Predicting currents at the *Gemini* wind farm

Analysis of Triaxys ADCP-data

L.W.M. Roest
Rotterdam, October 2015

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Report

L.W.M. Roest

This report is written for Van Oord as a part of my two month internship on the analysis of the data of the Triaxys wave and current buoy at the Gemini Wind Farm.

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Contents

Abstract

Van Oord is currently building the *Gemini Wind farm* in the North Sea. It is located 80km North of Schiermonnikoog. Before execution started some wave and current analysing buoys have been deployed to investigate the currents on the location of the wind farm for workability and insurance purposes. In this report the ADCP-wave data will be analysed.

The major finding is that maximum tidal currents do not occur in winter but in summer, since the tidal currents are influenced more by stratification than by wind influences.

L.W.M. Roest
Rotterdam, 5th of November, 2015

Chapter 1: Introduction

1.1 Research question

Van Oord is interested in a prediction of the workability for their equipment at the Gemini wind farm. Because operational costs are high it would be favourable to be able to predict the conditions as a part of the decision process whether floating equipment can be deployed or not, most notably our cable-lay vessels such as HAM602. Once the project is in execution, current information can be used to adapt the planning.

Therefore the following research question is proposed. *Is it possible to make a workability prediction for the Gemini Wind Farm based on the current data provided by the deployed buoys?*

Figure 1.1: HAM 602 laying the infield cables at Gemini, Aeolus is installing monopiles in the background. (Van Oord, 2015)

1.2 Location

The Gemini Wind Farm is a project of two new wind farms 80km off the coast of Ameland. This site is situated between the shipping lanes of the *Terschelling* and *East Friesland* Traffic Separation Schemes. Some wind farms are already present in this area and in the future even more will be built.

1.3 Matlab

All data has been analysed using Matlab, as a result a whole series of Matlab-scripts has been produced. In general these scripts should be usable also for other "Triaxys Directional Wave buoys". An overview of all scripts can be found in appendix E.

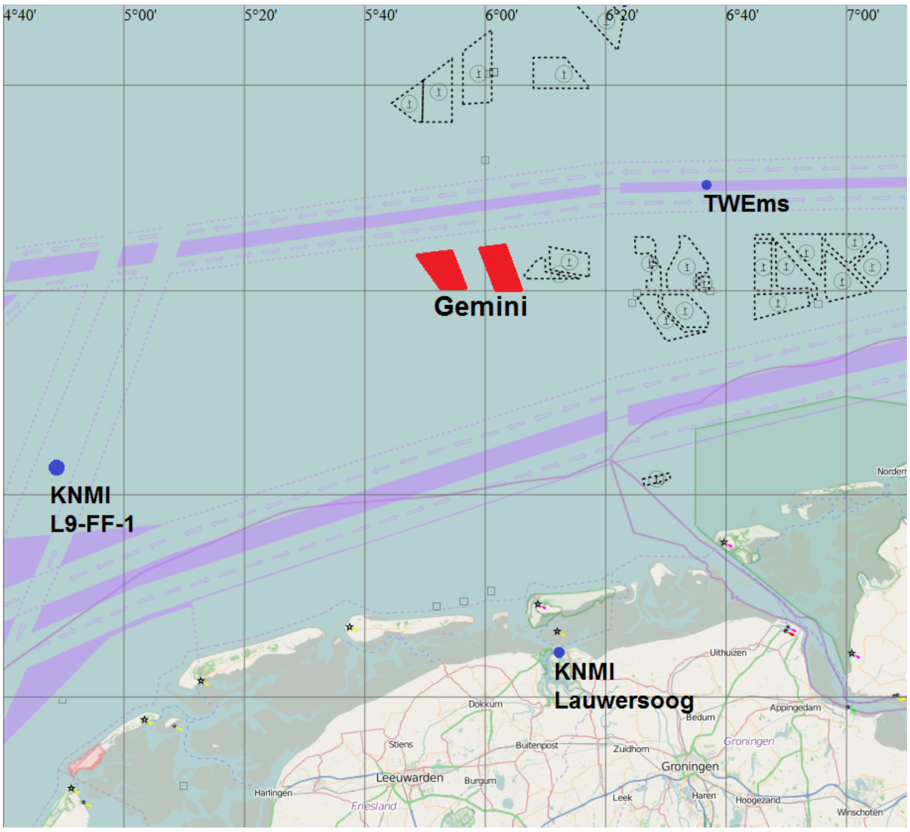


Figure 1.2: Location of the Gemini wind farm (in red) and nearby measuring stations, (OpenSeaMap, 2015).

Chapter 2: Measurements

2.1 Measurement campaign

At the *Gemini wind farm project* some Triaxys buoys have been laid-out to analyse the tidal currents. These buoys have been measuring the currents since the 16^{th} of February 2015. The main goal of the measurements is providing data for statistical analysis and prediction of workability conditions. Since when the magnitude of the current reaches a certain threshold, working activities will have to be stopped temporarily. Besides currents, also the wave climate is measured by the buoy, but this is beyond the scope of this report.

2.2 Triaxys-buoy

The deployed buoy is a *Triaxys next wave II Directional Wave Buoy* [Axys, 2015], from *Axys Technologies*, which is capable of measuring currents as well as waves. This buoy has the form of a sphere and has a diameter of 1.10m. The buoy is anchored to the seabed with a fairly long chain as the position varies about 40m around the central position in any direction, depending on the surface currents.

Figure 2.1: Exploded view of the Triaxys directional Wave buoy [Axys, 2015]

2.2.1 Equipment

The buoy is equiped with an ADCP (Acoustic Doppler Current Profiler) for measuring currents and a *Triaxys directional wave II sensor* for measuring the wave climate. A GPS receiver records the position of the buoy. For communication a VHF- and Iridium-transponder are available. Solar panels and batteries deliver power to the instruments. See [Axys, 2015].

2.2.2 Communication

As the position of the buoy is outside the range of the GSM network, communication is issued by an Iridium satellite uplink. This way the most important data is transferred with an hourly interval. Since communication via Iridium is quite expensive not all data which is measured and registered by the buoy, is being transferred. However, that data is probably available at the internal memory, which can be obtained at the next servicing of the buoy.

2.2.3 Measuring routine

The measurements have started on the 15th of February 2015 and useful data is available up till current date. New data is still registered and uploaded every hour. At the top of the hour a new measuring sequence is started which lasts for five minutes for currents and 20 minutes for waves ([van der Wel, 2015]). The transmitted values are an average of the measurements in the sequence.[1] Data of the currents is available at every ‘top’ of the hour, whereas the wave data *should* also be available at 20 and 40 minutes past the hour.

2.2.4 ADCP properties

The currents are measured using an ADCP (Acoustic Doppler Current Profiler) from Nortek, the Aquadopp 400kHz. This device sends out ‘sound’ at 400kHz in tree beams, placed under an

[1]It is still unclear how many measurements are performed in one sequence! However, concluding from the data, it is an average over multiple measurements.

angle with respect to each other. From the Doppler frequency shift of the reflected sound the velocity in the direction parallel to the beam can be calculated. Decomposing in vectors and addition of the three signals renders us the velocity in the plane perpendicular to the axis of the ADCP. A correction is made for the water temperature, as the speed of sound is dependent on the density of the water, which is dependent on the water temperature. Salinity is set as a fixed value. Additionally a correction is made for the tilting (deviation from horizontal plane) and heading (direction) of the buoy based on the internal compass. See also figure 2.2.

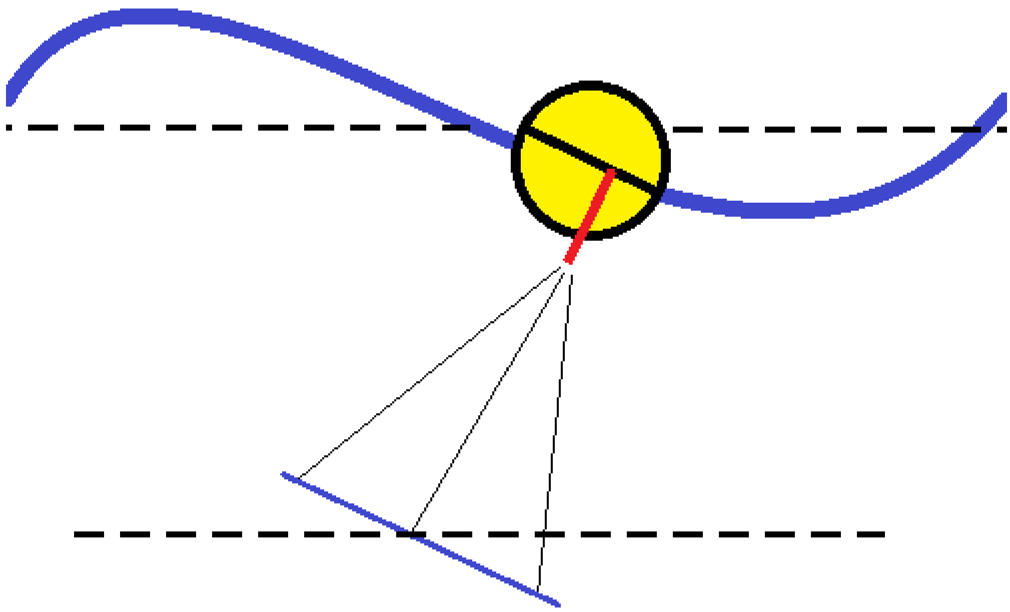


Figure 2.2: Schematisation of an ADCP measurement in a tilted buoy. Assumed plane of measurement (black, dashed) and actual plane of measurement (blue).

The ADCP registers the current in polar coordinates; magnitude and direction. The magnitude resolution is 0.01 m/s, with σ =0.1 m/s, the resolution of the direction is 1°, with $\sigma = 5°$. At Gemini measurements are performed in 20 bins over depth, of which the upper 16 or 17 are actually situated above the seabed, depending on the actual water depth at the moment of measuring. The actual water depth depends on the vertical tide and waves. Since ADCP's are not capable of measuring directly beneath the instrument, the first bin starts at 1.72m below the instrument, which is placed approximately 0.5m below the sea surface. Every bin then consists of 2.00m of water column. Velocities and directions are transformed from local (ADCP) coordinates to a cylindrical reference frame with respect to the buoy. Coordinates are: magnitude, direction relative to magnetic North and "bin". These transformations are performed on data from the internal ADCP compass. According to [Kashino et al., 2005] waves up to 2.4m significant wave height (H_s) and tilting up to 30° do not influence the ADCP-data more than 0.1 m/s.

2.2.5 Directional Wave properties

The wave registration is done using a *Triaxys Next Wave II* directional wave sensor. The sensor has been validated, according to [MacIsaac and Naeth, 2013]. The wave data is not taken into account in this report.

2.3 Current measurements

The ADCP, measures velocity using *Doppler frequency shift* of sound in water. The direction is obtained using the signals of three sound beams, which are placed under an angle with respect to each other. The resulting signals are processed and output in sense of magnitude and direction. In the depth the currents are measured in a total of 20 bins of 2.00m height, from which only the upper 17 bins contain actual water displacement, because of the total water depth at the buoy's location. Bin 18, 19 and 20 contain the reflected signal from the seabed. This is also in accordance with the estimated water depth of 30 to 35m, see also figure 2.3. Actually the number of bins being virtually above the sea bed is dependent on the vertical tide, which' range is in the order of 1m at the buoy location. Therefore, in cases of (extreme) set-up, more bins will register currents, since the reference frame is fixed to the floating buoy.

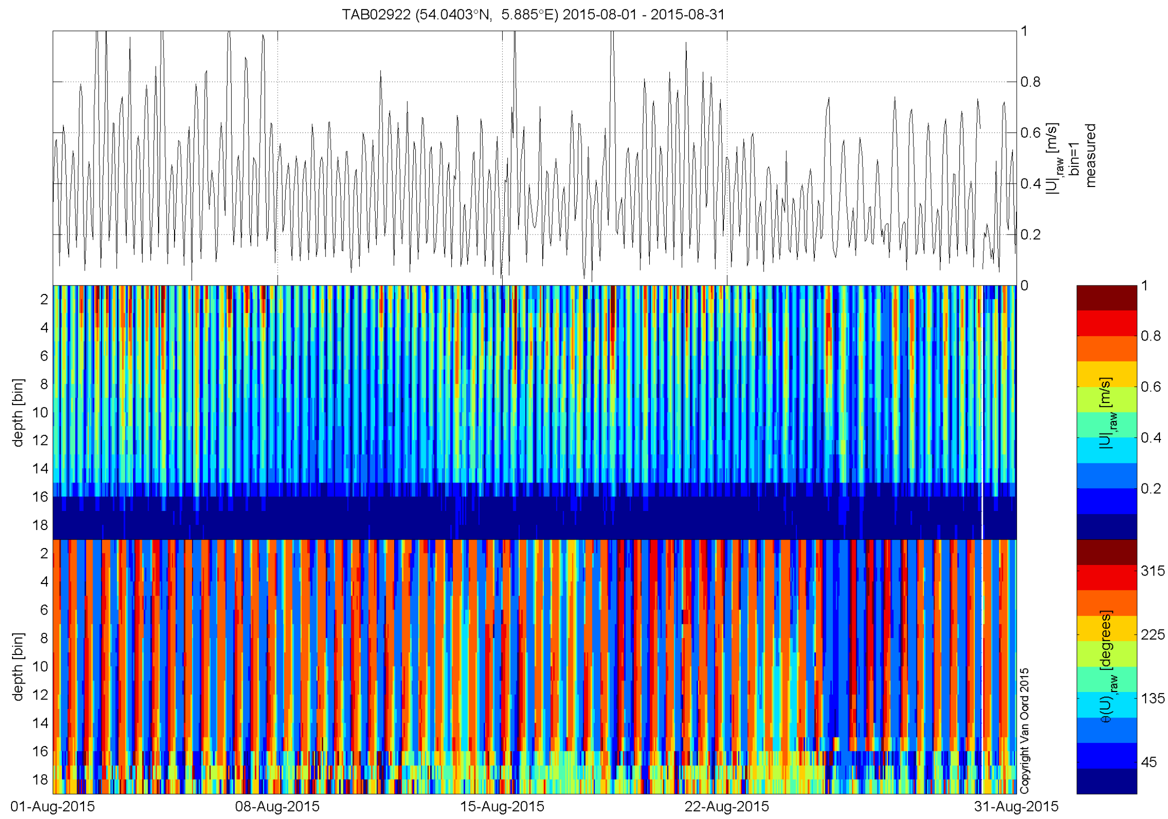


Figure 2.3: Raw data from the buoy, in the lower bins no currents are measured.

2.4 Other measurements

Apart from currents other quantities are also measured. An overview of all measured quantities is presented in table 2.1.

Table 2.1: Measured quantities by the Triaxys wave buoy.

Field	***Quantity***	***Units***
ADCP/Current-related		
FBD	Blanking Distance	[m]
SeaTemp	Sea surface temperature	[°C]
PRESS	Water Pressure	[hPa]
SPS	Speed of Sounds	[m/s]
NOB	Number of Bins	[-]
U	Current magnitude	[mm/s]
TH	Current direction	[°]
Wave-related		
H110	Highest 10th of Waves	[m]
HAVG	Average Wave Height	[m]
HMAX	Maximum Wave Height	[m]
HSIG	Significant Wave Height	[m]
Hm0	Significant Wave Height Spectral	[m]
MS	Mean Spread	[°]
MWD	Mean Wave Direction	[°]
T110	Average Period of Highest 10th	[s]
TMAX	Maximum Wave Period	[s]
TP5	Peak Period Read Method	[s]
TSIG	Significant Period	[s]
TZ	Mean spectral period	[s]
Tavg	Average Wave Period	[s]
Te	Energy Period	[s]
Tp	Peak Period	[s]
WPR	Wave Processing Return	[-]
WSt	Wave Steepness	[-]
ZCN	Number of Zero Crossings	[-]
Meta		
LAT	Latitude	[°N]
LON	Longitude	[°E]
LMC	Log Error Count	[-]
NoR	Number of Resets	[-]
SC	Solar Current	[A]
T	Average Temperature 1	[° C]
Time	Time	[UTC]
V	System Voltage	[V]
WCS	Watchcircle Status	[-]
WIV	Water Intrusion Voltage	[V]

Chapter 3: Data analysis

3.1 Pre-processing

First of all the raw data from the Triaxys buoy is loaded into Matlab, and put into vectors. In principle a data point is available every hour, however some data points are missing from the raw data. This is probably due to communication errors from the buoy to the satellite, or the FTP server collecting the data. To ease the processing, the time series are made equidistant and empty time slots are filled with “NaN”. Furthermore the raw data is also transformed from polar coordinates into Cartesian coordinates, as both coordinate systems have their specific advantages for post processing. Velocities are converted from mm/s to the more convenient m/s.

3.2 Tidal analysis

The currents are analysed using the *OpenEarthTools* branch of the Matlab toolbox *t_tide*, which performs a harmonic analysis for tidal constituents on a tidal time series [Pawlowicz et al., 2002]. A least squares fit is made to the input signal for the known tidal constituents. This analysis provides us with the time series of the astronomical tide, as well as the parameters of the tidal constituents. Data is input as coupled Cartesian vectors, velocities in x- and y-direction are analysed simultaneously, and as a result tidal ellipse parameters are output.

3.2.1 t_tide

t_tide is set-up to use a standard one hour interval, the constituents to fit are either ‘all’, or user-defined. Nodal corrections are taken into account at the ‘central time’ of the time series and latitude of the buoy. See 3.2.1 for the Matlab syntax. This t_tide call analyses the whole time series in one run, for each layer independently. The output consists of the analysed velocity time series and the following parameters for each constituent:

- Name
- Frequency
- Semi-major axis
- Semi-minor axis
- Inclination
- Phase
- respective 95% confidence intervals

Listing 3.1: t_tide calling

```
for iz=zmin:zmax    %For all layers from zmin to zmax;
    [H(iz),fit] = t_tide(ux0(:,iz) + sqrt(-1)*uy0(:,iz),... % u+i*v (currents)
        'interval',24*OPT.timestep,...% time step= 1hour
        'latitude',D.LAT(1),...     % buoy latitude
        'start',D.time(1),...       % start time
        'error','wboot',...         % error estimating
        'sort','-amp',...           % sort output constituents
        'output',logid,...          % write to log
        'diary',logid,...           % write to log
        'rayleigh',OPT.cons);       % analyse these constituents.
end
```

3.2.2 signal analysis

When tidal analysis is performed on the whole time series, with “all” constituents, the fit is quite good. Values of fitted variance are 89 to 94% over the first 15 layers, but rapidly decreasing to 35% for the bottom layers. Overall we can observe that the tide is predicted quite well. However, especially for large magnitudes of the tidal velocity t_tide will under predict. The difference between the measured magnitude and the analysed (astronomical) magnitude is caused by non-astronomical influences on the tidal currents, such as wind and stratification. An overall background current is observed, being 0.05 m/s in Easterly direction.

The tidal signal is analysed in two directions simultaneously, thus both magnitude and direction of the measured currents are analysed. By coincidence the major axis of the tide is nearly parallel to the x-axis of the Cartesian reference frame (East-West) and therefore the minor axis is parallel to the y-axis (North-South), see figure 3.1.

When the major and minor axis of the tidal ellipses are investigated separately some differences emerge. The major axis is predicted very well with predicted variances of over 90% of the observed, while the prediction of the minor axis very poor. Analysed amplitudes of the minor axis are in the same order of magnitude as the remainder signal, whereas for the major axis the magnitude of the analysis is much larger than the remainder of the measured signal, see figure 3.2. A possible cause for this is the small magnitude of the tide in the direction of the minor axis. Firstly the ADCP cannot measure the direction of the current accurately for very small magnitudes. Therefore directions may differ significantly from their real values, see [Kashino et al., 2005]. Secondly, other influences might dominate over the astronomical tide, such as wind-shear and density currents. Effectively 'pushing' the measured currents in a direction different from the astronomical tide.

Quantitatively it is observed that the magnitude of the currents remains under 0.6 m/s over 95% of the time, and only exceed 0.8 m/s less than 1% of the time, see 3.2. As observed in measurements from 16 February to 15 October 2015. For a whole year the probability of exceedance of the current magnitude might be slightly different, due to seasonal variability.

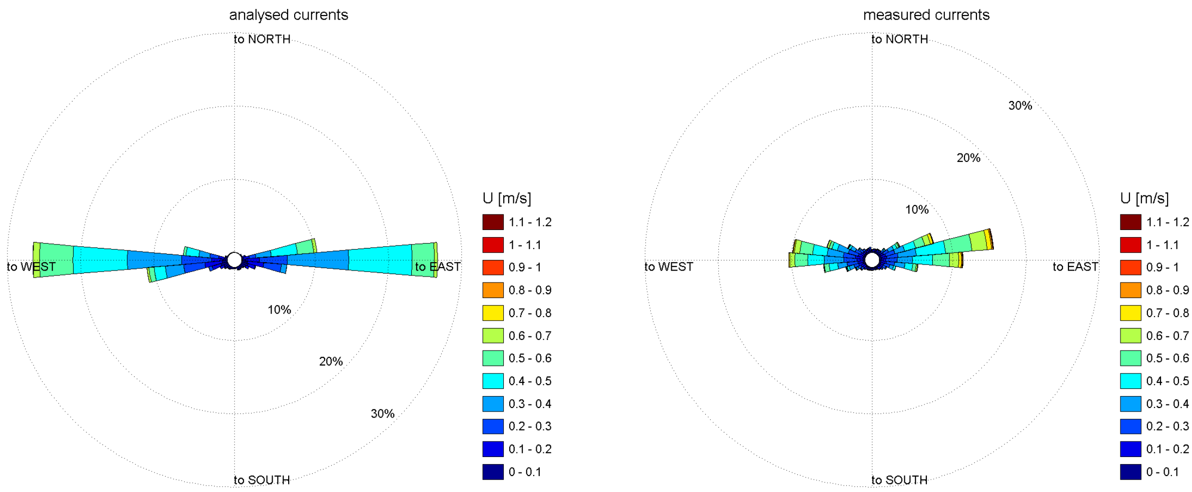


Figure 3.1: Current rose: directional probability of occurrence. Observations from 16 February to 15 October 2015.

3.3 Residual

The current time series do not only consist of the astronomical tide, other influences are also present. After substraction of the astronomic tide from the measured current, a residual that is not caused by astronomic forcing remains. Other influences on the currents at Gemini are, for instance, wind and density driven currents.

A correlation between the remainder and wind has thus far not been successful, insofar that no correlation is found between any combination of *Measured, Smoothed* and *Residual* of Wind and Currents, see also figures 3.3 and 3.4.

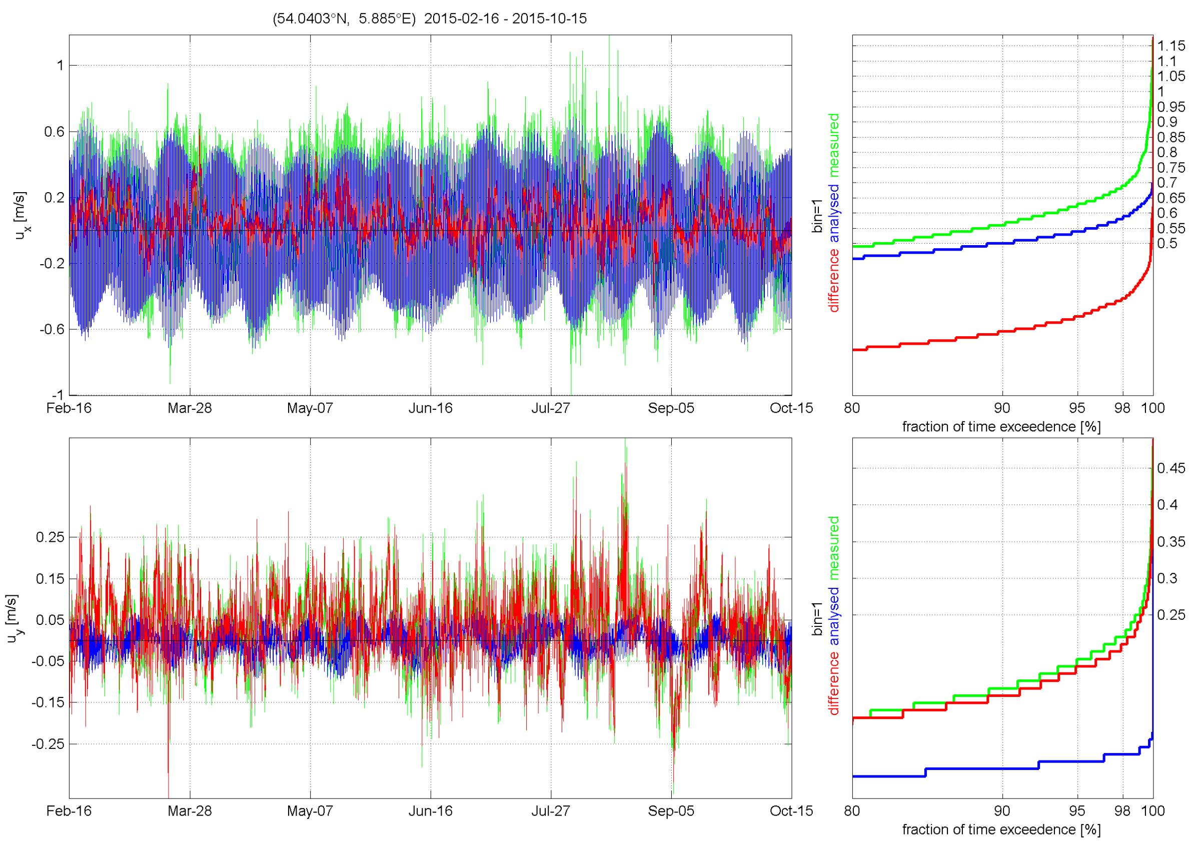


Figure 3.2: Time series of measured and analysed currents, and probability of occurrence. Observations from 16 February to 15 October 2015.

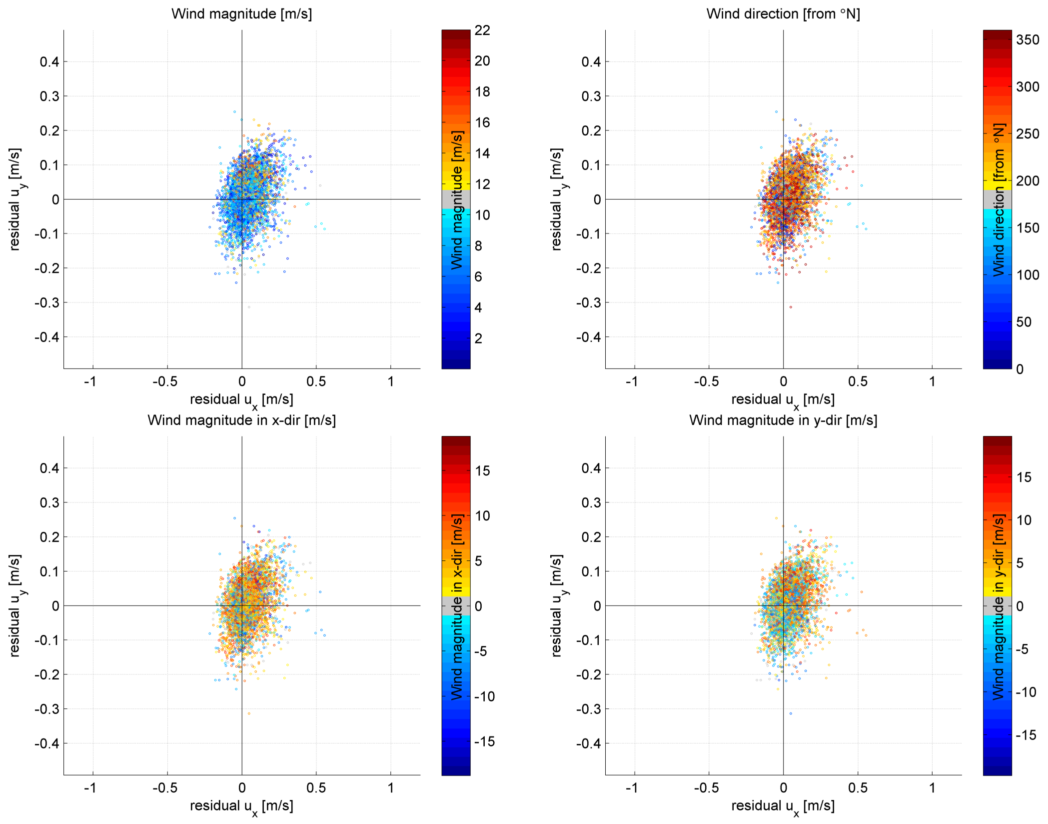


Figure 3.3: Colored scatter plot of currents, with wind as color coding.

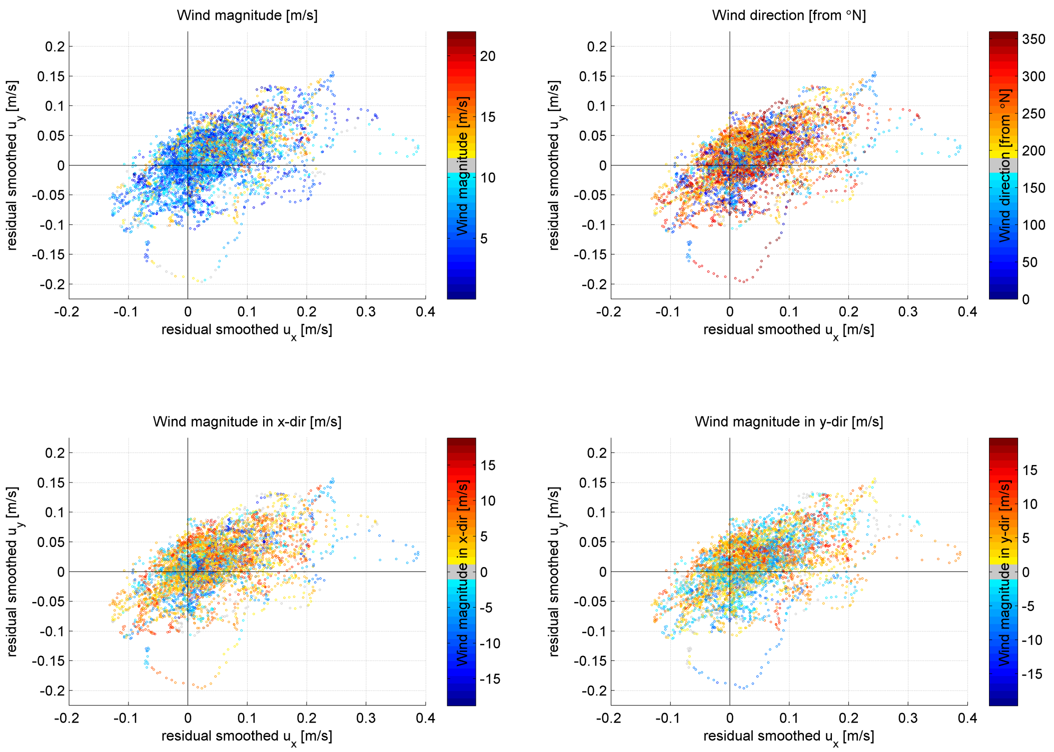


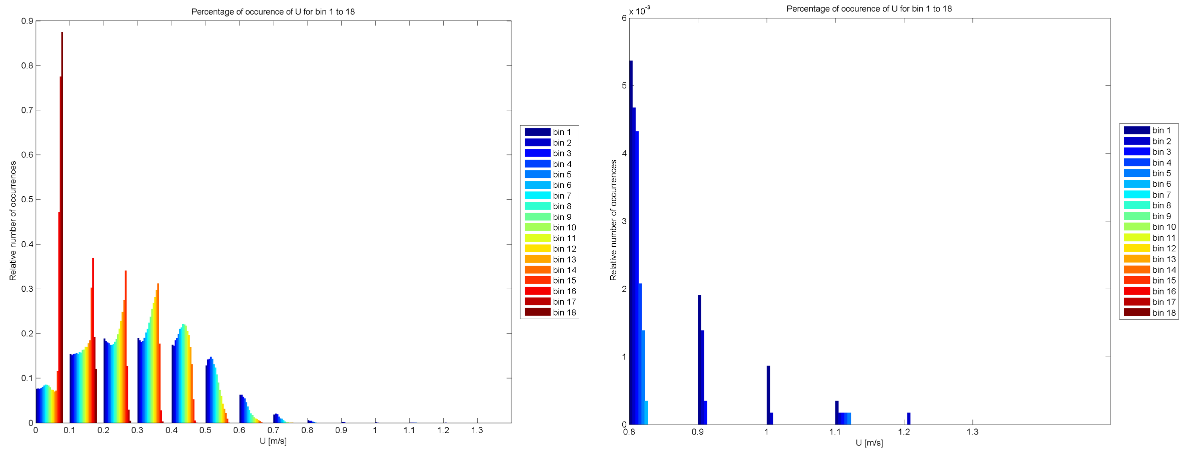
Figure 3.4: Colored scatter plot of the residual current with wind as color coding.

Chapter 4: Conclusions

4.1 Current magnitudes

The observed currents rarely exceed 0.80m/s and the highest registered current between 15 february and 15 october 2015 is 1.20m/s, see figure 4.1 As opposed from what was expected, the largest magnitudes do not occur in February or March, but in August. When looking at the timeseries more in-depth one can observe that April, June, September and October are fully dominated by the tide, see Appendix D. Whereas in March, May, July and August the tidal prediction is frequently exceeded. Hence large non-tidal currents are present in winter as well as in (late)-summer. The origin of these periods of larger currents is different.

One cause of increased non-tidal currents may be wind, however the influence of wind on the currents seems to be quite small. Also no direct correlation was found between wind and (residual)currents. The cause of the non-tidal currents in the winter is therefore not understood, perhaps other factors than the wind are at play. The current magnitude decreases with increasing depth, magnitudes in flood direction are generally larger than in ebb direction, see figure 4.2. This results in a net-current of approximately 0.05m/s in flood direction (East).



(a) All magnitudes.

(b) Magnitudes ≥0.8 m/s.

Figure 4.1: Histograms of the probability of occurrence of current magnitude for bin 1.

Considering large current magnitudes, one can observe two different regimes. In the first regime, the whole measured signal is shifted up or down. This results is a more or less constant residual current, and is found mostly in February, March, September and October. In the second regime the amplitude is larger, resulting in an alternating residual current. The system then overshoots in both directions. This regime is found most in June, July and August. See also the timeseries in Appendix D and F.

The large currents in August might be caused by stratification, fronts are known to exist in this part of the North-Sea. Throughout most of August a stratified situation was registered by the TWEms-buoy owned by the BSH[1], see figure 4.3. This buoy is situated 33km ENE from the Gemini Triaxys buoy [BSH, 2015]. Generally effects are measured later at the TWEms buoy than at Gemini, since both the residual current advecting the front and the tidal wave propagate to the East. It would be require further investigation to find a correlation between observed currents and stratification.

4.2 Current direction

The direction of the current is not always constant over depth, see figure 4.4 Especially the lower bins deviate a lot from the upper bin, although this must be taken with caution as for very low current magnitudes (<0.1 m/s) the ADCP is inaccurate in sense of direction. It has

[1]Bundesamt für Seeschifffahrt und Hydrographie, Germany

been observed that different bins can rotate in a different direction at the same time, see figure 4.5.

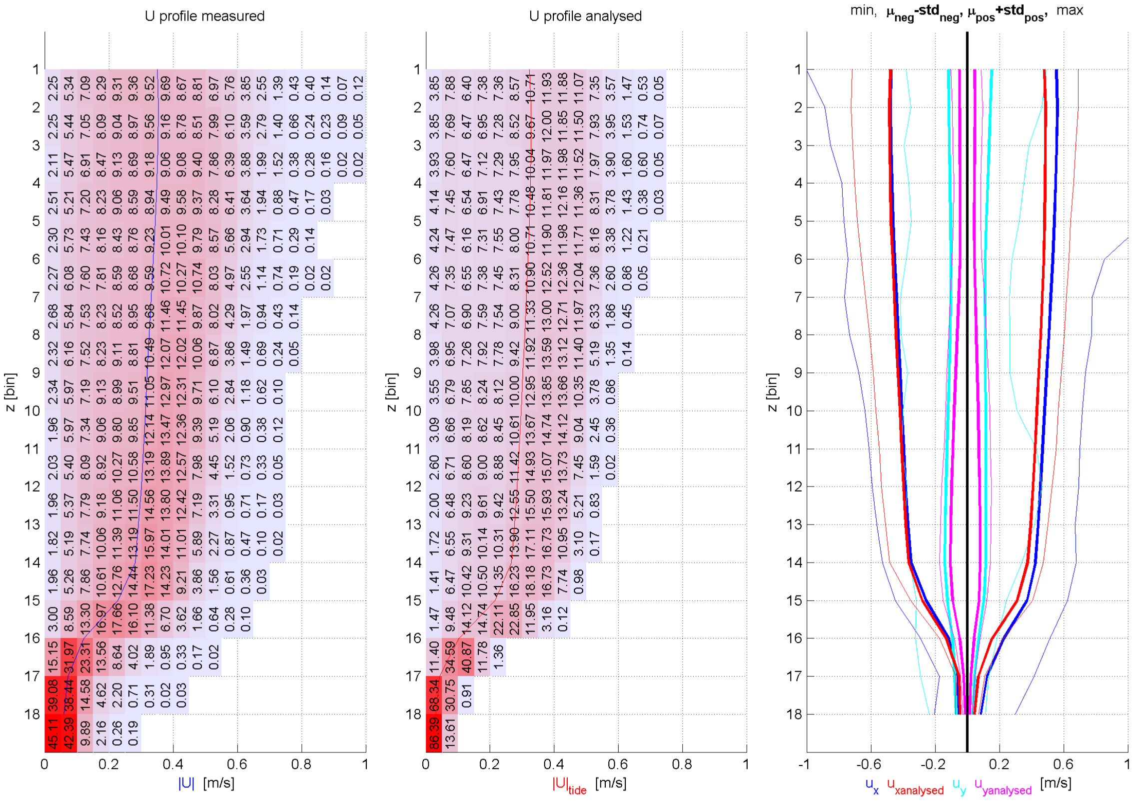


Figure 4.2: Statistical profile of the currents (totals to 100% per bin), for measured (left) and analysed data (center). Resulting profiles in x- and y-direction (right).

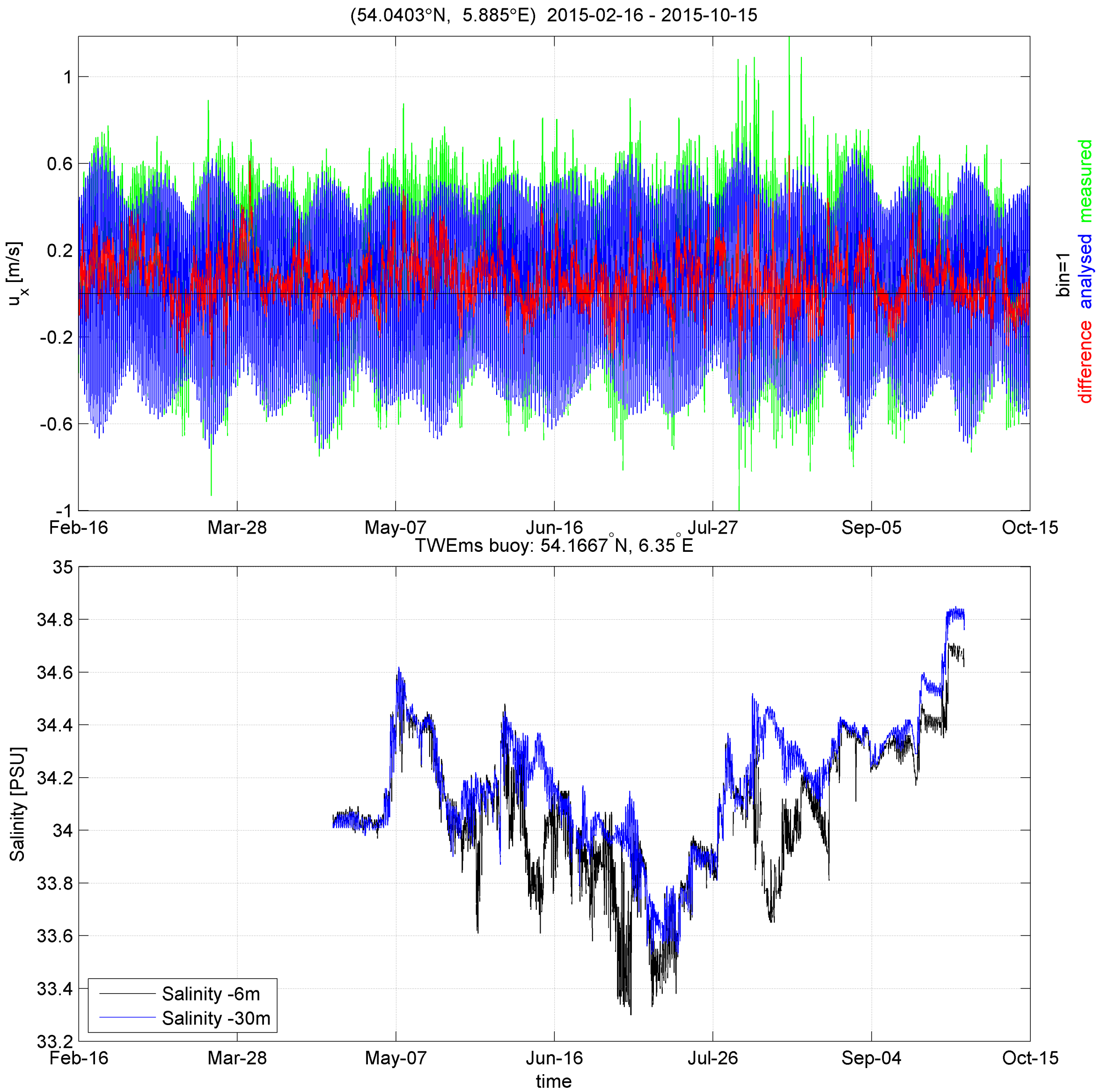


Figure 4.3: Timeseries of U_x (top) and Salinity measured by the TWEms buoy (bottom).

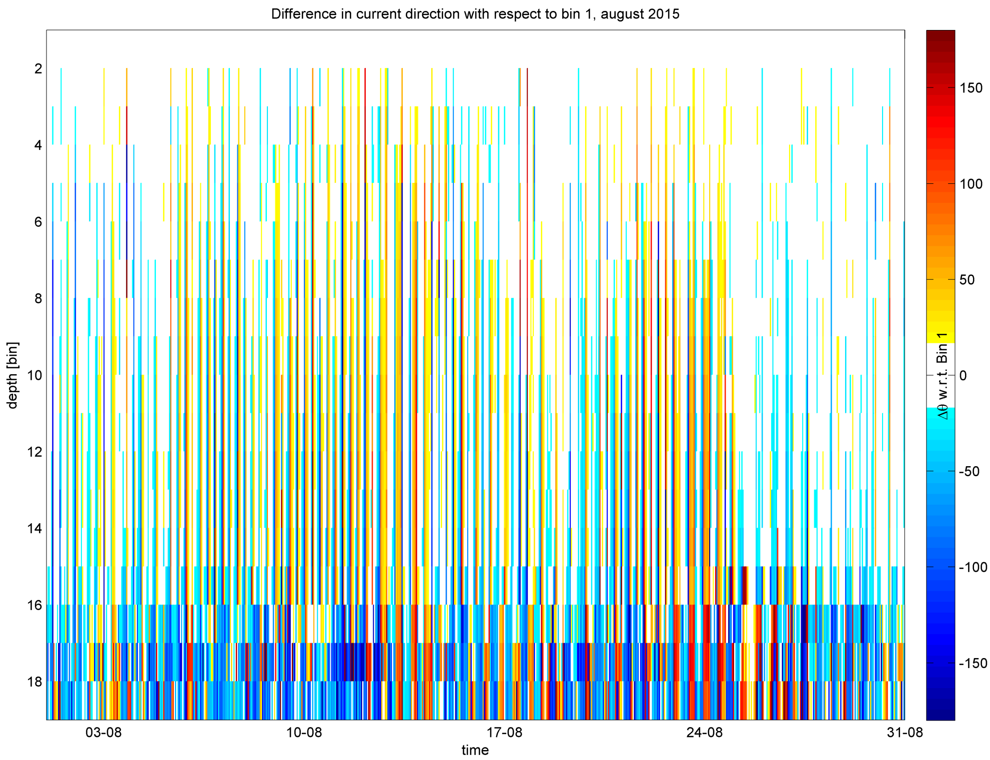


Figure 4.4: Difference of current direction w.r.t. bin 1, august 2015.

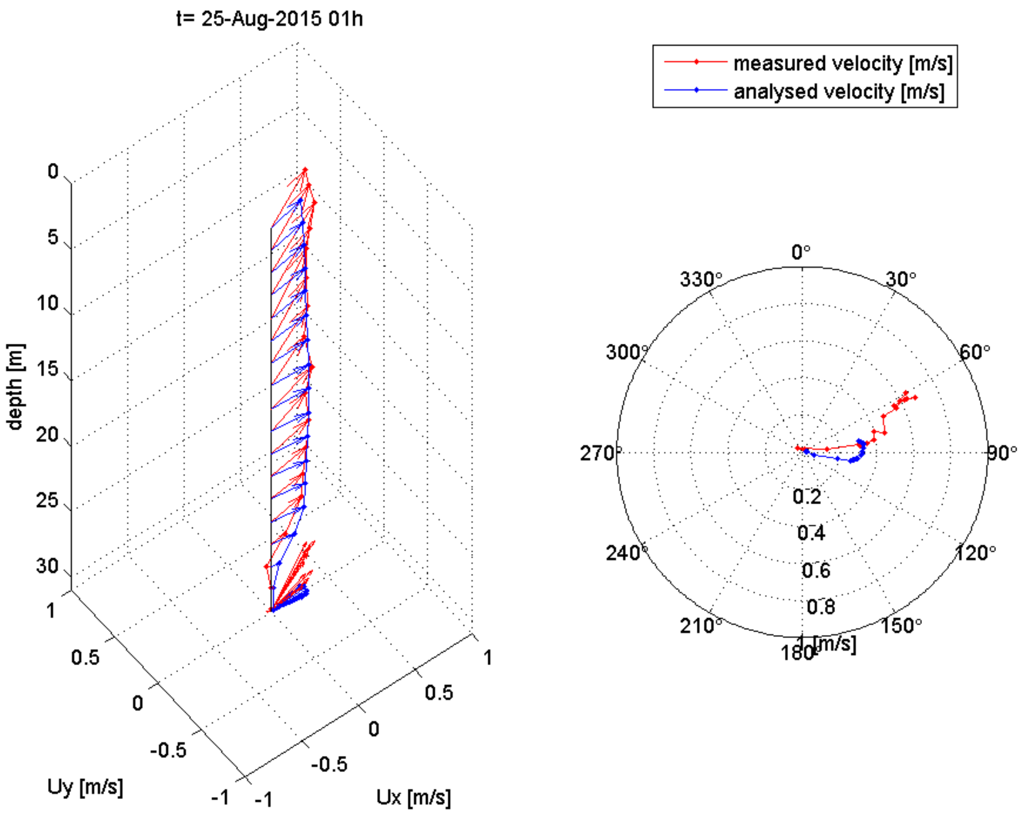


Figure 4.5: Current profile over depth (left) and top view (right). Observations 25 August 2015.

Bibliography

[Axys, 2015] Axys (2015). TRIAXYS wave and current buoy.

[BSH, 2015] BSH (2015). TWEms buoy data.

[Kashino et al., 2005] Kashino, R., Ethier, T., and Phillips, R. (2005). TRIAXYS acoustic doppler current profiler comparison study. In *OCEANS, 2005. Proceedings of MTS/IEEE*, pages 1–8. IEEE.

[MacIsaac and Naeth, 2013] MacIsaac, C. and Naeth, S. (2013). TRIAXYS next wave II directional wave sensor the evolution of wave measurements. In *Oceans-San Diego, 2013*, pages 1–8. IEEE.

[Pawlowicz et al., 2002] Pawlowicz, R., Beardsley, B., and Lentz, S. (2002). Classical tidal harmonic analysis including error estimates in matlab using t_tide. *Computers & Geosciences*, 28(8):929–937.

[van der Wel, 2015] van der Wel, P. (2015). E-mail correspondence.

Appendix A: Definitions

List of definitions used in this report:

- Analysed data: as output by t_tide.
- Current: displacement velocity.
- Direction: direction towards which the current moves.
- Magnitude: absolute value.
- Measured data: observed data.
- Residual data: (=observed-analysed).

In the scripts the following definitions are used

- Structs
  - Raw: raw data from the database.
  - D: Measured data.
  - F: Analysed data by t_tide.
  - M2: Analysed by t_tide, only M2 constituent.
  - P: Prediction from t_tide.
  - R: Residual (=D-F).
  - W: KNMI wind data.
- Fields
  - BD: Bin depth (size)
  - BIN: <useless>
  - FBD: Blanking distance
  - freq: Frequencies of analysed tidal constituents
  - LAT: Buoy latitude (GPS)
  - LON: Buoy longitude(GPS)
  - NOB: <useless>
  - meta: Meta of struct
  - name: Names of analysed tidal constituents
  - PRESS: Water pressure
  - SPS: Speed of sound
  - SeaTemp: Water temperature
  - sm: smoothed substruct
  - U: Current magnitude
  - ux: Velocity in x-direction (to East positive)
  - uy: Velocity in y-direction (to North positive)
  - uxmean: Running mean value of ux
  - uymean: Running mean value of uy
  - time: Time in Matlab datenums
  - tidecon: Tidal constituents
  - TH: Current direction
  - z: Bin numbers
- Almost all Matlab matrices are defined in a similar direction, higher dimensions only exist when applicable.
  - Dimension 1: time
  - Dimension 2: bins (depth)
  - Dimension 3: constituents
  - Dimension 4: constituent parameters

Appendix B: Settings of the Triaxys Directional Wave Buoy

The settings of the Triaxys Directional Wave Buoy are presented in this appendix.

Table B.1: Measured quantities by the Triaxys wave buoy.

Field	Quantity	Units	Source	Setting
time	Time	[UTC]	int. clock	UTC
LAT	Latitude	[°N]	GPS	
LON	Longitude	[°E]	GPS	
BD	Bin depth	[m]	Setting	2.00
FBD	Blanking Distance	[m]	Setting	1.72
SeaTemp	Sea surface temperature	[°C]	ADCP Temperature sensor	
PRESS	Water Pressure	[hPa]	ADCP Pressure sensor	
SPS	Speed of Sounds	[m/s]	ADCP	calculated
NOB	Number of Bins	[-]	Setting	20
U	Current magnitude	[m/s]	ADCP	calculated
TH	Current direction	[°]	ADCP	calculated

Table B.2: Deployment planning [van der Wel, 2015]

Quantity	Unit	Setting
Sound frequency	kHz	400
Cell Size	m	2.0
Number of cells	-	20
Average interval	s	1
Duration	s	300
Blanking Distance	m	1.72
Compass update rate	s	1
Assumed Salinity	PSU	35

Appendix C: Current-rose

This Appendix contains the “Current Roses”. For selected bins a figure is included, showing the directional probability of exceedance of current velocity. It is clearly visible that the directional spreading increases towards the bottom, whereas the magnitudes decrease.

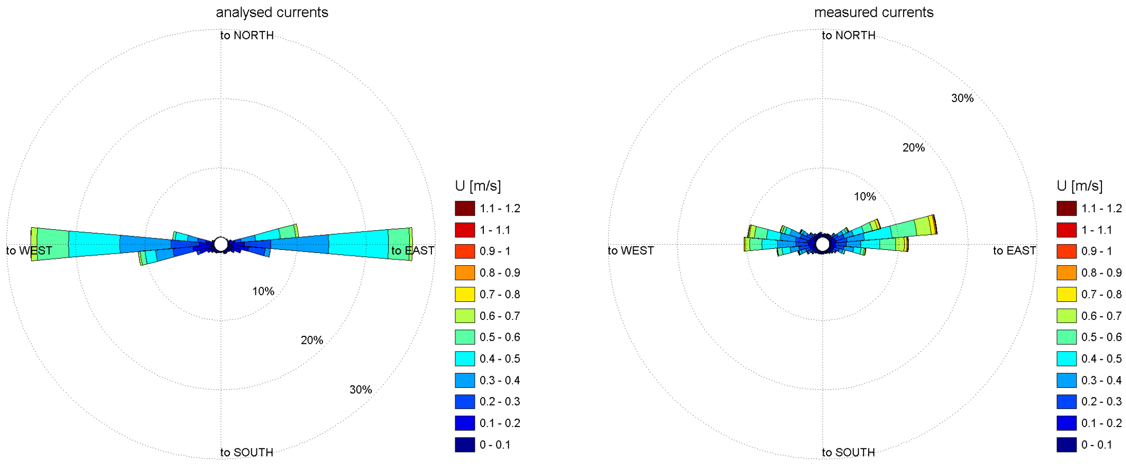


Figure C.1: Current-rose bin 01

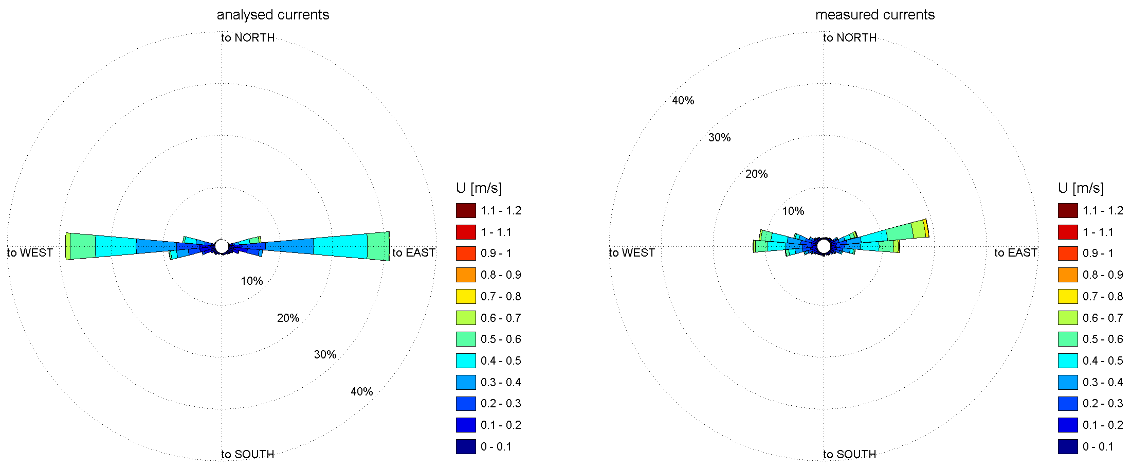


Figure C.2: Current-rose bin 05

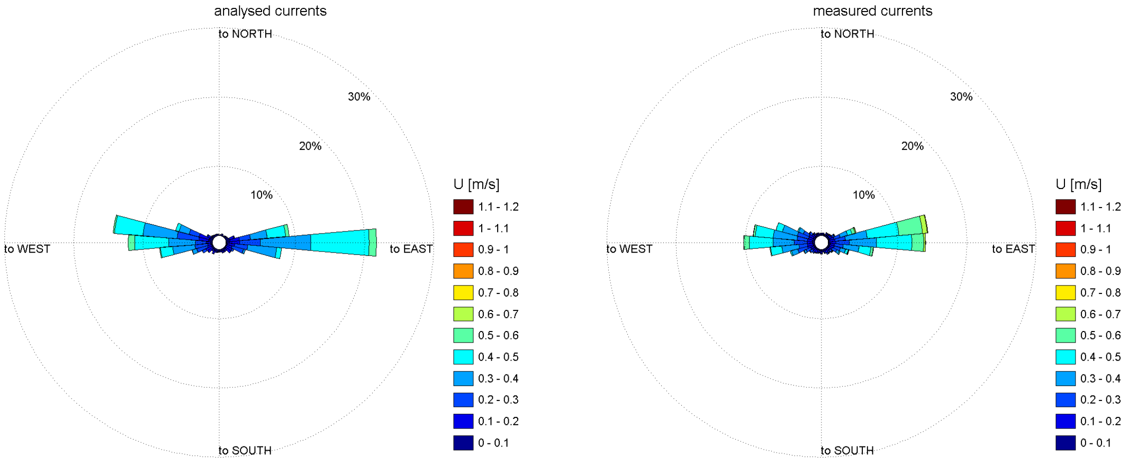


Figure C.3: Current-rose bin 10

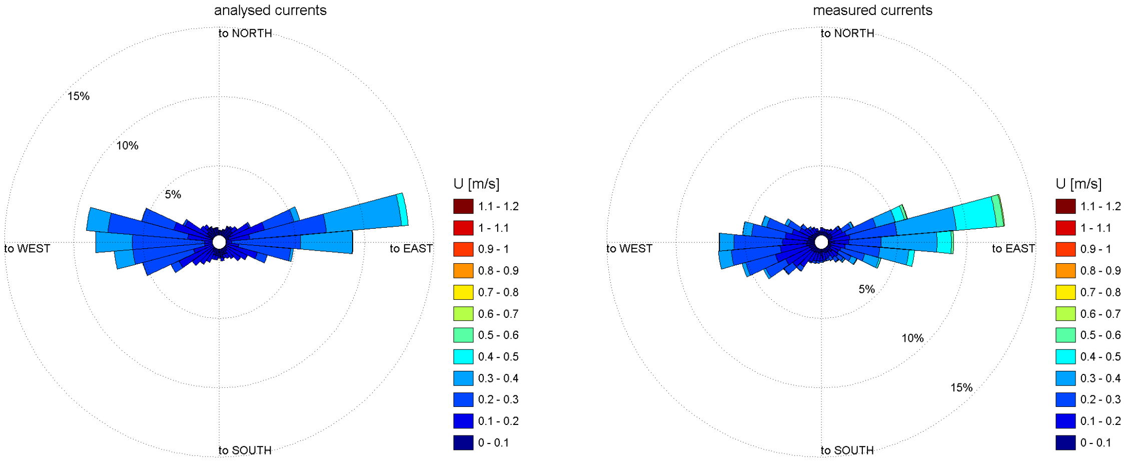


Figure C.4: Current-rose bin 15

Appendix D: Time series

This appendix contains the graphs of the time series for every month of bin 1.

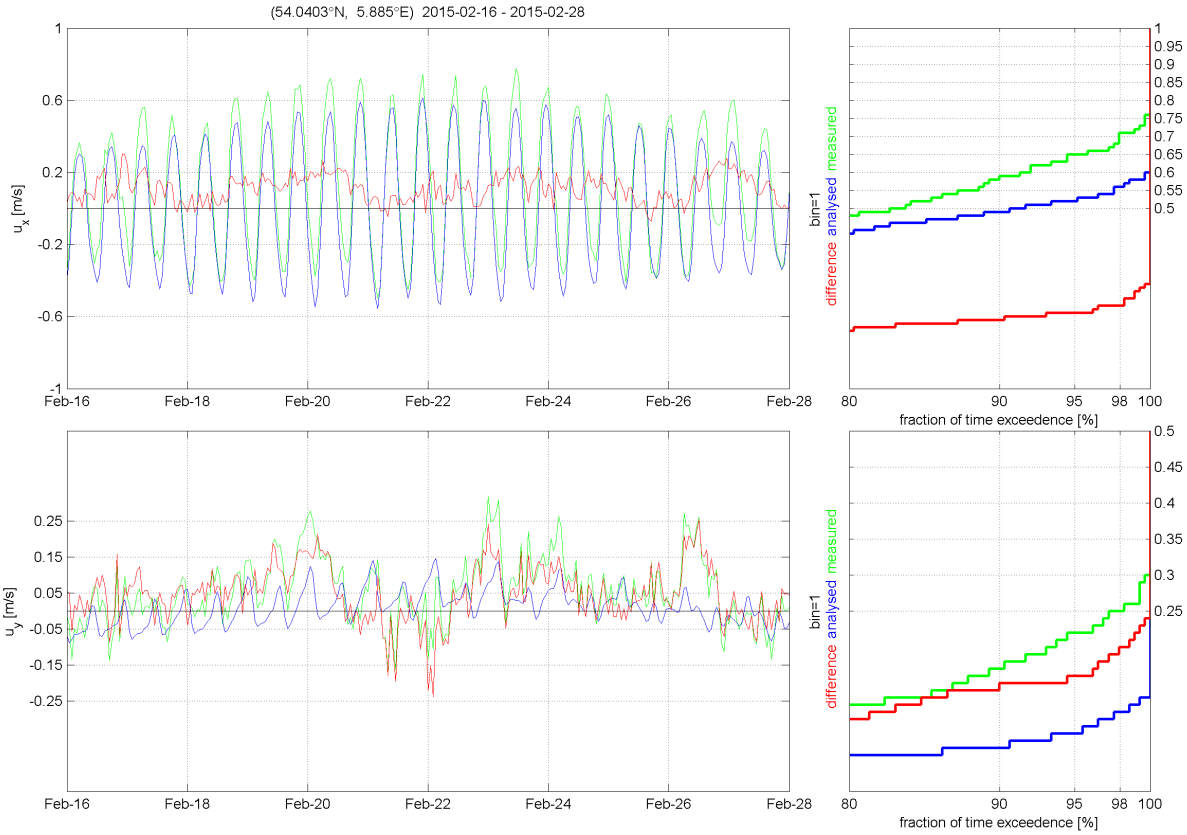


Figure D.1: Timeseries, measured and analysed, February 2015

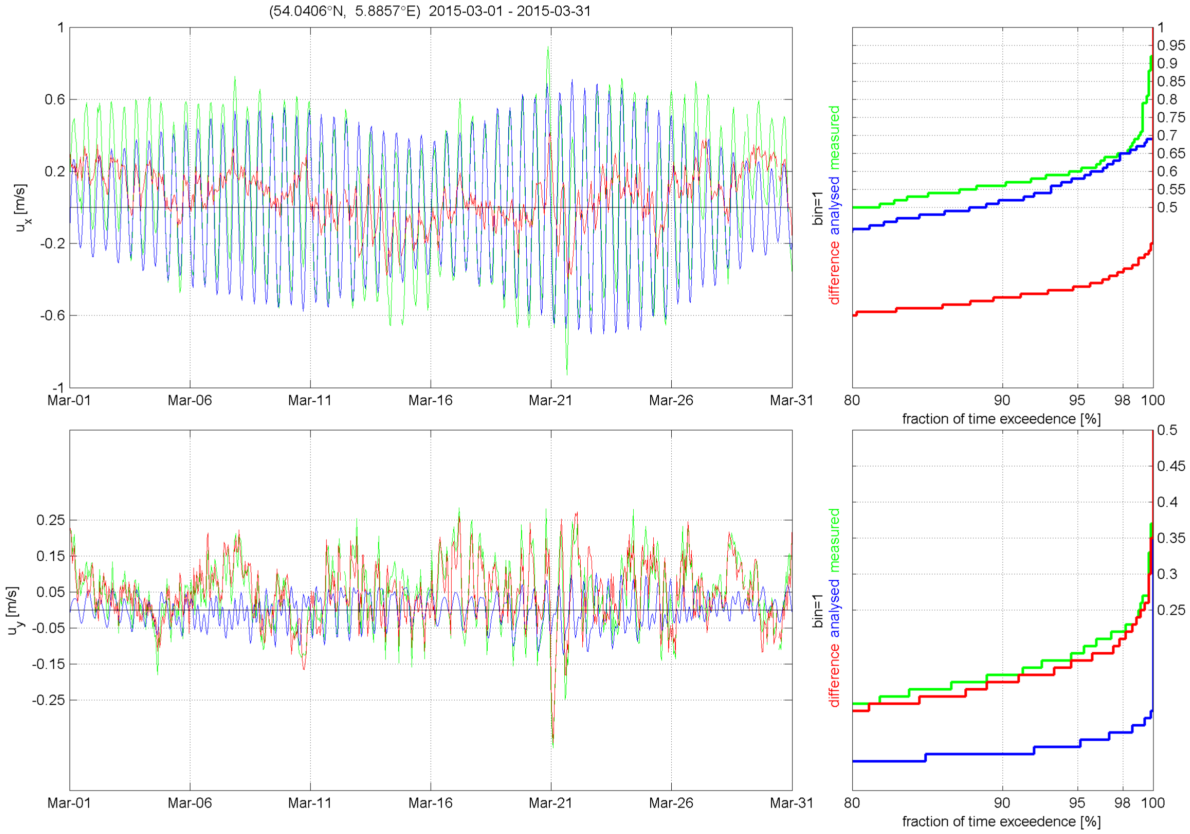


Figure D.2: Timeseries, measured and analysed, March 2015

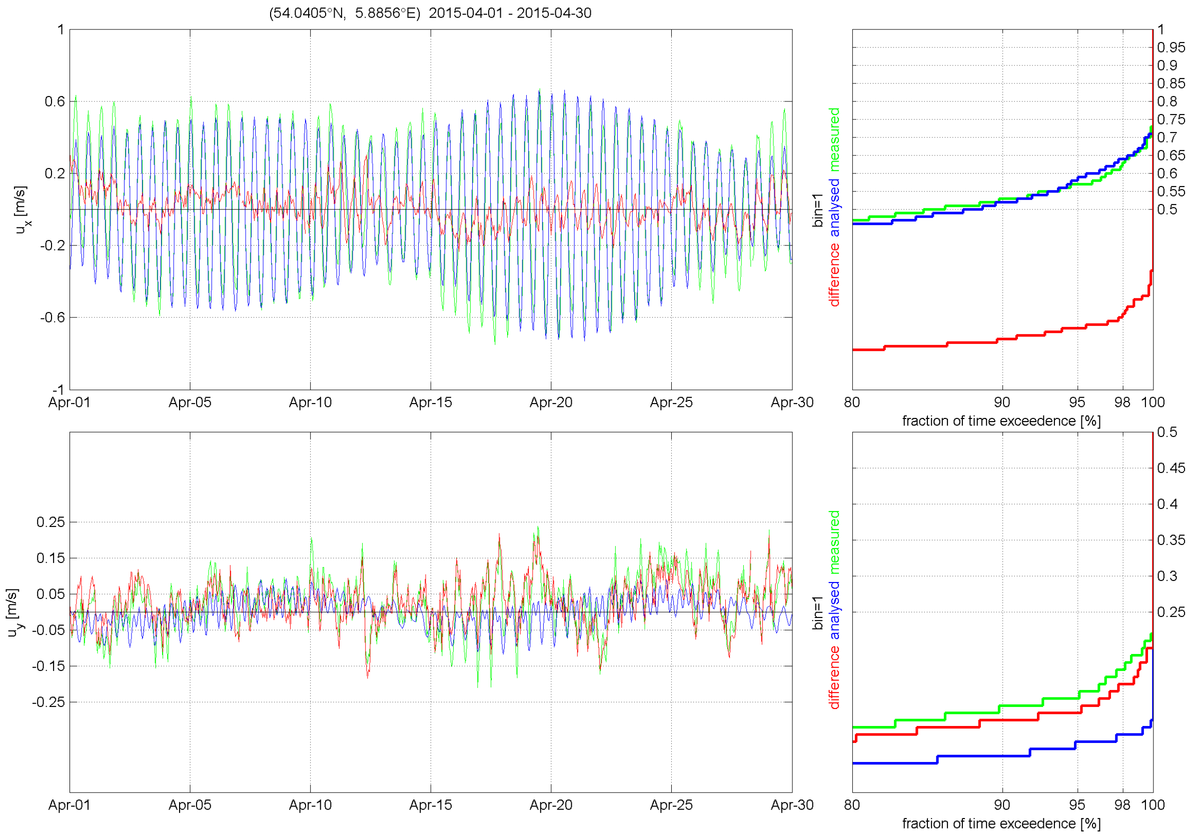


Figure D.3: Timeseries, measured and analysed, April 2015

Figure D.4: Timeseries, measured and analysed, May 2015

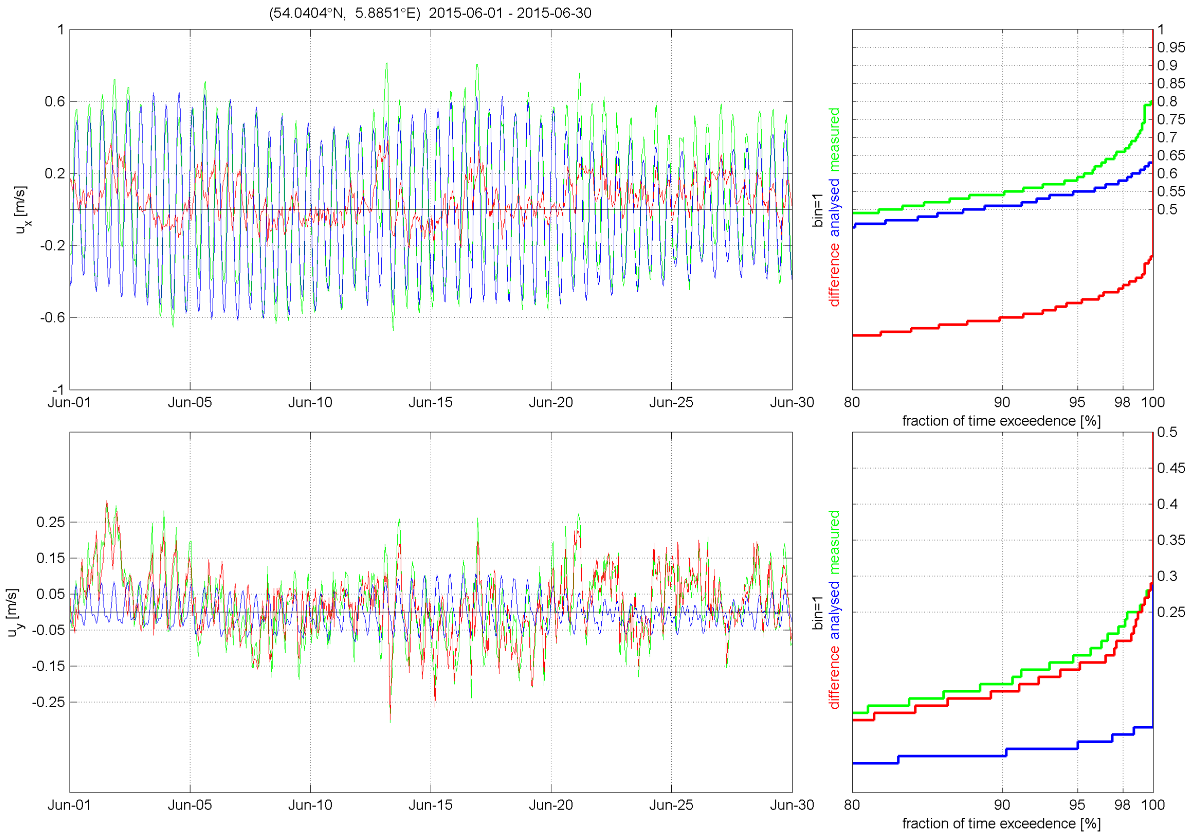


Figure D.5: Timeseries, measured and analysed, June 2015

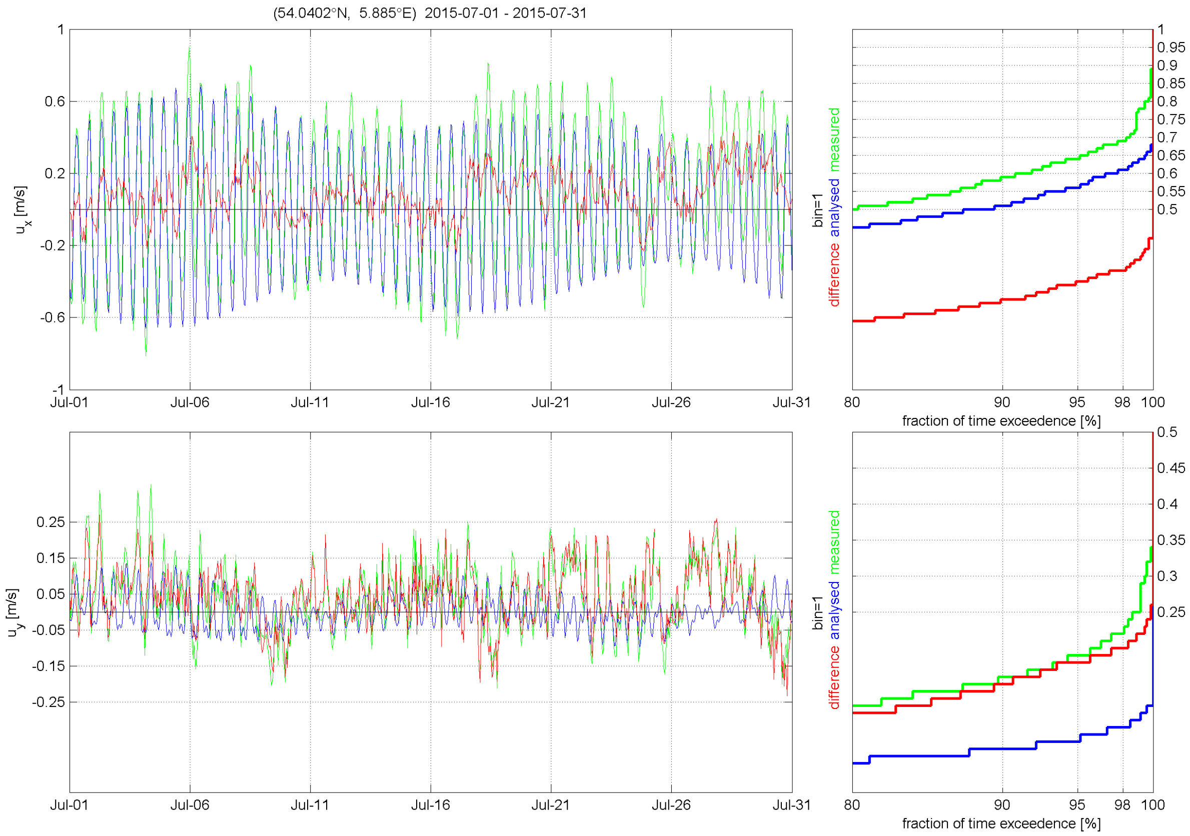


Figure D.6: Timeseries, measured and analysed, July 2015

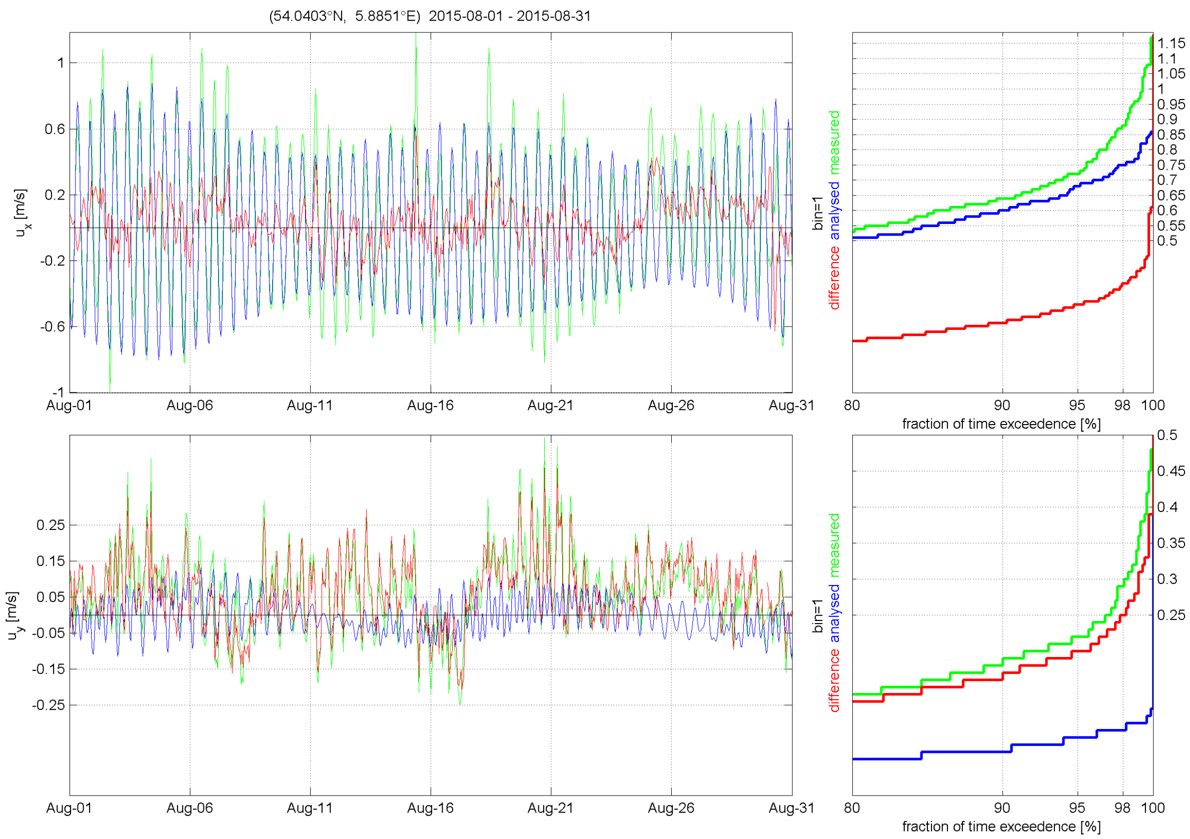


Figure D.7: Timeseries, measured and analysed, August 2015

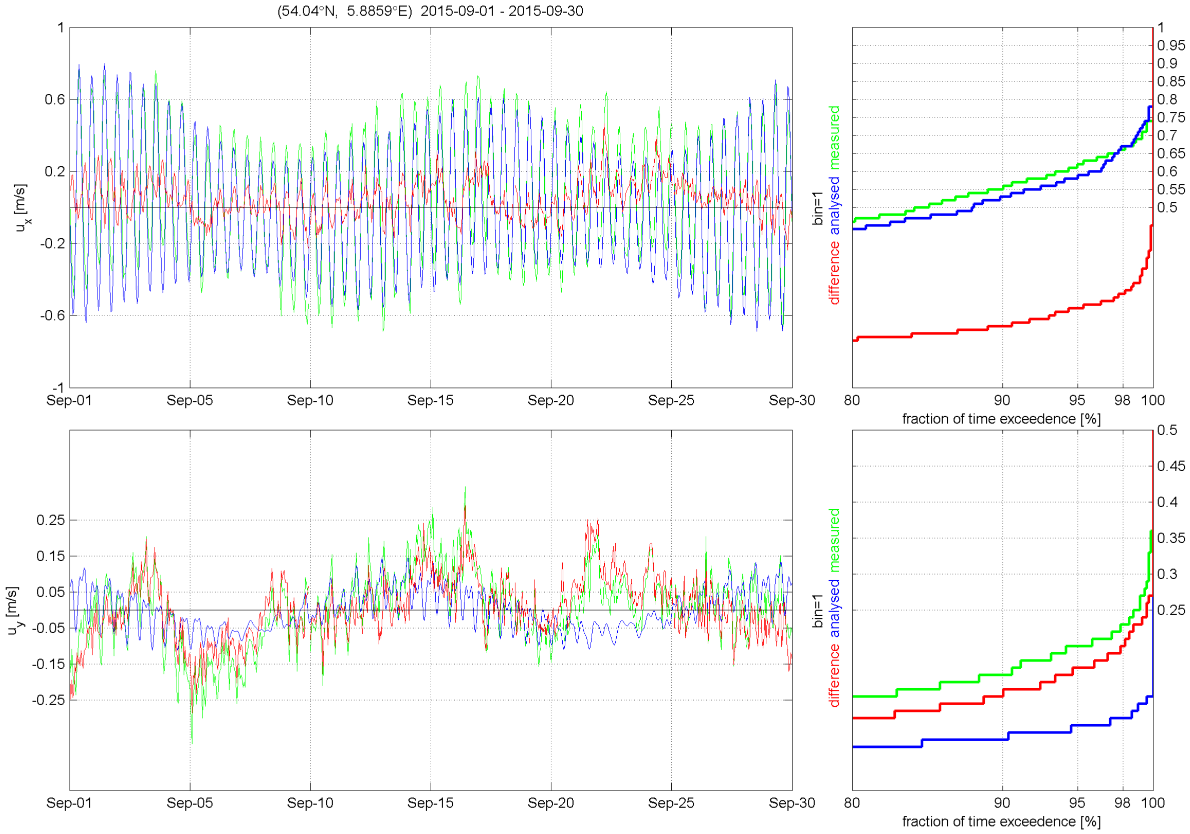


Figure D.8: Timeseries, measured and analysed, September 2015

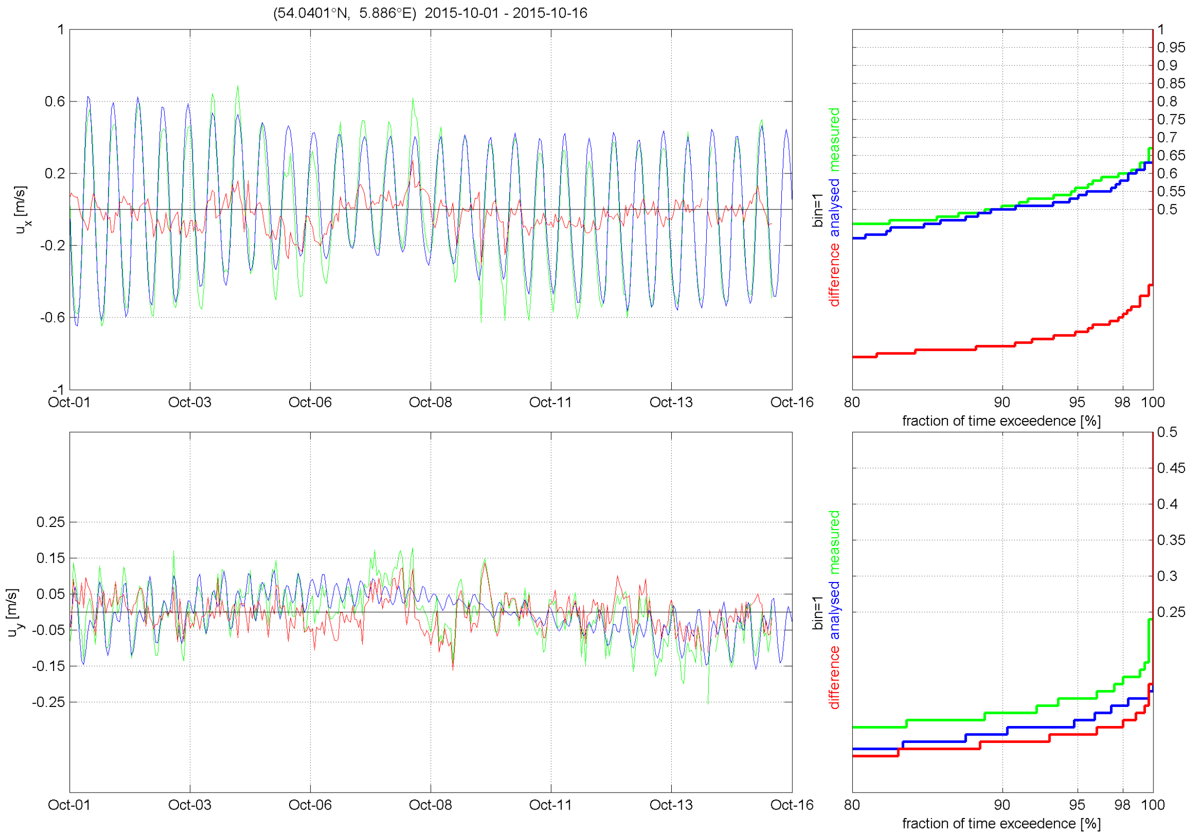


Figure D.9: Timeseries, measured and analysed, October 2015

Appendix E: Matlab code

This is an overview of all scripts made for the Gemini buoy data analysis, accompanied by a quick explanation of the contents. These Matlab tools are stored under version control in the internal Van Oord *voprojects* svn repository. For access, please contact Van Oord E&E Open Earth Data Management.

```
%Overview of GEMINI routines and functions.
%|
%|-gemini                           - Main function for gemini tidal analysis
%| |                                 for Gemini triaxys wave buoy ADCP.
%| |
%| |-gemini_settings                - Set input variables for GEMINI.
%| | |-gemini_estimate_timestep     - Estimates the timestep by rounding to
%| | |                               nearest time unit.
%| | |-gemini_estimate_timeseries   - Estimates the start and end time of a time
%| |                                 series.
%| |
%| |-gemini_load                    - Loads GEMINI data according to
%| |                                 GEMINI_SETTINGS.
%| |-gemini_smooth_signal           - Smoothes the GEMINI timeseries over
%| |                                 OPT.smooth.
%| |-gemini_tidal_analysis          - Runs T_TIDE with pre-defined parameters
%| |                                 from GEMINI_SETTINGS.
%| |
%| |-gemini_plot                    - Container for all gemini plot routines.
%| | |-gemini_pcolorplot            - Makes U(t,z) pcolor plot of the timeseries
%| | |-gemini_plot_constituents     - Plots the tidal frequencies and (major-)
%| | |                               amplitudes.
%| | |-gemini_plot_ekman            - Plot a static or moving 3D flow-profile
%| | |                               and polar top view.
%| | |-gemini_plot_ellipse_profiles - Plot tidal ellipse parameters.
%| | |-gemini_plot_ellipse_timeseries - Plot ellipse parameter timeseries for
%| | |                                 moving tidal analysis.
%| | |-gemini_plot_ellipse_timeseries_moving - Plot color ellipse parameters for
%| | |                                        moving tidal analysis.
%| | |-gemini_plot_envelope         - Plots the envelope of directional
%| | |                             - velocities.
%| | |-gemini_plot_perc_envelope    - Plots the envelope of directional
%| | |                               percentilevelocities.
%| | |-gemini_plot_phase_differences - Colorplot of directional difference with
%| | |                                respect to bin.
%| | |-gemini_plot_profiles         - Plot velocity profile statistics.
%| | |-gemini_plot_scatter          - Make scatterplot of data and analysis.
%| | |-gemini_plot_scatter_position - Plots relation between buoy position and
%| | |                               data.
%| | |-gemini_plot_scatter_currents - Scatterplot of data with colorcoding.
%| | |-gemini_plot_timeseries       - Plot timeseries of data and probability of
%| | |                               exceedance.
%| | |-gemini_plot_timeseries_xy    - Plot timeseries of data and probability of
%| | |                               exceedance in x and y-dir.
%| | |-gemini_plot_windrose         - Plots "WIND_ROSE" of tidal stream data.
%| |
%| |-gemini_compare_with_meteo      - Compare measured velocities with wind.
%| | |-gemini_meteo_plot            - Plots results from
%| |                                 gemini_compare_with_meteo.
%| |
%| |-gemini_meteo_correlation       - Correlates Wind data to stream data.
%| | |-gemini_meteo_correlation_plot - Plots correlation beteen meteo and
%| |                                  currents.
%| |
%| |-gemini_save                    - Saves mat-files of T_TIDE output for later
%| |                                 use.
%| |-gemini_load_previous           - Loads structs from a previous analysis
%| |                                 saved by GEMINI_SAVE.
```

```
%| |—gemini_save_utresh              — outputs the times and values a certain
%| |                                   value of U is exceeded.
%| |—gemini_help                     — display this file.
%|
%
%Depricated/unfinished:
%gemini_wave_timeseries              — reliminary attempt to visualise different
%                                      wave—parameters.
%gemini_meteo_windrose               — Plots a wind rose for some KNMI weather
%                                      station.
%gemini_map                          — Makes a map of the Gemini wind farm and
%                                      surroundings.
%gemini_per_month                    — Runs gemini per month (needs revision!)
%meteospul                           — Correlates Wind data to stream data.
%twems                               — Read TWEms net—cdf's.
```

Appendix F: Occurrence of extreme values

In this table an overview is given of all occurrences of a current magnitude greater than 0.80m/s, and Residual greater than 0.40m/s in bin 1, see also figure F.1 Exceedance is also observed in some other bins, but the time of occurrence would be the same.

Table F.1: Occurrences of |U|>0.80m/s and $U_{residual}$>0.4 in bin 1

Measured			Residual		
Bin	Date	|U| [m/s]	Bin	Date	|U| [m/s]
1	20-Mar-2015 20:00:00	0.842	1	20-Mar-2015 22:00:00	0.466
1	20-Mar-2015 21:00:00	0.907	1	20-Mar-2015 23:00:00	0.505
1	20-Mar-2015 22:00:00	0.815	1	05-May-2015 18:00:00	0.403
1	21-Mar-2015 15:00:00	0.841	1	09-May-2015 08:00:00	0.440
1	21-Mar-2015 16:00:00	0.940	1	09-May-2015 09:00:00	0.435
1	09-May-2015 10:00:00	0.839	1	09-May-2015 11:00:00	0.406
1	09-May-2015 11:00:00	0.885	1	09-May-2015 21:00:00	0.440
1	13-Jun-2015 17:00:00	0.819	1	17-Jun-2015 10:00:00	0.401
1	13-Jun-2015 18:00:00	0.827	1	06-Jul-2015 00:00:00	0.406
1	17-Jun-2015 08:00:00	0.820	1	06-Jul-2015 01:00:00	0.415
1	17-Jun-2015 09:00:00	0.846	1	02-Aug-2015 09:00:00	0.412
1	21-Jun-2015 11:00:00	0.801	1	02-Aug-2015 16:00:00	0.421
1	04-Jul-2015 04:00:00	0.814	1	04-Aug-2015 09:00:00	0.514
1	05-Jul-2015 22:00:00	0.801	1	06-Aug-2015 12:00:00	0.452
1	05-Jul-2015 23:00:00	0.915	1	07-Aug-2015 14:00:00	0.459
1	06-Jul-2015 00:00:00	0.824	1	11-Aug-2015 05:00:00	0.419
1	18-Jul-2015 09:00:00	0.812	1	15-Aug-2015 09:00:00	0.643
1	02-Aug-2015 08:00:00	0.861	1	15-Aug-2015 10:00:00	0.436
1	02-Aug-2015 09:00:00	1.083	1	18-Aug-2015 09:00:00	0.449
1	02-Aug-2015 10:00:00	0.916	1	18-Aug-2015 10:00:00	0.519
1	02-Aug-2015 16:00:00	1.023	1	18-Aug-2015 11:00:00	0.447
1	03-Aug-2015 10:00:00	0.974	1	20-Aug-2015 17:00:00	0.453
1	04-Aug-2015 05:00:00	0.859	1	25-Aug-2015 04:00:00	0.450
1	04-Aug-2015 09:00:00	1.068	1	25-Aug-2015 05:00:00	0.404
1	04-Aug-2015 10:00:00	1.066	1	17-Sep-2015 07:00:00	0.412
1	04-Aug-2015 11:00:00	0.857			
1	05-Aug-2015 18:00:00	0.829			
1	05-Aug-2015 19:00:00	0.844			
1	06-Aug-2015 11:00:00	0.986			
1	06-Aug-2015 12:00:00	1.091			
1	06-Aug-2015 13:00:00	0.895			
1	07-Aug-2015 00:00:00	0.895			
1	07-Aug-2015 01:00:00	0.883			
1	07-Aug-2015 12:00:00	0.888			
1	07-Aug-2015 13:00:00	0.985			
1	07-Aug-2015 14:00:00	0.964			
1	11-Aug-2015 05:00:00	0.844			
1	15-Aug-2015 09:00:00	1.190			
1	15-Aug-2015 10:00:00	0.834			
1	18-Aug-2015 09:00:00	0.992			
1	18-Aug-2015 10:00:00	1.116			
1	18-Aug-2015 11:00:00	0.971			
1	19-Aug-2015 10:00:00	0.811			
1	20-Aug-2015 05:00:00	0.837			
1	20-Aug-2015 17:00:00	0.955			
1	20-Aug-2015 18:00:00	0.820			
1	21-Aug-2015 06:00:00	0.838			
1	21-Aug-2015 12:00:00	0.819			
1	31-Aug-2015 16:00:00	0.810			

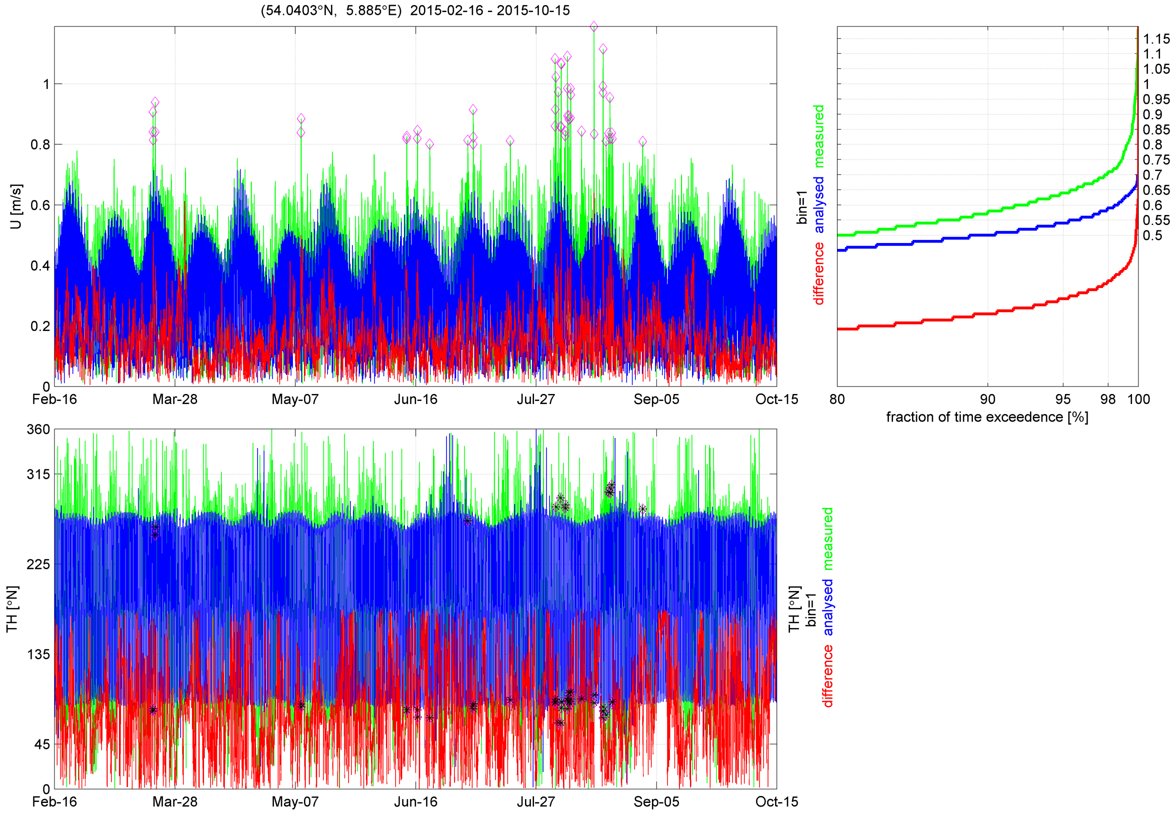


Figure F.1: Timeseries of bin 1, magenta diamonds indicate when |U| exceeded 0.8m/s.

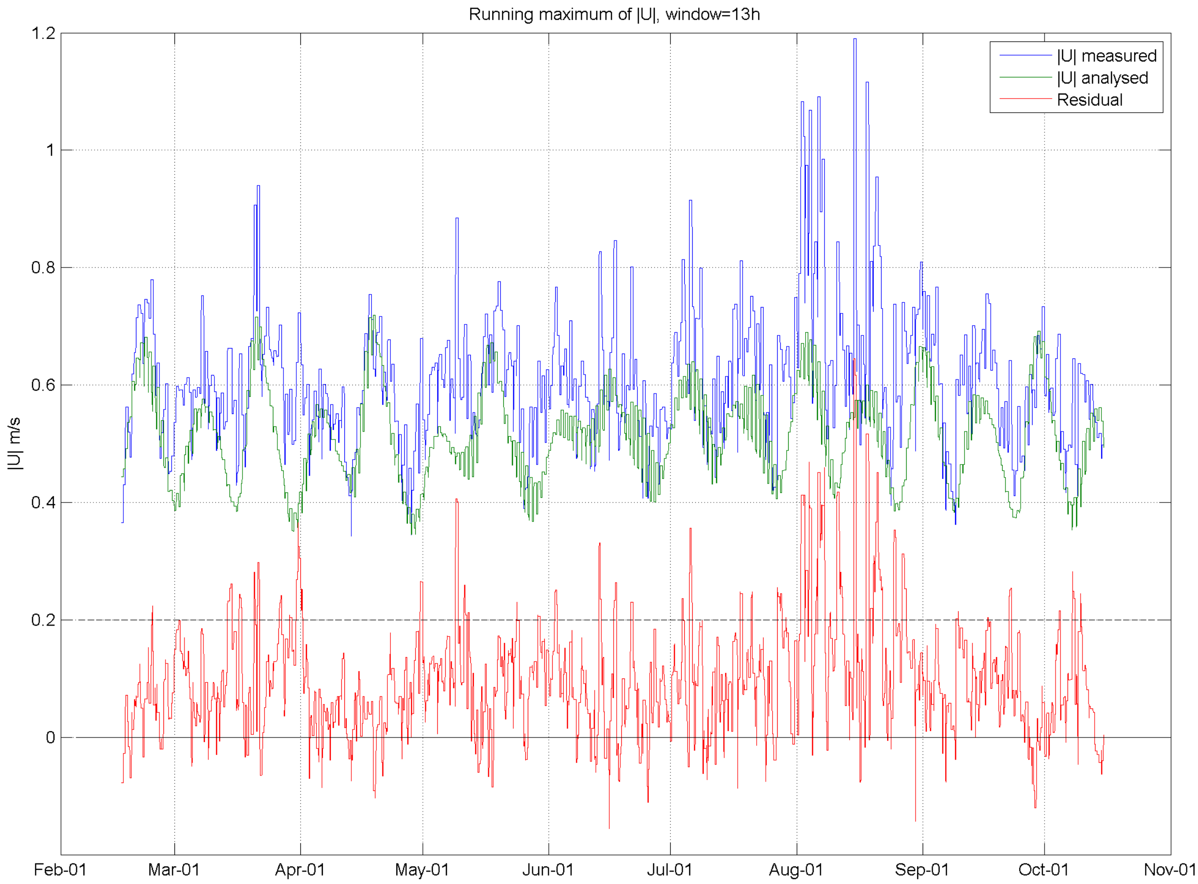


Figure F.2: Running maximum of the current magnitude, window: 13h.