BETTER SHIPS, BLUE OCEANS

Green Deal: Data driven operations

WP1 - in-service performance test protocol

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Green Deal: Data driven operations

WP1 - in-service performance test protocol

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REVIEW OF TABLES AND FIGURES

1 BACKGROUND

The determination of in-service performance of ships continues to be an important aspect, both in the acceptance of newbuilds as well as in the evaluation of existing operations. Prior to each ship's delivery, speed/power trials are conducted to verify contractual agreements on performance between the owner and the yard, as well as to verify compliance to IMO MEPC EEDI regulations. Once the vessel enters service, its speed, power, fuel consumption, etc. are nowadays often logged by a performance monitoring system and used for reporting total consumption levels. Also here, in operational use, it is of interest to evaluate not only total consumption, but to zoom in on the power requirement of the ship in different operational scenarios and compare them to e.g. predictions made before (validating predictions), or to pre-refit data (validating refit actions). This promises to offer validation of prediction techniques, emission reduction technologies and how changes in operational conditions or operational guidance impact the performance.

In-service performance testing comes with its own challenges. While one can choose to only select voyage segments with very benign weather conditions—getting rid of the associated uncertainties of weather effects on the performance—the main remaining uncertainty is the speed through water.

While during a speed/power trial reciprocal runs are performed to obtain the speed through water to an acceptable accuracy, the commercial operation does not allow spending half a day during a voyage to perform such runs. So, while a lot of challenges are similar for trials and operations, the operational constraints add a specific challenge in obtaining the speed through water during voyages.

With the issues in direct measurement still unresolved (*Hasselaar (2012), ITTC (2014), Øksnes (2021)*) alternative routes to getting speed through water in an accurate and reliable manner are explored. Work by *Giesberg (2017)* shows promise. The method can also be found in earlier work of *Premerlani (2009)*. It employs a simple vector calculus to derive the speed through water (or air as in Premerlani's work) from the speed over ground and heading vectors. This report explorers the merits of using such method to derive the speed through water during a ship's operation.

While for a reciprocal run (Figure 1-1) the vessel needs to be turned around 180 degrees, the 'zig-zag' protocol derived from Giesberg's and Premerlani's work allows steady-state runs to be carried out at much smaller heading deviations (Figure 1-1, bottom). At a heading deviation of 15 degrees, the loss of schedule is in the order of minutes for cargo vessels. It is expected however that at these lower angles, the constraints on weather limits (wind speed, wave height) is more stringent than for reciprocal runs. This task within the "Green Deal: Data driven operations" project aims to test this protocol and obtain more information on its applicability in the context of in-service ship performance.

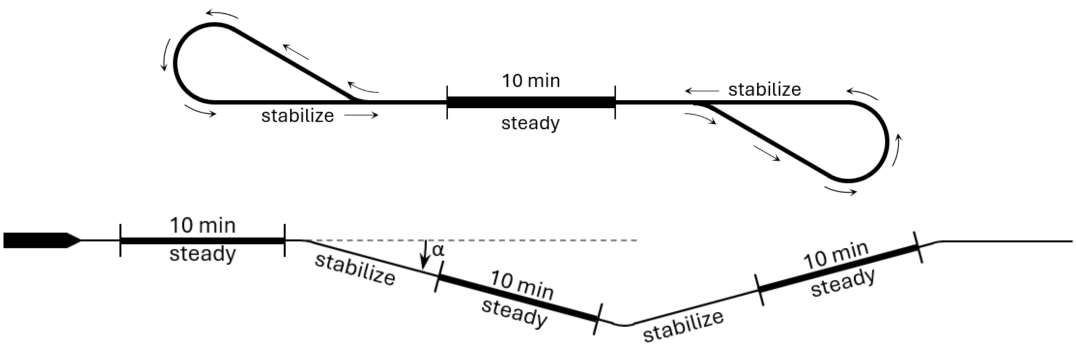

Figure 1-1: Reciprocal speed trial runs using Williamson turns (upper) and proposed in-service protocol using a zig-zag pattern (lower)

The MV MÁXIMA was kindly made available by Wagenborg Shipping to perform trials for this research.

2 EXPERIMENT SETUP

2.1 Test programme

To be able to compare results from both reciprocal speed runs and zig-zag runs, both approaches were tested on the same day, while a hydro-survey vessel was measuring the current and a wave buoy was measuring the sea state in the trial area. See Table 2-1 for an overview of the performed runs.

During the first part of the day, four zig-zag sequences of three runs per sequence were conducted (Table 2-1). Two of them starting into the dominant wind and wave direction (F), the other two in opposite direction (R). All zig-zag runs were performed at the same propeller setting (110.4 rpm, 81% pitch).

During the second part of the day, a full sequence of reciprocal speed runs were conducted in accordance with *ISO15016 (2015)* (Table 2-1). Runs were performed at four different propeller settings (74%, 81%, 89%, and 97% pitch at 110.4 rpm). The first and last run set consisted of one double run, while the second and third run set consisted of double-double runs (four single runs). Using this approach, we can perform current determination using both the iterative method (runs at multiple propeller settings spaced evenly over time), and Mean of Means method using the double-double runs (resulting in a simple mean for the double runs).

Table 2-1: Performed runs

Run no.	Run set	Run start (UTC)	Run stop (UTC)	Description	Run direction	Pitch setting
[-]	[-]	[HH:MM:SS]	[HH:MM:SS]	[Type-run set-run subno.]	F/R	%
1	1	06:01:26	06:11:26	ZZ-1-1	F	81%
2	1	06:19:18	06:29:18	ZZ-1-2	F	81%
3	1	06:37:25	06:47:25	ZZ-1-3	F	81%
4	2	07:02:32	07:12:32	ZZ-2-1	R	81%
5	2	07:18:55	07:28:55	ZZ-2-2	R	81%
6	2	07:36:25	07:46:25	ZZ-2-3	R	81%
7	3	08:02:50	08:12:50	ZZ-3-1	F	81%
8	3	08:20:34	08:30:34	ZZ-3-2	F	81%
9	3	08:39:37	08:49:37	ZZ-3-3	F	81%
10	4	09:08:53	09:18:53	ZZ-4-1	R	81%
11	4	09:25:45	09:35:45	ZZ-4-2	R	81%
12	4	09:46:30	09:56:30	ZZ-4-3	R	81%
13	1	10:28:31	10:38:31	SP-1-1	F	74%
14	1	11:03:52	11:13:52	SP-1-2	R	74%
15	2	11:30:18	11:40:18	SP-2-1	F	81%
16	2	12:04:24	12:14:24	SP-2-2	R	81%
17	2	12:36:45	12:46:45	SP-2-3	F	81%
18	2	13:02:40	13:12:40	SP-2-4	R	81%
19	3	13:30:48	13:40:48	SP-3-1	F	89%
20	3	14:02:52	14:12:52	SP-3-2	R	89%
21	3	14:31:05	14:41:05	SP-3-3	F	89%
22	3	15:00:20	15:10:20	SP-3-4	R	89%
23	4	15:30:50	15:40:50	SP-4-1	F	97%
24	4	15:59:35	16:09:35	SP-4-2	R	97%

2.2 Measurement equipment

The used equipment on the MV MAXIMA as well as deployed from the hydro-survey vessel are detailed below.

Setup on board MV MÁXIMA

Shaft power

The shaft power was measured by installing MARIN's Power Measurement System (PMS). This system measures the propeller shaft's torsional strain using a full-bridge strain gauge glued to the shaft. Using the shaft dimensions and material properties, the shaft torque can be calculated. Multiplying by shaft speed measured by an optical pickup, the shaft power can be obtained.

GNSS

The ship's speed over ground, course over ground, heading, latitude and longitude are measured by dedicated twin D-GPS antenna installed on the bridge top.

Wind

The apparent (relative) wind speed and direction are measured by dedicated ultrasonic anemometer installed in the ship's mast.

Figure 2-1: Ultrasonic anemometer installed in the ship's mast, and twin D-GPS (encircled) installed on the bridge top

Rudder angle

The ship's rudder angle was measured by a wire sensor attached to the rudder stock, on the steering gear.

Motions

The ship's motions were measured by a motion reference unit (MRU) installed on the bridge.

In-situ conditions

The following equipment was used from a hydro-survey boat (G2-Xception) drifting in the area during the tests:

<u>Current</u>

The current in the test area was measured by an ADCP deployed from the hydro-survey boat. After processing the boat's slowly changing position and orientation, the earth-fixed current velocity and direction are delivered for different depths. The depth range from the surface up to the vessel's draught is averaged to yield the current experienced by the vessel.

Figure 2-2: The hydro-survey boat in the test area, as seen from the MV MÁXIMA upon passing

<u>Waves</u>

A free-drifting wave buoy was deployed from the hydro-survey boat. The sea state in terms of directional spectra and statistical values such as significant wave height, period, and direction are obtained.

Figure 2-3: Wave buoy used during the tests

3 RESULTS

3.1 Reciprocal runs

The reciprocal runs are analysed using STAIMO in accordance with ISO15016:2015. Both the Mean of Means method and the Iterative Method are used to calculate the current component in ship's direction, see Figure 3-1 for the results.

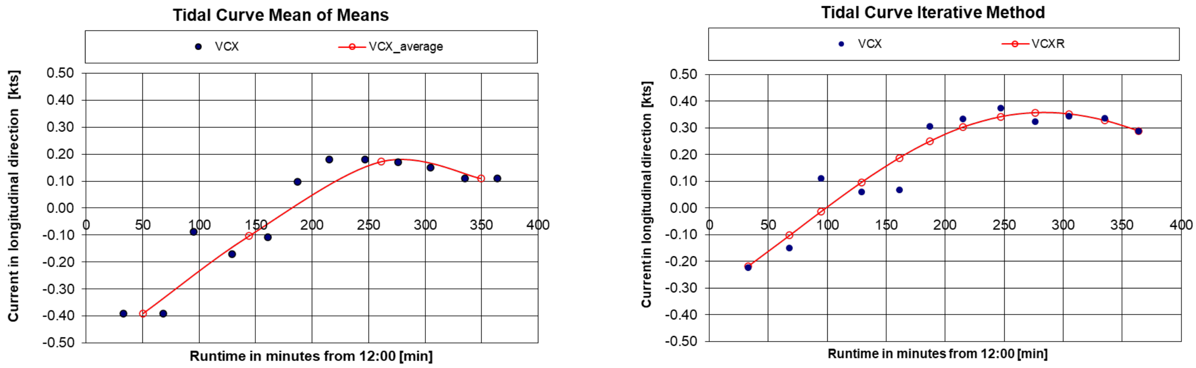

Figure 3-1: Current in ship's direction from MoM (left) and Iterative (right) methods

3.2 Zig-zag runs

Using the zig-zag approach, the speed through water and current are calculated as in the vector representation in Figure 3-2. Here the time-averaged values over the steady runs are taken for speed over ground and course over ground to yield ground speed vector $\vec{V}_G$, while the heading is used to make a unit heading vector $\vec{H}$. The speed through water is then obtained from a run pair in two different directions as:

$$\left\|\vec{V}_W\right\| = \frac{\left\|\vec{V}_{G2} - \vec{V}_{G1}\right\|}{\left\|\vec{H}_2 - \vec{H}_1\right\|}$$

From this, the current vector $\vec{V}_C$ can be obtained via vector calculus (see also Figure 3-2):

$$\vec{V}_C = \vec{V}_G - \vec{V}_W$$

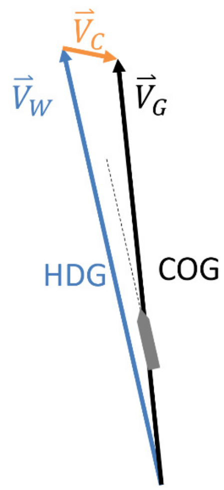

Figure 3-2: Vector calculation of current and speed through water

For each run set, the results from different run pairs can be visualised as in Figure 3-3. Here, the average current vector from all run pairs in the run set is also depicted. In this vector visualisation one can judge both the direction and magnitude of the average current vector and compare this to the average of the ADCP current measurements in black.

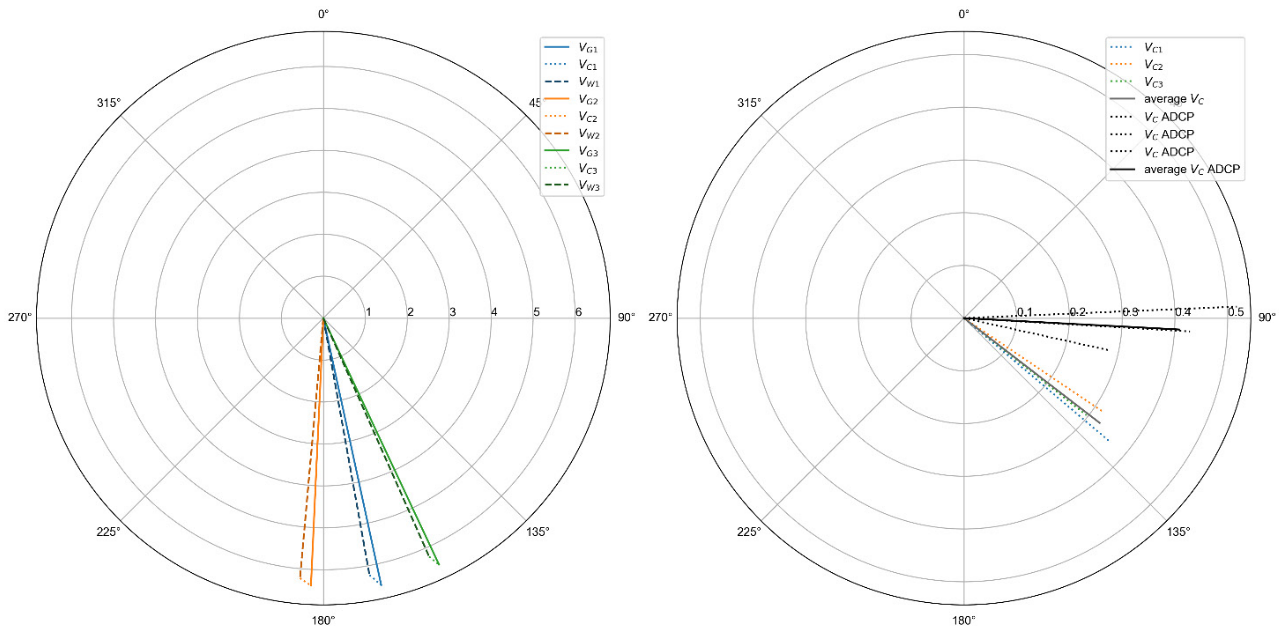

Figure 3-3: Example result of zig-zag analysis

3.3 Comparison to current measurements

The results of the different methods can be compared to the measured current from the ADCP. As the reciprocal runs only yield the current component in the ship's direction, all other results are decomposed in that direction as well. The results are shown in Figure 3-4. As can be seen, the results from the reciprocal runs (second part of the day, in green) give a satisfactory comparison to the ADCP measurements, especially using the iterative method. The results from the zig-zag runs show larger deviation from the ADCP reference.

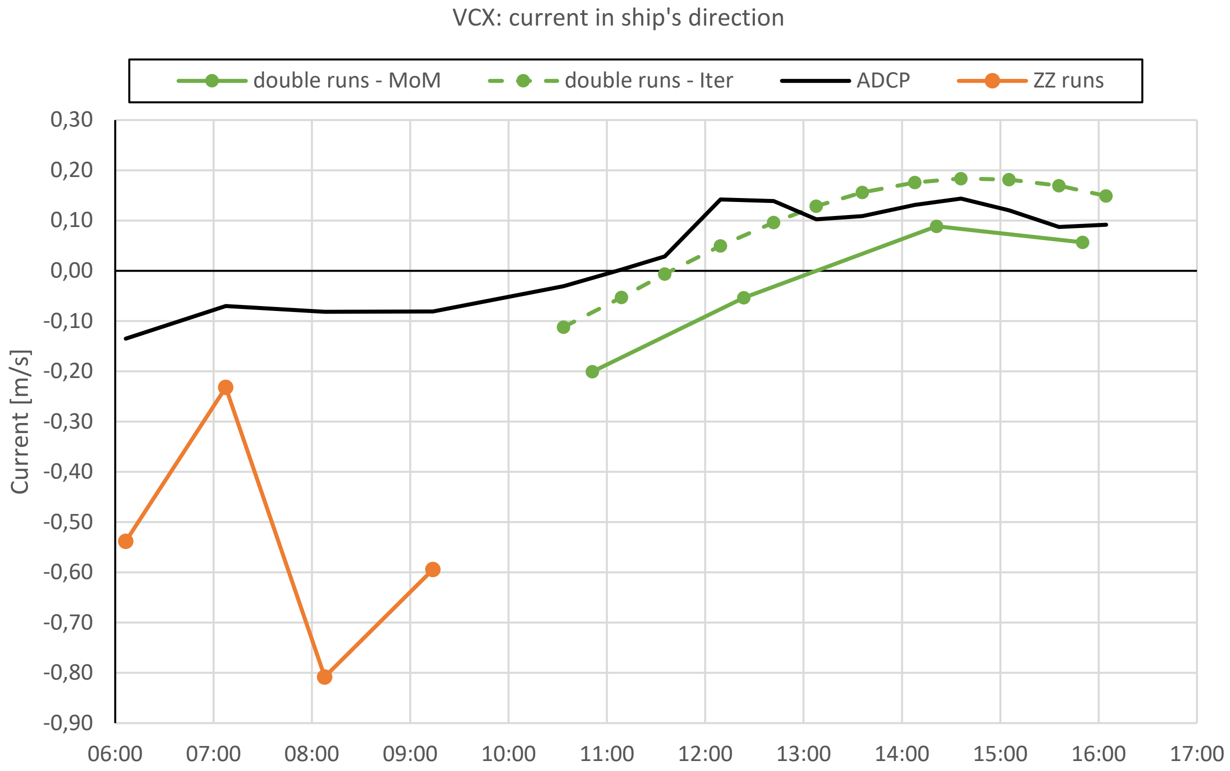

Figure 3-4: Current in ship's direction, comparison between different methods and ADCP measurements

Discussion

It can thus be concluded that, for this ship in these conditions (Beaufort 3, sea state 3, significant wave height between 0.7 - 0.9 m) the zig-zag protocol does not yield results of sufficient accuracy (target: within 0.1 kn / 0.05 m/s). From the weather corrections made in the analysis of the reciprocal runs, we can observe the wind effect to be the dominant effect, at about 8% of power when heading into the wind. The wave effect is about 3% of power.

To find practical limits of application of the zig-zag protocol (in terms of maximum wind speed and/or wave height), further experimental work is needed to observe more situations (ship, weather, current conditions). A desk study modelling—as far as possible—all disturbing effects can offer the possibility to systematically investigate the sensitivities.

4 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions summarise the findings of the present project:

- Both reciprocal runs according to ISO15016 as novel steady-state zig-zag runs have been tested on board of the MV MÁXIMA. At the same time, the current conditions and sea state were recorded in the area by means of a hydro-survey vessel equipped with ADCP and a wave buoy, respectively.
- In mild conditions of Beaufort 3, sea state 3 (significant wave height between 0.7 - 0.9 m), the following can be observed:
  - The current estimate from the reciprocal protocol reproduce the current measured by ADCP within 0.09 m/s if the iterative method is used, and within 0.17 m/s if the Mean of Means method is used. Using the iterative method, the target accuracy of 0.05 m/s was achieved for about half the runs.
  - When comparing current estimates from the zig-zag runs to the current measured by ADCP differences between 0.20 to 0.73 m/s are observed.
- From the above observations it can be concluded that while the results from the reciprocal runs using iterative method is mostly satisfactory, the results from the zig-zag runs are not as accurate.
- It is expected that the zig-zag runs will perform better in milder weather conditions, and in general need a lower limit on wind speed and wave height than the reciprocal run protocol. To find practical limits of application of the zig-zag protocol, further experimental work is needed to observe results at more conditions (ship, weather, current conditions). A desk study modelling all expected disturbing factors systematically could also yield valuable insights.

Wageningen, July 2025
MARITIME RESEARCH INSTITUTE NETHERLANDS

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Manager Performance at Sea

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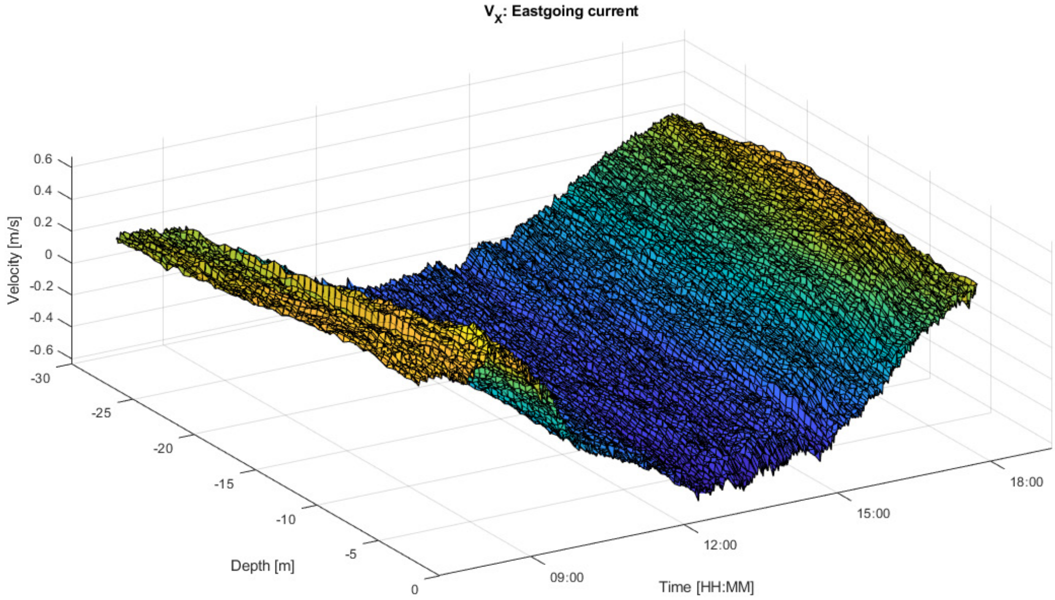
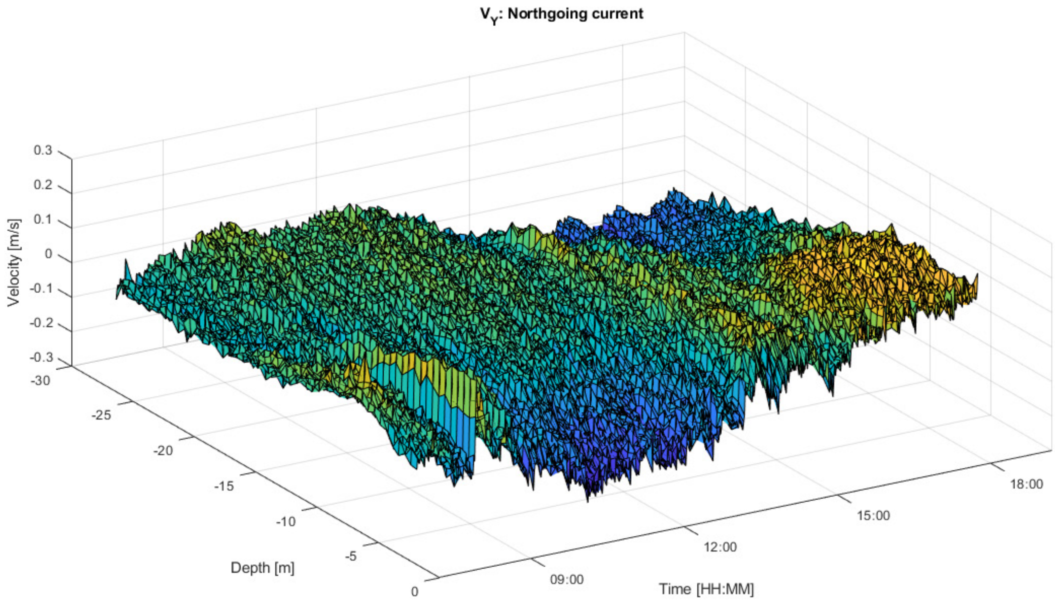
APPENDICES

APPENDIX 1 WEATHER CONDITIONS

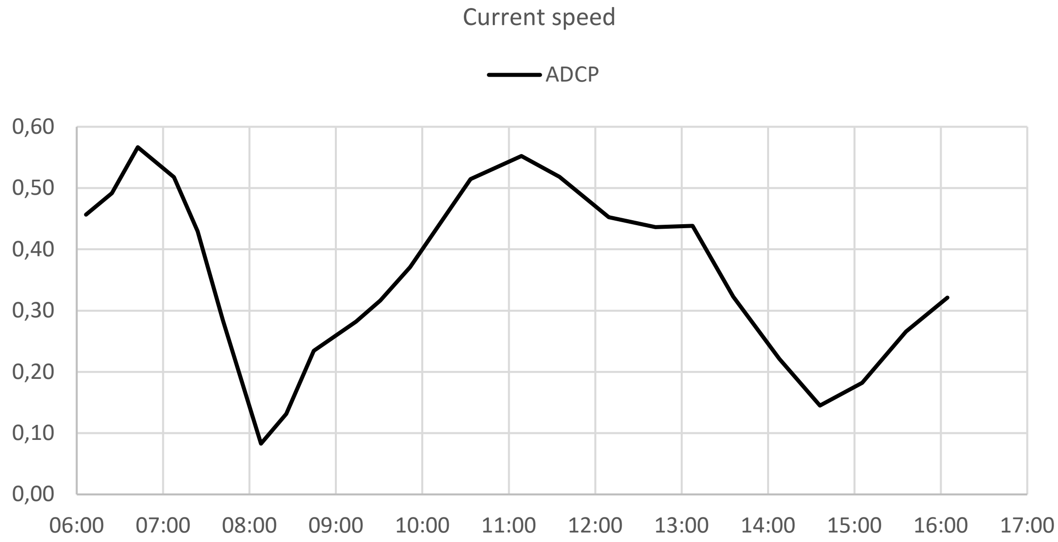
Measured current (ADCP)

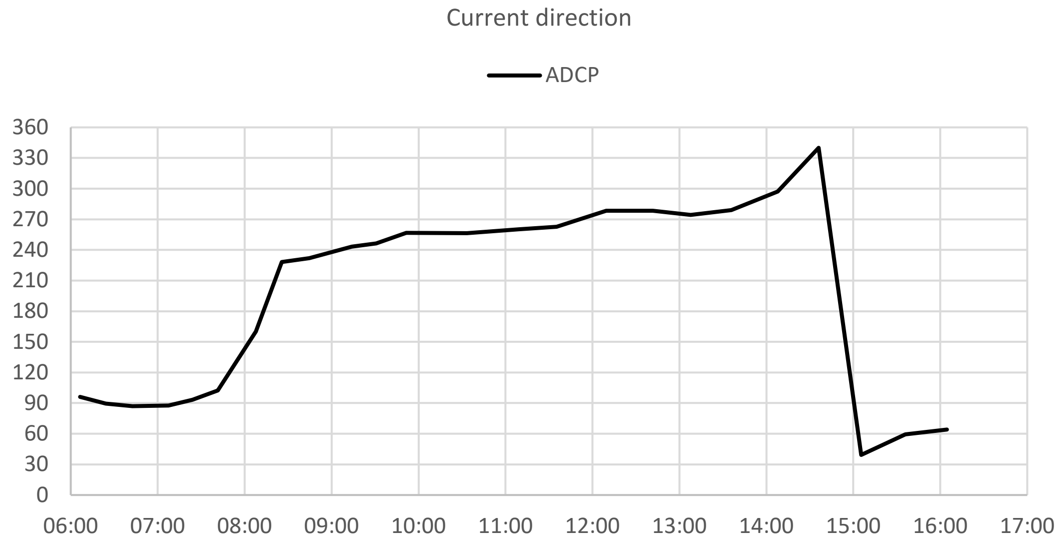
Full results over depth



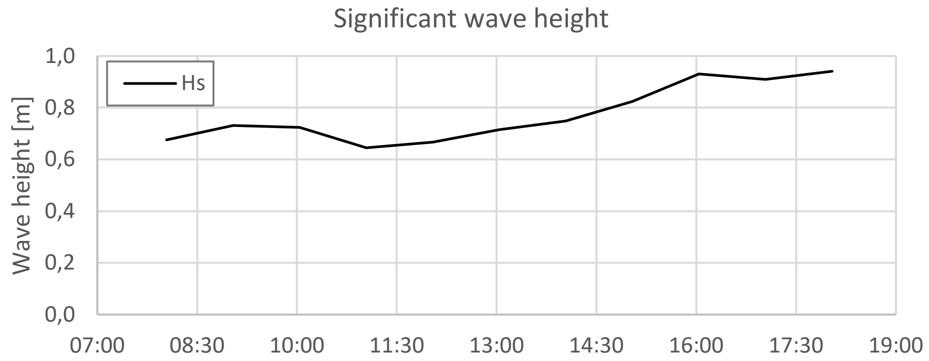


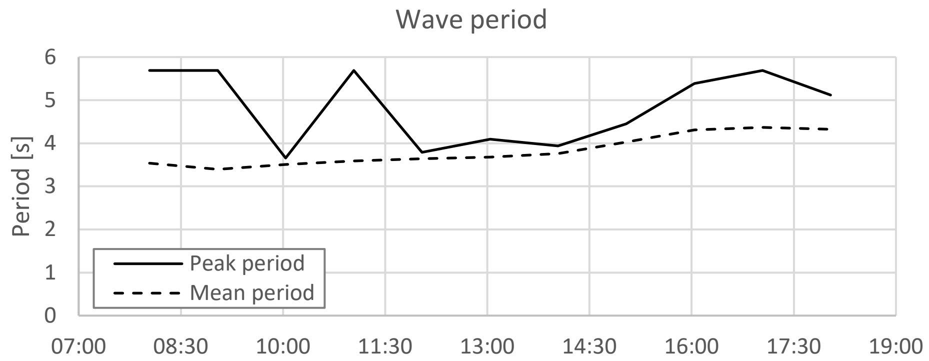
Averaged result between surface to 5.17 m depth

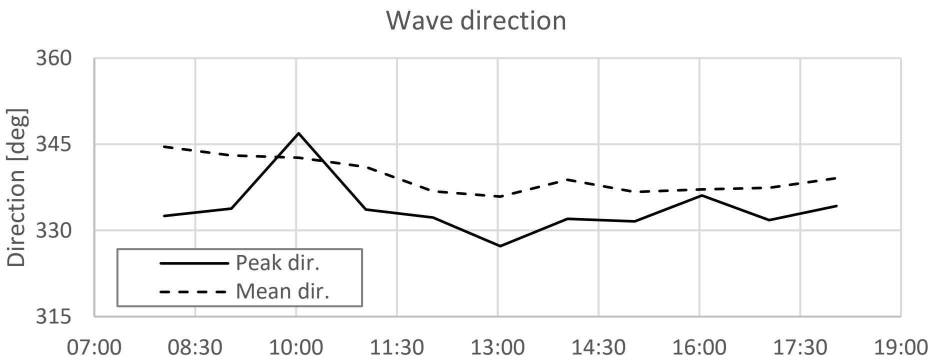


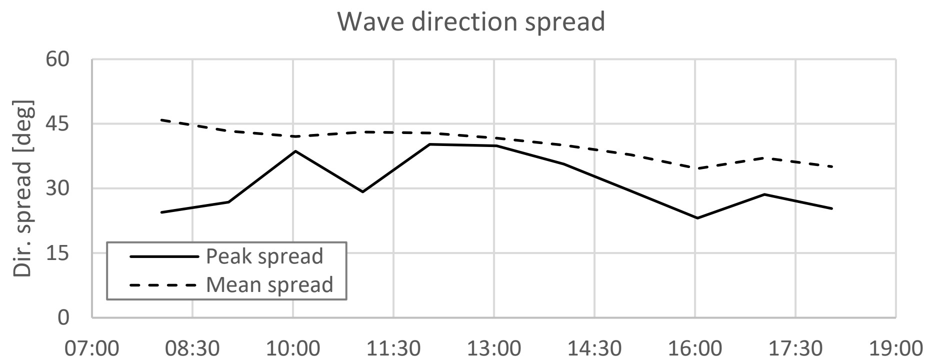


Measured wave (wave buoy)



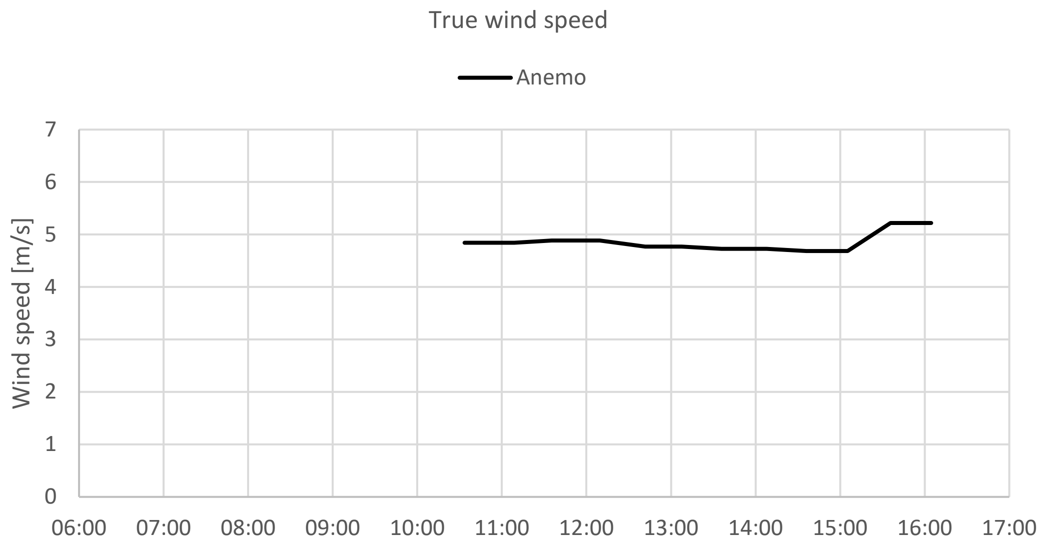


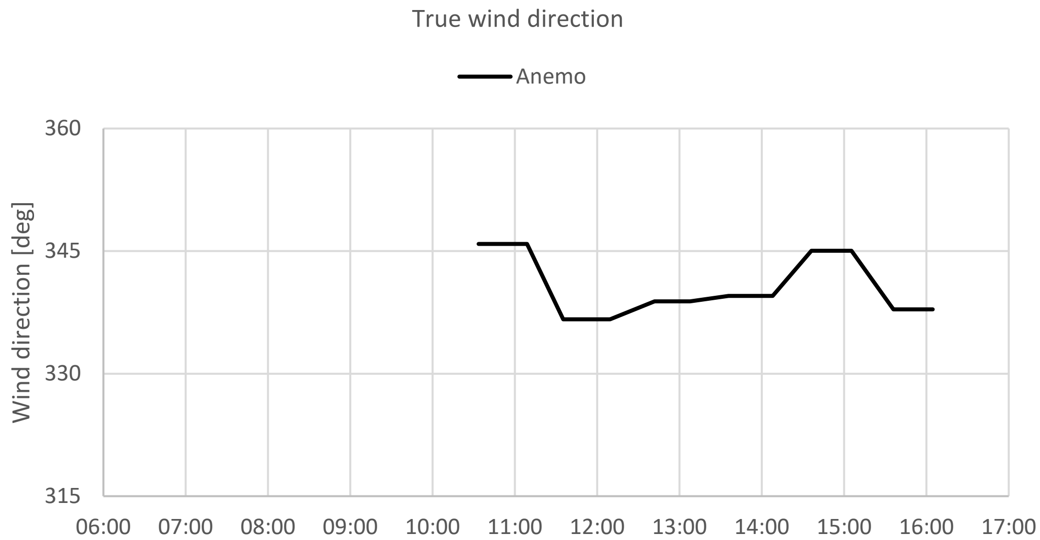




Measured wind (anemometer)

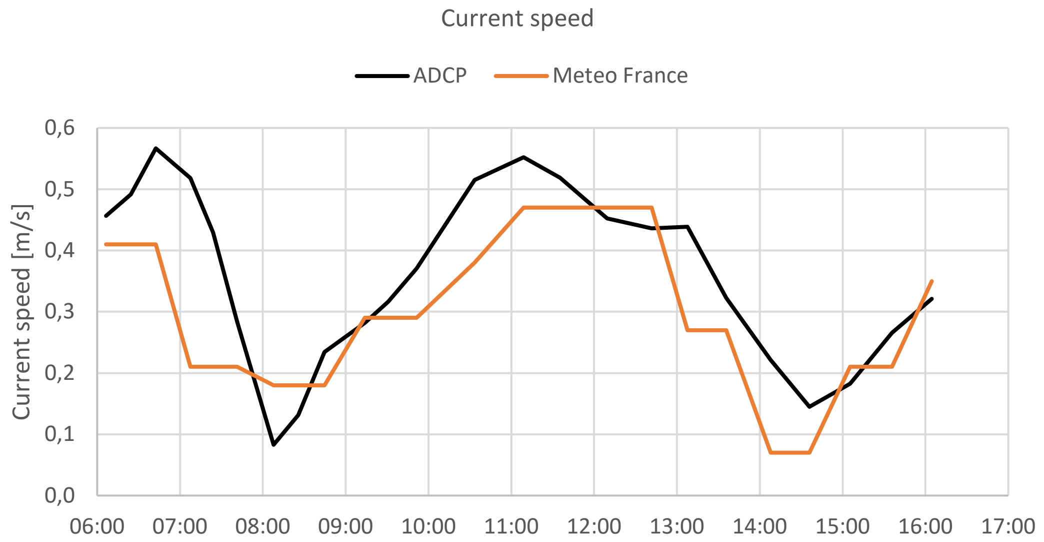
True wind analysed from reciprocal runs

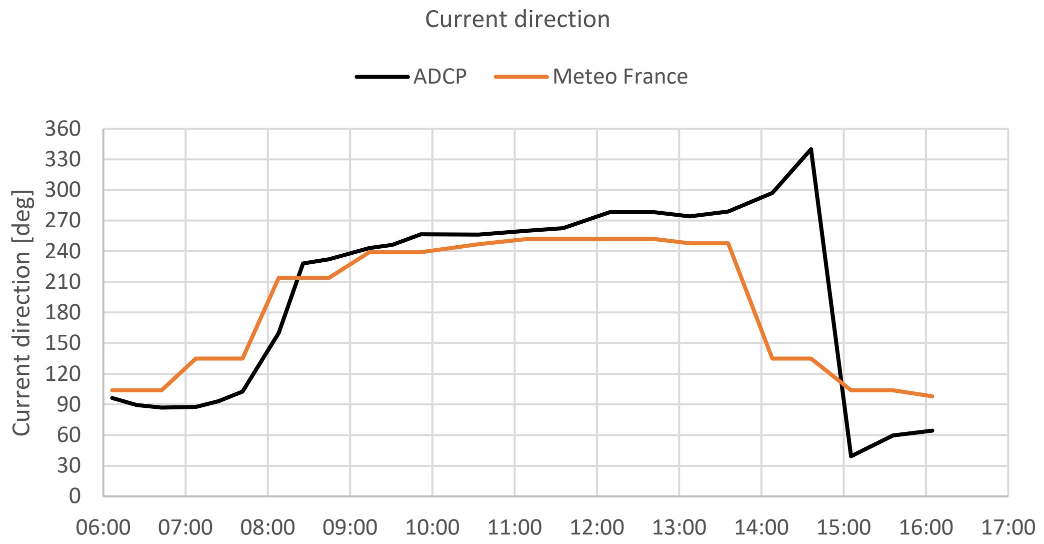




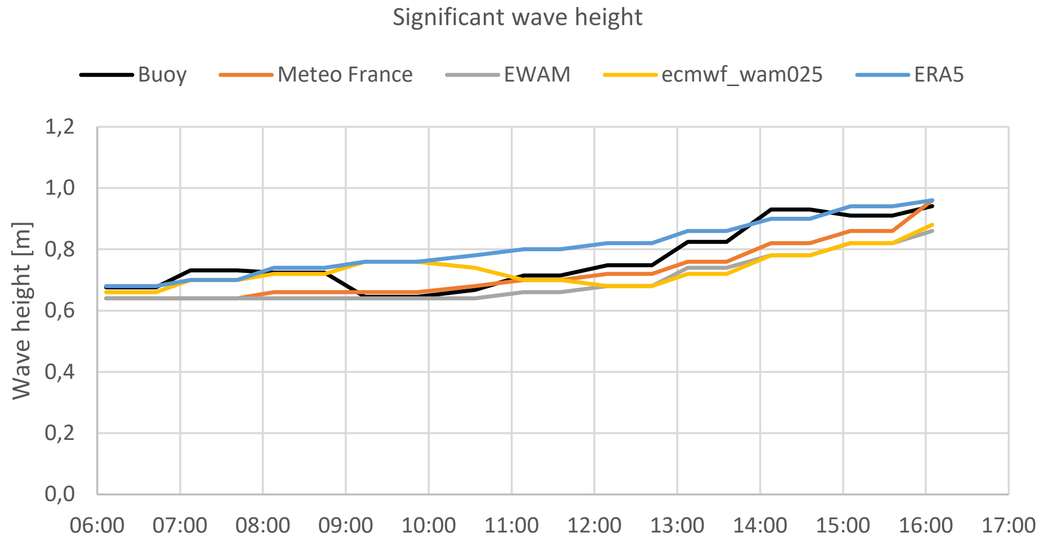
Hindcast comparisons

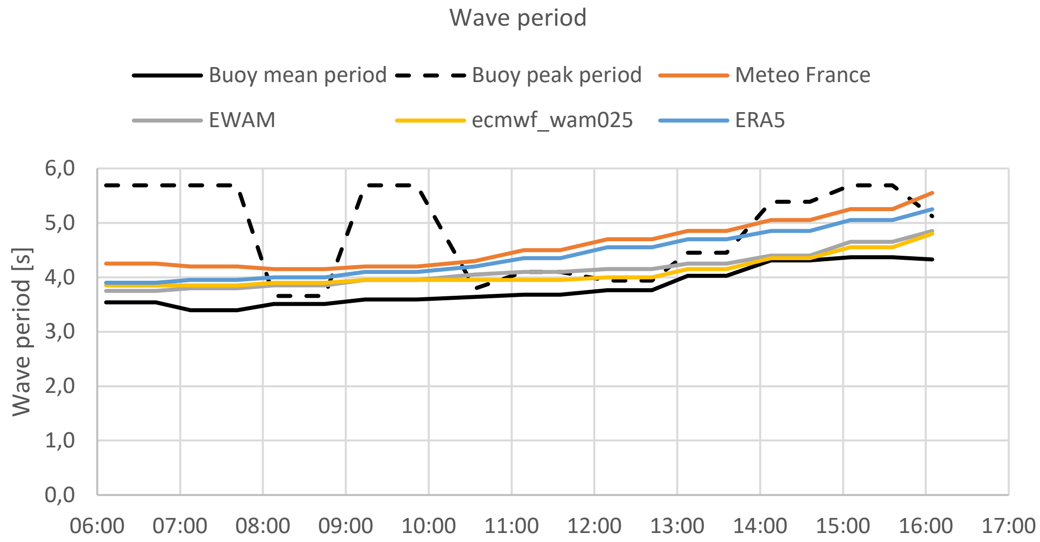
Current





Waves


Significant wave height
Buoy
Meteo France
EWAM
ecmwf_wam025
ERA5
Wave height [m]
1,2
1,0
0,8
0,6
0,4
0,2
0,0
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00


Wave period
Buoy mean period
Buoy peak period
Meteo France
EWAM
ecmwf_wam025
ERA5
Wave period [s]
6,0
5,0
4,0
3,0
2,0
1,0
0,0
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07:00
08:00
09:00
10:00
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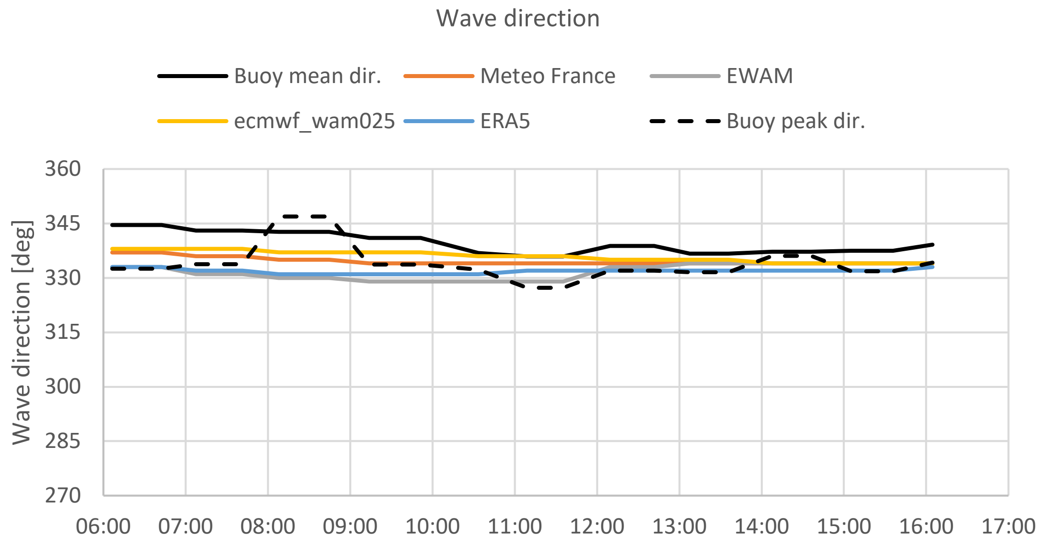
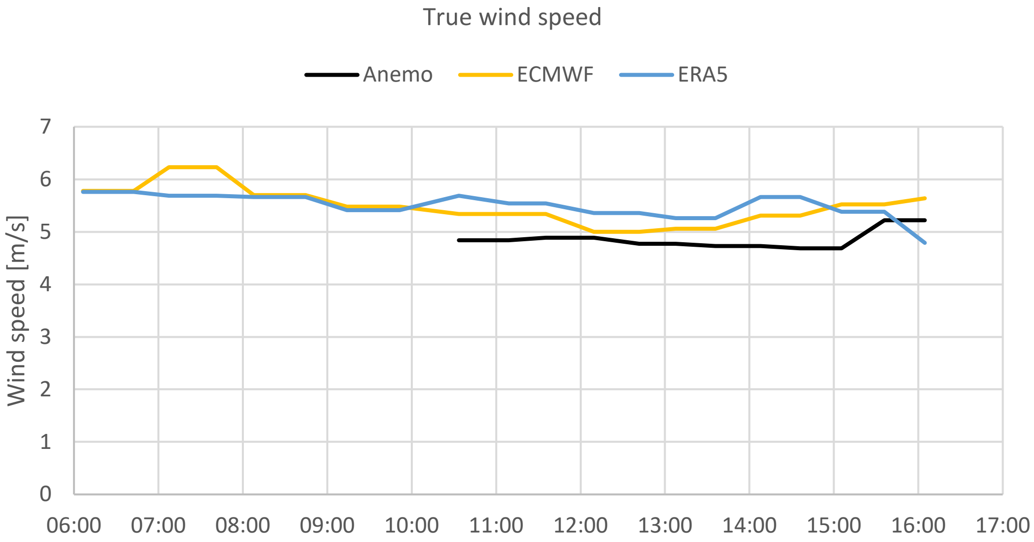
16:00
17:00


Wave direction
Buoy mean dir.
Meteo France
EWAM
ecmwf_wam025
ERA5
Buoy peak dir.
Wave direction [deg]
360
345
330
315
300
285
270
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00

Wind


True wind speed
Anemo
ECMWF
ERA5
Wind speed [m/s]
0
1
2
3
4
5
6
7
06:00
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09:00
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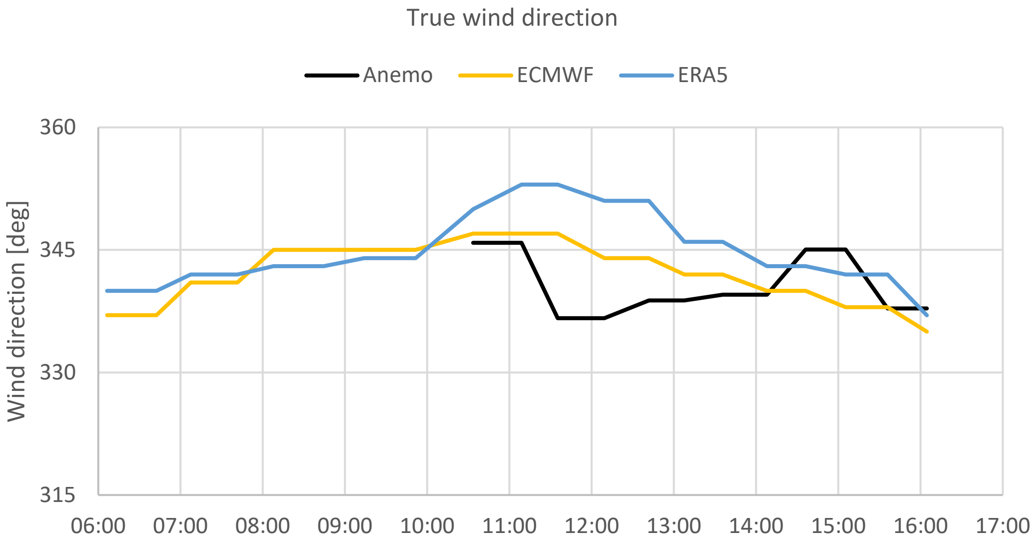
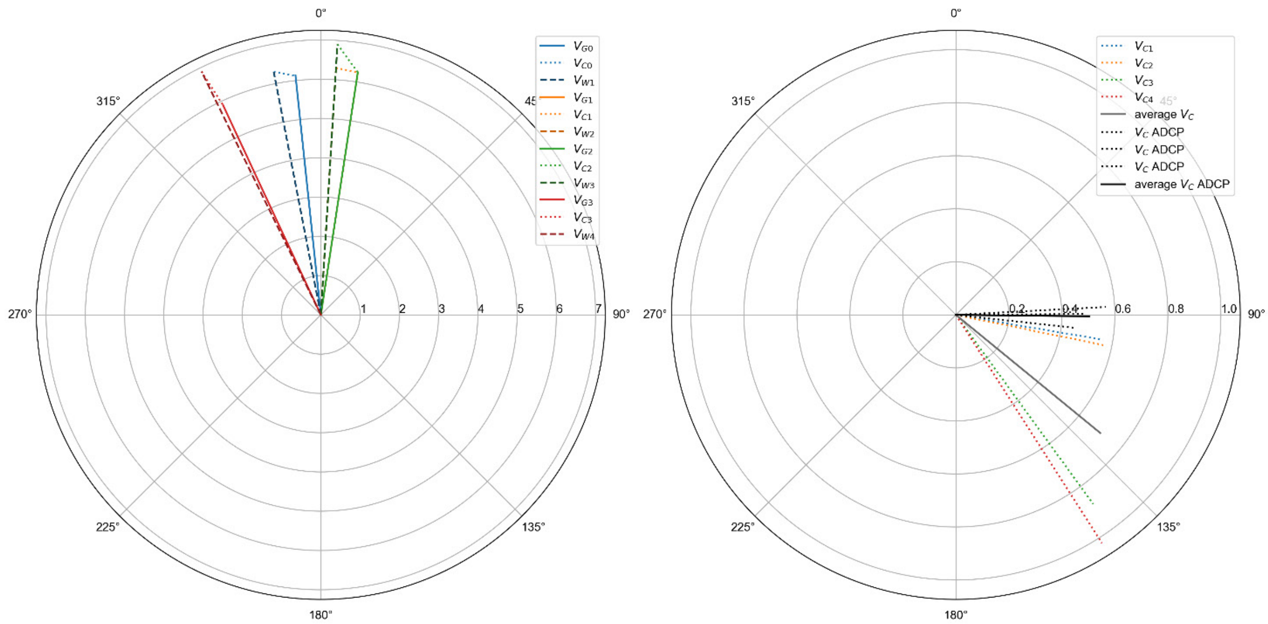
15:00
16:00
17:00

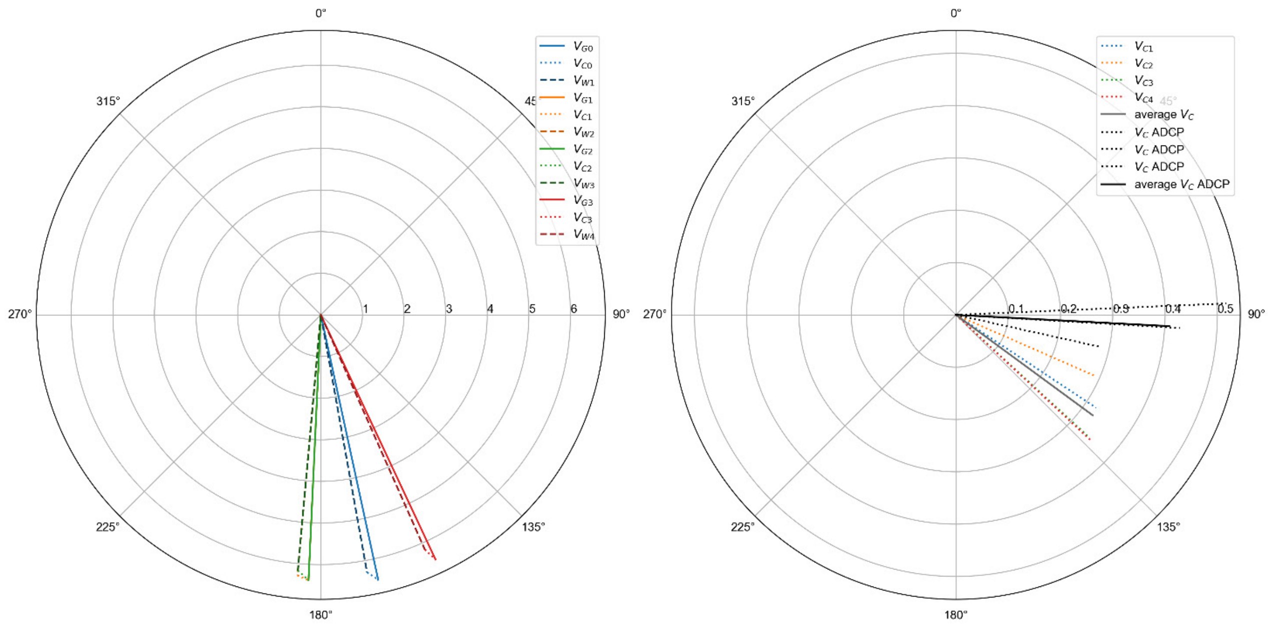

True wind direction
Anemo
ECMWF
ERA5
Wind direction [deg]
315
330
345
360
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00

APPENDIX 2 ZIG-ZAG RUNS RESULTS

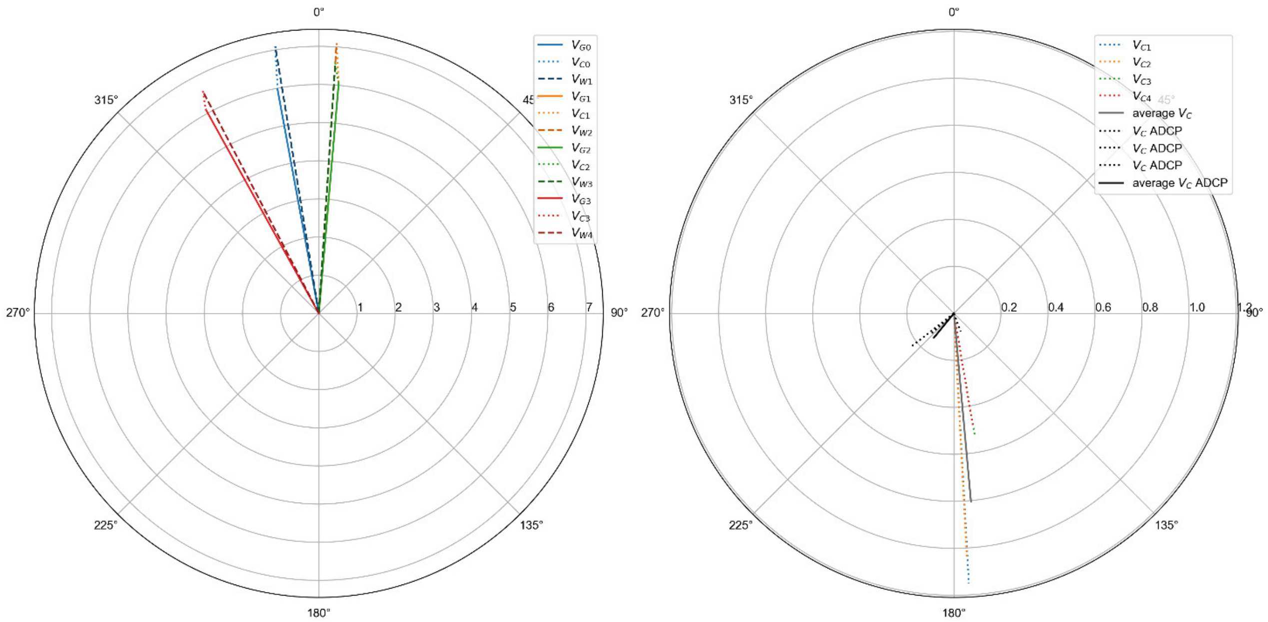
Runset 1
avg current: 0.70 m/s to 129.3 deg



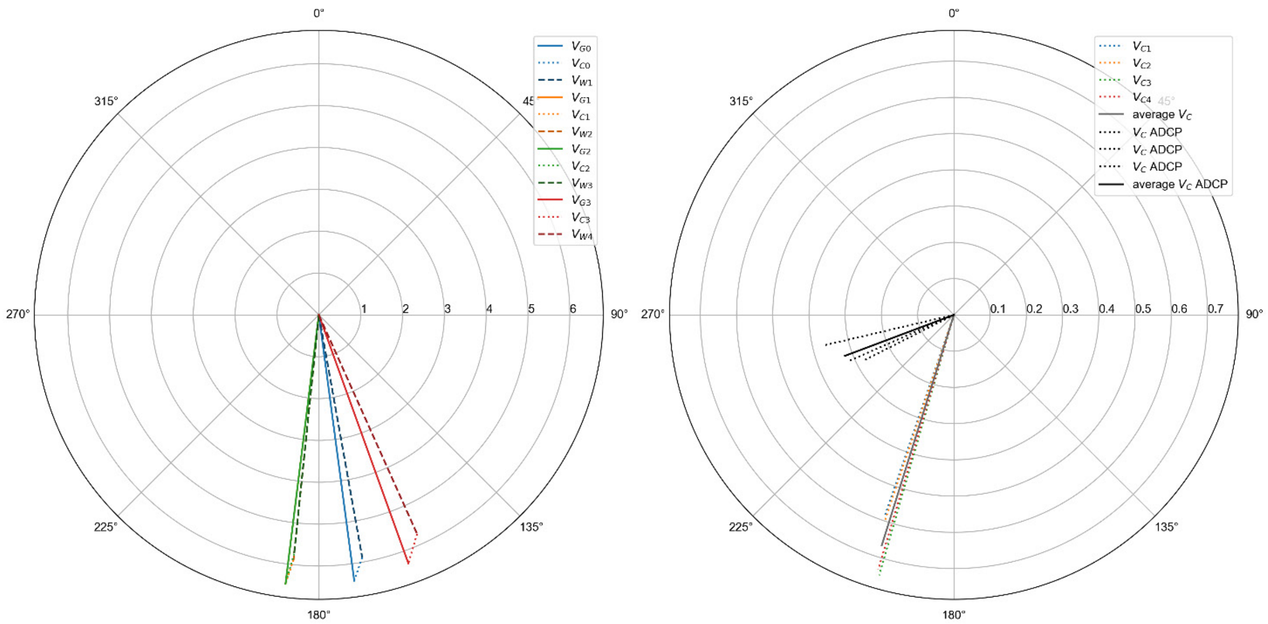
Runset 2
avg current: 0.32 m/s to 126.3 deg



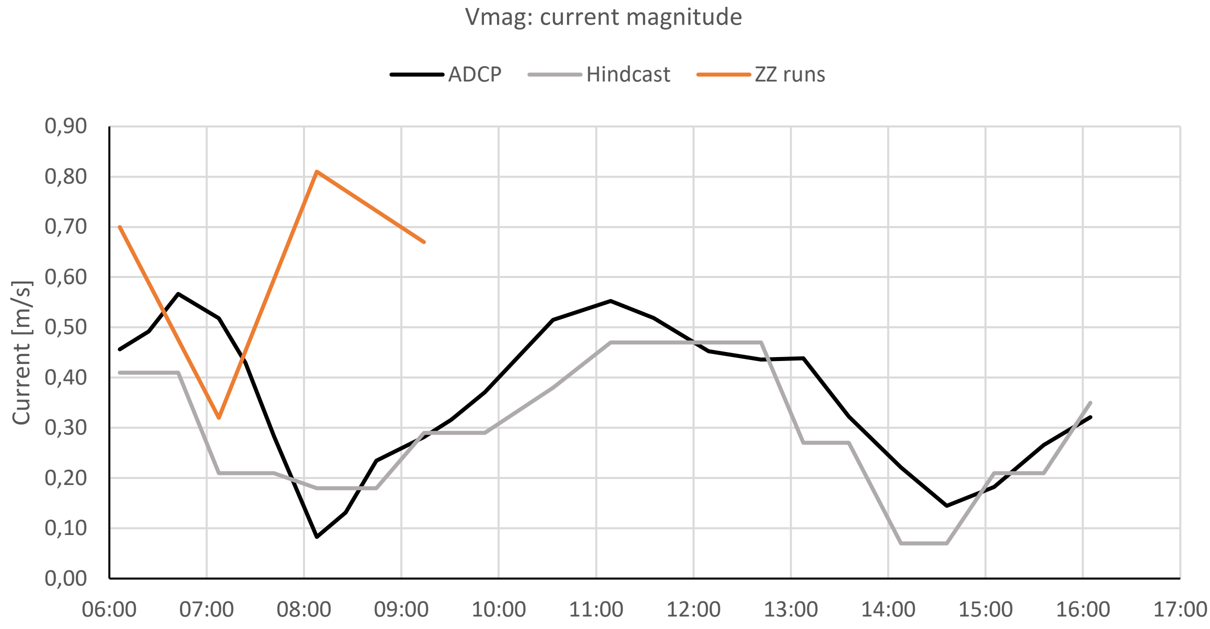
Runset 3
avg current: 0.81 m/s to 174.8 deg

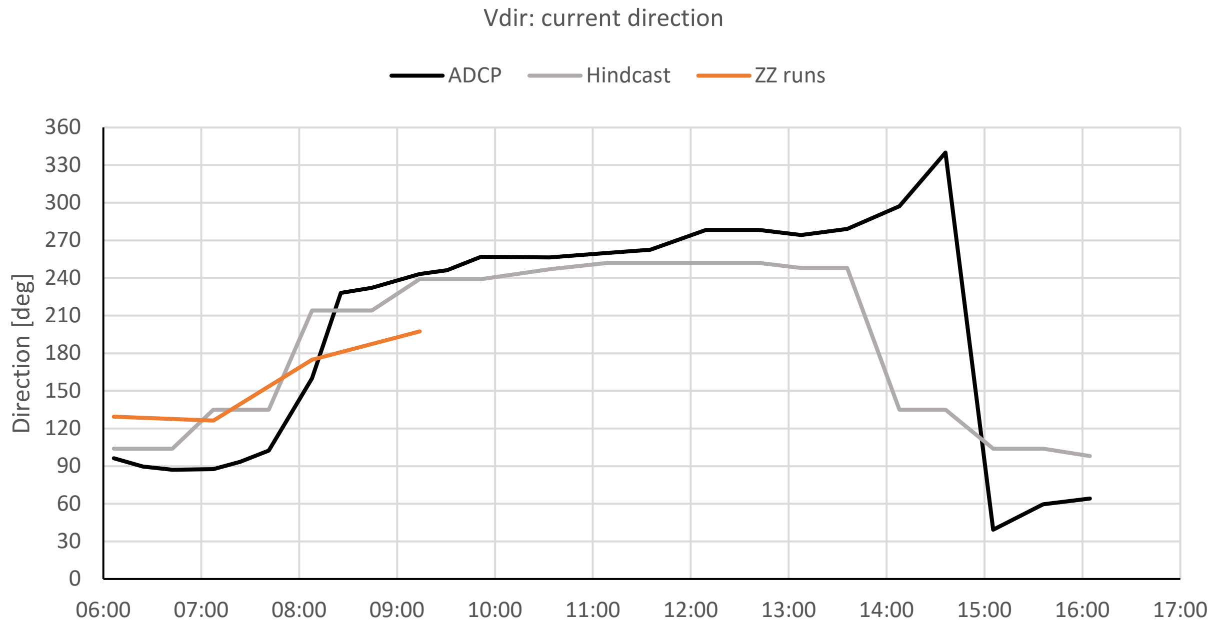


Runset 4
avg current: 0.67 m/s to 197.4 deg



APPENDIX 3 COMPARISON RESULTS





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