Wind-assisted ship propulsion - full-scale trials with wind field measurements

MIIP021

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1 INTRODUCTION

MARIN and eConowind jointly carried out full-scale trials on board the MV Ankie, equipped with two eConowind Ventifoil units on the forecastle. The Ventifoils are boundary layer suction wing sails, offering a large lift coefficient, providing added thrust and thus wind-assisted ship propulsion. With the aim to learn more about their real-world behaviour, and the importance of realistic wind field data therein, a MIIP project was carried out by MARIN and eConowind, with the kind support of Van Dam Shipping.

Full-scale measurements were carried out to obtain the powering performance with and without using the foils. The wind conditions were measured by a novel wind scanning LiDAR capable of scanning in any direction with its movable scanning head. This was the first time such a device was used to measure wind from on board a ship. This device enables whole fields of wind to be resolved in a single sweep. As a remote sensing optical technique, it delivers undisturbed wind fields outside the influence of the vessel itself. This report outlines the results of the trials in terms of powering performance and the wind measurement results, offering a good indication of future possibilities of using such device on shipboard measurements.

Figure 1: MV Ankie (Van Dam Shipping)

2 MEASUREMENT SETUP

To obtain the objectives, the following equipment was installed by MARIN (see APPENDIX 1 for photos of the installed equipment):

- Wind scanning LiDAR (Leosphere WindCube 200S) - for remote scanning of wind field (Figure 12)
- 3 ultrasonic anemometers (Gill Windsonic) in the forward mast (at 2.5, 5 and 10 m height from the base of the Ventifoils) - for local wind (Figure 16)
- Motion Reference Units (MRU) - one inside the wheelhouse, one at the base of the WindCube
- Twin DGPS - for vessel position, speed over ground, course over ground, and heading (Figure 12
- Wire sensor on the rudder stock - for measuring the rudder angle (Figure 13)
- MARIN PMS (Power Measurement System) - for measuring propeller shaft power & shaft speed (Figure 14, Figure 15)

Furthermore, manual readings from the bridge instruments were taken for: wind speed and direction, measured from the ship's anemometer on the bridge top.

3 TRIAL CONDUCT

3.1 Trial area

The trials were performed on 24 March 2021 about 40 nm west of IJmuiden, NL. Here, a suitable stretch of water was found of sufficiently deep water with no traffic lanes.

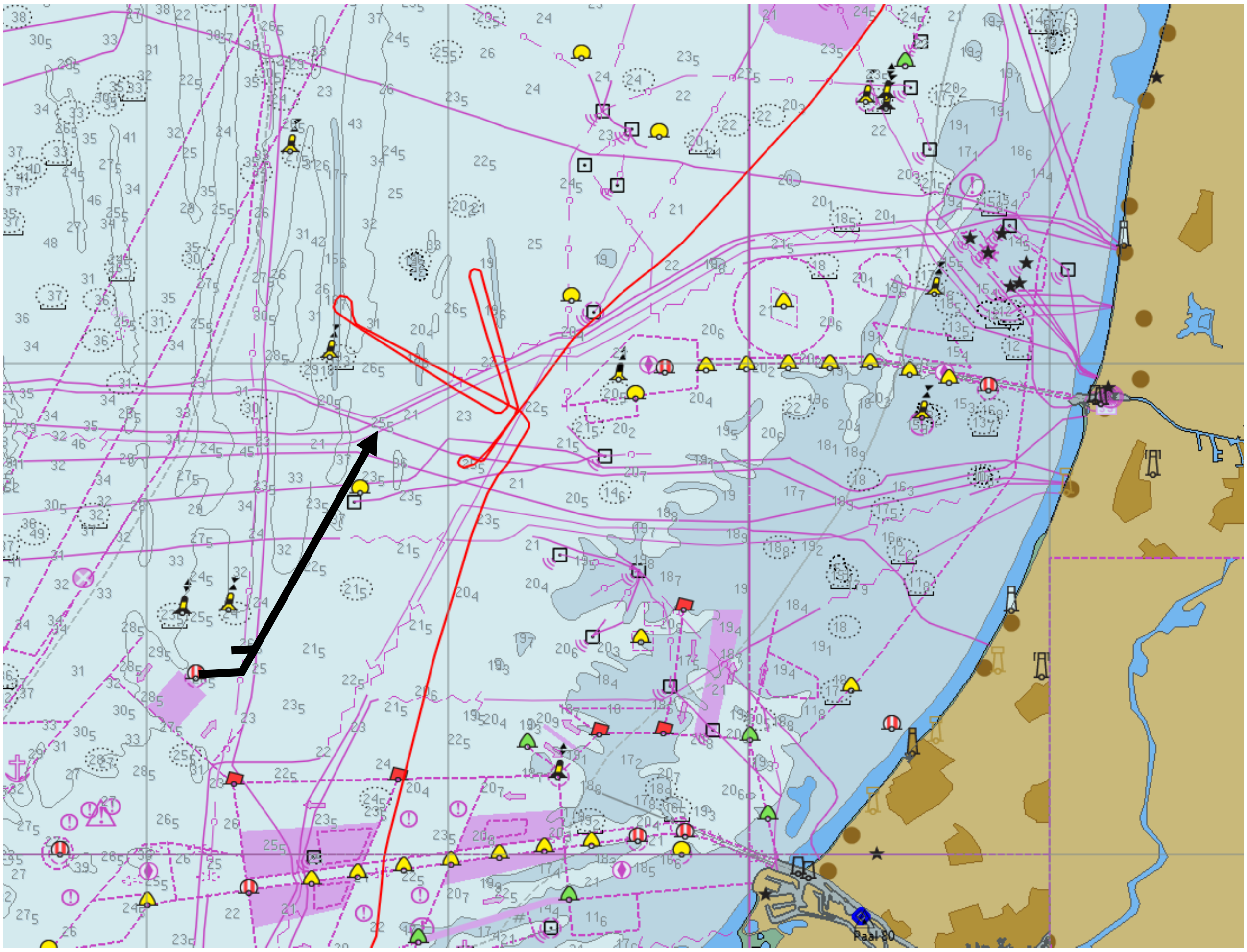


Figure 2: Sailed track (red) during test runs, true wind direction indicated with black arrow

3.2 Trial programme

Runs were performed at a single power setting, with the lever setting fixed at 75% (190.7 rpm), resulting in ship speeds around 12 knots. At this setting, runs are made in different direction w.r.t. the true wind direction:

- Beam reach (true wind angle 90 degrees off the bow)
    - This wind direction could be executed as a double run, in opposite direction
- Broad reach (true wind angle 135 degrees off the bow)
- Close hauled (true wind angle 45 degrees off the bow)
- Head winds (true wind angle 0 degrees off the bow)
- Following winds (true wind angle 180 off the bow)

Before each run, a DBS scan (see Figure 5) was performed for reference. Thereafter, steady state measurement of 15 minutes were taken with the foil up and down. This resulted in the performed runs 1-15 as depicted in Table 1. Runs 16-18 were performed later in the day as extra checks.

Table 1: Trial runs performed on 2021-03-24

ID [-]	Start UTC	End UTC	Heading [deg]	Wind scan pattern [-]
1-beam reach-Foil_up	03:29	03:36	298	DBS
2-beam reach-Foil_up	03:36	03:51	300	PPI
3-beam reach-Foil_down	03:55	04:10	300	PPI
4-beam reach-Foil_down	04:39	04:46	120	DBS
5-beam reach-Foil_down	04:46	05:01	119	PPI
6-beam reach-Foil_up	05:14	05:29	117	PPI
7-broad reach-Foil_up	05:39	05:48	345	DBS
8-broad reach-Foil_up	05:48	06:03	345	PPI
9-broad reach-Foil_down	06:04	06:19	345	PPI
10-close hauled-Foil_down	06:27	06:31	166	DBS
11-close hauled-Foil_down	06:31	06:46	166	PPI
12-close hauled-Foil_up	06:52	07:07	165	PPI
13-head wind-Foil_down	07:13	07:28	217	RHI
14-down wind-Foil_down	07:51	08:06	38	RHI
15-down wind-Foil_up	08:14	08:29	35	PPI
16-broad reach-Foil_up	16:29	16:44	103	RHI, PPI
17-AWA 30 anemo dwn-Foil_down	16:55	17:02	225	RHI
18-AWA 30 anemo up-Foil_down	17:02	17:07	176	RHI

3.3 Metocean conditions

As reference, the wind and wave conditions during the runs are given in APPENDIX 2. The wave data were taken from the Rijkswaterstaat 'IJgeul 1' wave buoy in the vicinity (about 30 nm from the test area). Wind conditions were taken from the GFS model. For the runs in the morning (between 03:30 and 08:30 UTC) the averaged conditions are given in Table 2.

Table 2: Average metocean conditions during runs 1-15

Averages 03:30 - 08:30 UTC			**Description**
H1/3	0.54	m	Average height of highest 1/3rd of waves
Hm0	0.61	m	Significant wave height from 0th-order spectral moment
T1/3	5.3	s	Average wave period of longest 1/3rd of waves
T2	3.5	s	Wave period from 0th- and 2nd-order spectral moment
Tp	4.2	s	Wave period at spectral peak
Th0	244	degT	Average direction in spectral domain
TWS	13.5	kn	True Wind Speed
TWD	224	degT	True Wind Direction

4 TRIAL RESULTS

4.1 Wind analysis

In below sections, the wind data from different sources is analysed and compared. Firstly, data from the forward anemometers is compared to the ship's own anemometer on the bridge top. The wind field data from the wind scanner is compared to the anemometer in the forward mast, and further analysed.

4.1.1 Anemometer wind data

The results in terms of apparent wind speed (AWS) and apparent wind angle (AWA) are given in Table 3 (see for the full table). Readings from the ship's anemometer (positioned on the bridge top) were manually taken from a display in the wheelhouse. The data from the set of three anemometers (at 2.5, 5, and 10 m above the Ventifoil's base) in the forward mast are averages from time traces at 1 Hz over the run duration.

Table 3: Results from anemometers, AWA from port in red, from starboard in green, AWS coloured by magnitude, values in red font indicates obstruction of air flow by searchlight (see Figure 3)

	Apparent Wind Angle				Apparent Wind Speed			
	SHIP	**FWD ANEMO**			**SHIP**	**FWD ANEMO**		
ID	AWA ship deg	AWA 2.5 deg	AWA 5 deg	AWA 10 deg	AWS ship kn	AWS 2.5 kn	AWS 5 kn	AWS 10 kn
1-beam reach-Foil_up		-39	-37	-47		24.5	23.9	23.4
2-beam reach-Foil_up	-45	-40	-38	-49	19.0	23.7	23.2	22.6
3-beam reach-Foil_down	-45	-45	-42	-49	19.0	22.6	22.1	21.3
4-beam reach-Foil_down	45	57	57	51	17.0	20.8	13.2	17.9
5-beam reach-Foil_down	40	58	57	51	18.0	21.1	13.0	18.1
6-beam reach-Foil_up	40	56	54	51	18.0	19.2	13.6	17.6
7-broad reach-Foil_up	-75	-60	-58	-71	8.0	14.2	13.8	13.4
8-broad reach-Foil_up	-75	-61	-58	-72	8.5	13.9	13.4	13.1
9-broad reach-Foil_down	-70	-73	-74	-79	7.0	12.2	11.7	11.8
10-close hauled-Foil_down	18	37	30	29	28.0	26.4	14.4	23.7
11-close hauled-Foil_down	20	38	36	31	26.0	26.1	13.4	23.3
12-close hauled-Foil_up	17	35	38	30	26.0	23.9	12.9	22.7
13-head wind-Foil_down	-6	5	5	-2	31.0	25.5	26.8	25.0
14-down wind-Foil_down	40	-60	-86	-141	2.0	1.2	1.3	1.4
15-down wind-Foil_up	-130	170	168	172	3.0	1.0	1.1	1.5
16-broad reach-Foil_up	50	1	67	56	8.5	1.5	1.3	9.0
18-AWA 30-Foil_down	50	36	33	29	8.5	24.9	13.5	23.0

From this, the following observations are made:

- A searchlight in the forward mast obstructs the air flow to the anemometer placed at 5 m height (see Figure 3). This can be observed by the lower average wind speeds (depicted in red font) for the runs with wind coming from starboard (AWA's highlighted in green).
- The anemometer at 2.5 m height often reads the highest wind speeds. This could be an overspeed zone (Figure 4) just above the forecastle deck edge.
- The absolute values for AWA are in most cases larger for the forward anemometers than the ship's anemometer aft. This indicates a flow straightening effect of the ship's hull and superstructure.
- Comparing AWS10 (in forward mast, 10 m above deck level) with the ship's anemometer (on the bridge top, at similar height), the wind speed forward is usually higher, except when sailing close hauled (AWA forward around 30 deg) and in head winds, a possible effect of the overspeed zone (Figure 4).

Figure 3: The searchlight obstructing the air flow to the anemometer at 5 m height

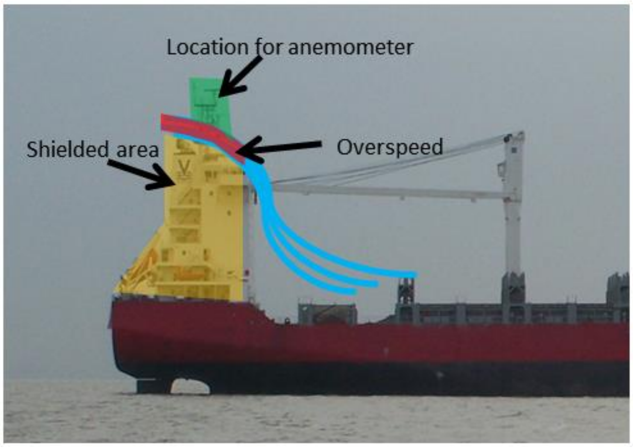


Figure 4: Illustration of the overspeed zone near sharp edges of superstructure

4.1.2 Wind scanner field data

Remote wind scans are performed using a WindCube 200S LiDAR wind scanner. Based on sensing Doppler-shift of aerosol particles, this device delivers radial wind speed, i.e. wind speed in the direction of the optical head. With its movable scanning head, this device is capable of performing the following scan patterns (Figure 5):

- PPI: Horizontal sweeps (e.g. along horizon)
- RHI: Vertical sweeps (e.g. between wings)
- DBS: Vertical scans upward

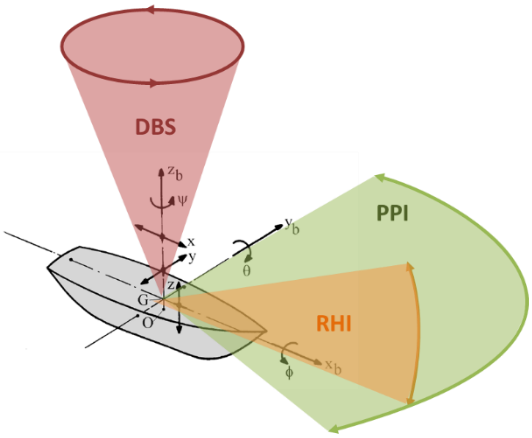


Figure 5: Wind scan patterns: PPI (green), RHI (orange), DBS (red)

Instantaneous wind field data

See Figure 6 for an example of instantaneous wind field from a horizontal (PPI) scan (run 2, wind about 50 degrees from port side). Here one can observe how, at about 90 degrees to the wind, the radial wind speed goes to zero as the wind component of the wind in the beam direction tends to zero. Further visible is the interference in the signal where it bounces off solid structures. In this case this effect is are sharply visible at the location of the Ventifoils, and could even be used to check alignment.

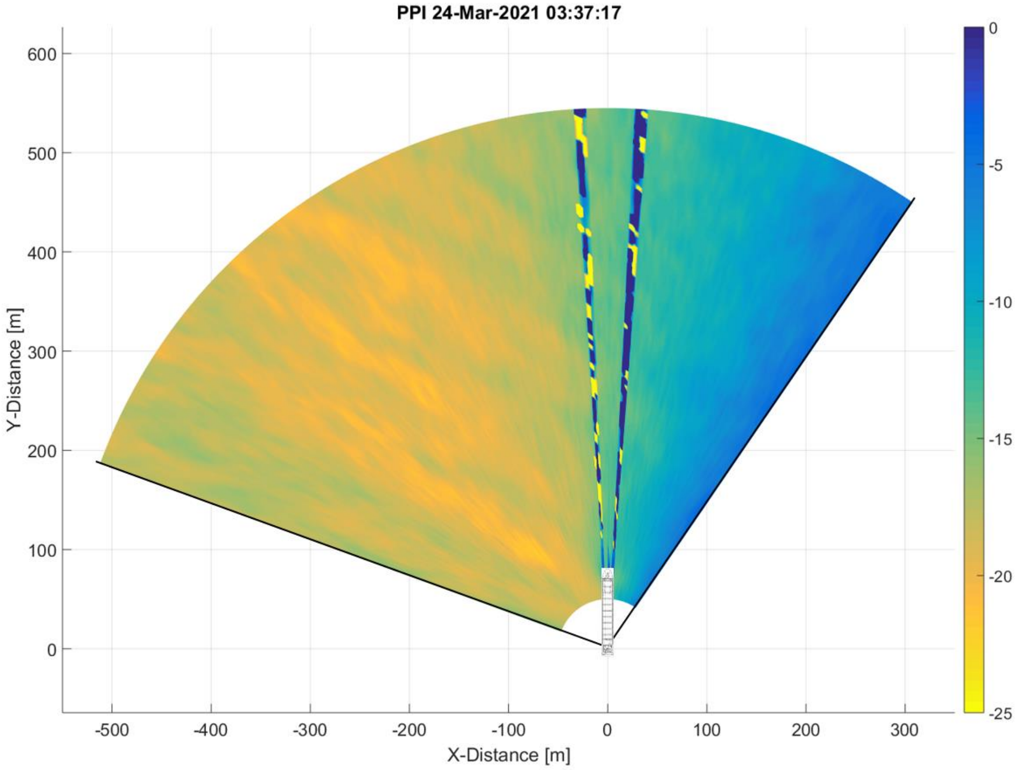


Figure 6: Example of PPI scan, colour scale denoting instantaneous radial wind speed [kn], AWA from PS bow quartering, interference in signal by foils visible, ship drawing inserted at scale for reference

Figure 7 offers an example of instantaneous wind field from a vertical (RHI) scan. Also here, noisy parts of the signal can be used to recognise hard objects, which could aid in alignment. In this example, the scan was purposely aimed to hit the horizontal spreader of the forward mast, resulting in the noise in the segment at 50 - 100 m from the scanning head. From here, the location of the anemometer at 10 m could be pinpointed for comparison.

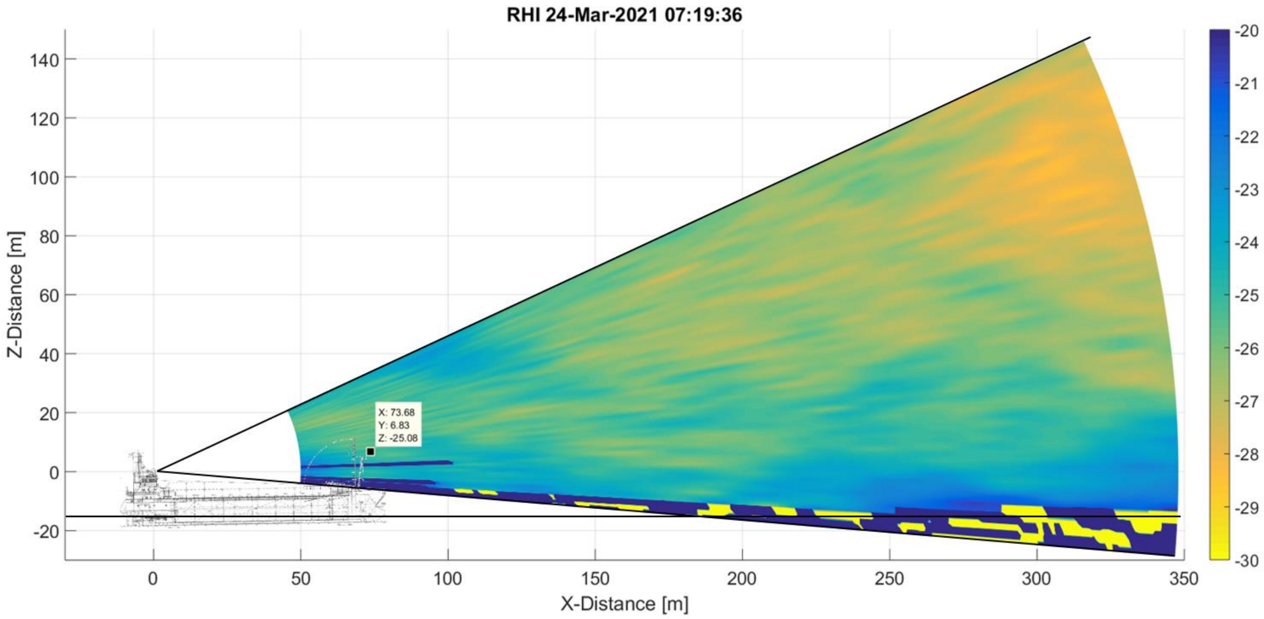


Figure 7: Example of vertical (RHI) scan along the anemometers in forward mast, colour scale denoting instantaneous radial wind speed [kn], run 13 in head winds, interference in signal by mast spreaders visible, datatip denotes the location of anemometer at 10 m, ship drawing inserted at scale for reference

Comparison to anemometer data

Using the vertical (RHI) scans in head winds, the measured radial wind speeds at the anemometer location in the scans for run 13 are compared to the anemometer data, see Figure 8. A good agreement is shown, with the average of the wind speed measured by the wind scanner 3% lower than the anemometer.

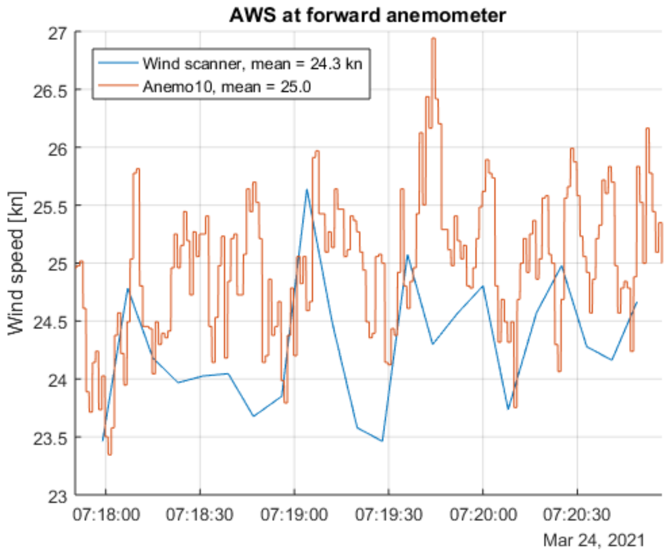


Figure 8: Time trace comparison of wind scanner data at anemometer location, and anemometer data during run 13 in head winds

Vertical wind profile

Another useful capability of the vertical (RHI) scan is to extract vertical wind profiles. Figure 9 shows the measurements (taken along a vertical line ahead of the vessel) for run 13 in head winds (instantaneous values in grey, average over the run duration in black), compared to a power law curve. This type of new data offers insight into the actual behaviour of the undisturbed wind over height in these situations.

The 1/7 power law curve is used in the ISO15016:2015 standard for speed/power trials for translating the measured wind data from height of measurement (usually in the mast on the bridge top) to a reference height of 10 m.

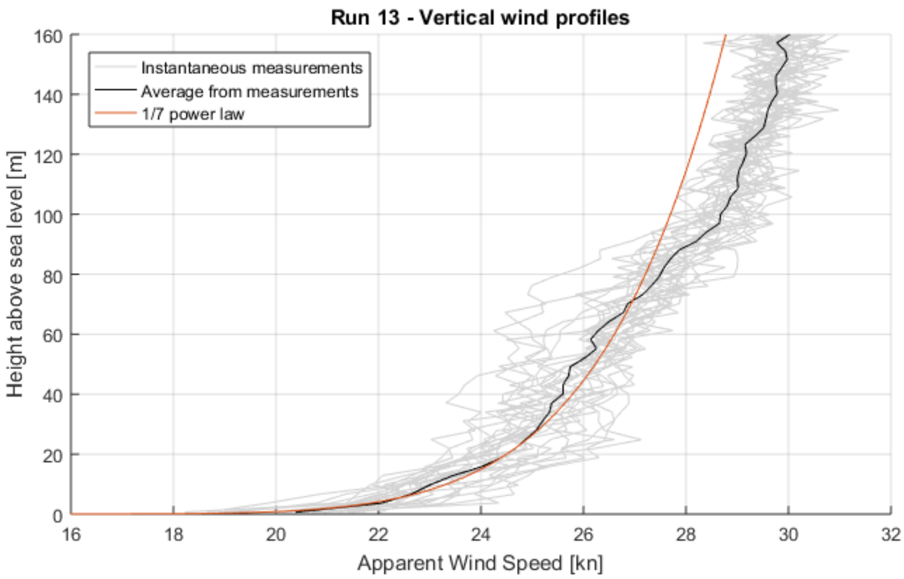


Figure 9: Measured instantaneous vertical wind profiles over run 13 (grey lines) and 1/7 power law fitted to 10 m reference value (red)

Wind volume analysis

Horizontal (PPI) scans from the wind scanner are processed to convert from radial wind speed to wind vectors in the horizontal plane using a post-processing method supplied with the device. An example result from run 2 is depicted in Figure 10, see APPENDIX 5 for scan results of other runs. Obtaining this offers good insight into the undisturbed wind field outside the influence of the ship, aiding a proper comparison to predictions at the correct input wind speed and direction.

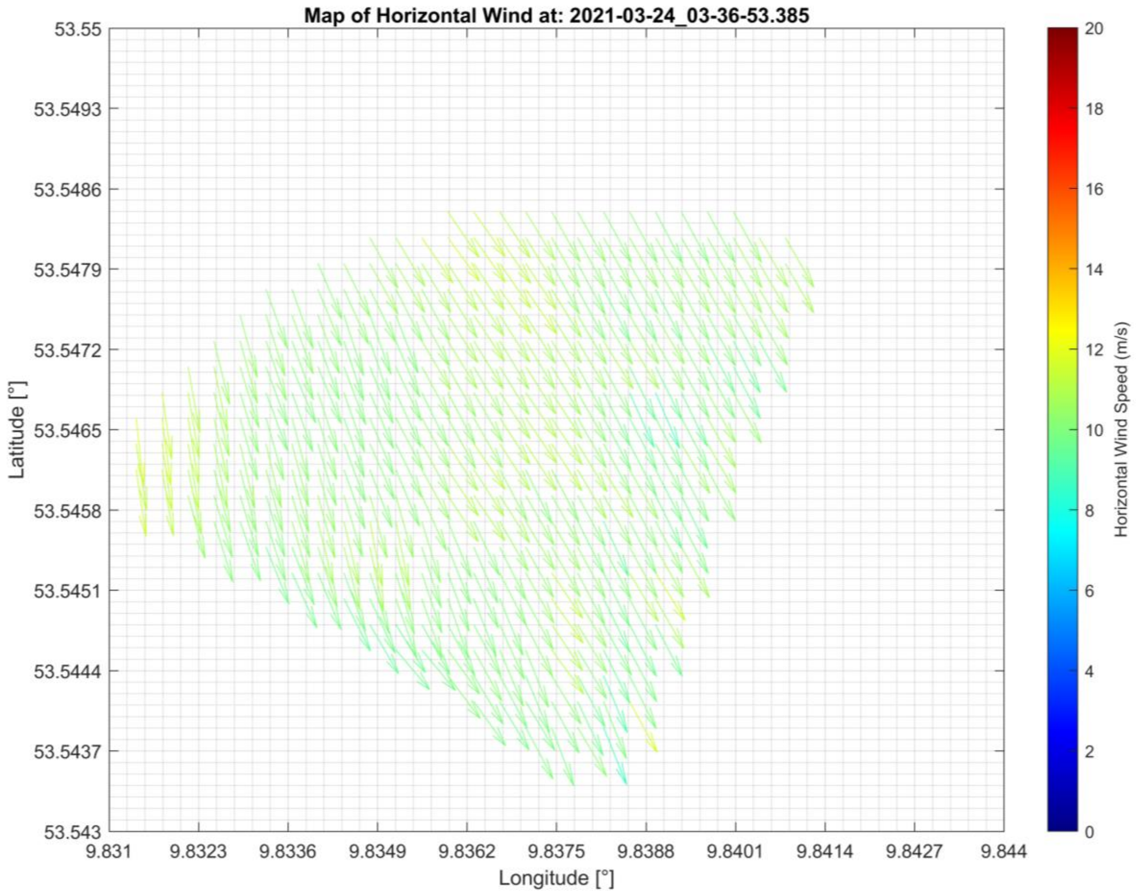


Figure 10: Example result of horizontal wind field from run 2

4.2 Powering performance

Differences in propeller shaft power (from main engine to the propeller) were recorded during the different runs, both with the Ventifoil up and down (i.e. the system being active and inactive respectively). Differences in speed and power between the foils up and downs are depicted in Figure 11.

From the double run in beam wind, averages could be taken to correct for current effect on ship speed. A speed/power curve derived from long-term monitoring data of the vessel is used to intersect the averaged trial points. Intersecting the obtained curves at 12 knots ship speed, shows that in these conditions (moderate true wind speeds of about 13.5 kn), a decrease in shaft power of 1.8% is achieved when the Ventifoil is up and operating.

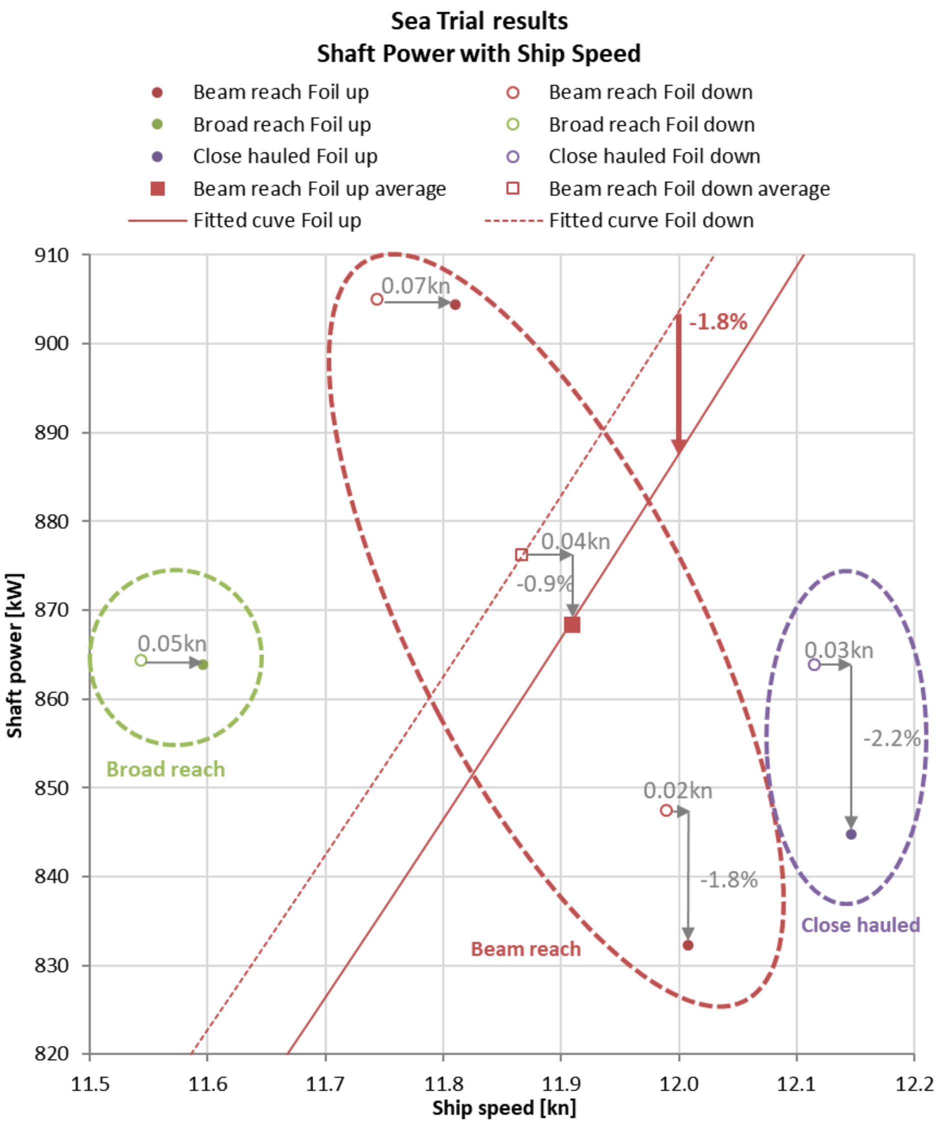


Figure 11: Speed/power result, averages from beam reach single runs (red circles) depicted in red squares, single runs from broad reach (green) and close hauled (purple) conditions plotted for reference

5 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions summarise the findings of the present project:

- Successful trials have been conducted on the MV Ankie on 24 March 2021, employing for the first time a wind scanner LiDAR on a ship.
- On the local wind measurements with ultrasonic anemometers in the forward mast, and the ship's anemometer on the bridge top:
  - The absolute values for apparent wind angle are in most cases larger for the forward anemometers than the ship's anemometer aft. This indicates a flow straightening effect of the ship's hull and superstructure.
  - Comparing the wind speed at the anemometer forward (at 10 m above deck) with the ship's anemometer on the bridge top (at similar height), the wind speed forward is usually higher, except when sailing close hauled and in head winds, a possible effect of an overspeed zone.
- Far-field wind data was successfully obtained using the wind scanning LiDAR:
  - Good instantaneous results could be obtained, with objects such as the Ventifoils and forward mast well recognisable in the data.
  - Comparing wind values in the winds scan data at same location as the anemometers at 10 m in the forward mast showed fair comparison.
  - Vertical wind profiles could be obtained from the vertical scan patterns (RHI) and be compared to a power law assumption for wind profiles.
  - Wind vectors (magnitude and direction) could successfully be calculated from the measured radial wind speed data in the horizontal scans (PPI).
- In the test conditions (moderate true wind speed of 13-14 knots), a propeller shaft power decrease of 1.8% is achieved at a ship's speed of 12 knots when the Ventifoil is up and operating.

With the trials performed in rather mild conditions (moderate true wind speed of 13-14 knots, a wave height of about 0.6 m, no significant ship motions), the obtained wind data was of good quality. It is expected that in more severe conditions, ship motions will impair the wind scanner results. It is recommended to investigate further the effect of ship motions on the resulting wind measurements from a LiDAR scanner, and possibly develop a correction method using synchronous motions data.

Wageningen, June 2021
MARITIME RESEARCH INSTITUTE NETHERLANDS

Dr. ir. H. Bogaert
Manager Performance at Sea

APPENDICES

APPENDIX 1 PHOTOS OF EQUIPMENT

Figure 12: WindCube 200S (red) and DGPS (green)

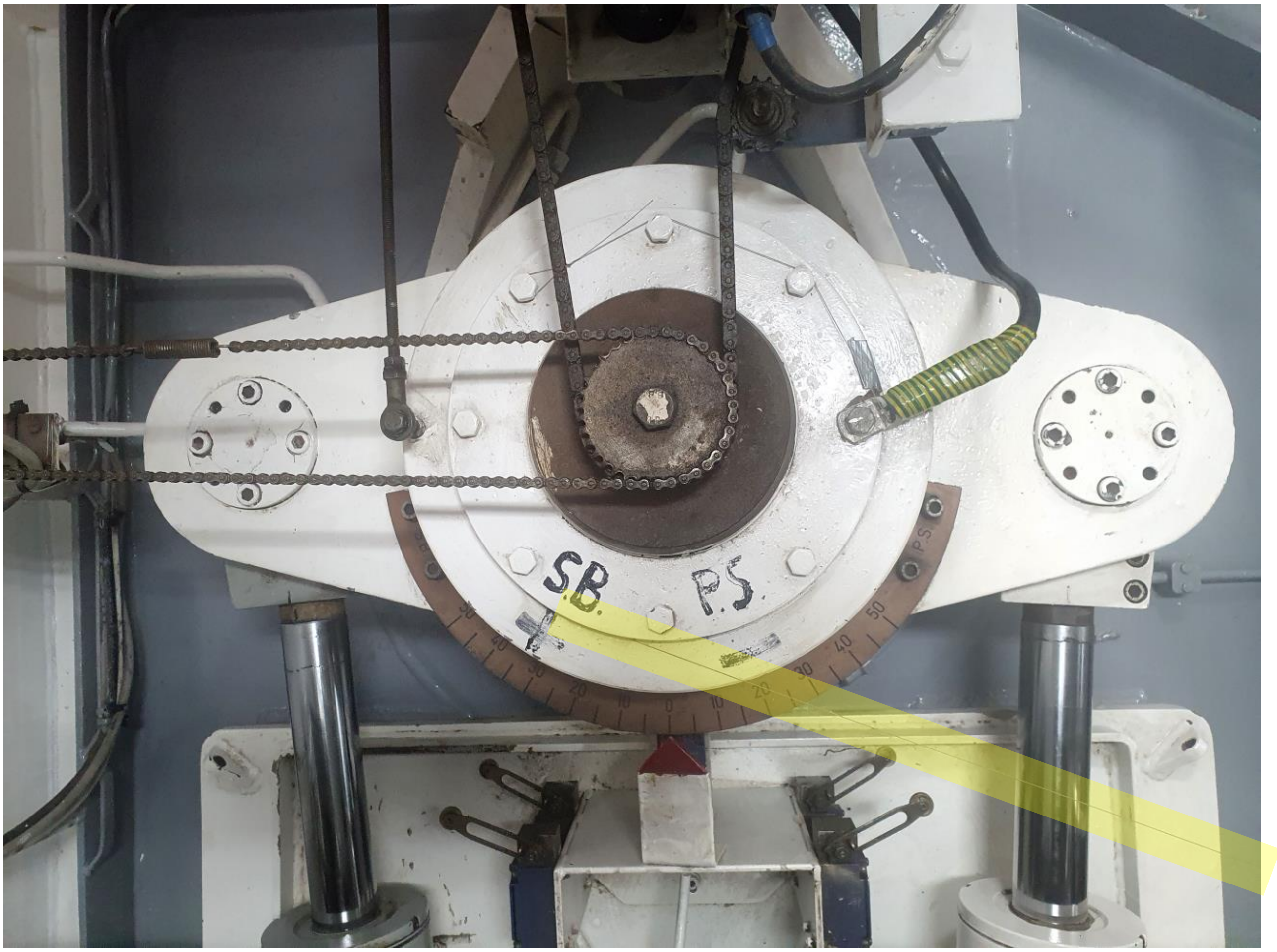


Figure 13: Wire around rudder stock to wire sensor (yellow)

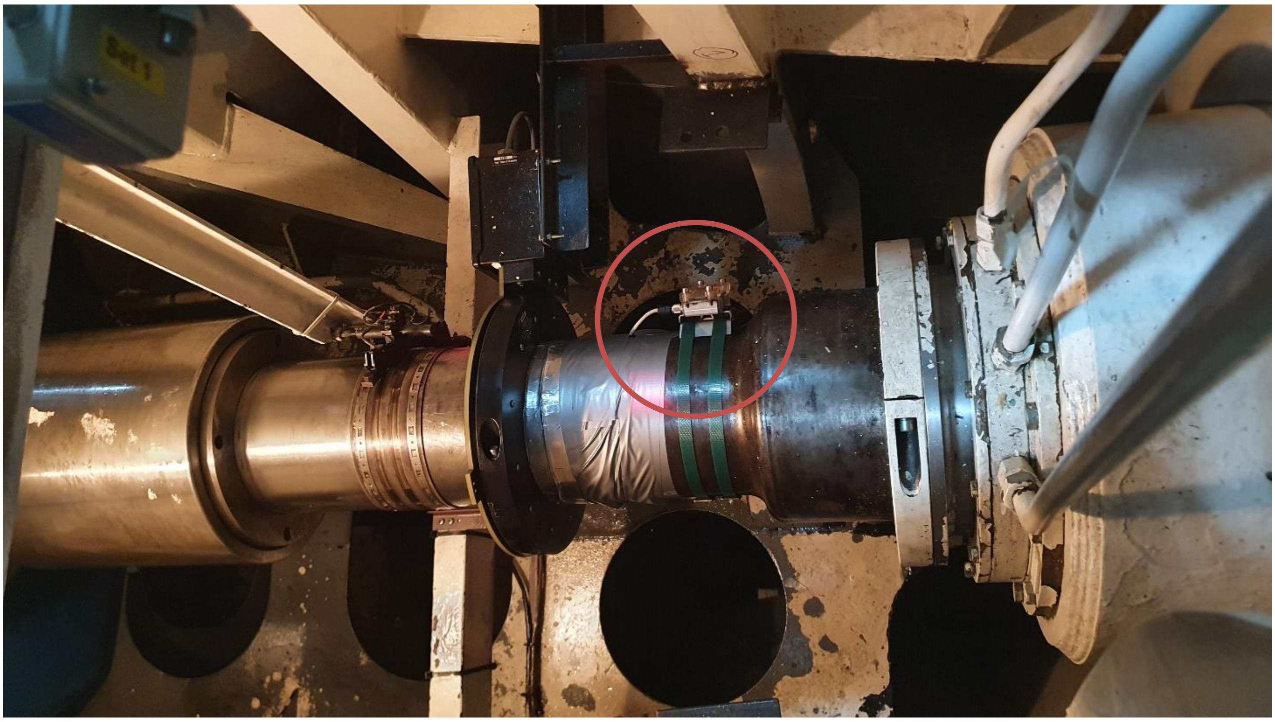


Figure 14: MARIN PMS unit on shaft (red)

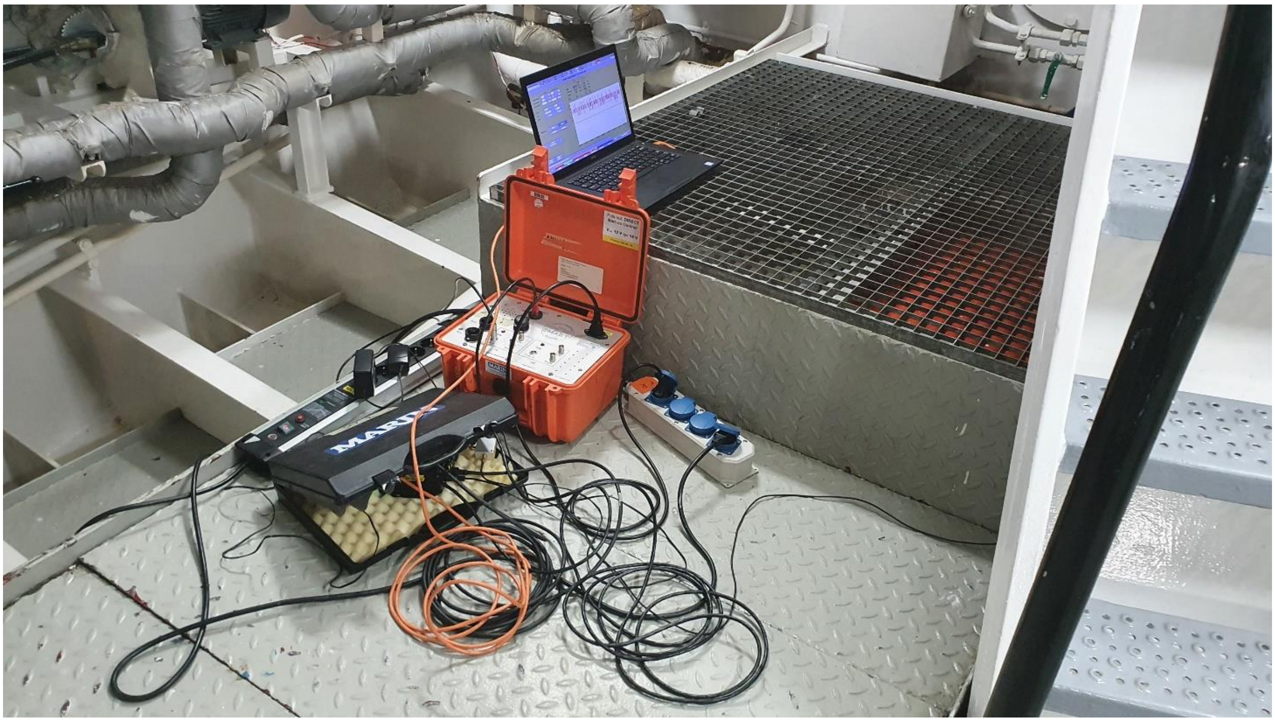


Figure 15: MARIN PMS system at shaft

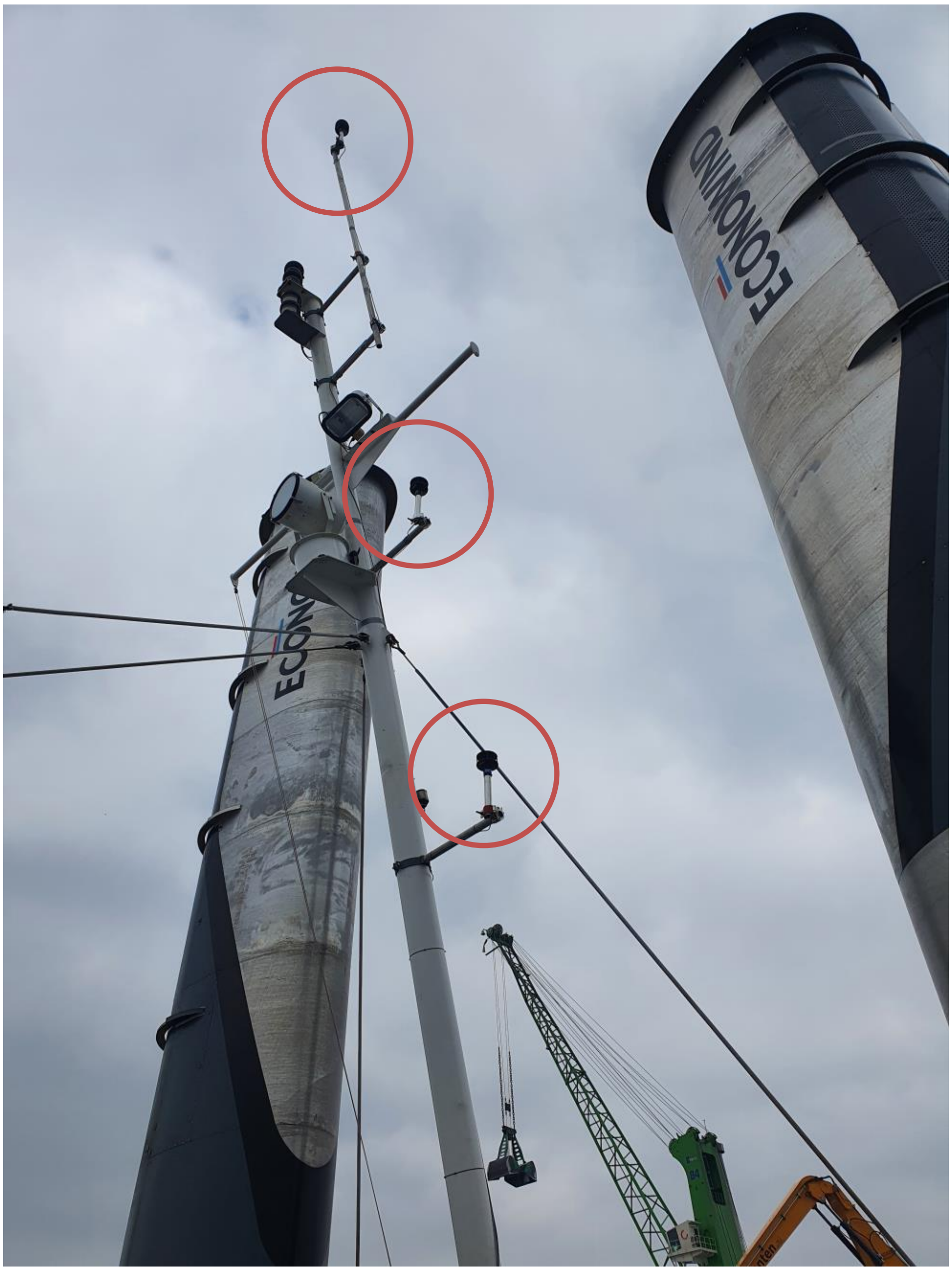


Figure 16: Ultrasonic anemometers (red) in forward mast at 2.5, 5 and 10 m above deck

APPENDIX 2 METOCEAN REFERENCE DATA

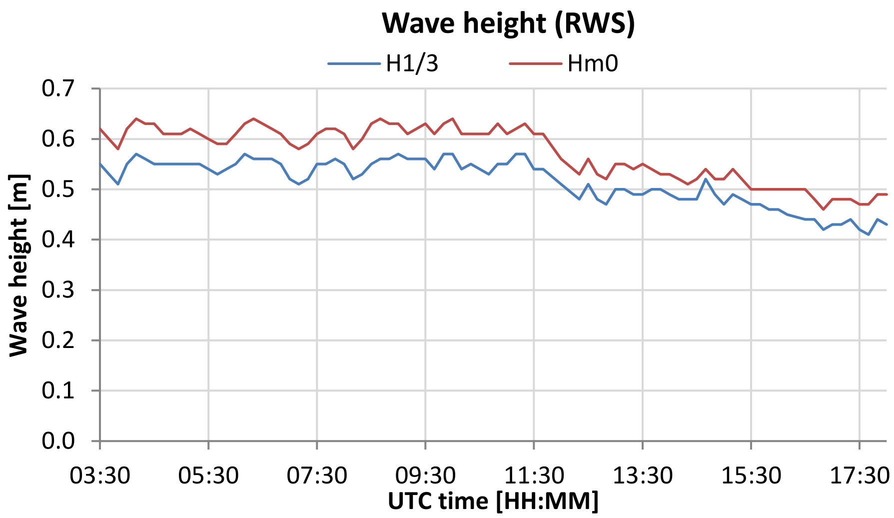


Figure 17: Wave height during tests (from RWS buoy)

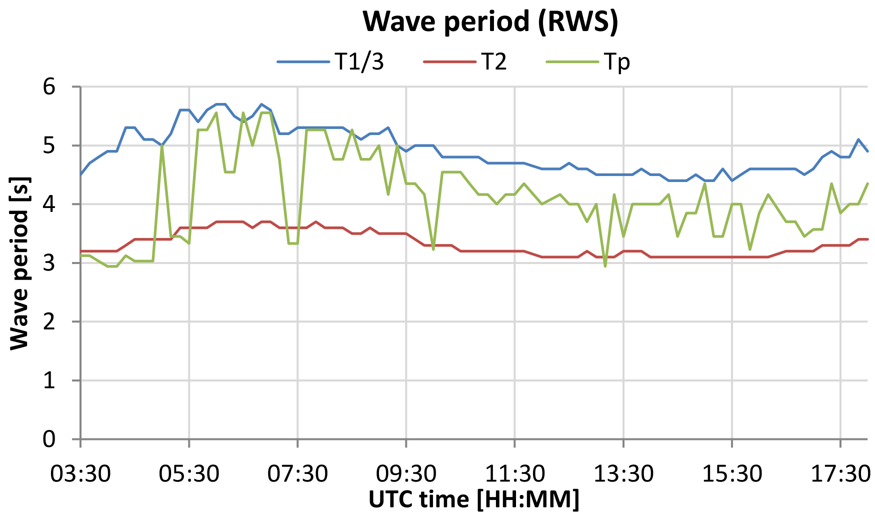


Figure 18: Wave period during tests (from RWS buoy)

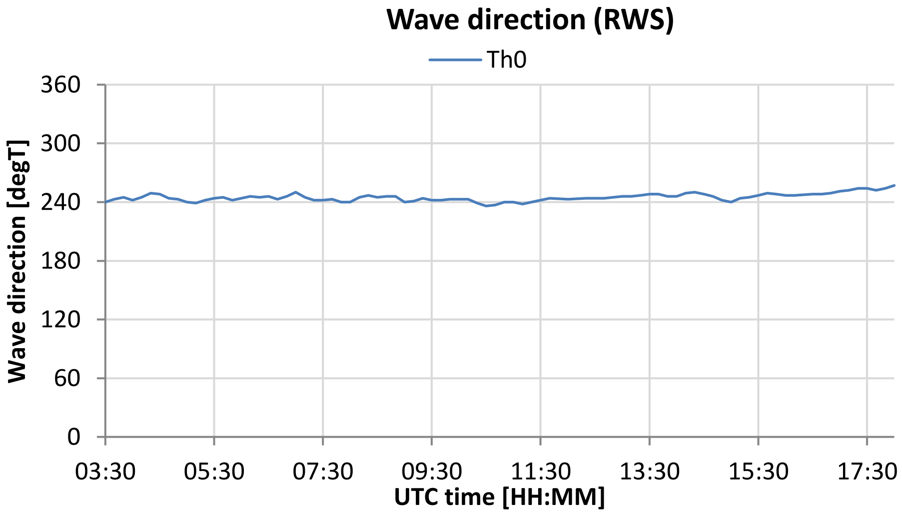


Figure 19: Wave direction during tests (from RWS buoy)

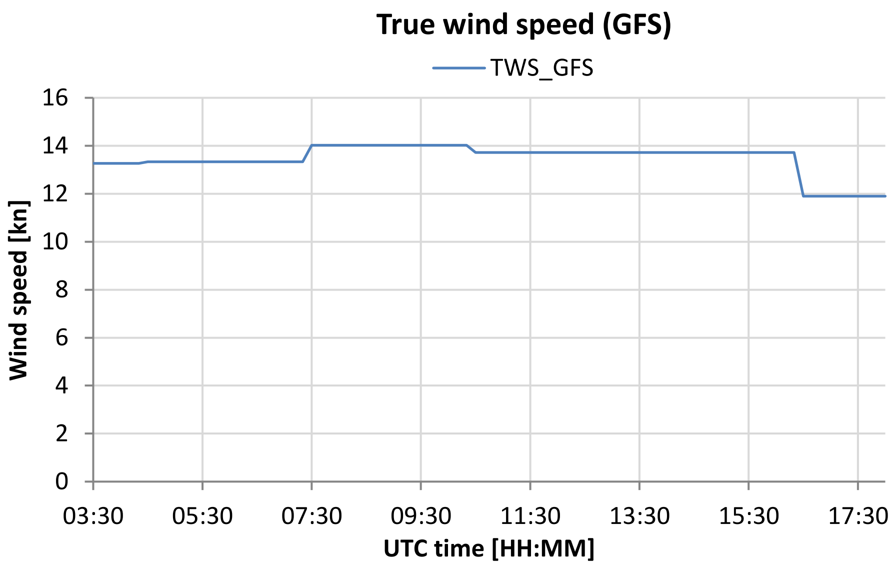


Figure 20: True wind speed during tests (from GFS model)

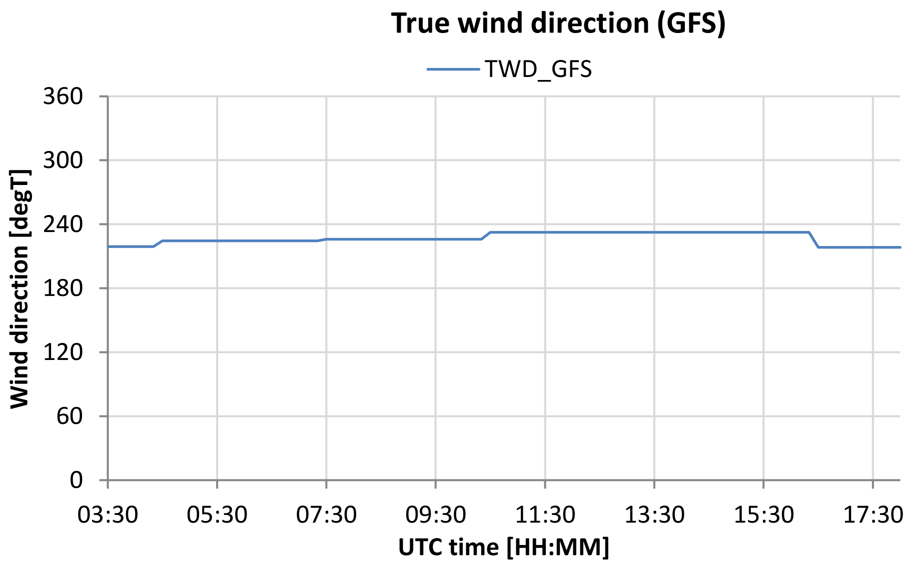


Figure 21: True wind direction during tests (from GFS model)

APPENDIX 3 RUN AVERAGES

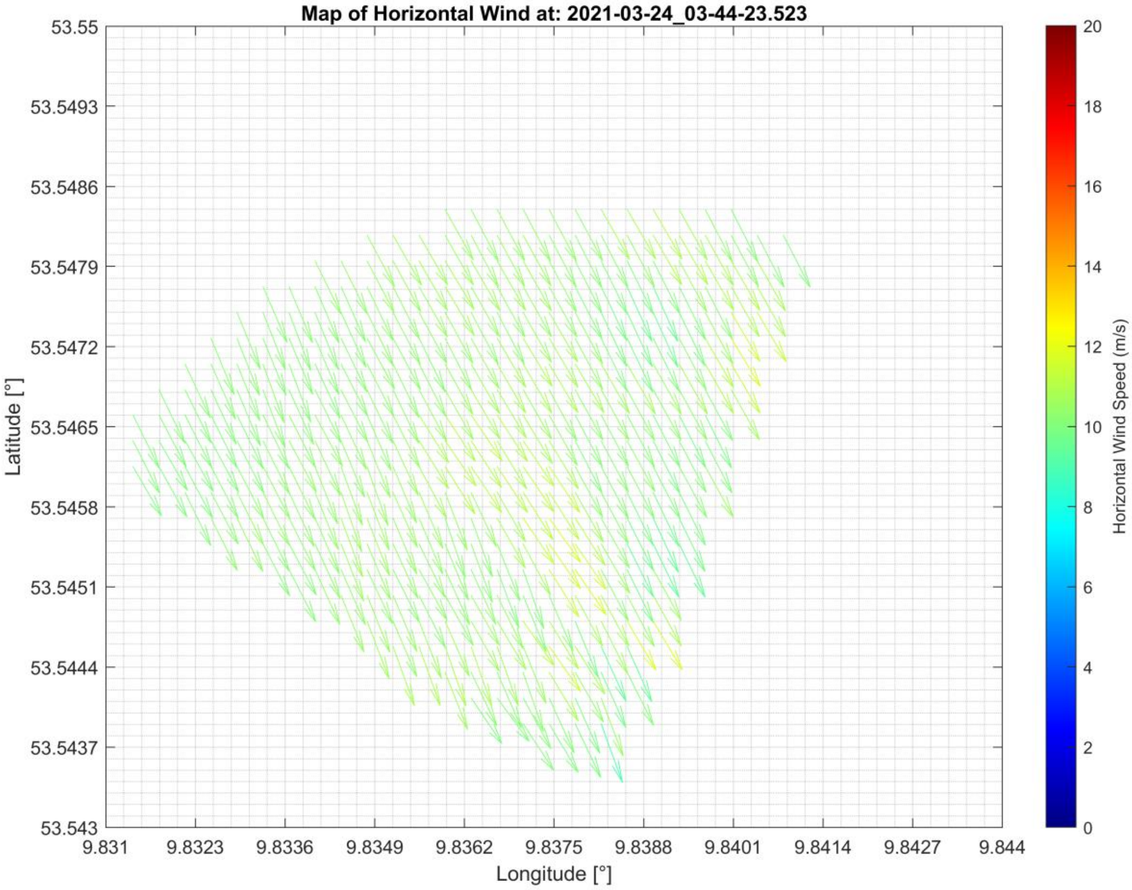
ID	Start	End	WindScan pattern	SOG	Heading	COG	Rudder angle	Shaft power	Shaft torque	Shaft speed
[-]	UTC	UTC	[-]	[kts]	[deg]		[deg]	[kW]	[kNm]	[rpm]
1-beam reach-Foil_up	03:29	03:36	DBS	11.84	298	298	1.8	905	45.3	190.7
2-beam reach-Foil_up	03:36	03:51	PPI 290-30/0-5	11.81	300	299	1.9	904	45.3	190.7
3-beam reach-Foil_down	03:55	04:10	PPI 290-30/0-5	11.74	300	298	2.0	905	45.3	190.7
4-beam reach-Foil_down	04:39	04:46	DBS	12.07	120	124	0.5	898	45.0	190.7
5-beam reach-Foil_down	04:46	05:01	PPI SB 325-70	11.99	119	123	0.5	847	42.4	190.7
6-beam reach-Foil_up	05:14	05:29	PPI SB 325-70	12.01	117	122	0.6	832	41.7	190.6
7-broad reach-Foil_up	05:39	05:48	DBS	11.53	345	342	1.9	866	43.4	190.7
8-broad reach-Foil_up	05:48	06:03	PPI PS Broad	11.60	345	342	1.9	864	43.3	190.7
9-broad reach-Foil_down	06:04	06:19	PPI PS Broad	11.54	345	344	2.0	864	43.3	190.7
10-close hauled-Foil_down	06:27	06:31	DBS	12.13	166	166	0.5	865	43.3	190.7
11-close hauled-Foil_down	06:31	06:46	PPI SB 325-70	12.12	166	165	0.7	864	43.3	190.7
12-close hauled-Foil_up	06:52	07:07	PPI SB 325-70	12.15	165	164	1.2	845	42.3	190.7
13-head wind-Foil_down	07:13	07:28	RHI	12.13	217	216	1.0	887	44.4	190.7
14-down wind-Foil_down	07:51	08:06	RHI+PPI+/-30(+15)	12.01	38	39	1.3	848	42.5	190.6
15-down wind-Foil_up	08:14	08:29	PPI+/-30(+15)	12.16	35	37	1.3	847	42.4	190.6
16-broad reach-Foil_up	16:29	16:44	RHI 358/0-2, PPI 340-50	13.19	103	103	0.6	864	43.2	190.7
17-AWA 30 anemo dwn-Foil_down	16:55	17:02	RHI	10.62	225	221	0.9	887	44.4	190.8
18-AWA 30 anemo up-Foil_down	17:02	17:07	RHI	12.11	176	173	-1.5	1324	66.4	190.4

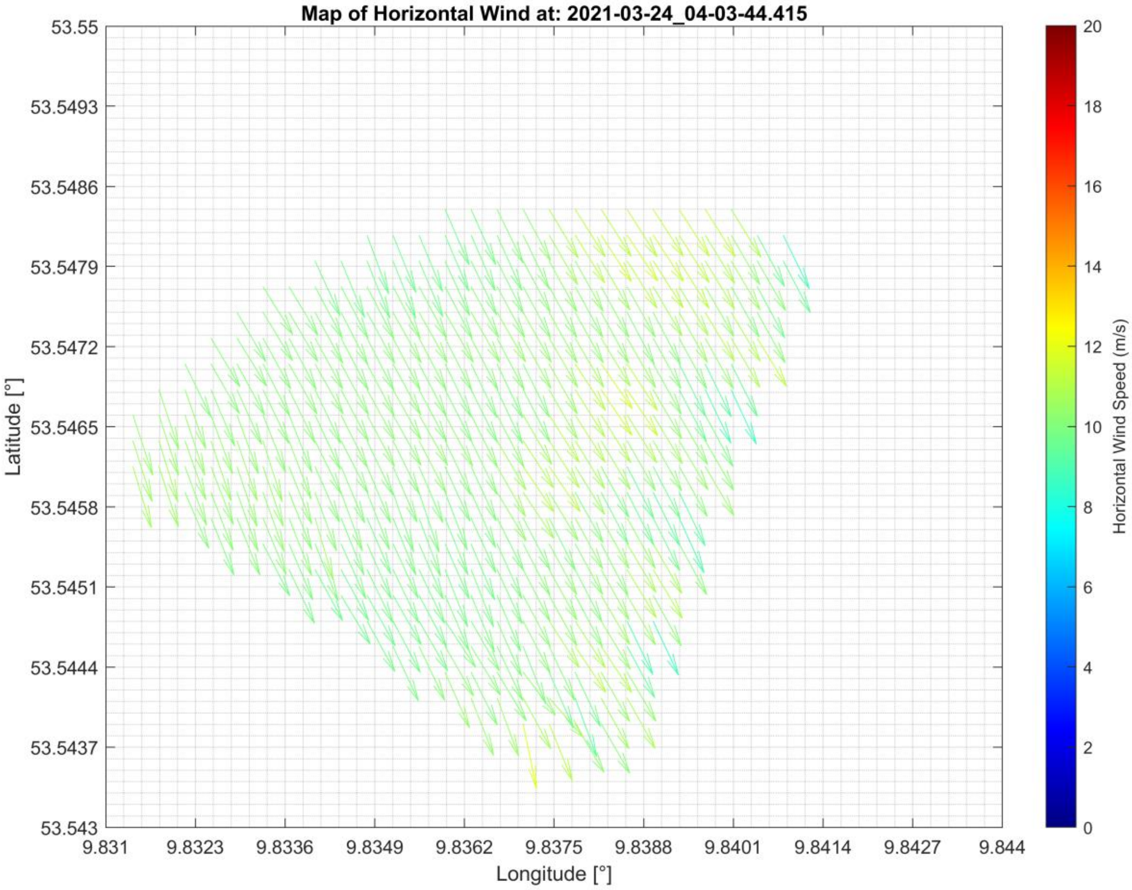
APPENDIX 4 ANEMOMETER RESULTS

Results from anemometers, left to right tables: AWA from port in red, from starboard in green, AWS coloured by magnitude, differences in degrees of absolute AWA between forward anemometers and ship's anemometer at bridge top (i.e. positive difference indicates a higher AWA on the forward anemometer), relative difference in AWS as percentage of ship's anemometer, values in red font indicates obstruction of air flow by searchlight (see Figure 3)

	Apparent Wind Angle				**Apparent Wind Speed**				**Apparent Wind Angle**			**Apparent Wind Speed**		
	SHIP	**FWD ANEMO**			**SHIP**	**FWD ANEMO**			**FWD ANEMO - SHIP**			**FWD ANEMO / SHIP**		
ID	AWA ship	AWA 2.5	AWA 5	AWA 10	AWS ship	AWS 2.5	AWS 5	AWS 10	absdiff AWA2.5	absdiff AWA5	absdiff AWA10	diff AWS2.5	diff AWS5	diff AWS10
	deg	deg	deg	deg	kn	kn	kn	kn	deg	deg	deg	%	%	%
1-beam reach-Foil_up		-39	-37	-47		24.5	23.9	23.4						
2-beam reach-Foil_up	-45	-40	-38	-49	19.0	23.7	23.2	22.6	-5	-7	4	25%	22%	19%
3-beam reach-Foil_down	-45	-45	-42	-49	19.0	22.6	22.1	21.3	0	-3	4	19%	17%	12%
4-beam reach-Foil_down	45	57	57	51	17.0	20.8	13.2	17.9	12	12	6	22%	-22%	5%
5-beam reach-Foil_down	40	58	57	51	18.0	21.1	13.0	18.1	18	17	11	17%	-28%	1%
6-beam reach-Foil_up	40	56	54	51	18.0	19.2	13.6	17.6	16	14	11	7%	-24%	-2%
7-broad reach-Foil_up	-75	-60	-58	-71	8.0	14.2	13.8	13.4	-15	-17	-4	78%	72%	67%
8-broad reach-Foil_up	-75	-61	-58	-72	8.5	13.9	13.4	13.1	-14	-17	-3	63%	58%	54%
9-broad reach-Foil_down	-70	-73	-74	-79	7.0	12.2	11.7	11.8	3	4	9	74%	68%	68%
10-close hauled-Foil_down	18	37	30	29	28.0	26.4	14.4	23.7	19	12	11	-6%	-49%	-15%
11-close hauled-Foil_down	20	38	36	31	26.0	26.1	13.4	23.3	18	16	11	0%	-49%	-10%
12-close hauled-Foil_up	17	35	38	30	26.0	23.9	12.9	22.7	18	21	13	-8%	-50%	-13%
13-head wind-Foil_down	-6	5	5	-2	31.0	25.5	26.8	25.0	-1	-1	-4	-18%	-13%	-19%
14-down wind-Foil_down	40	-60	-86	-141	2.0	1.2	1.3	1.4	20	46	101	-38%	-37%	-29%
15-down wind-Foil_up	-130	170	168	172	3.0	1.0	1.1	1.5	40	38	42	-66%	-63%	-49%
16-broad reach-Foil_up	50	1	67	56	8.5	1.5	1.3	9.0	-49	17	6	-82%	-84%	6%
18-AWA 30-Foil_down	50	36	33	29	8.5	24.9	13.5	23.0	-14	-17	-21	193%	58%	171%

APPENDIX 5 WIND FIELD RESULTS


Map of Horizontal Wind at: 2021-03-24_03-44-23.523
Latitude [°]
53.55
53.5493
53.5486
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Longitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Horizontal Wind Speed (m/s)
0
2
4
6
8
10
12
14
16
18
20


Map of Horizontal Wind at: 2021-03-24_04-03-44.415
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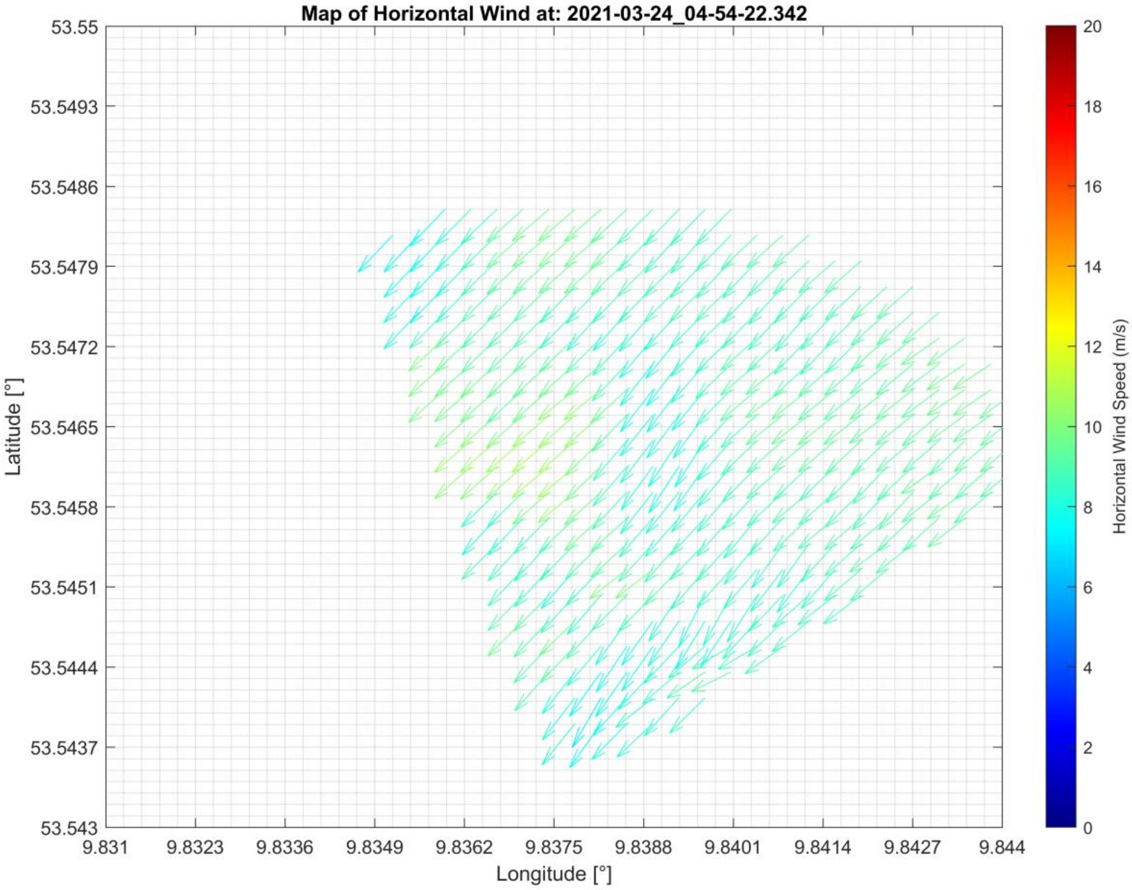
53.5458
53.5451
53.5444
53.5437
53.543
Longitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Horizontal Wind Speed (m/s)
0
2
4
6
8
10
12
14
16
18
20


Map of Horizontal Wind at: 2021-03-24_04-54-22.342
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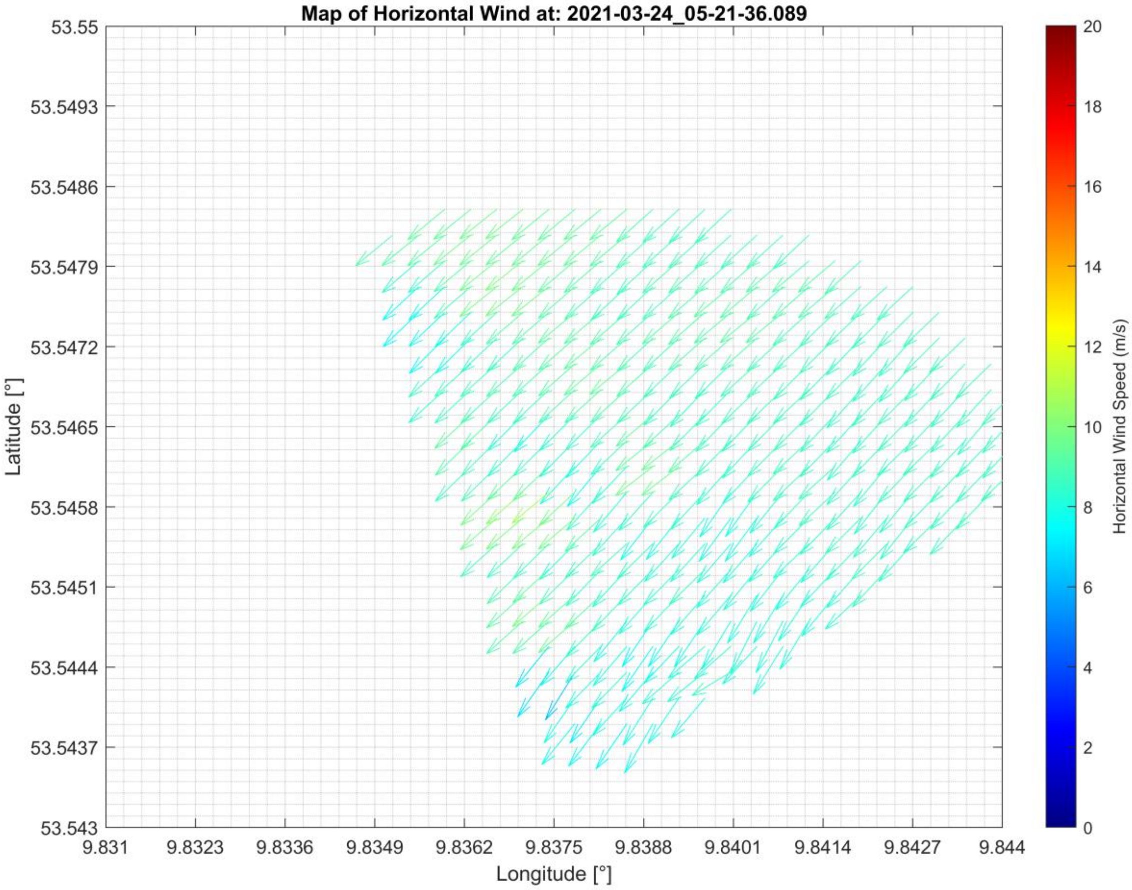
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
20
18
16
14
12
10
8
6
4
2
0
Horizontal Wind Speed (m/s)


Map of Horizontal Wind at: 2021-03-24_05-21-36.089
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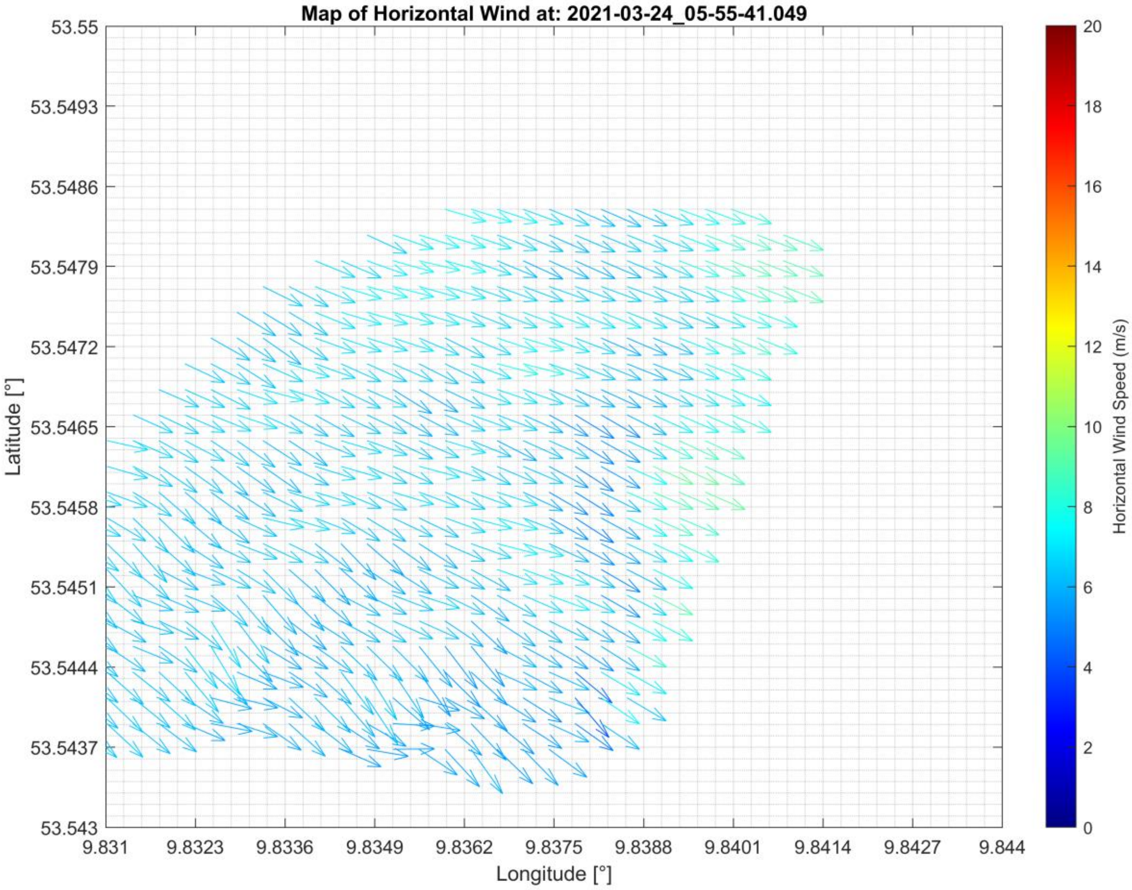
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
20
18
16
14
12
10
8
6
4
2
0
Horizontal Wind Speed (m/s)


Map of Horizontal Wind at: 2021-03-24_05-55-41.049
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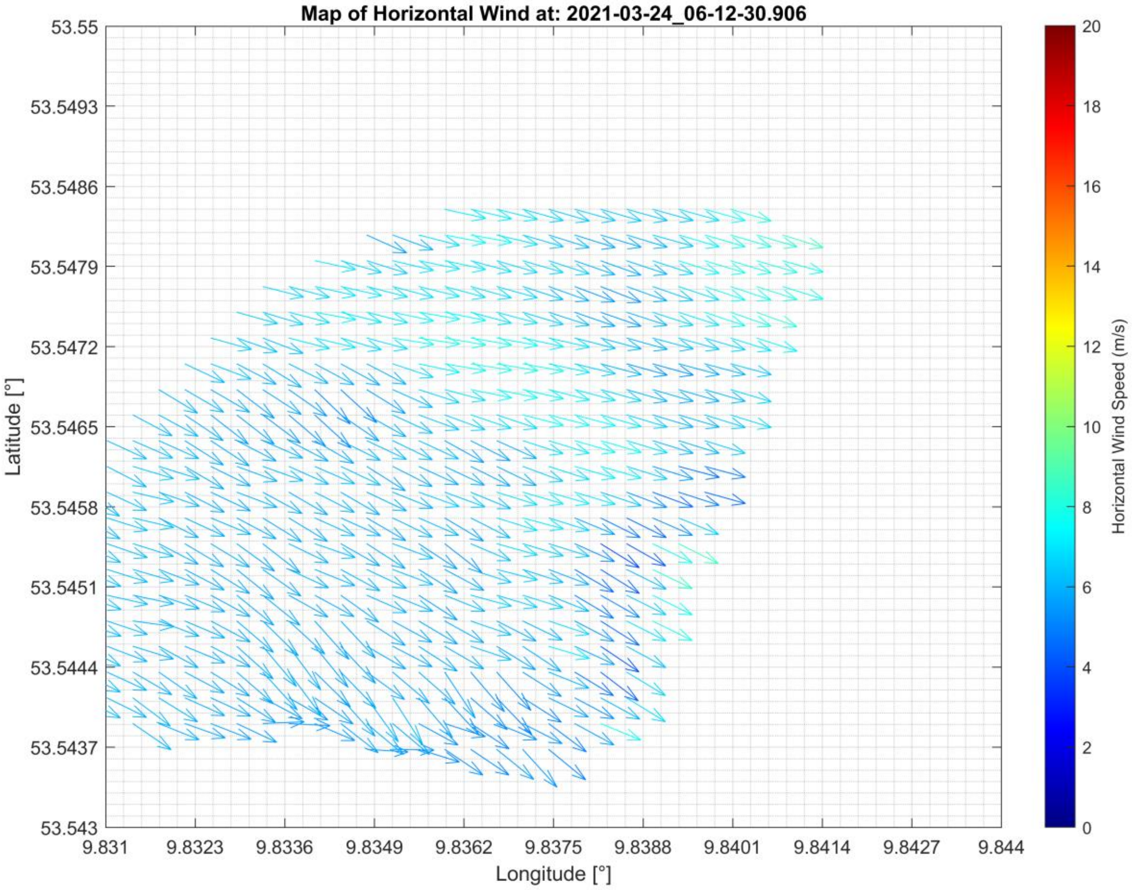
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
20
18
16
14
12
10
8
6
4
2
0
Horizontal Wind Speed (m/s)



Map of Horizontal Wind at: 2021-03-24_06-12-30.906
Latitude [°]
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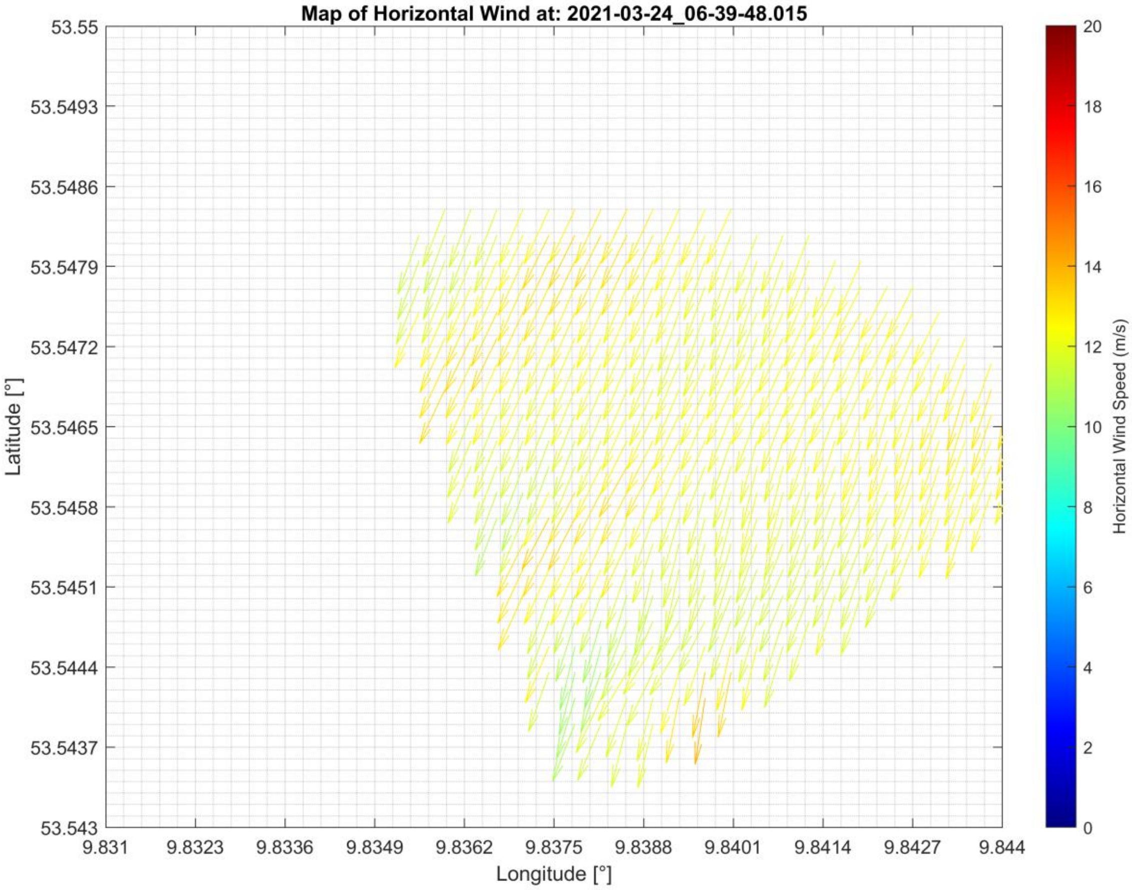
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Longitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Horizontal Wind Speed (m/s)
0
2
4
6
8
10
12
14
16
18
20



Map of Horizontal Wind at: 2021-03-24_06-39-48.015
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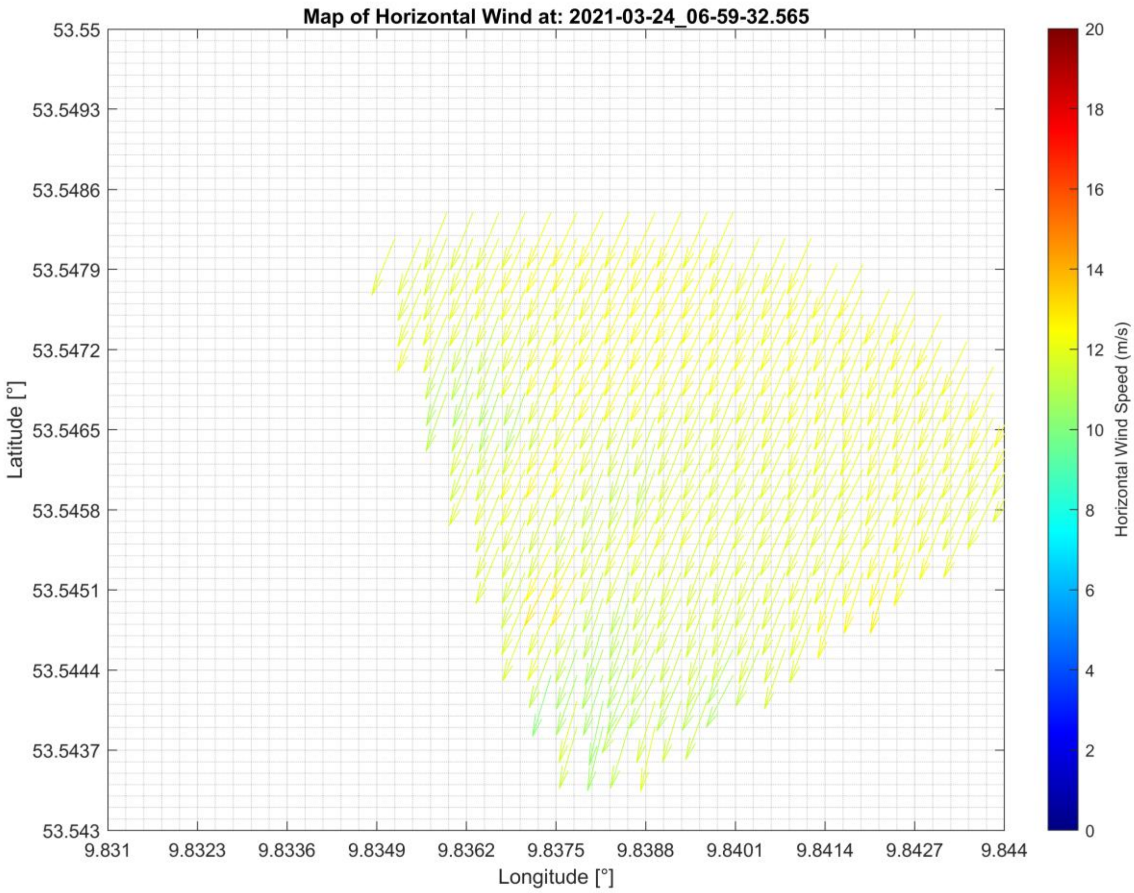
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
20
18
16
14
12
10
8
6
4
2
0
Horizontal Wind Speed (m/s)


Map of Horizontal Wind at: 2021-03-24_06-59-32.565
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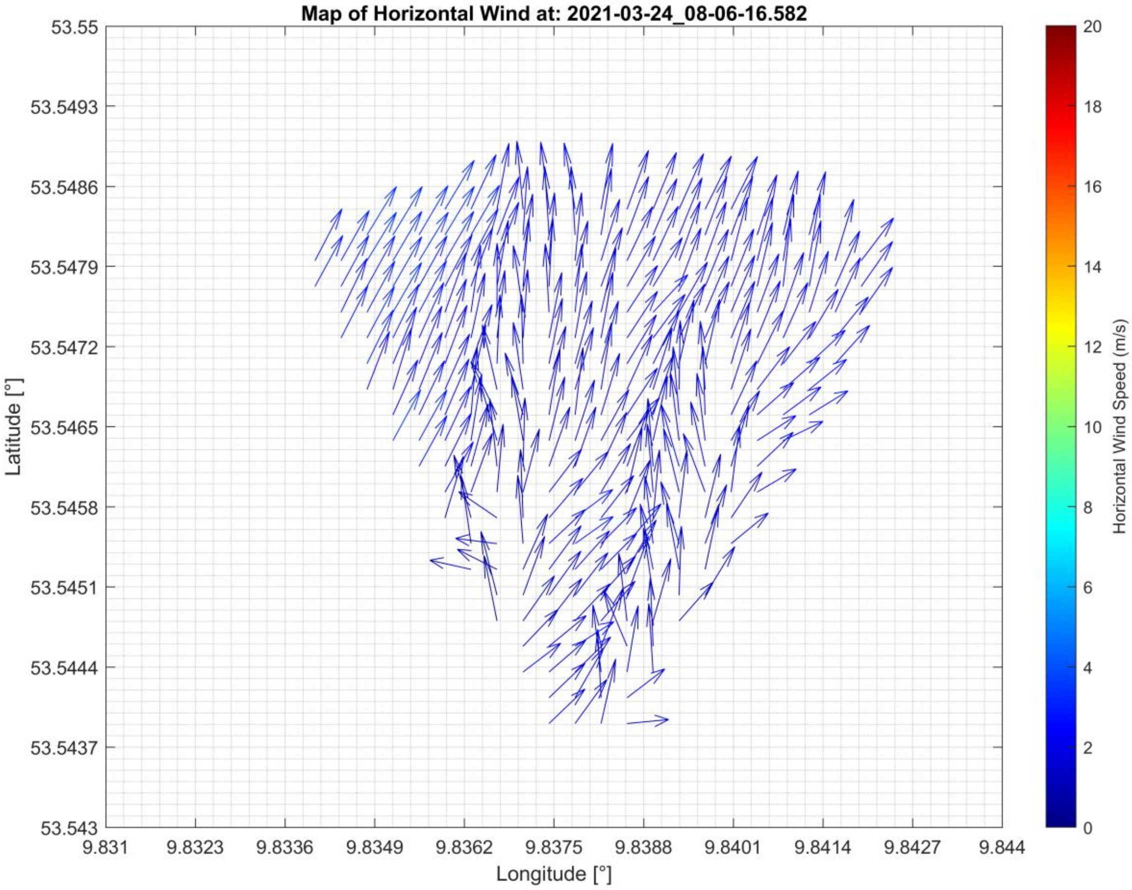
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
20
18
16
14
12
10
8
6
4
2
0
Horizontal Wind Speed (m/s)


Map of Horizontal Wind at: 2021-03-24_08-06-16.582
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53.5486
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
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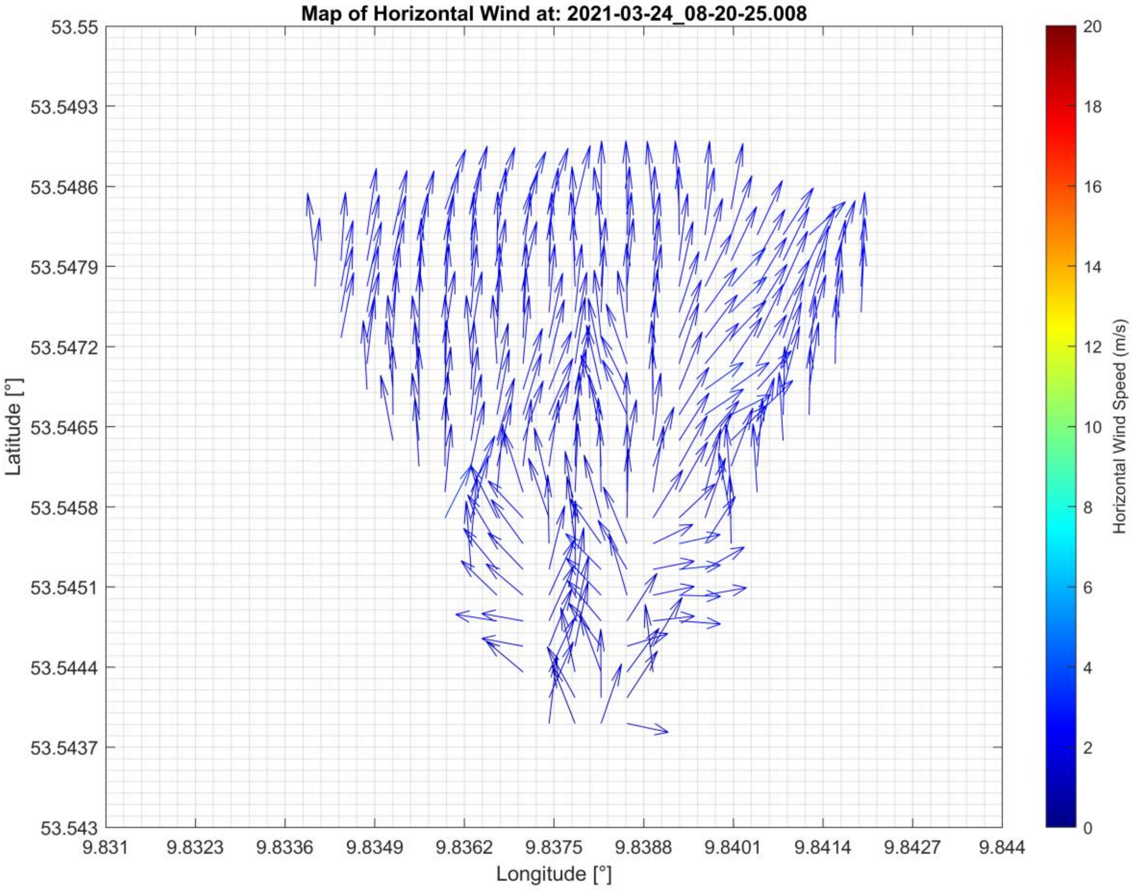
Horizontal Wind Speed (m/s)


Map of Horizontal Wind at: 2021-03-24_08-20-25.008
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53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Latitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Longitude [°]
Horizontal Wind Speed (m/s)
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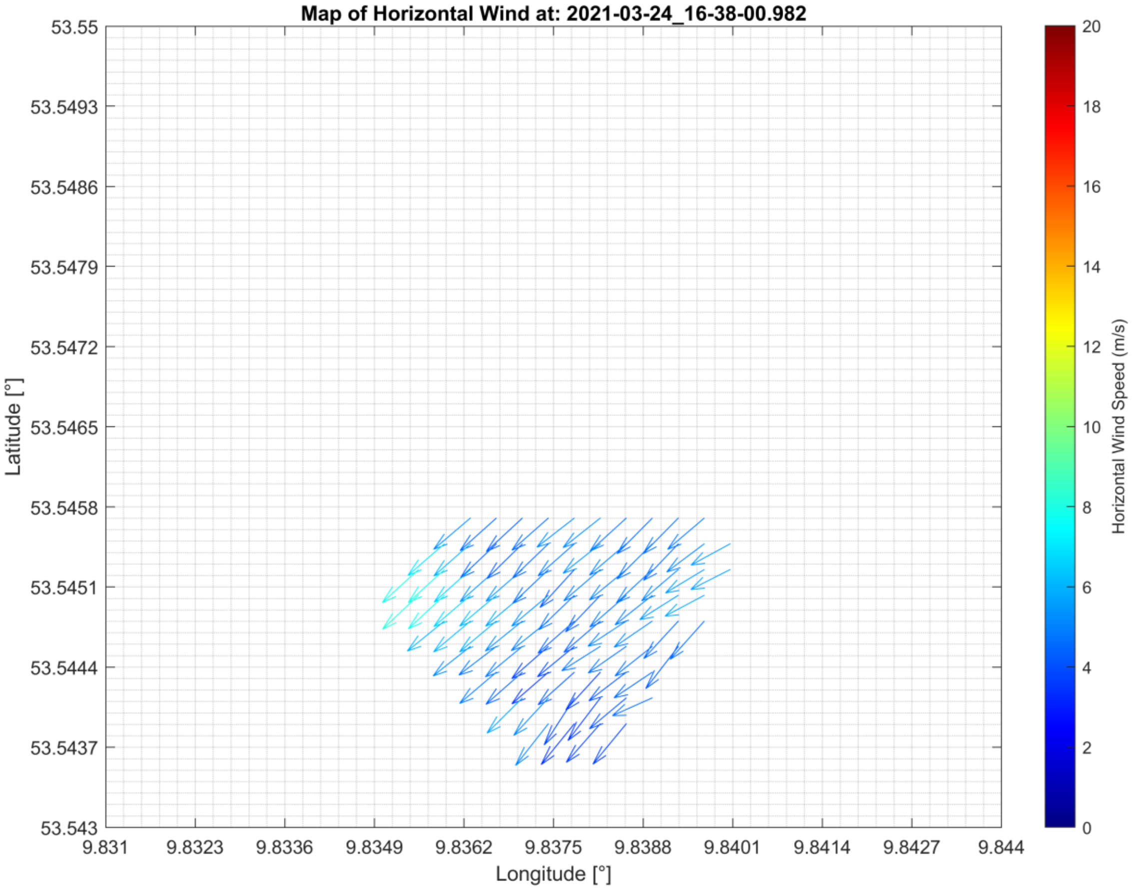
Map of Horizontal Wind at: 2021-03-24_16-38-00.982
Latitude [°]
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53.5486
53.5479
53.5472
53.5465
53.5458
53.5451
53.5444
53.5437
53.543
Longitude [°]
9.831
9.8323
9.8336
9.8349
9.8362
9.8375
9.8388
9.8401
9.8414
9.8427
9.844
Horizontal Wind Speed (m/s)
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