approaches that we came up with.

1.1 Motivation

With growing international trade the need for cost efficient transportation of goods rises to levels one could never have dreamt of. A big share of this transportation is held by vessel traffic occupying the oceans. Those huge vessels carry thousands of the well known standardized containers and depend heavily on the weather conditions at sea. Whereas the safety of the vessel itself is not in danger in severe weather conditions (in which small recreational boats would have been swallowed by the sea already) the freight of the big vessel can go overboard and cause a unnecessary financial loss. Furthermore – especially with rising fuel prices – the influence on the cost effectiveness of a particular route is of great importance to the shipowners. And, as one might correctly guess, that effectiveness depends on the weather conditions at the time of travel.
To give both laymen and professionals a good reference on the weather conditions, a clear and simple visualization is key when displayed along a ship route on a map. This makes sure that the map doesn't get too cluttered visually which would cause a higher cognitive load on the user and thereby cause the application to feel unpleasant to use [see 1, pp. 178 sq.].

[1] http://www.maritimedatasystems.com

Chapter 2

Weather Data

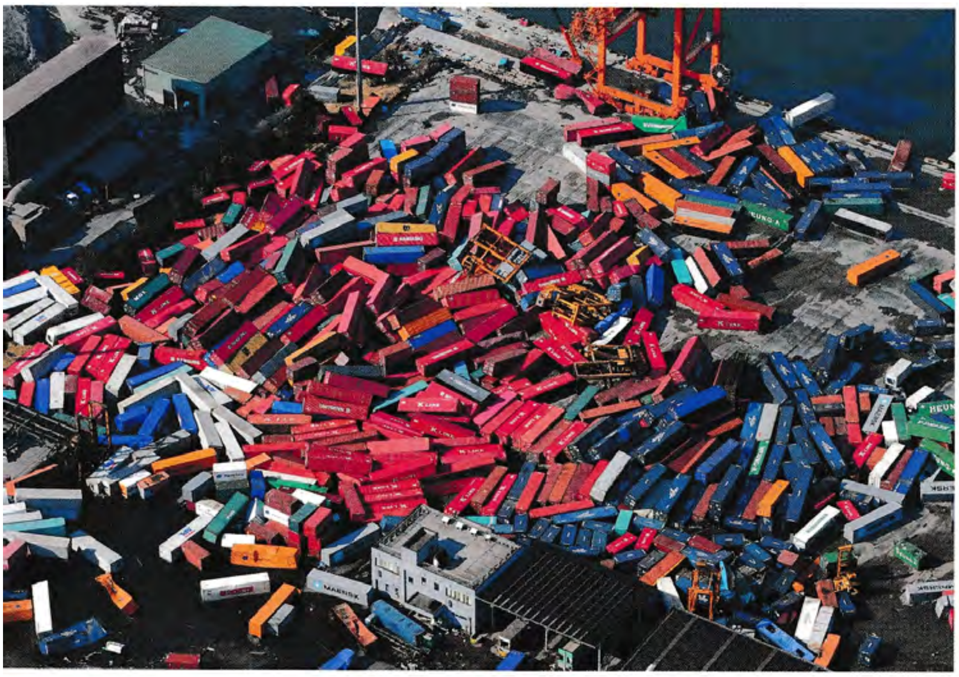

Figure 2.1: Sendai in March 2011 after a tsunami hit Japan with waves of up to 40m height [image from 2]

Weather is a chaotic system which relies on a great range of variables. Differences between these variables cause the weather at any location. The three main variables determining the weather are **Pressure**, **Humidity** and **Temperature** of the air. Weather by definition is "the state of the air and atmosphere at a particular time and place"[5].

In a chaotic system a small change to one input variable can have a big impact on the system as a whole. It is hard to predict how such a system will react to changing variables. And in case of the weather the outcome of these reactions can reach catastrophic levels. We are constantly reminded of this by what we call natural disasters. An example is the tsunami that hit Japan in 2011 and played with those containers weighing several tons as if they were Lego® bricks (see Figure 2.1).

2.1 Sources

If you want to obtain weather data the sources that qualify heavily depend on your requirements. If you want for example weather data for German cities for daily forecasts, you would have to buy data from German providers to satisfy your needs regarding accuracy. Those providers maintain a dense network of weather stations to provide you with better predictions.
But if you need weather for the oceans you don't need those providers as they don't maintain stations on the oceans. In this case the **National Oceanic and Atmospheric Administration (NOAA)** has all the data you need. The NOAA is an organization that is part of and funded by the United States Department of Commerce and releases all their data as public domain. They operate a large network of buoys, satellites, planes and ships to measure the weather, calculate weather forecasts and warn in case of earthquakes, hurricanes and more [see 3].

2.2 Types

You can get a lot of data from the NOAA. Ranging from temperatures high in the sky to currents deep in the ocean. For example the NOAA calculates a forecast for the next 166 hours (six days) and offers atmospherical reanalyses available for the last 66 years. The following four sections will outline the data we where interested in.

2.2.1 atmospherical data

Atmospherical data contains most of the variables one would expect for a weather application. Here we find the temperature of the air in different heights, the direction and force of the wind and much more. The data used by Maritime Data Systems origins from the NOAAs **Global Forecasting System (GFS)** which forecasts the next 144 hours as already noted. Because of inaccuracies in this data only the next three days are used my Maritime Data Systems. This model is updated every six hours and approximates 200 MB in size for the 0.5 degree grid. There is also a denser grid with 0.25 degrees resolution available. The resolution of the grid that spans the earth determines the amount of geocoordinates for which the weather variables are stored in the dataset.

2.2.2 oceanographic data

As waves are important for the efficiency of a ship that data is needed as well. For this data Maritime Data Systems uses the WaveWatch III model [see 8]. The main data taken from this model is the wave height, direction and period. The wave period describes the length of a single wave.
The WaveWatch III model results in less data (80 MB every six hours) because for waves only geocoordinates on water surfaces are of importance. So land or ice covered areas can be ignored.

2.2.3 ocean currents data

Another interesting dataset is delivered by the HYCOM model [see 6] which slices the oceans into 50 depth layers and contains among other things the ocean currents. For the use-case of routing vessels only the 5m layer was picked as it affects the vessels the most.

2.2.4 historical data

Finally there is a fourth source of data which takes effect if the requested date for the weather is outside of the three day window covered by the forecast. The NOAA offers atmospherical reanalyses of the past that are physically plausible states. The weather measurements at that moment in time are validated and combined in such a way that discordant values (outliers) are evened out.
Maritime Data Systems first keeps the forecasts and replaces them with said reanalyses when they become available. Currently the stored data dates back until 2012 but historical data of the last 66 years is available.
This data is used if there are request for weather in the past or if the requested date is more than three days in the future. In the second case the historical data is used to give a vague prediction by using different statistical methods to combine the data from the years available.

2.3 Processing

Luckily I didn't need to fight with the raw data. The meteorologist of Maritime Data Systems had my back. He wrote the code needed for the data processing. He used a combination of Bash and Python scripts to retrieve and process the data periodically. The Climate Data Operators (CDOs [see 9]) are used to check the plausibility of the data, extract the variables needed and interpolate them into one GFS model. Furthermore the scientific units are converted into user friendly units (e.g. Kelvin to Celsius). The processing results in 6.5 million new datasets every six hours which are saved into a PostgreSQL database.

In the end I just had to access a REST-API, that gave me the processed data ready to be worked with. I could request data via one or multiple pairs of date and position and got a response with a great range of weather variables (see Figure 2.2).


```json
[
    {
        "ts": "2015-12-02T14:00:00.000Z",
        "id": "4671331937",
        "time": "2015-12-02T14:00:00.000Z",
        "lon": "8.0",
        "lat": "54.0",
        "tmp2m": "10.2",
        "tmpsfc": "9.4",
        "tmax2m": "10.3",
        "tmin2m": "10.1",
        "rh2m": "90.9",
        "prmsl": "1022.1",
        "ugrd10m": "7.7",
        "vgrd10m": "6.4",
        "gustsfc": "14.9",
        "tcdc": "100.0",
        "apcp": "0.1",
        "prate": "0.0",
        "icecsfc": "0.0",
        "landsfc": 0,
        "wavehgt": "1.6",
        "waveprd": "6.8",
        "wavedir": "275.6",
        "geo_points": "0101000020E610000000000000000020400000000000004B40",
        "water_u": "0.4",
        "water_v": "0.3",
        "salinity": "34.2"
    }
]
```


Figure 2.2: JSON formatted response from the weather API of Maritime Data Systems. The temperature values (e.g. `tmax2m`) are already converted to a user friendly unit (degrees Celsius) instead of the scientific unit used in the raw data (degrees Kelvin). The position for this data is in the North Sea between Cuxhaven and Helgoland.

Chapter 3

Weather Visualization

After outlining the weather data available the next question is: How to visualize that data? How can you visualize differences between places and picture pressure, humidity or temperature?

Figure 3.1 shows a common and very basic approach. The weather is visualized by the use of icons (in this case mostly suns with clouds) and by color coding the map with the forecasted maximum temperatures (see the key on the bottom of the image). While this approach is very intuitive to users, it's only a help when deciding whether you have to take an umbrella or jacket with you.

Figure 3.1: Simple map with iconic visualization [see 14]

Another visualization can be seen in figure 3.2. While this approach looks pretty sophisticated it just shows the temperatures. You may notice that the data source attributed in the image mentions the NOAA as their origin.

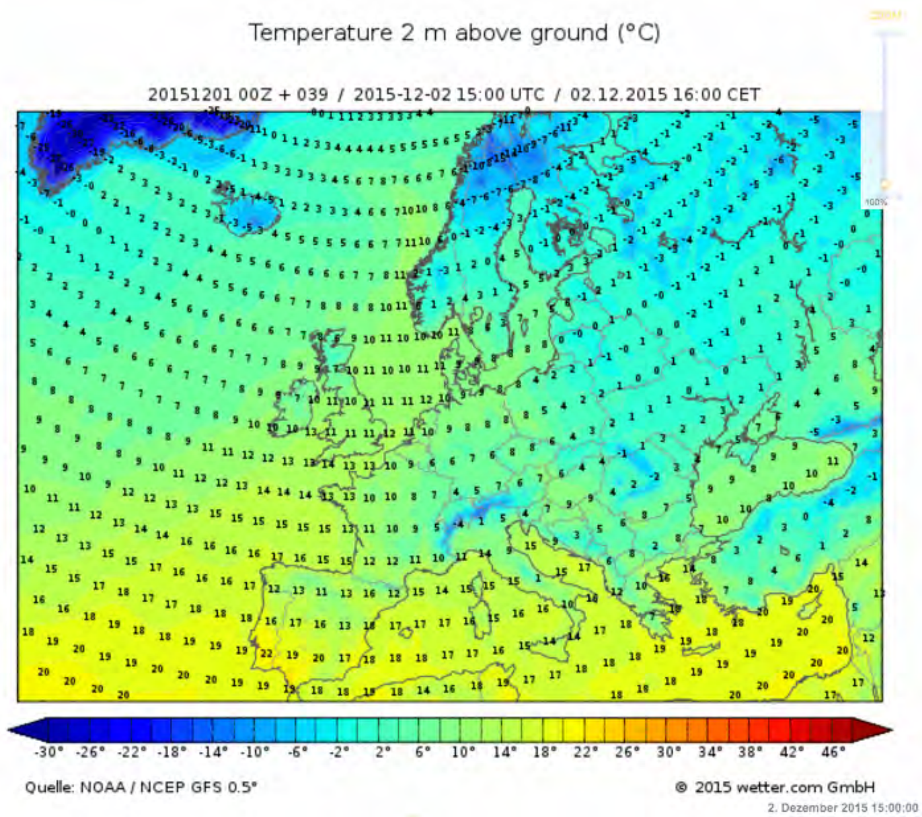

Figure 3.2: Map visualizing the temperature 2 meters above ground [see 12]

Simple visualizations can easily lack precision as one can see in figure 3.3. The map shows the wind speeds in different locations across the map. The problem becomes apparent if you have lots of large arrows. It is hard to know whether the head, the middle or the tail of the arrow determines the position of the stated wind force on the map.

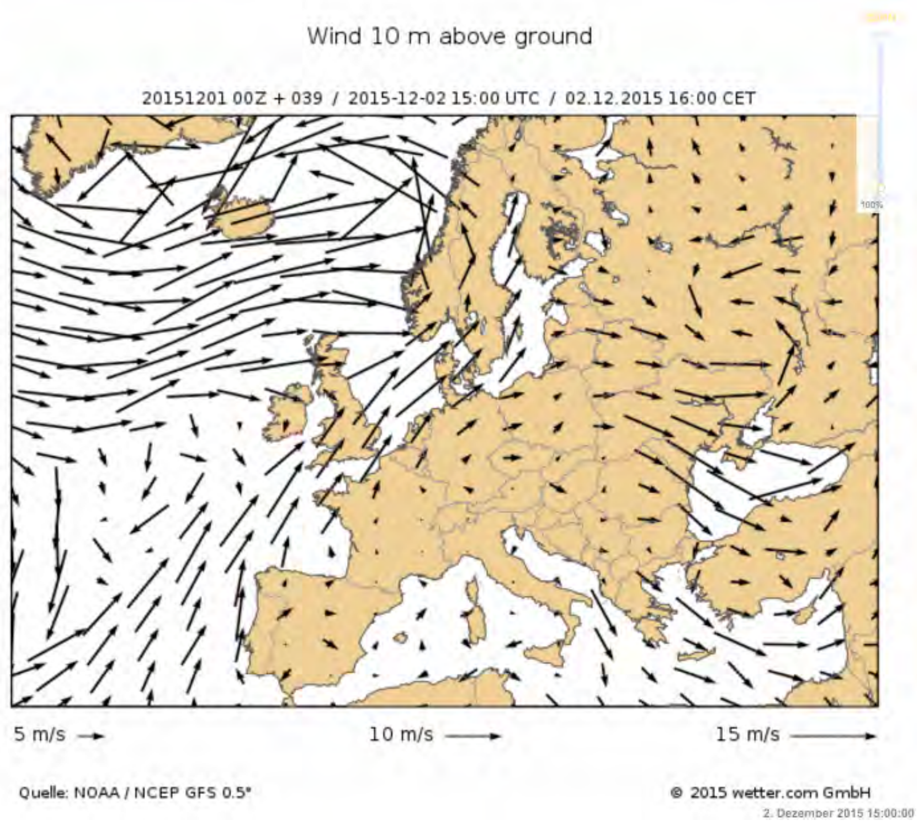

Figure 3.3: Map visualizing the wind speeds 10 meters above ground [see 13]

Of course there are more advanced visualizations available that tackle such problems. But as one compresses the information, the visualization becomes less intuitive and hard to understand without using a key. Germany's National Meteorological Service offers a wide range of maps for different use-cases. The most common advanced weather map can be seen in figure 3.4. It features isobars (lines of same air pressure, comparable to contour lines on topographic maps) and marked areas of high or low pressure. Warm, cold and mixed (occlusion) fronts of air are drawn with bigger lines and color coded depending on their type.

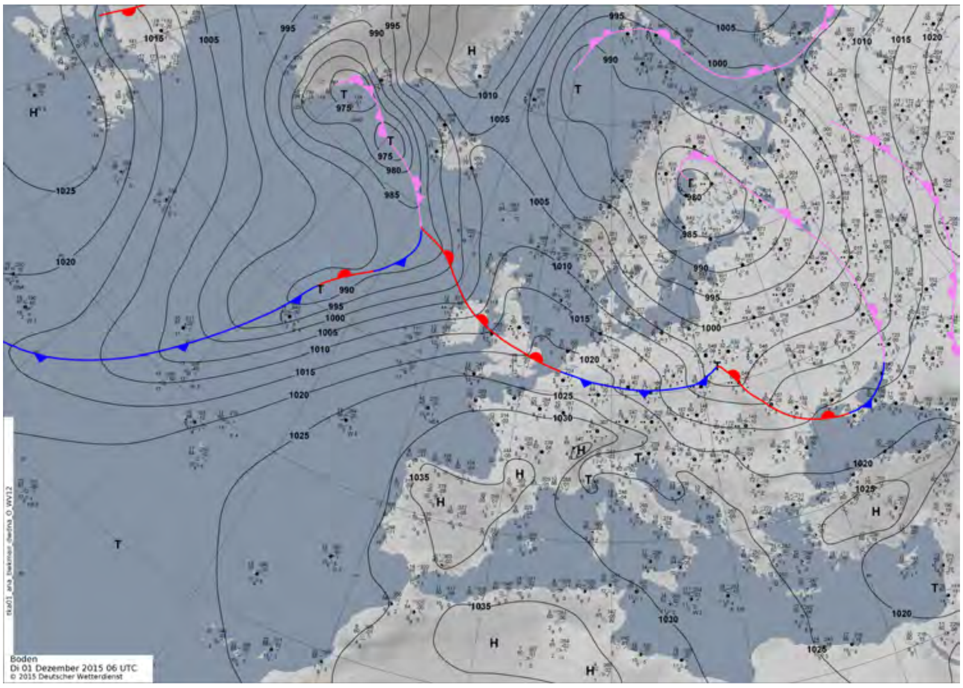

Figure 3.4: Weather map with isobars [see 4]

The wind direction and speed can be derived from the position of areas of high and low pressure and the distance between two isobars. If multiple isobars are close to each other that results in strong winds as the greater pressure difference desires to balance out. This information cannot be seen directly on the map which makes it harder to read for laymen and the uninitiated. There is even more information "hidden" in the map. In figure 3.5 a smaller cutout is presented.

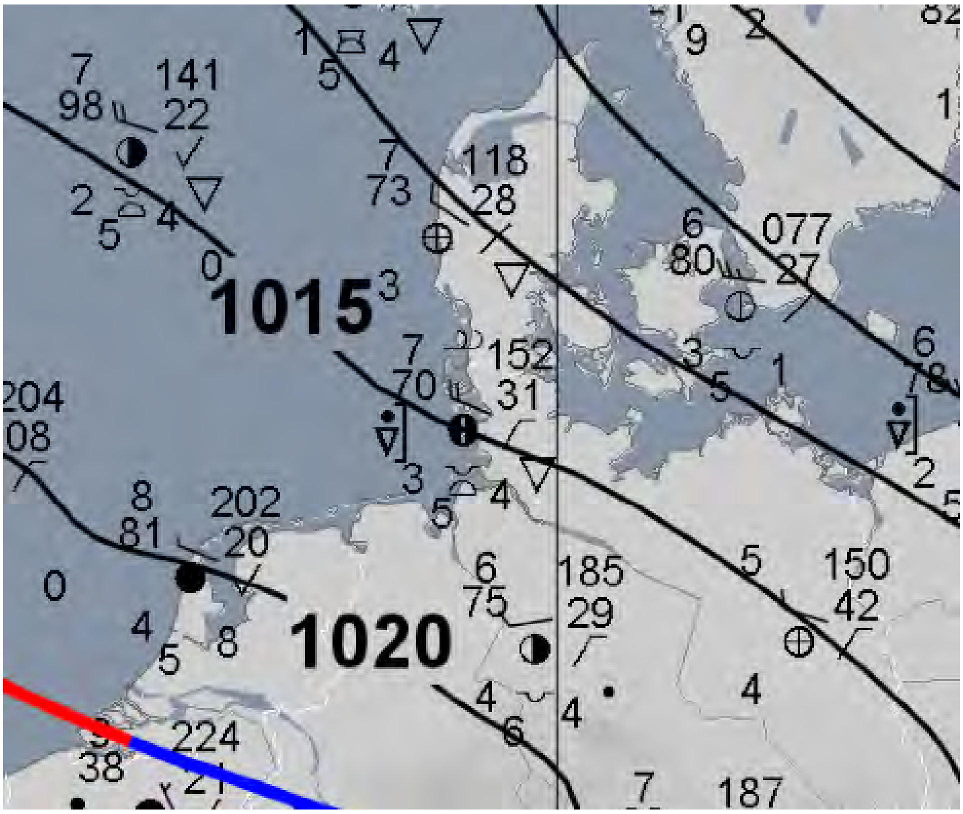

Figure 3.5: Cutout of weather map that shows the different cryptic symbols and numbers around a weather station.[see 4]

The numbers and symbols you see are always arranged around a weather station where those measurements were taken. The “wind barbs” right above the center indicated the wind speed and direction. The “feathers” of a barb account for five knots of wind for a short feather and ten knots for a long feather. The 7 above the 70 for the station in the center of the image describes the temperature of seven degrees Celsius. The 70 below resolves to 20 kilometers of sight distance. Last but not least the 152 above the 31 describes the last two digits and one decimal place of the air pressure (so 152 means 1015.2hPa). The 31 notes the change of air pressure in the last three hours (meaning it went up to 1015.2hPa from 3.1hPa less = 1012.1hPa).

If you compare this data to the result of the weather API in figure 2.2 on page 5 which shows the weather data for one day later than this map, you notice that the air pressure (json property **prmsl**) went up further to 1022.1hPa and the temperature (**tmp2m**) rose to 10.2 degrees Celsius.

Chapter 4

Industry Approaches

The former ways of visualizing the weather were either pretty simple and targeted at laymen or cryptic and unintuitive. But to forgive them, they weren't tailored to the use-case of supporting ship route decisions. So this chapter takes a look at two companies and their products that were developed for the mariner.

4.1 NavSim Technology Inc.

NavSim Technology Inc. is a company located in Poland and Canada which offers navigation solutions and communication services for land, marine and aeronautical applications.

4.1.1 NaviWeather

NaviWeather is their product to visualize weather on maps. It is highly configurable and allows for a high range of different visualizations. The software works on GRIB files which are often used to download weather data via satellite connections onto ships far away from internet access.

Figure 4.1 shows a visualization with wind indicators and clouds. The wind indicators are different to those in figure 3.3 in such a way that they don't indicate the wind speed by their length but rather by their amount of "feathers" at their tails. The equal distribution of arrows across the map and their similarity in size increase the overall readability by resulting in a better alignment of those objects [more about effects of proper alignment in 1, pp. 24 sq.].

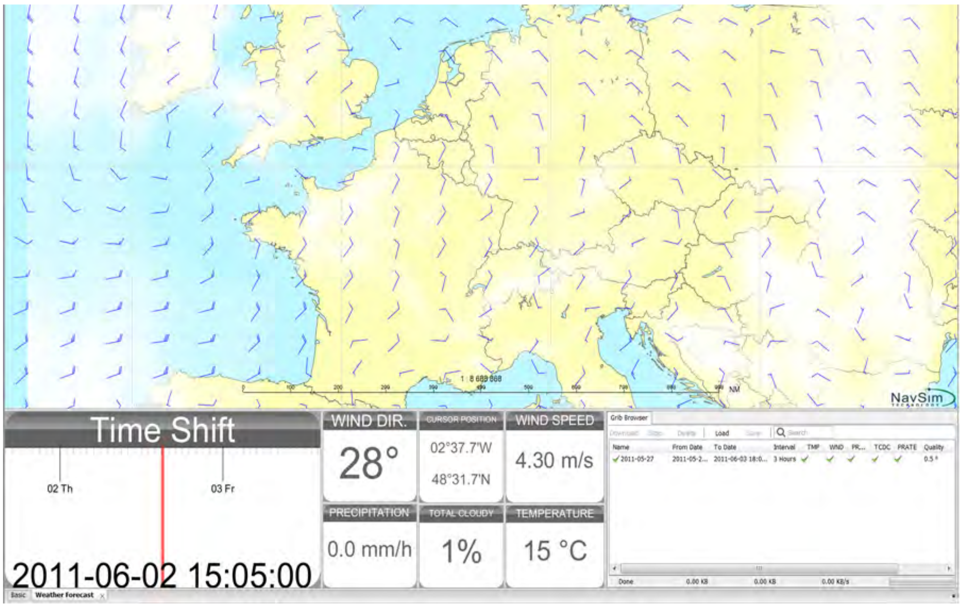

Figure 4.1: Visualizing wind and clouds in NaviWeather [see 10]

The software also allows multiple maps and different graphic representations for wind arrows. This degree of configurability can be seen in figure 4.2.

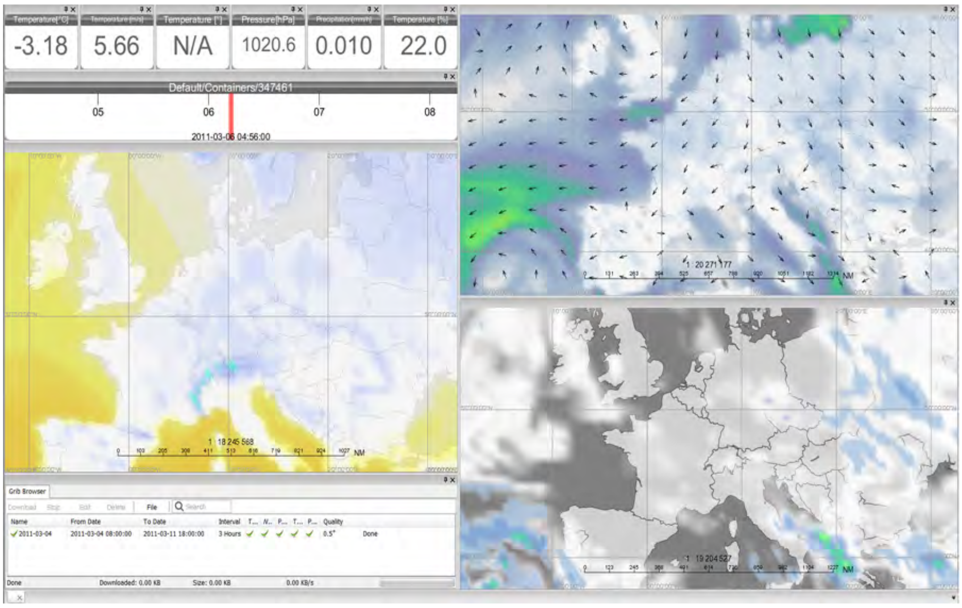

Figure 4.2: Configuration of three maps each visualizing different aspects of the weather [see 10]

The user is free to choose what he likes to see and what not. In figure 4.3 the isobars, the wind and the precipitation rate (amount of rain per time) can be seen.

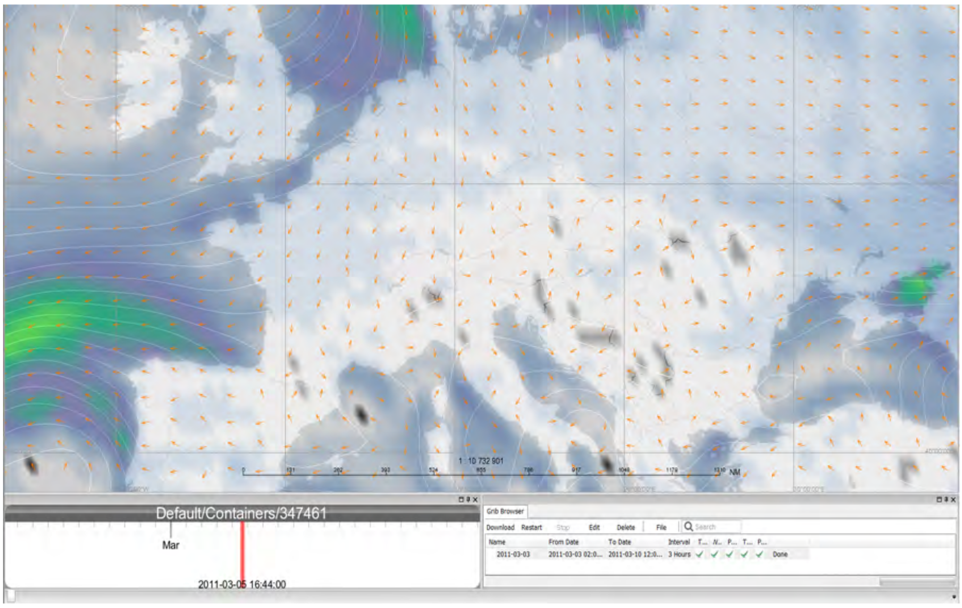

Figure 4.3: Isobars, Wind and Precipitation rate [see 10]

But as often the case: If you let users decided upon their fate, they can go wild and end up with results that are hardly readable and just look like colorful art (see figure 4.4). Imagine having to visualize a route on the same map, too.

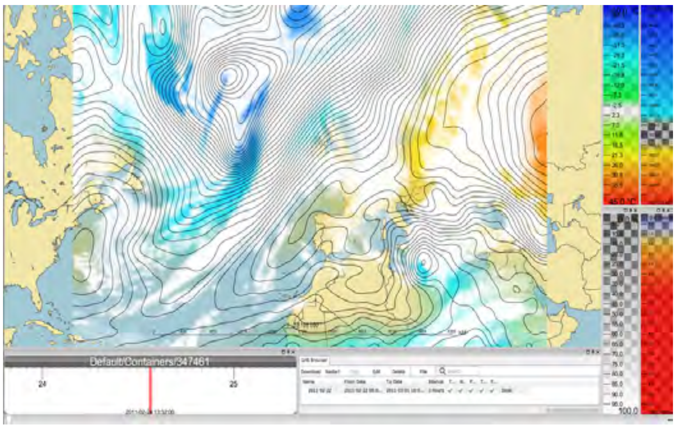

Figure 4.4: A piece of art [see 10]

4.2 Jeppesen

Jeppesen belongs to the aircraft manufacturer Boeing and is the world's largest producer of vector-based electronic charts and charting systems with a focus on aviation and a very strong marine portfolio.

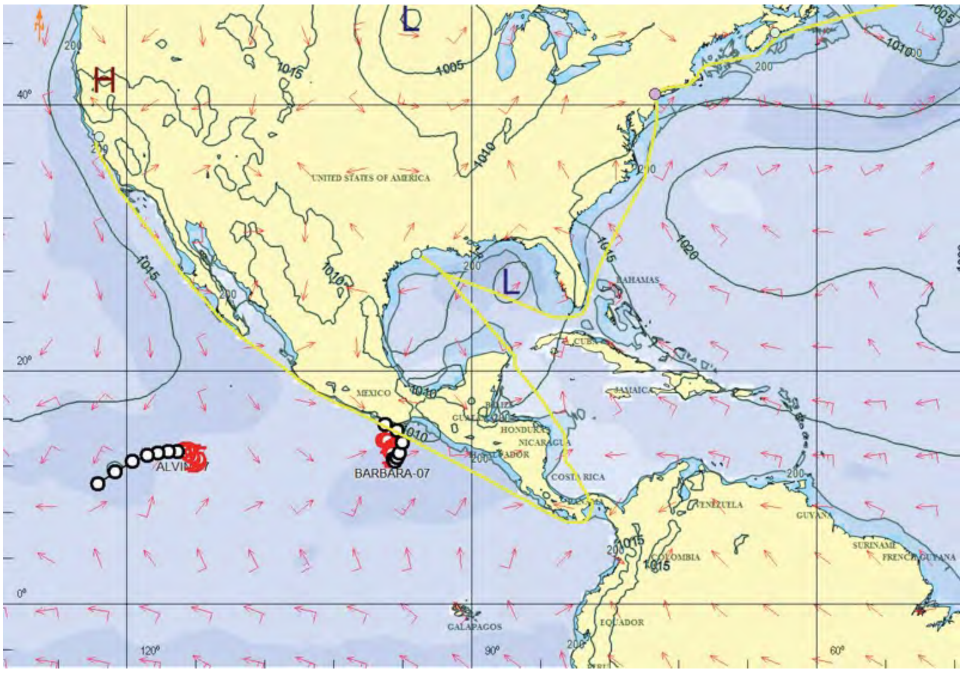

Figure 4.5: Visualizing the travel path of hurricanes [see 11]

Jeppesens weather software *WeatherNav* can visualize hurricanes and the directions in which they wander. In figure 4.5 the hurricanes Alvin and Barbara that hit Mexico in 2013 are visualized. You can as well spot the known isobars and low and high pressure areas (marked with L and H respectively).

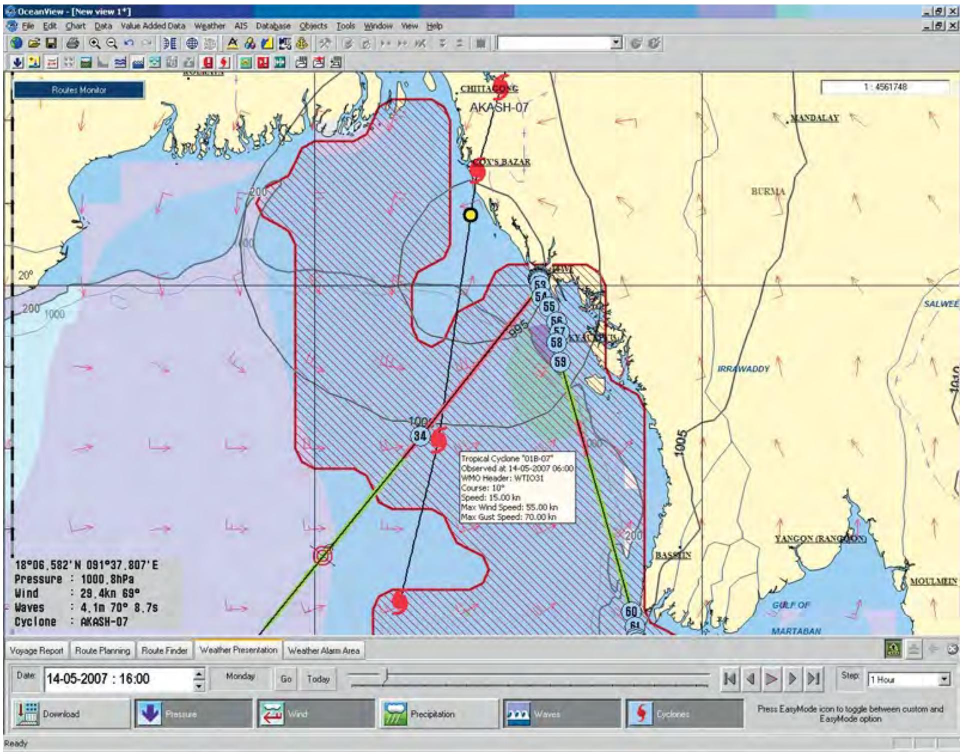

Figure 4.6: Cyclone Akash, Myanmar in 2007 [see 11]

Another screenshot from their Windows desktop application (see figure 4.6) visualizes the Cyclone Akash (2007, Myanmar).

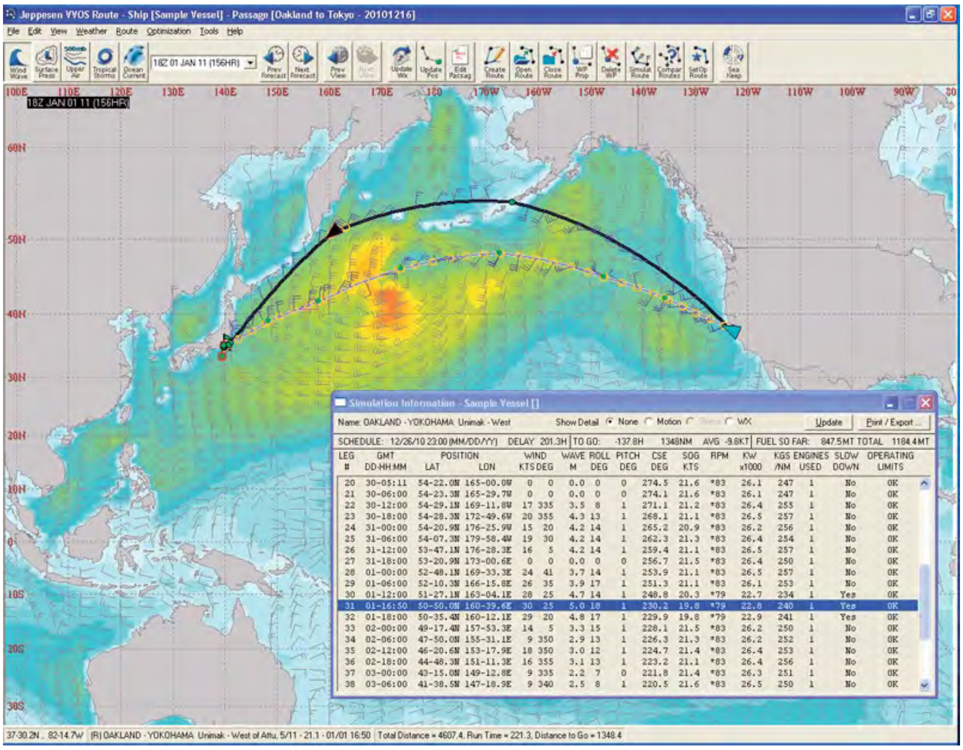

Figure 4.7: Wind and waves [see 7]

Figure 4.7 displays a route from Oakland, US to Yokohama in Japan. On water surfaces the wind and waves are visualized using what is called a heatmap. Heatmaps are colored maps where the color depends on a selected value. The software also suggest you the best engine speed for the current conditions on the route (see the table on the small overlaying window).

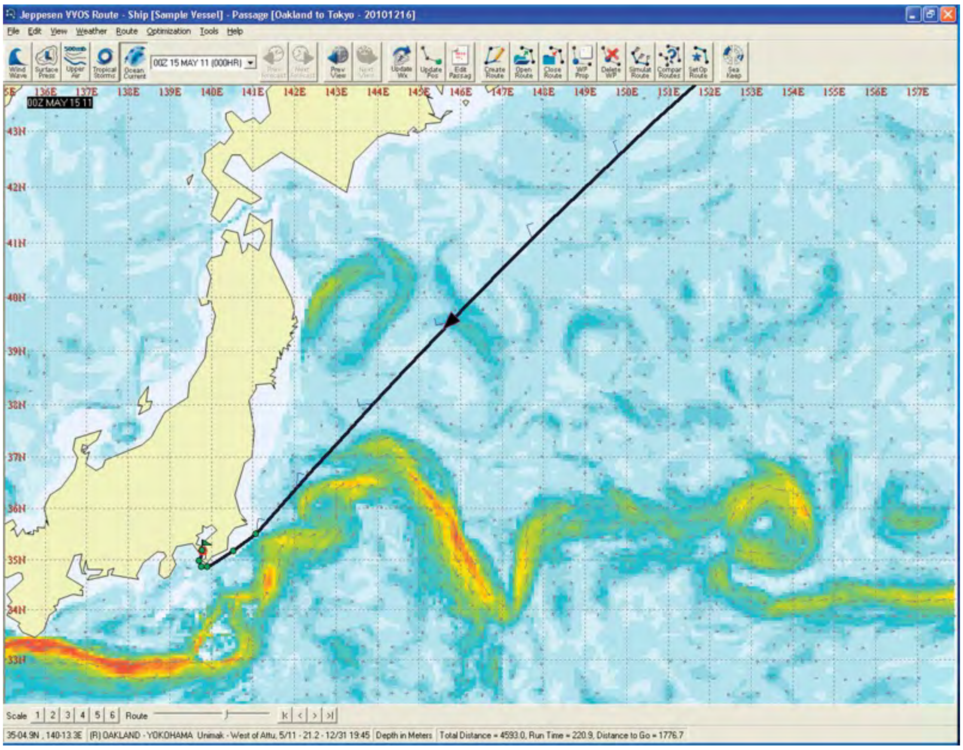

Figure 4.8: Ocean currents [see 7]

The visualization of ocean currents for the same route as prior can be seen in figure 4.8. Strong currents are marked with red whereas light or no currents are marked in green or light blue.

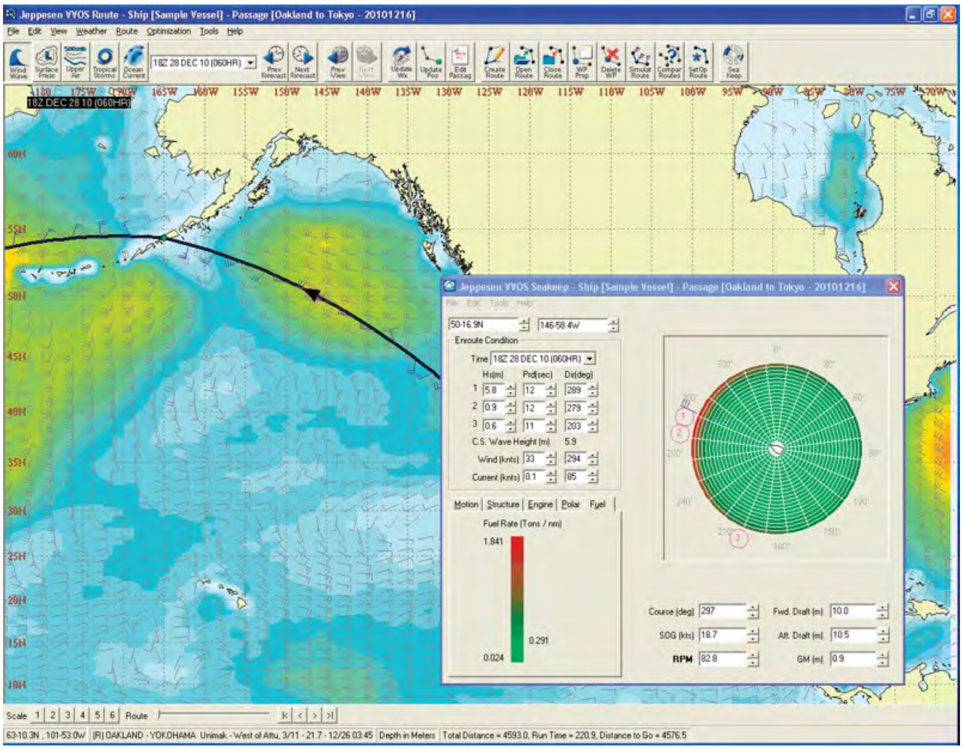

Figure 4.9: Fuel rates [see 7]

Figure 4.9 displays once again the wind and waves impact on the route. The second window overlaying the map displays the fuel rate on the current position of the ship indicator on the map.

Chapter 5

Web Visualizing

5.1 Seatracks.com

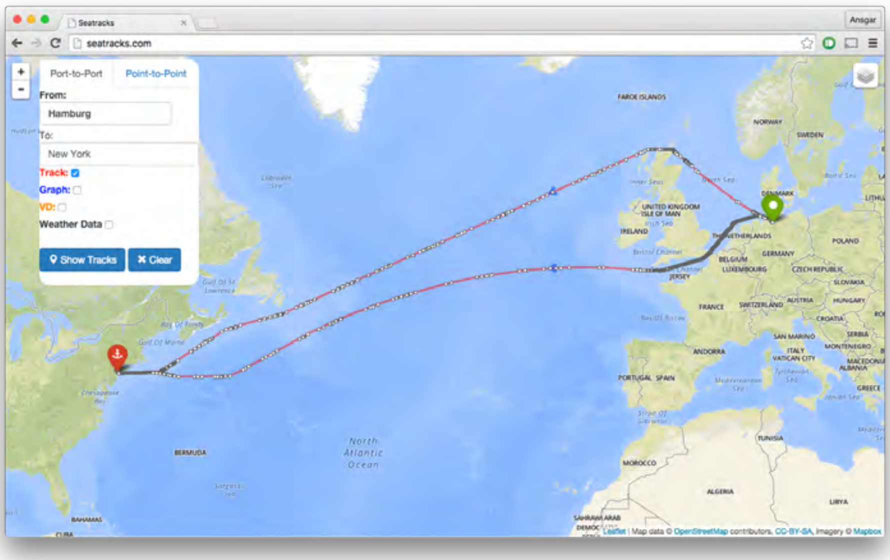

Figure 5.1: Seatracks.com

Seatracks is the web frontend to Maritime Data Systems ship routing service. You enter two harbors and routing options and get one or multiple routes as a result. The challenge was to include weather data into the map without disturbing the map visually.

As Seatracks was under rapid development it was decided to build a prototype that allows to play with different kinds of visualizations.

5.2 Visualization Prototype

The prototype was built with React and Nodejs and looks similar to the Seatracks application. To keep things simple it was just connected to the weather API and not to the routing backend.
As an example of visualizing the concept of a heatline was picked. A heatline is similar to a heatmap in such a way that a heatline is just a line colored instead of the whole map. As there was already a route on the map it was simple to get the coordinates of the line to be colored. Furthermore a heatline doesn't clutter the map and has an appealing minimalistic design.

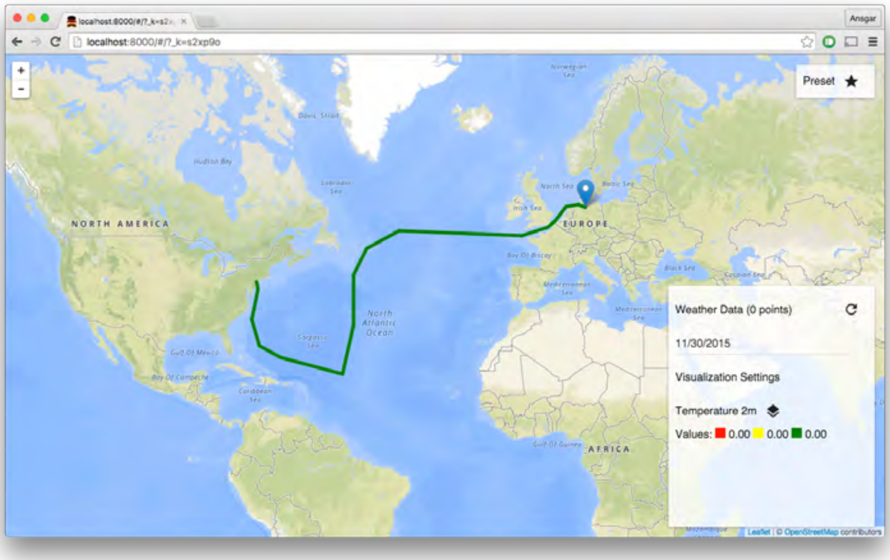

Figure 5.2: Prototype with React and Nodejs

In the panel on the bottom right the weather variable, whose values should be used for coloring, could be selected (see figure 5.3).

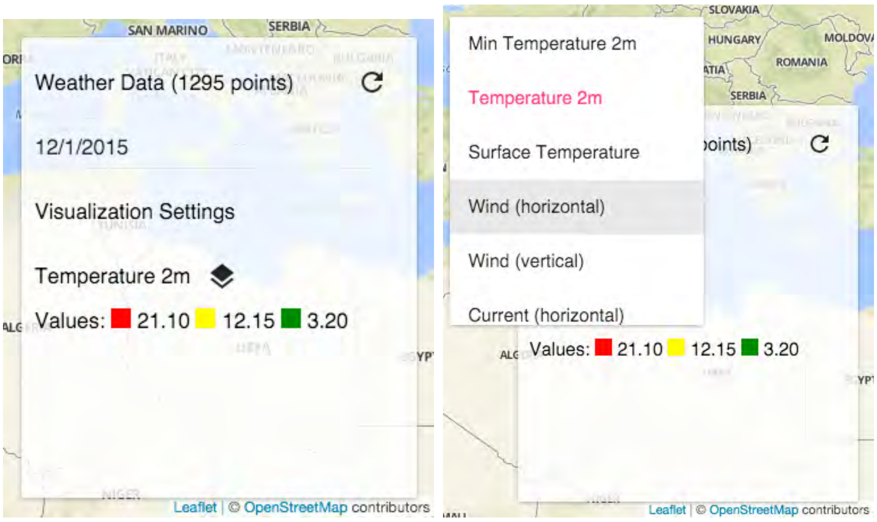

Figure 5.3: Selecting a variable to visualize on the settings panel

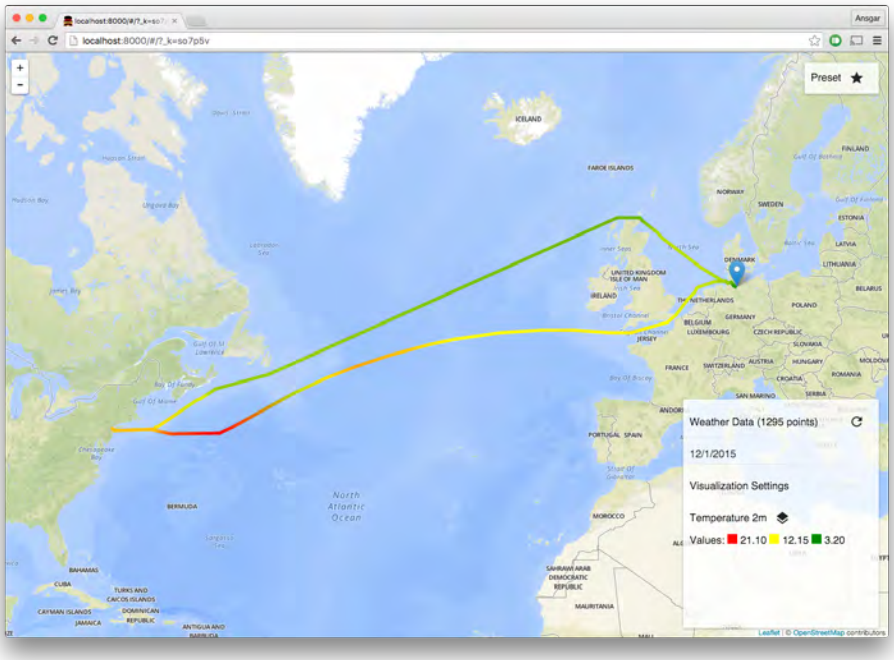

Figure 5.4

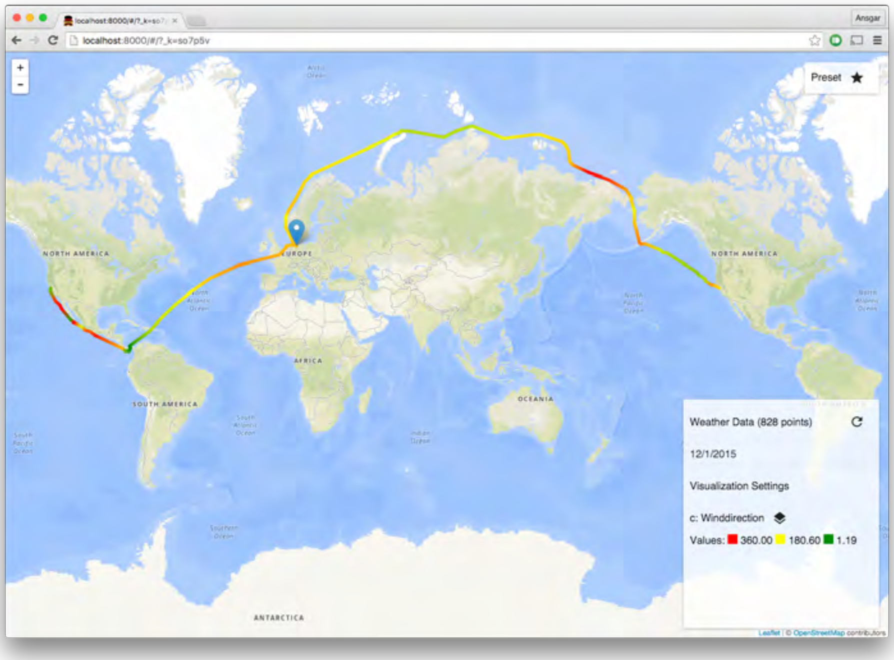

Figure 5.5

Figure 5.4 and 5.5 show the heatline in action.

In further coordination with Maritime Data Systems a heatline which is colored depending on the current direction of the ship relative to the ocean currents and their force was integrated into the Seatracks application. So for example a current against the ship is colored red, a current with the traveling direction of the ship is colored green and no noticeable current is colored blue.

Chapter 6

Prospects

While a heatline was certainly a good decision to use for the visualization along the ship route it can only convey a very limited amount of information. To show more weather data at the same time other methods have to be used for visualization.
Using different layers that can be switched on and off would be a solution to still allow the map to stay uncluttered in contexts in which the further weather information is not needed.
Another option to keep the map visually uncluttered is using a particle system to visualize weather variables with a direction and a speed (such as waves, wind or ocean currents). It stays uncluttered because the moving particles are perceived as the background. This happens as long as one only allows particles on water surfaces and land surface is still visible at the same time to give the particles a visual boundary. With such a boundary and enough particles that move into the same direction the human mind interprets them as related and in the background [see "Common Fate" in 1, pp. 50 sq.]. An example of such a particle system can be experienced on Windyty [1].

[1] https://www.windyty.com

References

Literature

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[2] Munich RE. *Ein Meer an Gefahren*. Münchner Rückversicherungs-Gesellschaft, Königinstraße 107, 80802 Munich, Jan. 2013 (cit. on p. 2).

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