Memo

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Subject
Post-project evaluation, round-the-world currents for TAN

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1 Introduction

This is the final Memo summarizing the post-project evaluation of the task of providing Team AkzoNobel surface current forecasts while preparing for and sailing on the 2017-2018 Volvo Ocean Race.

Deltares led the consortium developing and implementing the operational system; this effort lasted between 1 June 2017 until 1 July 2018. Other members of the consortium are: Sailing Team AkzoNobel (navigators and skipper), Top Sector Water & Maritiem, The Rijkswaterstaat, Provincie Zuid Holland, and Van Oord. Also a TKI (*Top Kennis en Innovatie*) subsidy contributed to the effort.

2 Work Plan

Operational Forecasting & Navigation - The Global Tide and Surge Model (GTSM) is run operationally at Deltares, producing 10 day water-level and storm surge forecasts on a global scale every 6 hours. Such forecasting services are used not only for early-warning of extreme water levels, but also for navigation purposes (including a unique combination of tidal and deep-sea currents). GLOSSIS can accurately predict tidal currents along the coast, and can be coupled to operational ocean models (e.g. HYCOM) to incorporate a proper representation of currents in the deep ocean.

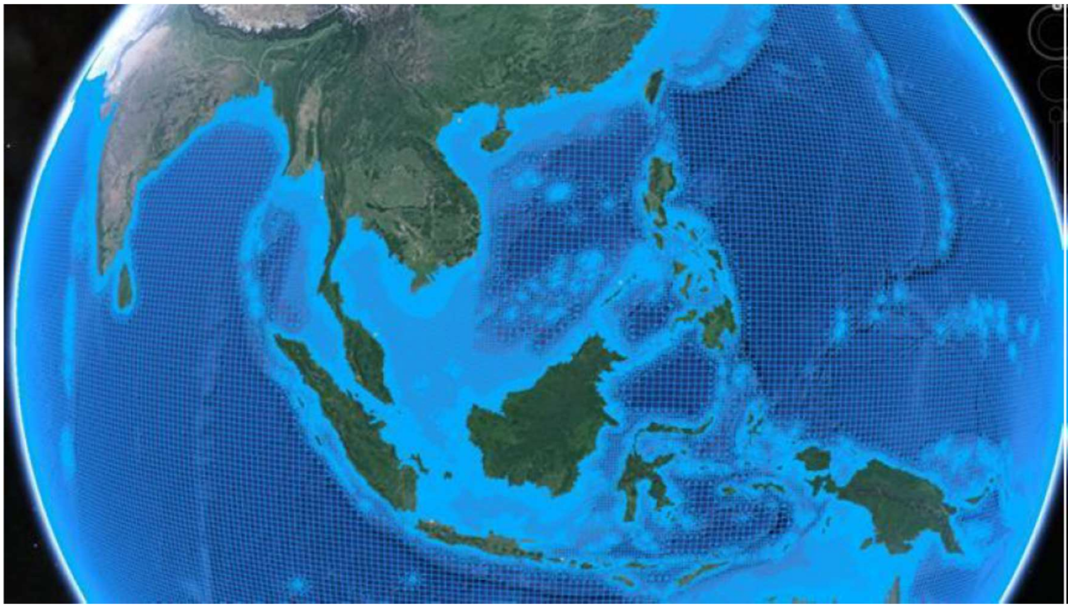


Figure 2.1 GTSM coverage & resolution over SE Asia. See also www.globalfloodforecast.com/

To achieve the goals mentioned above, a 14-month work plan was devised spanning between June 2017 and July 2018 (see next page). This is an applied research cooperation between Deltares and the Sailing Team AkzoNobel, in which the software developed by Deltares is improved to produce steady global results, and the surface current predictions (the model's accuracy and the system's reliability) are checked by the Sailing Team AkzoNobel in harsh and competitive environments of the Volvo Ocean Race. The schedule included several face-to-face meetings (at least four), to which many email and phone iterations between the team navigators and Deltares experts were added.

Furthermore, the forecasts will also be provided to other partners in the cooperation project (like Van Oord, Rijkswaterstaat and the Province of South Holland) to discuss the usability and reliability of the predictions for their own specific needs.

A major part of the proposed activities is the delivery of surface current predications for up to 7 days in advance in a number of areas around the globe, corresponding to the planned legs of the Volvo Ocean Race. The selection of the areas and the timeframes is derived from the discussions with partners about their specific needs, and their on-going feedback about the predictions as they are produced. The following figures show the requested output tiles for the legs between Lisbon and Cape Town (November 2017) and between Cape Town and Melbourne (December 2017).

Horizontal resolution of the tiles differs depending on the location. The white sub-tiles have a resolution of 0.025°, and the larger, yellow sub-tiles have a resolution of 0.050°. The yellow tiles are in areas that are far enough away from the continental shelf. The results of the GTSM will be exported as GRIB files on a regular grid for the end-users to download and use. The results include surface currents that are composed of components from tidal currents (GTSMO and non-tidal currents (from the global HYCOM model). The latter model provides "near surface" currents at approximately 4m below MSL.

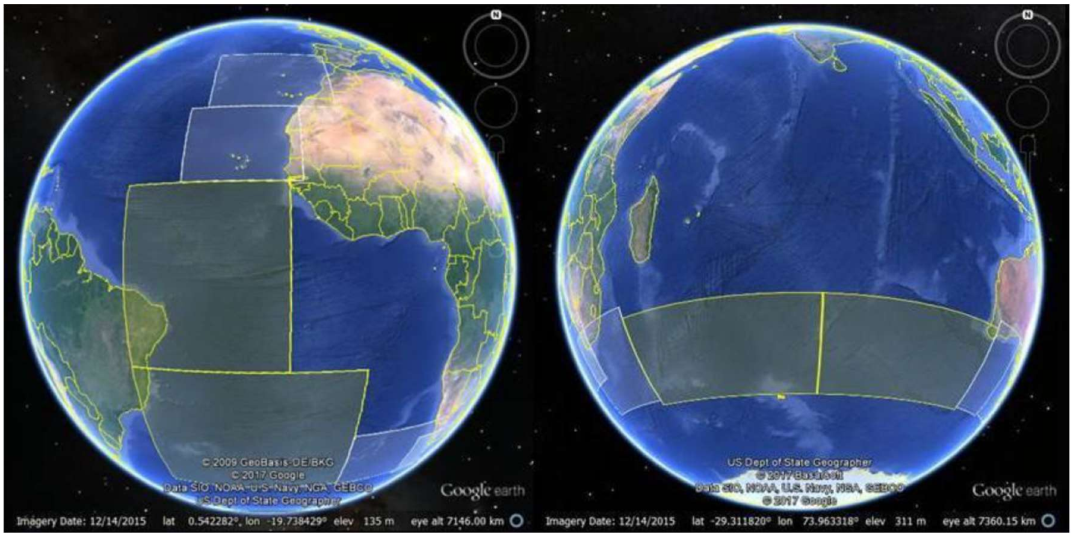


Figure 2.2 'Forecast tiles' for Legs 2 and 3

The last two legs of the race (legs 10 & 11) took place in the North Sea. Unlike the 'rest of the world' where the forecasts provided to TAN were a combination of the GTSM and NOAA's HYCOM, on the North Sea results were taken directly from the Dutch Continental Shelf Model. The DCSM is a joint development between Deltares and Rijkswaterstaat. For this reason the discussion of the comparison between modelled and measured surface currents is divided into two separate chapters. In Chapter 4, the results are discussed for the 'Rest of the World' (legs 2 to 9) and in Chapter 5, the results are discussed for the North Sea (legs 10 and 11).

3 Data compared

This evaluation compares these two datasets:

1 the surface current forecasts provided to Team AkzoNobel on the morning of each Leg departure, i.e. containing 'seven usable days'. These results were a combination of two different models containing different physics and using different resolutions (GTSM with depth-averaged tide-only, HYCOM with ocean-circulation only, 4m below MSL). The combined results were exported onto a third grid. The GRIB files contained current magnitudes and directions at hourly intervals, in matrices with regular-spaced cells of either 0.025° or 0.050° resolutions, depending on the tile.

2 the currents as measured at the boat. These data have varying quality, as they were taken at an unknown depth, they are affected by wave pounding, and admittedly in some legs the sensor failed and TAN had to use the less-accurate GPS speed-over-ground to estimate absolute velocities.

Some extra remarks:

- Navigator Jules Salter was not onboard during Leg 1 (from Alicante) nor during Leg 5 (motoring from Hong Kong), thus no measured data exists for those segments.
- In some legs (e.g. 7 or 9) the boat track deviated outside of the forecast 'tiles', thus no model data is available for comparison. The tile 'sizes' were all pre-determined together with the navigators' team.
- The horizontal resolution of the GTSM varies between 2.5 (at continental shelf) and 25km (in deeper ocean). A numerically-predicted current averaged over 25x25km^2 cannot be expected, especially over weaker flows, to match exactly what is measured aboard a 65-foot boat. We expect to see consistent patterns, especially when the flow is stronger.
- It is difficult to record the 'background' current around a competitive racing sailboat, as those currents are typically less than 10% of the absolute boat speed.

4 Results for 'Rest of the World', Legs 2-9

Figures Figure 4.1 through Figure 4.7 show map overview snapshots of modelled vs. measured currents, for legs 2-4 and 6-9 respectively.

Figure 4.1 shows a moment about 6 days into Leg 2. In this figure one can see the transition from a finer 'tile' to a coarser 'tile'. At that moment (and indeed during that leg) the modelled and measured currents did not match very well. We were later informed that the current sensor had stopped functioning early one, so the 'measurements' were based on estimates from the much less accurate GPS.

Figure 4.2 shows a moment about 1 day into Leg 3. Although near the (generally eastward) Southern Ocean, at that moment the TAN boat was on the very narrow and intense (westward) Agulhas current. This figure is an example of how, generally speaking, clear features were well captured in the forecasts. The same can be seen in Figure 4.3 (leg 4) and in Figure 4.4 (leg 6), at the edge of the continental shelf out of Melbourne and over a strong eddy out of Hong Kong, respectively.

Figure 4.5 and Figure 4.6 show moments in legs 7 and 8, respectively, when there was not a good match between modelled and measured currents but which are a bit 'suspicious'. In the former the TAN boat was over the (steadily eastward) Southern Ocean, but travelling North. The modelled current is consistent with expectations, whereas the measured value is a strong northward vector. Often times it appears the measured current has a tendency to be biased in the direction of the ship motion. Admittedly, it is difficult to record the 'background' current around a competitive racing sailboat, as those currents are typically less than 10% of the absolute boat speed. Such 'corrections' may have a great impact on the corrected measured current. Figure 4.6 illustrates a similar case, when the TAN boat is over the (strongly southward) Brazil current, but the measured value points strongly in the direction of travel.

Figure 4.7 shows a moment about 4 days into Leg 9. This was the leg during which TAN beat the 24-hour speed record. In such conditions, the model did very well and shown here; strong currents (>1m/s) are well captured in both speed and direction. Anecdotal reports also indicate that spatially the Gulf Stream was well-contained in our model, which provided a competitive advantage for TAN in beating the speed record.

Figure 4.8 - Figure 4.11 show time series of measured vs. modelled currents, for the entire (forecasted period of) leg 2, leg 4, leg 6 and leg 9 respectively.

Figure 4.8 for Leg 2, as mentioned above, should not be expected to offer a great match as the speed sensor was malfunctioning. Measured speeds are typically 1 m/s during the first days, then suddenly 0.1-0.2 m/s for the remaining period. Modelled speeds are steadier, always around 0.1-0.2 m/s. For some period on November 9 the current directions are a great match.

Figure 4.9, Figure 4.10 and Figure 4.11 for legs 4, 6 and 9 respectively show a good agreement between measured and modelled currents, given all the limitations discussed above. Mean current magnitudes and many of the clearer peak speeds are relatively well-reproduced. The interpretation with directions is less clear-cut, but also relatively consistent. For these and other legs, if not always an exact match, at least the correlations are high – see also the plots in the Appendix.

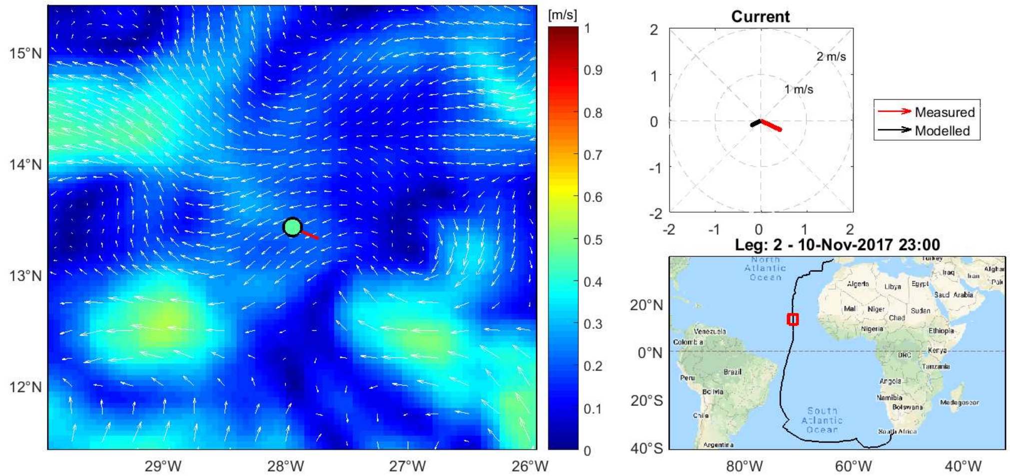


Figure 4.1 *Leg 2, from Lisbon to Cape Town.*

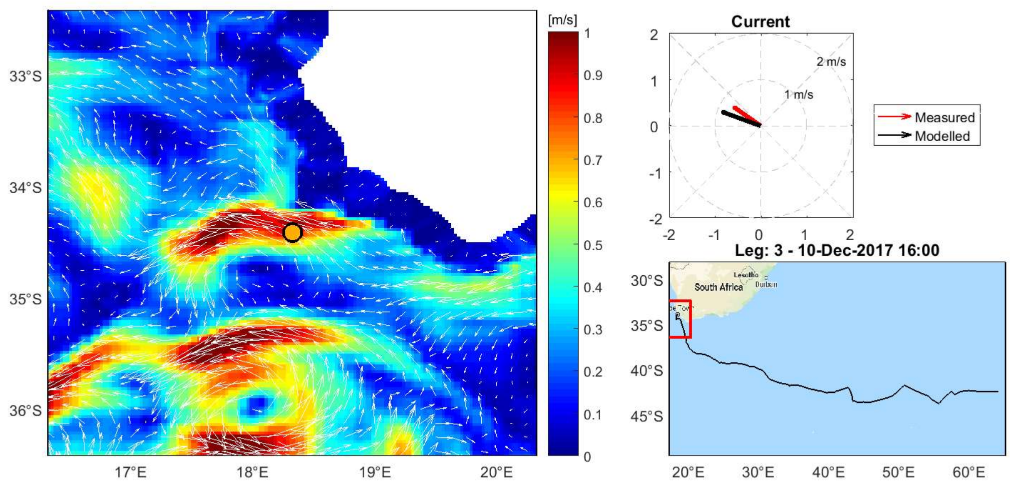


Figure 4.2 *Leg 3, from Cape Town to Melbourne*

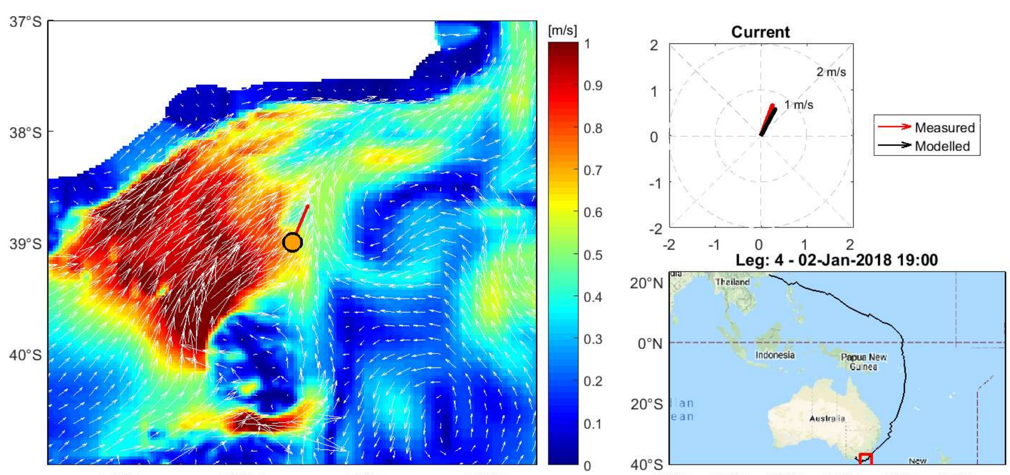


Figure 4.3 *Leg 4, from Melbourne to Hong Kong.*

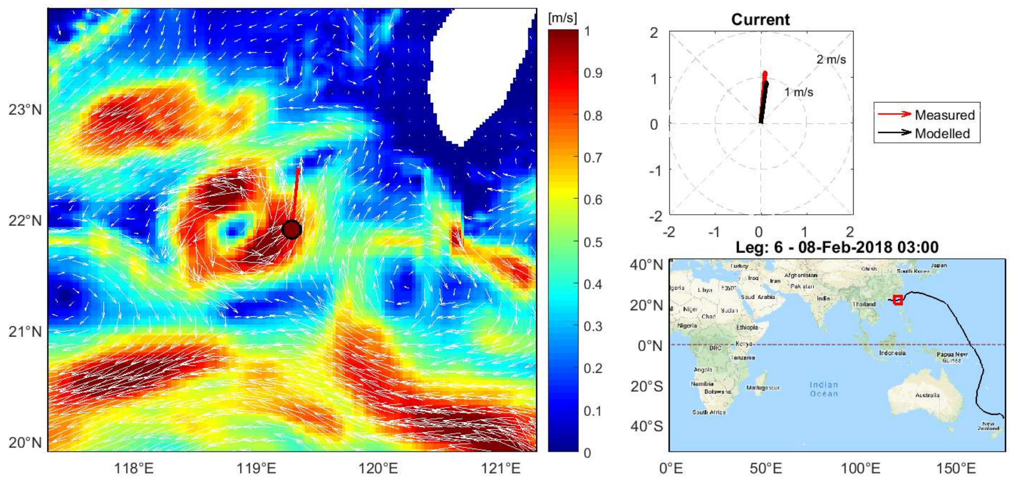


Figure 4.4 *Leg 6, from Hong Kong to Auckland.*

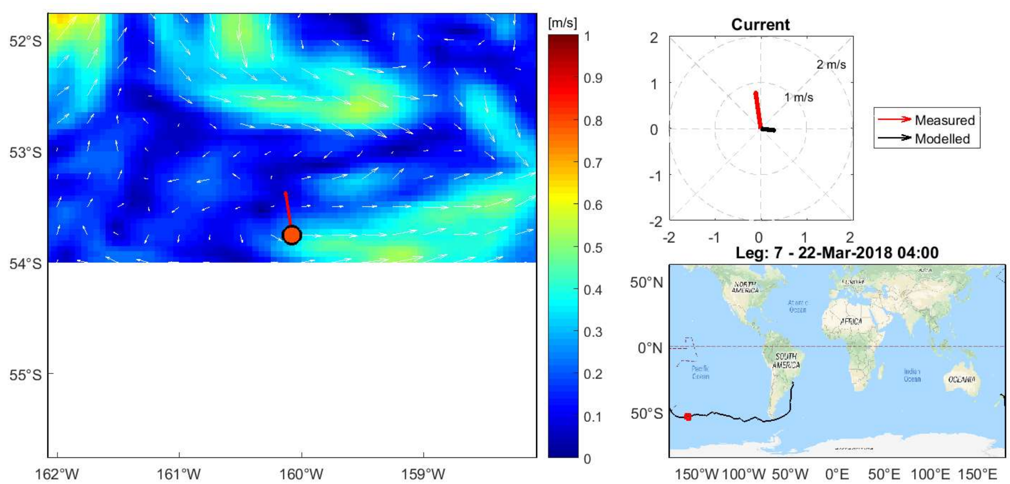


Figure 4.5 *Leg 7, from Auckland to Itajaí.*

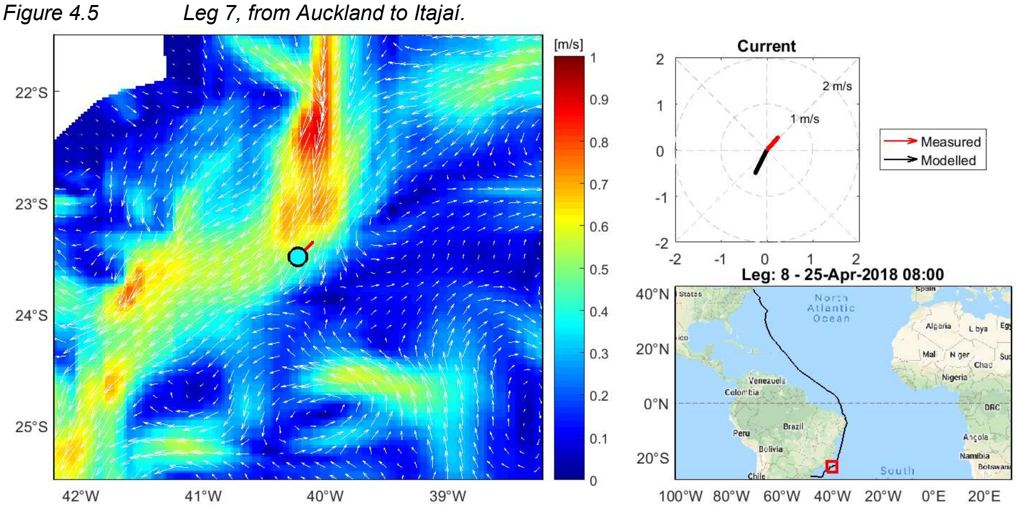


Figure 4.6 *Leg 8, from Itajaí to Newport.*

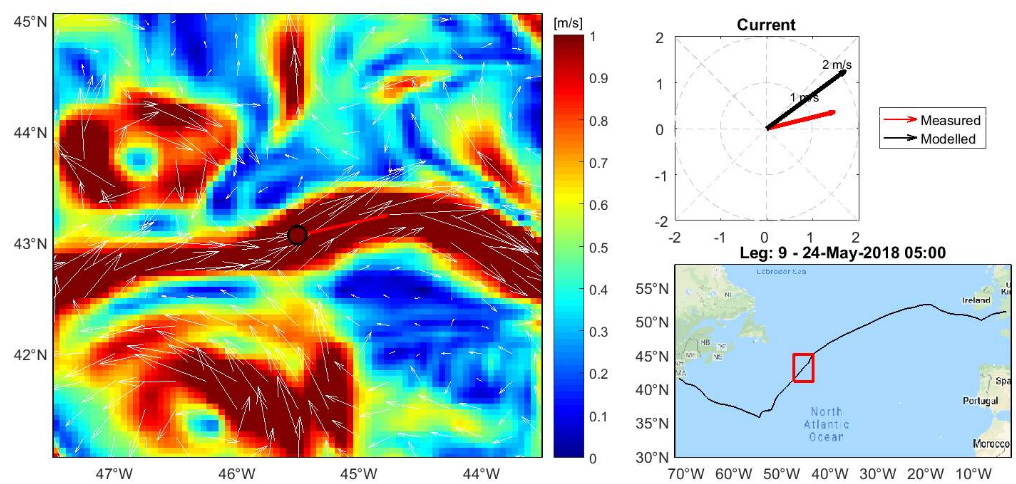


Figure 4.7 *Leg 9, from Newport to Cardiff.*

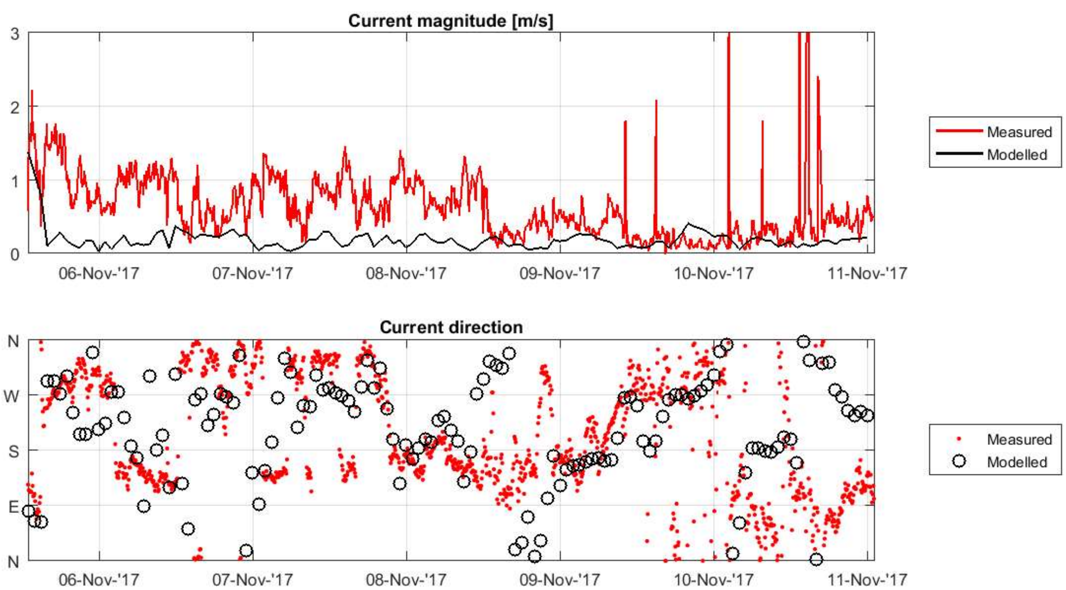


Figure 4.8 *Leg 2*

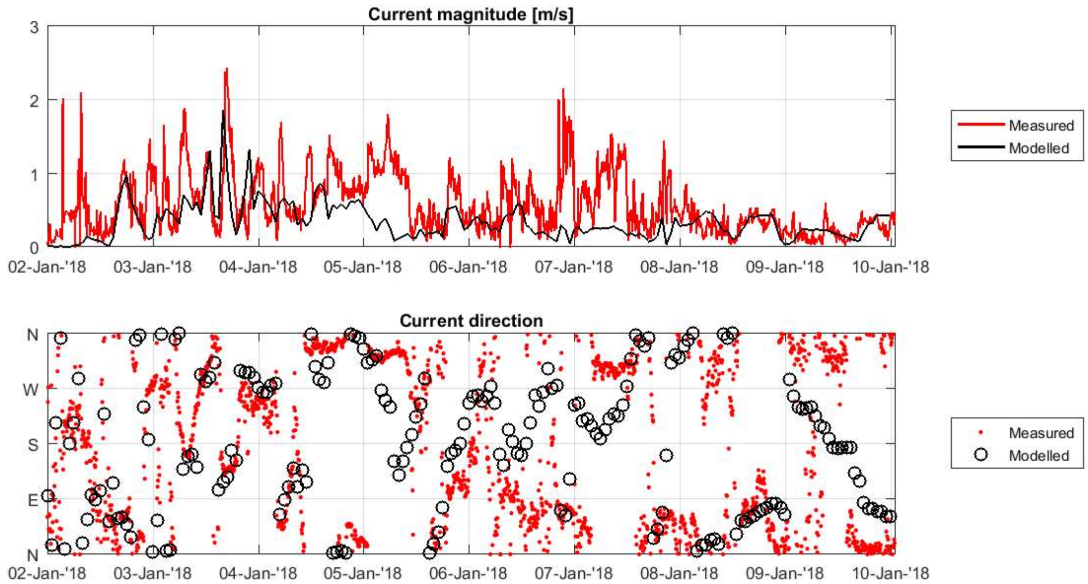


Figure 4.9 Timeseries for Leg 4. Current speeds (top) and directions (bottom).

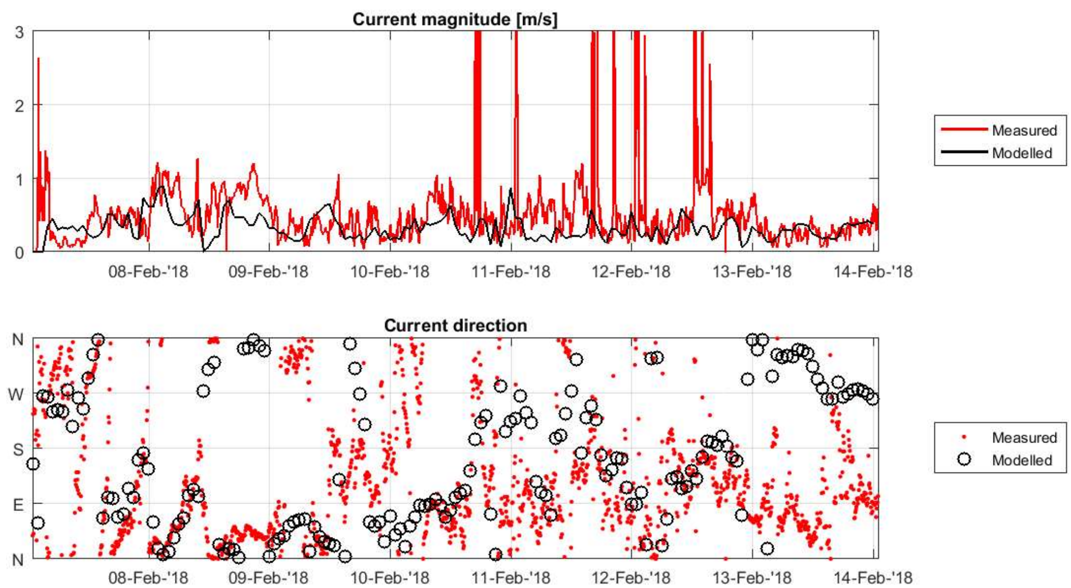


Figure 4.10 Timeseries for Leg 6. Current speeds (top) and directions (bottom).

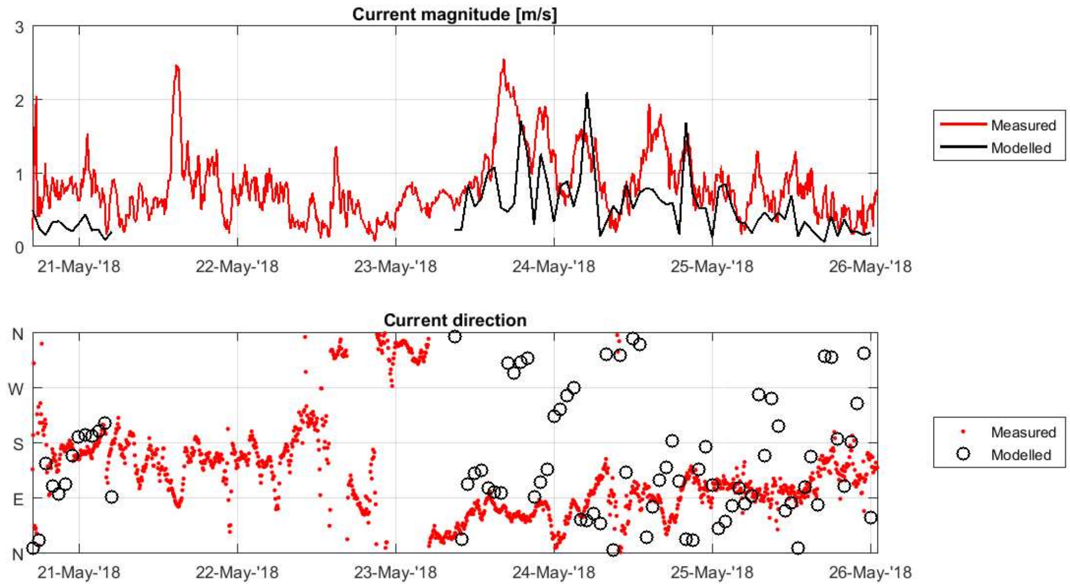


Figure 4.11 Timeseries for Leg 9. The period without modelled currents was when the TAN boat was 'outside' of the modelling 'tiles'. Current speeds (top) and directions (bottom).

5 Results for North Sea domain, Legs 10 and 11

For the North Sea legs of the race, modelled results were taken directly from the Dutch Continental Shelf Model (DCSM) with a resolution of 1 nm. The operationalization of the latest-generation 3D version of DCSM has been improved during this project, but did not always operate problem-free by the time the VOR fleet reached the Eastern Atlantic in May 2018. Therefore, for the sake of reliability, during the last legs of the race it was decided to use modelled results from the 2D, depth-averaged operational model (forced by tides and by wind and pressure gradients). As a general ‘rule of thumb’ in the North Sea, experience at Deltares suggests that surface currents are at least 20% stronger than the depth-averaged currents. For certain wind conditions and especially during Summer with stronger stratification, surface currents can be even faster. Nevertheless, the results were expected to be ‘better’ in the North Sea because the DCSM has a finer resolution than the global models applied elsewhere, and the DCSM has been improved over many ‘model generations’.

Modelled and measured currents showed a good match in the North Sea. Figure 5.1 and Figure 5.2 show moments during leg 10 and leg 11, respectively, when the comparison was just ok, but this might be explained by the aforementioned tendency for the measurements to be biased in the direction of the ship motion.

Figure 5.3 illustrates the measured-to-modelled current comparison for the entire last leg, which concluded the Volvo Ocean Race in The Hague. As explained above, a certain underestimation was expected but the general correlation is shown to be very good with respect to current speeds. Current directions are also very comparable (interpretation less intuitive), especially in the second half of the leg. For these and other legs, if not always an exact match, at least the correlations are high – see also the plots in the Appendix.

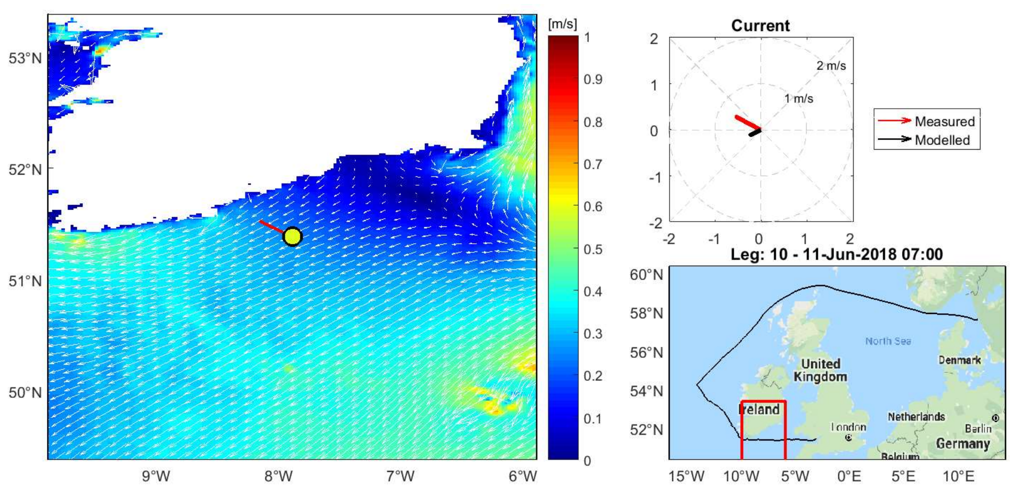


Figure 5.1 Leg 10, from Cardiff to Gothenburg.

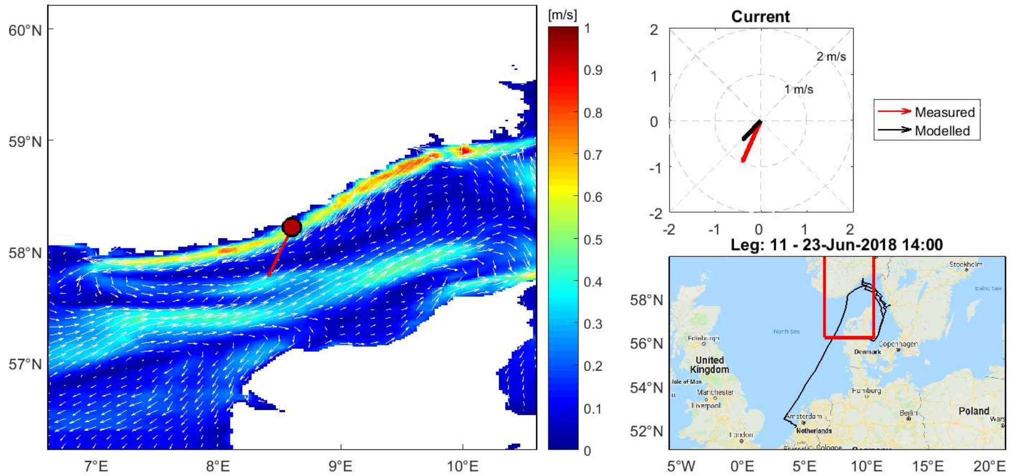


Figure 5.2 Leg 11, from Gothenburg to The Hague.

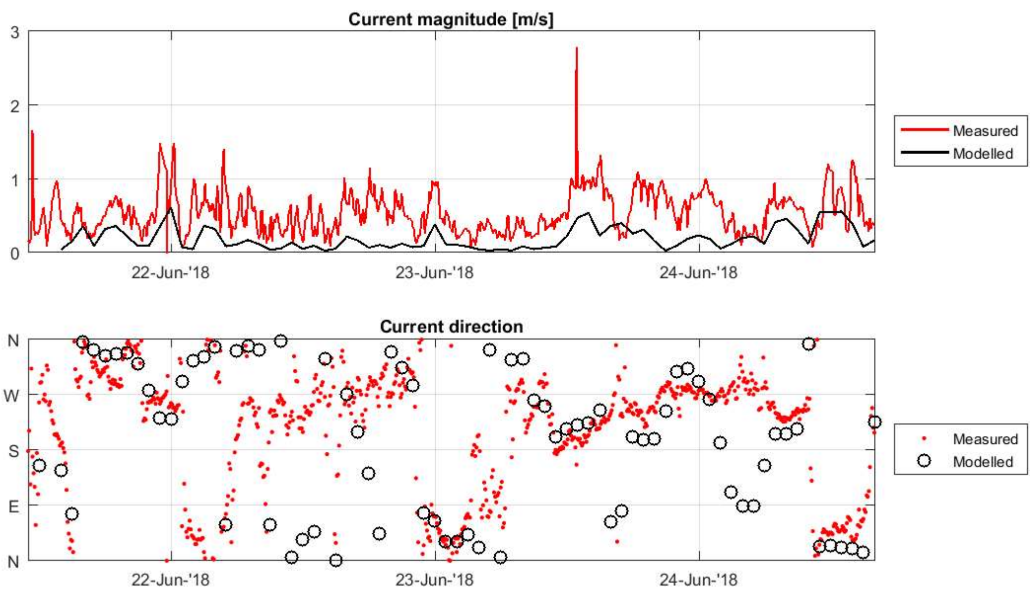


Figure 5.3 Timeseries for Leg 11. Current speeds (top) and directions (bottom).

6 Summary of Conclusions

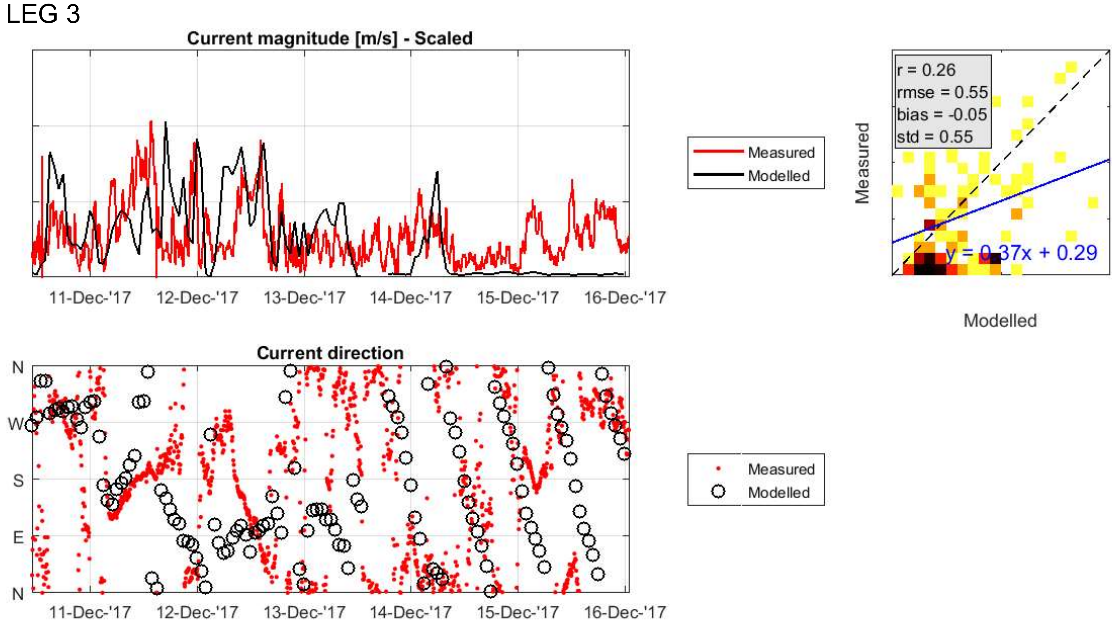
The previous chapters describe how the surface current forecasts provided to Team AknoNobel (TAN) were generated, and how they compared to measured currents on TAN's boat. Limitations of the measurements and of the modelling results were explained. Overall the comparison is according to expectations, with some exceptions which – at least partially – can be attributed to some biases in the measurements. For example, often times it appears that the measured current has a tendency to be biased in the direction of the ship motion. Or in Leg 2, when the current sensor failed and the reported currents were based on the (less accurate) onboard GPS. The modelled currents for the North Sea legs, although based on a finer model were obtained 2DH simulations, which are known to underestimate surface speeds but were here demonstrated to yield a very close correlation with observed data.

In terms of the models' (GTSM and DCSM) future improvements, but also when designing future operational systems for similar users, these insights can be very useful.

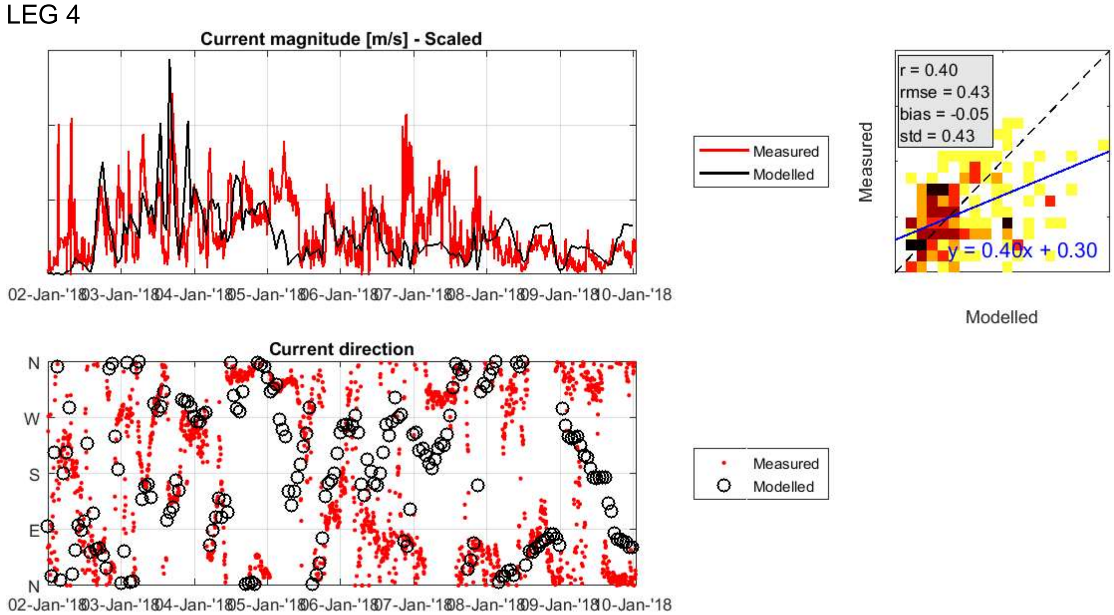
7 Appendix

Extra plots showing correlations and R2, RMSE, bias.
*The plots below are some early examples of correlation plots based on **scaled** data.*

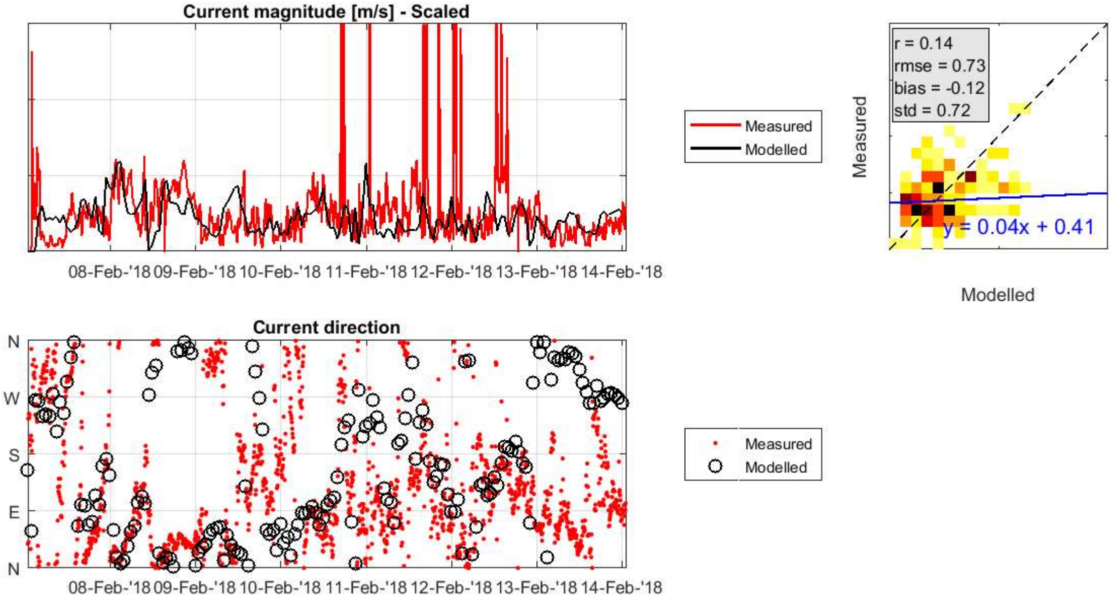
LEG 3



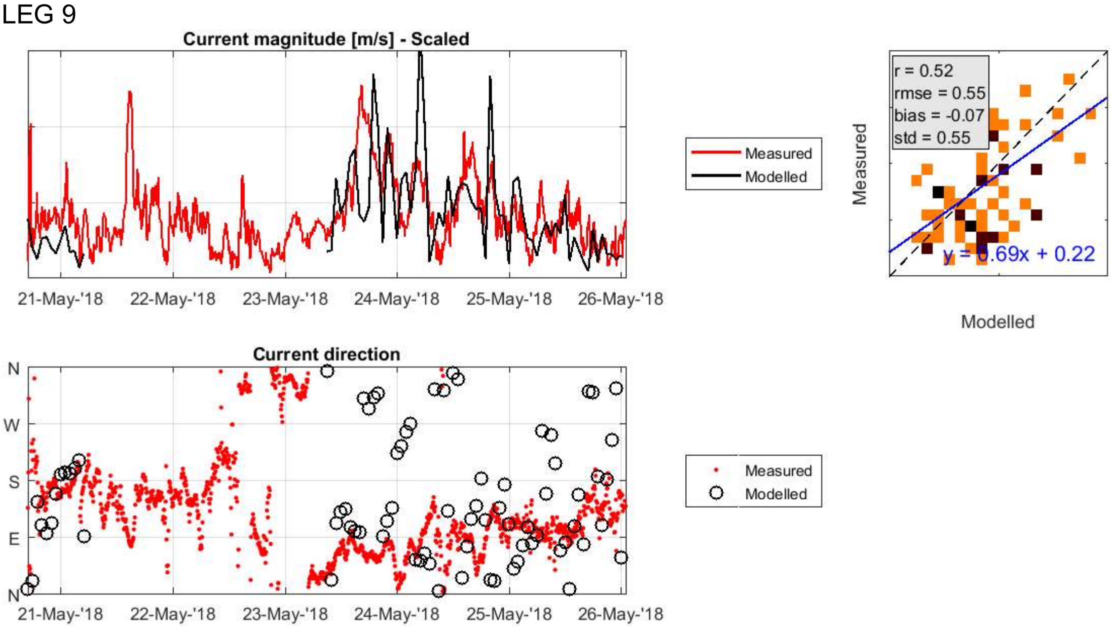
LEG 4



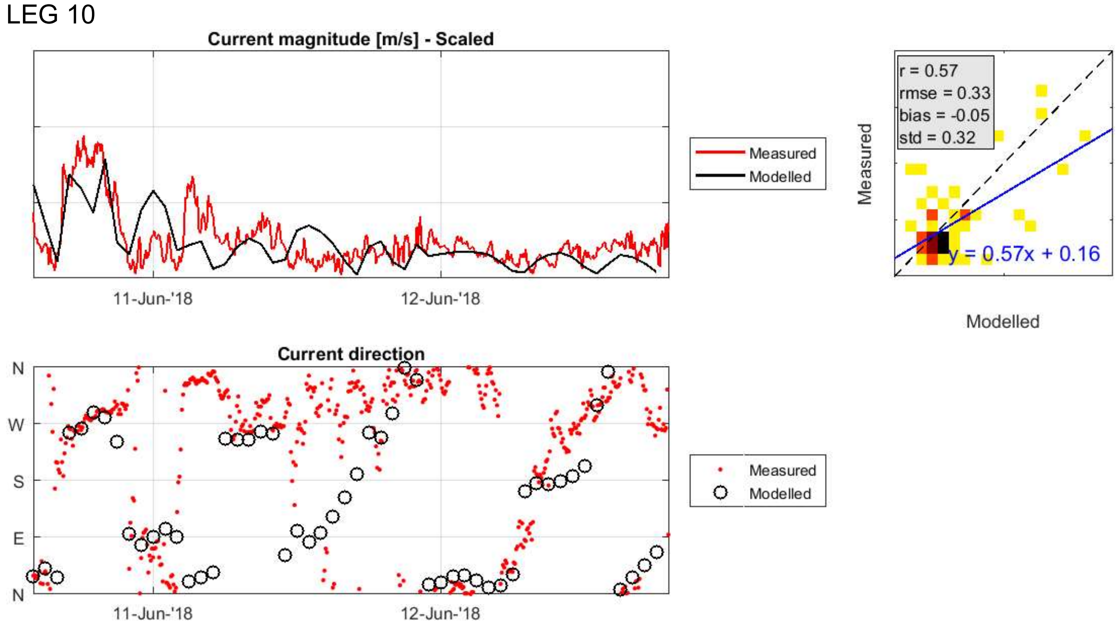
LEG 6


Current magnitude [m/s] - Scaled
08-Feb-'18 09-Feb-'18 10-Feb-'18 11-Feb-'18 12-Feb-'18 13-Feb-'18 14-Feb-'18
Measured
Modelled
r = 0.14
rmse = 0.73
bias = -0.12
std = 0.72
y = 0.04x + 0.41
Measured
Modelled
Current direction
N
W
S
E
N
08-Feb-'18 09-Feb-'18 10-Feb-'18 11-Feb-'18 12-Feb-'18 13-Feb-'18 14-Feb-'18
Measured
Modelled

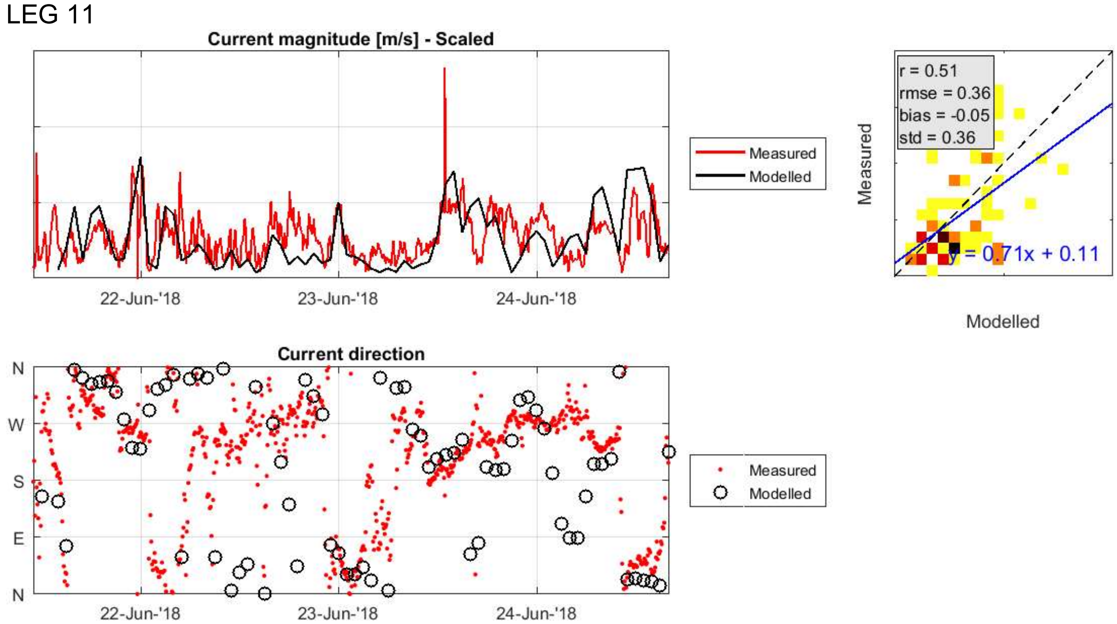
LEG 9


Current magnitude [m/s] - Scaled
21-May-'18 22-May-'18 23-May-'18 24-May-'18 25-May-'18 26-May-'18
Measured
Modelled
r = 0.52
rmse = 0.55
bias = -0.07
std = 0.55
y = 0.69x + 0.22
Measured
Modelled
Current direction
N
W
S
E
N
21-May-'18 22-May-'18 23-May-'18 24-May-'18 25-May-'18 26-May-'18
Measured
Modelled

LEG 10


Current magnitude [m/s] - Scaled
11-Jun-'18
12-Jun-'18
Measured
Modelled
r = 0.57
rmse = 0.33
bias = -0.05
std = 0.32
y = 0.57x + 0.16
Measured
Modelled
Current direction
N
W
S
E
N
11-Jun-'18
12-Jun-'18
Measured
Modelled

LEG 11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22-Jun-'18
23-Jun-'18
24-Jun-'18
Measured
Modelled
r = 0.51
rmse = 0.36
bias = -0.05
std = 0.36
y = 0.71x + 0.11
Measured
Modelled
Current direction
N
W
S
E
N
22-Jun-'18
23-Jun-'18
24-Jun-'18
Measured
Modelled