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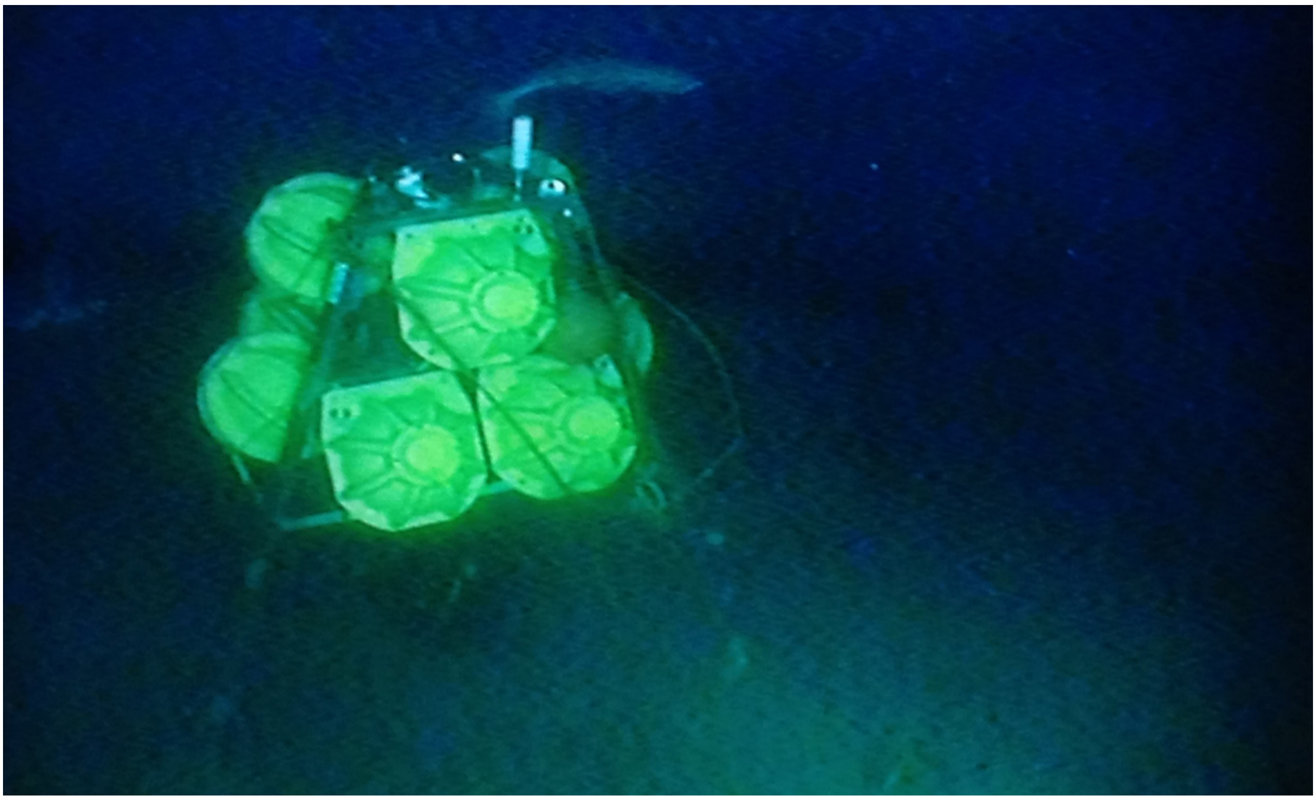
Long term current monitoring at U-864 location outside Fedje 2014-2015



Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

Main Office
Gaustadalléen 21
NO-0349 Oslo, Norway
Phone (47) 22 18 51 00
Telefax (47) 22 18 52 00
Internet: www.niva.no

NIVA Region South
Jon Lilletuns vei 3
NO-4879 Grimstad, Norway
Phone (47) 22 18 51 00
Telefax (47) 37 04 45 13

NIVA Region East
Sandvikaveien 59
NO-2312 Ottestad, Norway
Phone (47) 22 18 51 00
Telefax (47) 62 57 66 53

NIVA Region West
Thormøhlens gate 53 D
NO-5006 Bergen Norway
Phone (47) 22 18 51 00
Telefax (47) 55 31 22 14

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Author(s) Pierre Jaccard, Andre Staalstrøm, Odd Arne Skogan	Topic group Marine Monitoring	Distribution
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Abstract

In January 2014, NIVA participated in a survey by the wreck of submarine U-864 outside Fedje. NIVA's role was to carry out environmental monitoring during the survey. The cruise was ended by the deployment of an acoustic current profiler close to the wreck. The purpose was to perform a long term current monitoring of one year in the area and provide detailed information about current conditions for planning future subsea activities.

The current profiler was deployed at 152 m depth between the two pieces of the submarine U-864 wreck. A trench with depths of about 174 m is found to the north of the site. The measurements started January 14, 2014 and ended 23 March, 2015. This represent at valuable and rare time series of current conditions in the Norwegian coastal current.

The currents vary with depth, and the observations are divided into three layers: a bottom layer from 125m to 150m, an intermediate layer from 30m to 125m and a surface layer from 0m to 30m. The most striking characteristics of the current field are that the flow occurs mostly in the northerly direction and with a relatively high current speed.

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3. Strømmålinger	3. Current measurements
4. Overvåking	4. Monitoring

Sigurd Øxnevad
Project Manager

Kai Sørensen
Research Manager

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Long term current monitoring at U-864 location outside Fedje 2014-2015

Preface

NIVA has done environmental monitoring during a survey by the wreck of submarine U-864, outside Fedje. The survey was carried out in January 2014 on vessel "M/S Geosund" from DOF Subsea Norway. It was ended by the deployment of an acoustic current profiler. Measurement lasted for one year until spring 2015. Instrumentation was recovered by vessel "M/S Solvik". Sigurd Øxnevad has been the project leader. This report presents results from this long term current monitoring.

Oslo, June 5, 2015

Pierre Jaccard

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Summary

In January 2014, NIVA participated in a survey by the wreck of submarine U-864 outside Fedje. NIVA's role was to carry out environmental monitoring during the survey. The cruise was ended by the deployment of an acoustic current profiler close to the wreck. The purpose was to perform a long term current monitoring of one year in the area and provide detailed information about current conditions for planning future subsea activities.

The current profiler was deployed at 152 m depth between the two pieces of the submarine U-864 wreck. A trench with depths of about 174 m is found to the north of the site. The measurements started January 14, 2014 and ended 23 March, 2015. This represent at valuable and rare time series of current conditions in the Norwegian coastal current.

The currents vary with depth, and the observations are divided into three layers: a bottom layer from 125m to 150m, an intermediate layer from 30m to 125m and a surface layer from 0m to 30m. The most striking characteristics of the current field are that the flow occurs mostly in the northerly direction and with a relatively high current speed. Current conditions in the three layers can be summarized in a table:

Typical current values within the main flow direction in each layer.

	Mean (cm/s)	Max (cm/s)	95%-limit (cm/s)	Direction
Surface Layer 0-30m	35	135	70	0°-30°
Intermediate Layer 30-125m	30	100	55	0°-30°
Bottom Layer 125-150m	16	65	35	330°-30°

Sammendrag

I januar 2014 deltok NIVA på et tokt ved ubåt U-864 utenfor Fedje. NIVAs rolle var å utføre miljøovervåking. Toktet ble avsluttet med utsetting av en akustisk strømmåler som skulle stå der i ett år og foreta langtidsmålinger av strømforholdene gjennom hele vannsøylen. Instrument ble satt ut ved 152m dyp mellom begge vrakdelene. Målingene ble utført mellom 14. januar 2014 og 23. mars 2015 og bidrar til verdifull informasjon om den Norske Kyststrømmen.
Utfra observasjonene ble det mulig å dele opp vannsøylen i 3 forskjellige lag: et bunnlag som strekker seg fra 125m til 150m, et intermediært lag mellom 125m og 30m og helt øverst en overflate lag fra 30m og oppover. Målingene viser at vann strømmer stort sett bare mot nord og med relativ høy hastighet.

Hovedstrømbildet i de 3 lagene er vist i tabellen under.

	Middelverdi (cm/s)	Maksverdi (cm/s)	95%-limit (cm/s)	Hoved retning
Overflatelag 0-30m	35	135	70	0°-30°
Intermediære lag 30-125m	30	100	55	0°-30°
Bunnlag 125-150m	16	65	35	330°-30°

1. Background

In February 1945 the German submarine U-864 was sunk outside Fedje, on the south western coast of Norway. The submarine was torpedoed mid ship, broke in two and sank. It is located at 150 m depth. U-864 is assumed to have had 67 tons of liquid mercury onboard, stored in 1857 carbon steel cans in holds within the keel. When torpedoed, the mid-section of the submarine was blown up, and an unknown number of the steel cans were destroyed and mercury was spread to pollute the surrounding seabed. Some mercury cans also corroded during the decades since the event.

Authorities have decided to further evaluate two different methods of pollution abatement:

- Seal-in the polluted area, utilizing sand with special characteristics
- Retrieve the mercury cans from the keel section and seal-in the polluted area

NIVA has been involved several times in activities related to U-864. Current measurements were already performed during a 2 weeks period in 2006 (Uriansrud et al., 2006). The area outside Fedje is known for strong currents. Therefore, knowledge about direction, magnitude and variability is necessary in order to plan long term operations or environmental interventions. Hence, a long term current monitoring was necessary.

2. Methods and Instrumentation

Due to the length of the deployment, it was decided to avoid any items at surface or within the water column. This would avoid interferences with other objects or activities, although the considered area is restricted to navigation. Therefore, a bottom tripod frame was used with an upward looking acoustic Doppler current profiler (Nortek Continental 190 kHz). It was equipped in addition with 2 battery packs, one acoustic release (IXBlue Oceano 2500) and one ARGOS beacon (SMM500). The latter was installed as a safety measure should the mooring surface earlier than expected. A schematic drawing of the installation and a video image of the deployed instrument are shown in Figure 1 and 2.

Instrumentation was placed on the site (60.46N, 04.35E) between the two wrecks parts at 152m depth (see Figure 3). The trench on the north side is 175 m deep. There are also two small elevations on the western and eastern side of the site. These are approximately 140 m and 145 m deep. Instrumentation was deployed on January 14, 2014 and recovered on March 23, 2015.

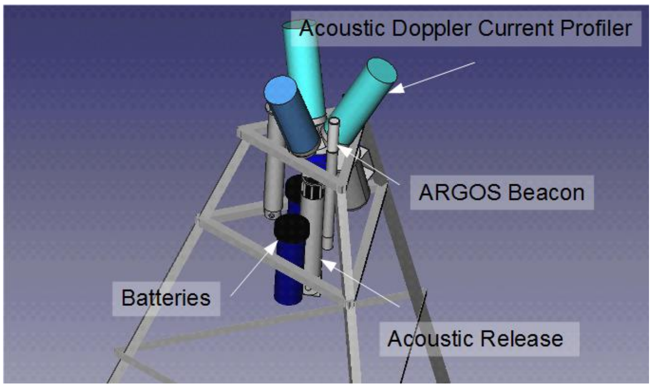

Figure 1 Schematic of the deployed bottom frame and instrumentation.

Figure 2 Bottom frame deployed on bottom

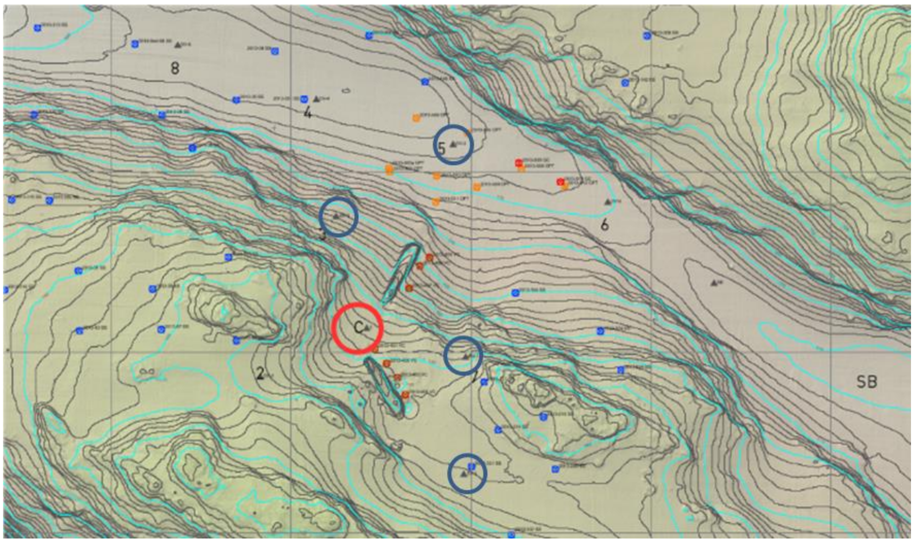

Figure 3 Location of the mooring between both wreck parts at point C is shown with a red circle. The 4 other blue circles show the places where current was measured in 2006.

Currents were measured with an upward looking Nortek Continental. This instrument uses Acoustic Doppler technology to profile currents through the water column. With an acoustic frequency of 190 kHz, one can profile good quality measurements up to a distance of 200m. Sampling interval was set to 4 minutes continuous sampling every hour. With this configuration, the horizontal accuracy is estimated to be of 1.3 cm/s. Table 1 summarizes the feature of the current meter under the configuration used during deployment.

Data were downloaded from recovered instrument and quality assessed. This step included

- Removal of acoustic side lobe effects from surface
- Detection of acoustic amplitude outliers
- Removal of low quality signal averages
- Detection of signal correlation outliers
- Removal of deployment and recovery noise

Table 1 Features of the current meter Nortek Continental under the configuration used

Frequency	*190kHz*
Sampling Interval	*240s every 3600s*
Measurement Load	*100%*
Bin Size	*5m*
Number of bins	*30*
Range	*>150m*
Velocity Standard Deviation	*1.3cm/s*

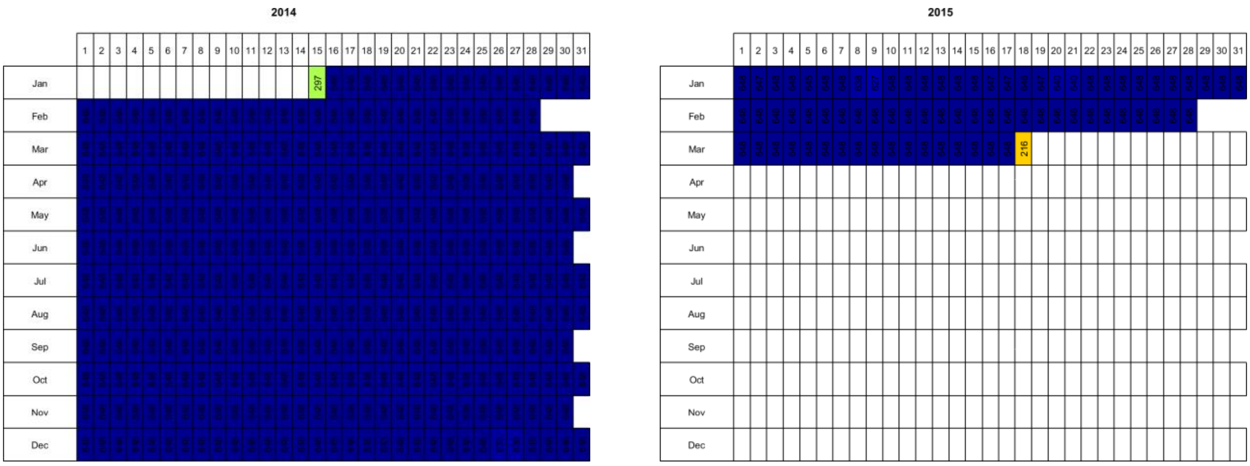

Figure 4 Days with good measurements. The colour scale for cells goes from red to blue, where blue are days with the maximum number lot of good quality measurements.

3. Results

Once quality control was performed, remaining data did extend over the period between 2014-01-15 13:11:36 and 2015-03-18 07:11:36. Figure 4 shows yearly calendars with the number of good data per day. The colour scale used for the cells goes from red to blue and correspond to bad and good days respectively. Current data from the depths listed in Table 2 have been processed.

Table 2 Measurement depths in meter.

148	143	138	133	128	123	118	113	108	103	98	93	88	83	78
73	68	63	58	53	48	43	38	33	28	23	18			

A global progressive vector diagram is presented in Figure 5. It gives an idea of current direction, magnitude and variations for the whole measurement period and all depths. The colour scale goes to blue at bottom to red at surface. Displacement due to the first measurement is at the plot origin (0,0), while that from the last one is at the end of the line. At first glance, one can see that the current is mainly northward. This is due to the presence of the Norwegian Coastal current in this area (Sætre and Mork 1981). Measurements close to surface include most variations. The reason is the influence from atmospheric conditions. Otherwise, the current is nearly barotropic (it changes little with depth) and rotates westwards close to bottom due to friction but also topographic features. Therefore, in the rest of this report, we will consider the 3 layers defined in Table 3.

Table 3 Vertical layers derived from the measurements with start and stop depths in meter.

	From	***To***
Surface	0	30
Intermediate	30	125
Bottom	125	150

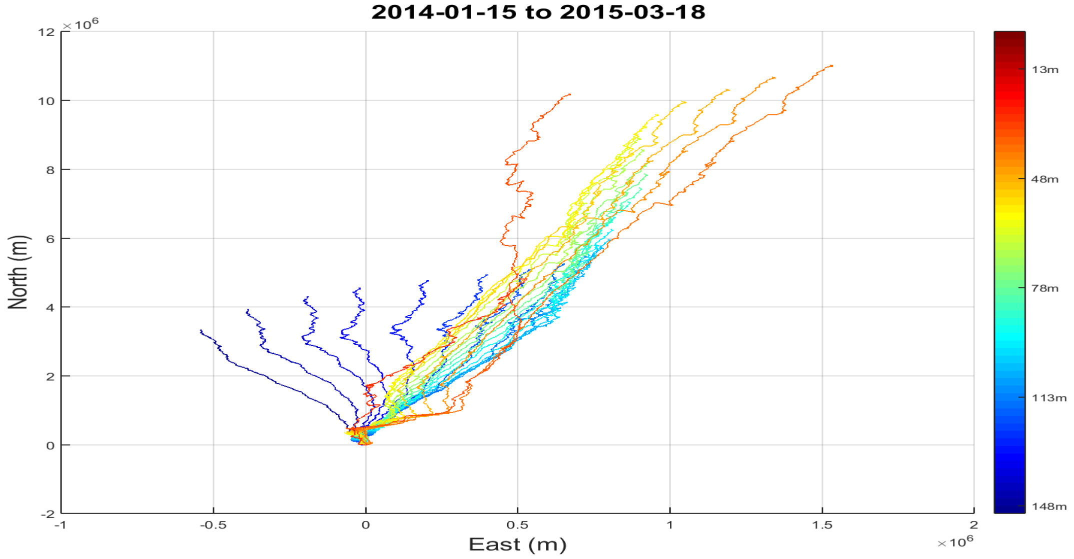

Figure 5 Progressive vector diagrams for the whole measurement period and all measurement depths. Red lines correspond to surface measurements while blue ones are close to bottom.

3.1 Bottom Layer

The bottom layer is the most important since it can transport suspended sediments. Figure 6 shows time series and histogram of currents for the whole deployment period. Note that current direction in the timeseries plot has been unwrapped in order to provide a continuous curve and provide better image about variations. Unless values on the vertical scale are wrapped back to the range 0 to 360, this curve does not give much information about the physical direction of the flow. For this information we refer to the polar plots in Figure 7.

The different plots in Figure 7 provide statistical information about current measurements for the different direction sectors, except for the scatter plot. The meaning of the latter is to deliver a fast visual qualitative control of the other polar plots. Statistical values for these plots are given in Table 4. A complete list of current histogram values is presented in Table 5.

Table 4 Statistical values for current magnitude in the bottom layer for the whole deployment period. Units for speed are in cm/s and m^3/m^2 for transport. *Horizontally:* the different direction sectors. *Vertically:* a selection of statistic functions.

(cm/s)	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**
	30	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**
mean	16.3	14.7	7.3	5.3	5.5	5.9	6.4	6.2	5.3	6.8	13.1	16.4
median	15.1	12.3	6	5	4.9	5.3	5.9	4.9	4.5	5.8	10.9	15.3
sdev	9.4	9.9	5	3.4	4	3.5	3.6	5.4	3.5	4.4	9.4	9.2
max	64.8	54.7	26.4	15.9	19.3	18.2	19.1	49.3	27.7	36.9	60.5	59
95%-limit	34.2	34.5	18.1	12.1	13.5	12.5	13.1	15.4	11.3	14.1	31.2	32.7
transport *(m^3/m^2)*	16294.2	5894.5	734.2	290.8	256	346.2	442.6	478.9	477.6	1094.1	6705.9	18277

Table 5 Current histogram values as number of observations for the bottom layer and the whole deployment period. *Horizontally:* the different direction sectors. *Vertically:* the current magnitude bins in cm/s. Most right column and bottom rows include the corresponding totals.

		0	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	
(cm/s)		**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**	***Total***
0	**10**	786	445	225	138	111	141	157	177	233	366	644	873	*4296*
10	**20**	1136	374	48	14	18	22	34	30	16	77	535	1241	*3545*
20	**30**	605	195	8	0	0	0	0	6	2	5	163	741	*1725*
30	**40**	191	74	0	0	0	0	0	0	0	1	52	193	*511*
40	**50**	46	19	0	0	0	0	0	1	0	0	21	39	*126*
50	**60**	5	4	0	0	0	0	0	0	0	0	9	16	*34*
60	**70**	2	0	0	0	0	0	0	0	0	0	1	0	*3*
Total		*2771*	*1111*	*281*	*152*	*129*	*163*	*191*	*214*	*251*	*449*	*1425*	*3103*	*10240*

As mentioned earlier, the main flow above bottom is confined to the sector NW to NE, with a mean magnitude close to 20cm/s. However, current speed up to 70cm/s was observed, although the 95% of all measurements are below 40cm/s.

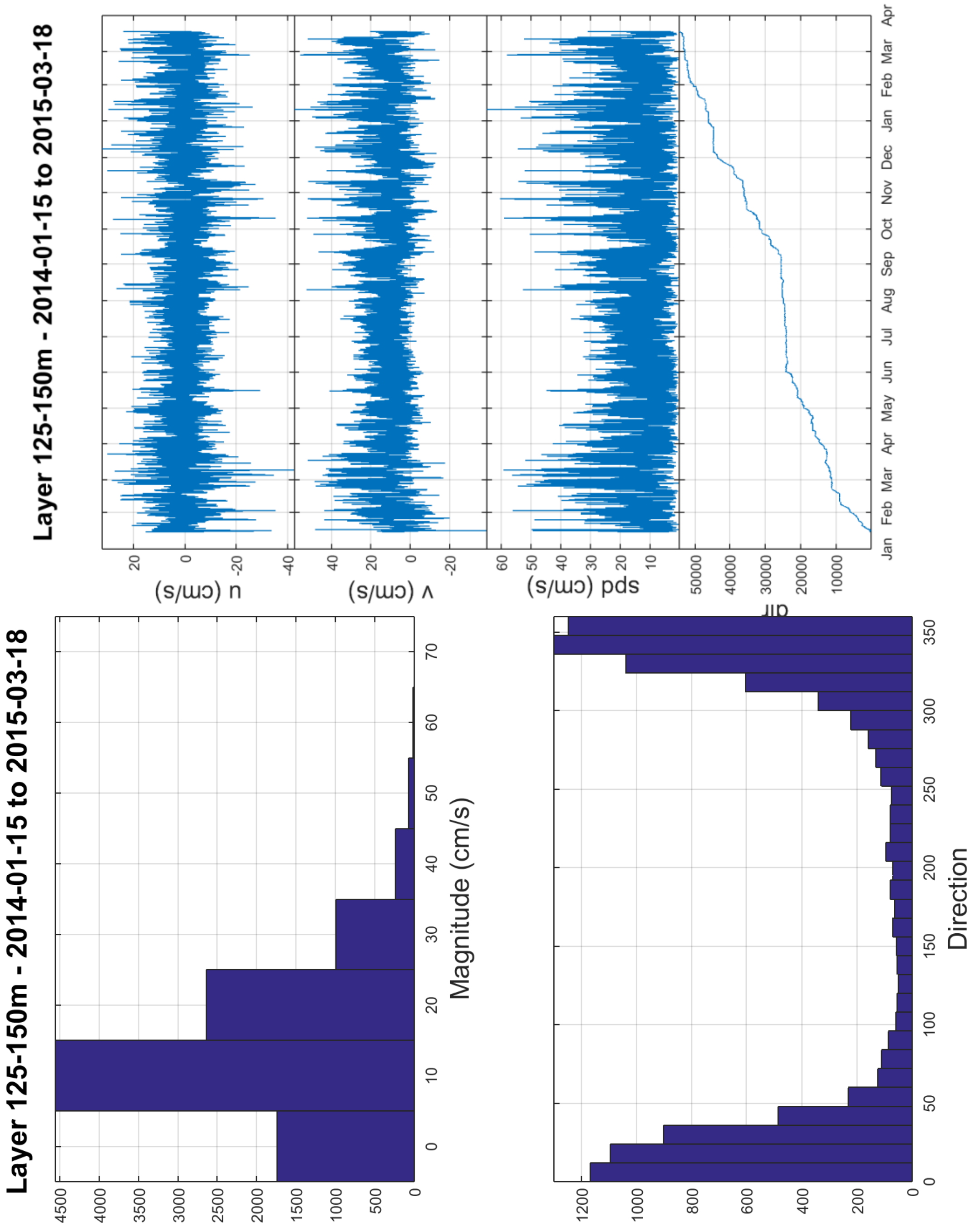

Figure 6 Timeseries and histograms of bottom layer for the whole deployment period. Note that the direction in the timeseries plot has been unwrapped

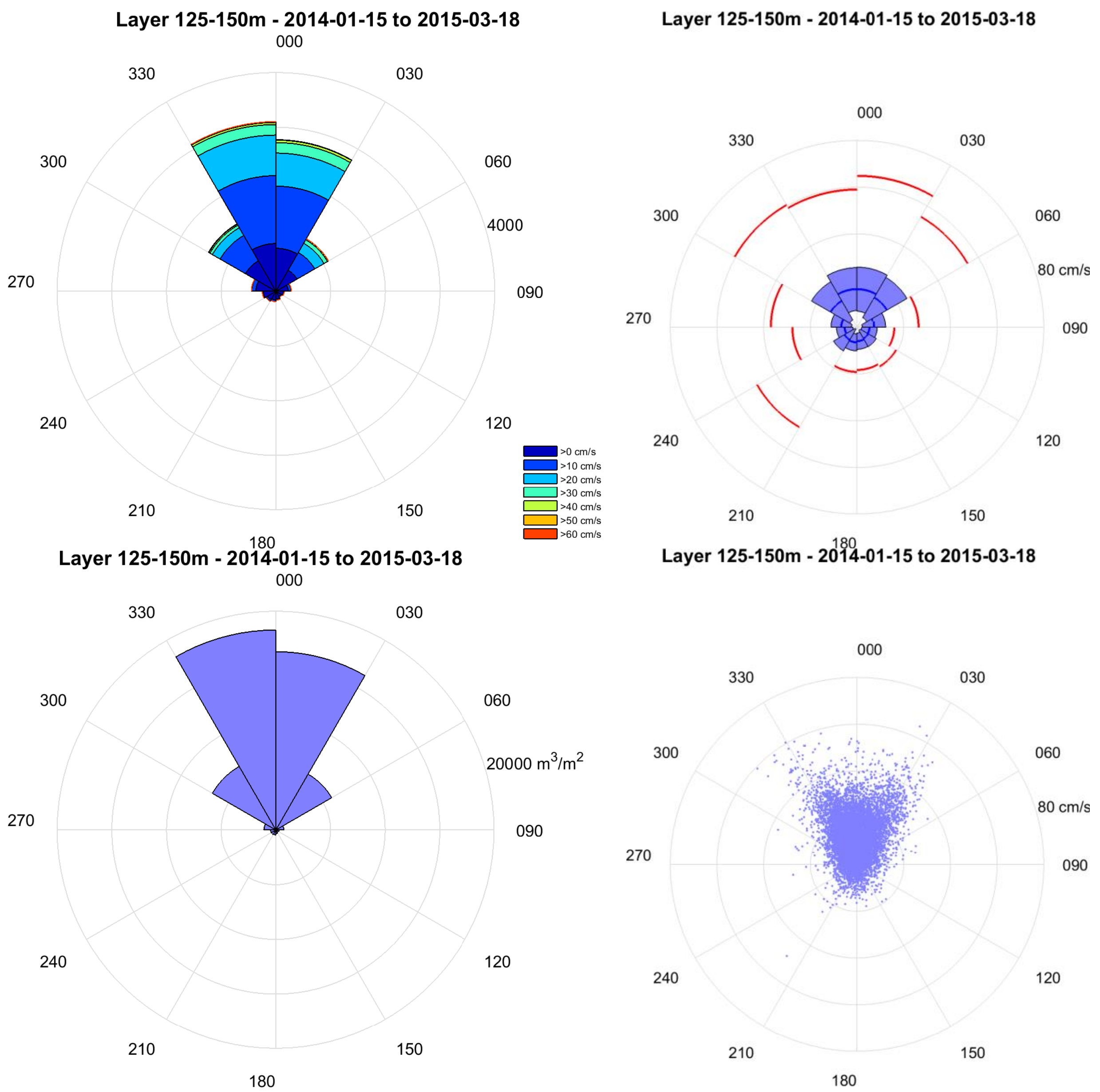

Figure 7 Polar plots of the bottom current during the whole deployment period. *Upper left:* current histogram by directions sectors. *Upper right:* blue arcs correspond to the mean current value within the direction sector. Blue areas are standard deviation extending on each side of the mean value. Red arcs are the maximum current value observed. *Lower left:* estimated transport integrated over the deployment period. *Lower right:* scatter plot of all observations.

3.2 Surface Layer

This layer is expected to have the largest variations because of the influence from meteorological conditions. Similar tables and figures as those shown for the bottom layer can be found in Table 7, Table 8, Figure 8, and Figure 9.

Table 6 Statistical values for current magnitude in the surface layer for the whole deployment period. Units for speed are in cm/s and m^3/m_2 for transport. *Horizontally:* the different direction sectors. *Vertically:* a selection of statistic functions.

	0	30	60	90	120	150	180	210	240	270	300	330
(cm/s)	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**
mean	35.1	19.1	15.3	11.1	14.3	17.2	14.2	8.6	8.3	8.5	11.9	25.8
median	31.6	15.5	12.5	8.8	10.6	11.8	11	8.1	7.4	7.5	10.6	22.4
sdev	19.9	13.3	11.7	8.3	11.1	13.9	11.1	5	4.5	5.2	6.8	16.3
max	136.9	68.4	98	50.7	54	54.2	57.6	28.4	21.2	40.5	40.8	135.9
95%-limit	71.8	46.9	33.9	25.4	32	45.6	37	17.1	17.6	17.3	25.3	58.9
transport *(m^3/m^2)*	62238.7	4391	969.7	420.4	519.7	799	1446.6	723.1	607.1	785.9	2486.5	24227

Table 7 Current histogram values as number of observations for the surface layer and the whole deployment period. *Horizontally:* the different direction sectors. *Vertically:* the current magnitude bins in cm/s. Most right column and bottom rows include the corresponding totals.

		0	30	60	90	120	150	180	210	240	270	300	330	
(cm/s)		**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**	***Total***
0	**10**	339	178	71	59	47	55	129	154	144	183	271	335	*1965*
10	**20**	907	227	57	30	25	33	93	73	57	66	247	785	*2600*
20	**30**	1047	108	36	15	21	16	30	6	2	6	51	692	*2030*
30	**40**	909	67	7	0	5	12	19	0	0	1	11	349	*1380*
40	**50**	620	37	1	0	1	11	6	0	0	1	2	188	*867*
50	**60**	473	16	3	1	2	2	5	0	0	0	0	152	*654*
60	**70**	340	6	0	0	0	0	0	0	0	0	0	65	*411*
70	**80**	179	0	0	0	0	0	0	0	0	0	0	24	*203*
80	**90**	74	0	0	0	0	0	0	0	0	0	0	9	*83*
90	**100**	20	0	1	0	0	0	0	0	0	0	0	4	*25*
100	**110**	10	0	0	0	0	0	0	0	0	0	0	2	*12*
110	**120**	3	0	0	0	0	0	0	0	0	0	0	2	*5*
120	**130**	2	0	0	0	0	0	0	0	0	0	0	0	*2*
130	**140**	4	0	0	0	0	0	0	0	0	0	0	1	*5*
Total		*4927*	*639*	*176*	*105*	*101*	*129*	*282*	*233*	*203*	*257*	*582*	*2608*	*10242*

As expected, current magnitude values cover a much larger range and there were observations up to 140cm/s. As for bottom current, most of the flow is confined within direction sector NW to NE, although sector N-NE is about twice as dominant.

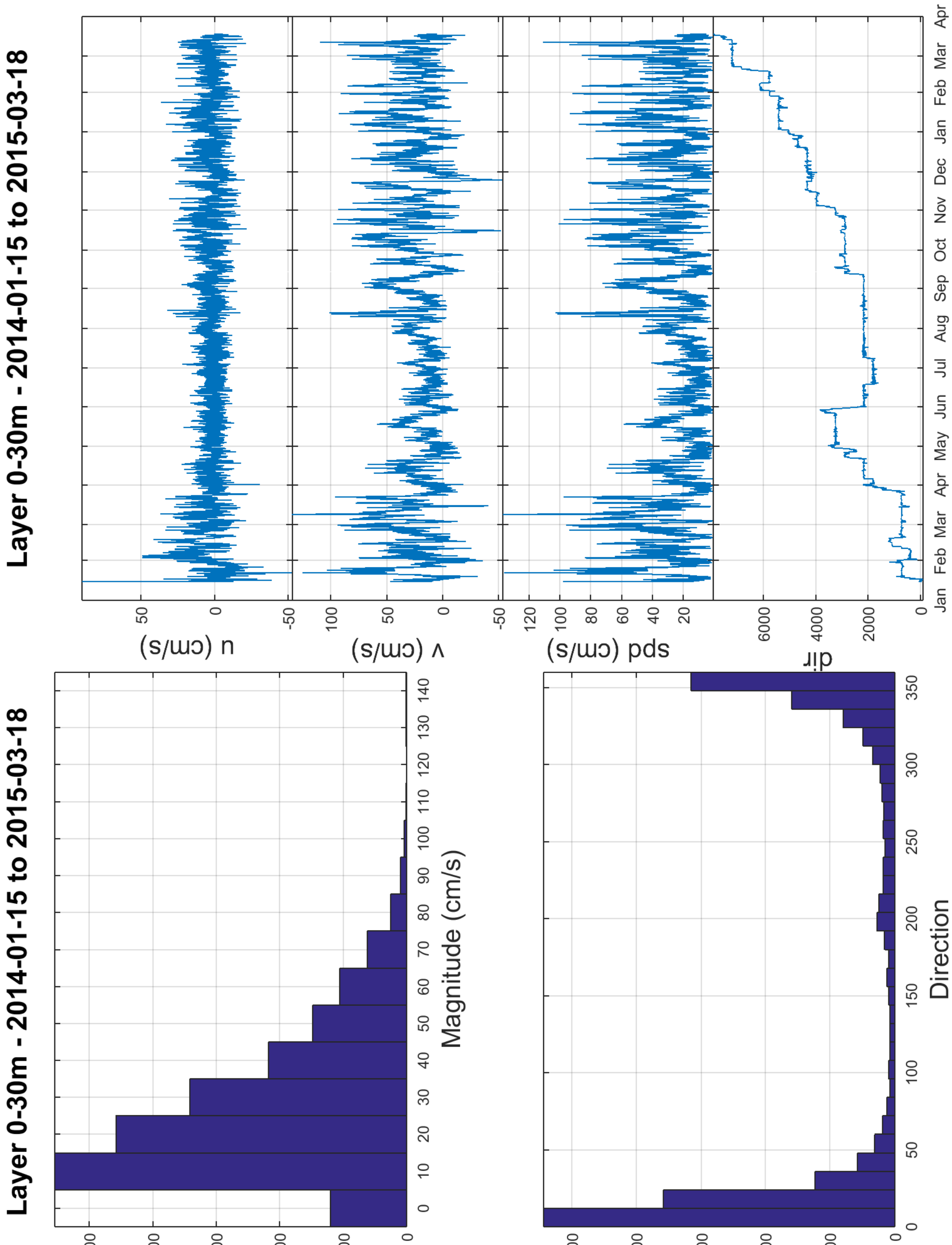

Figure 8 Timeseries and histograms of surface layer for the whole deployment period. Note that the direction in the timeseries plot has been unwrapped

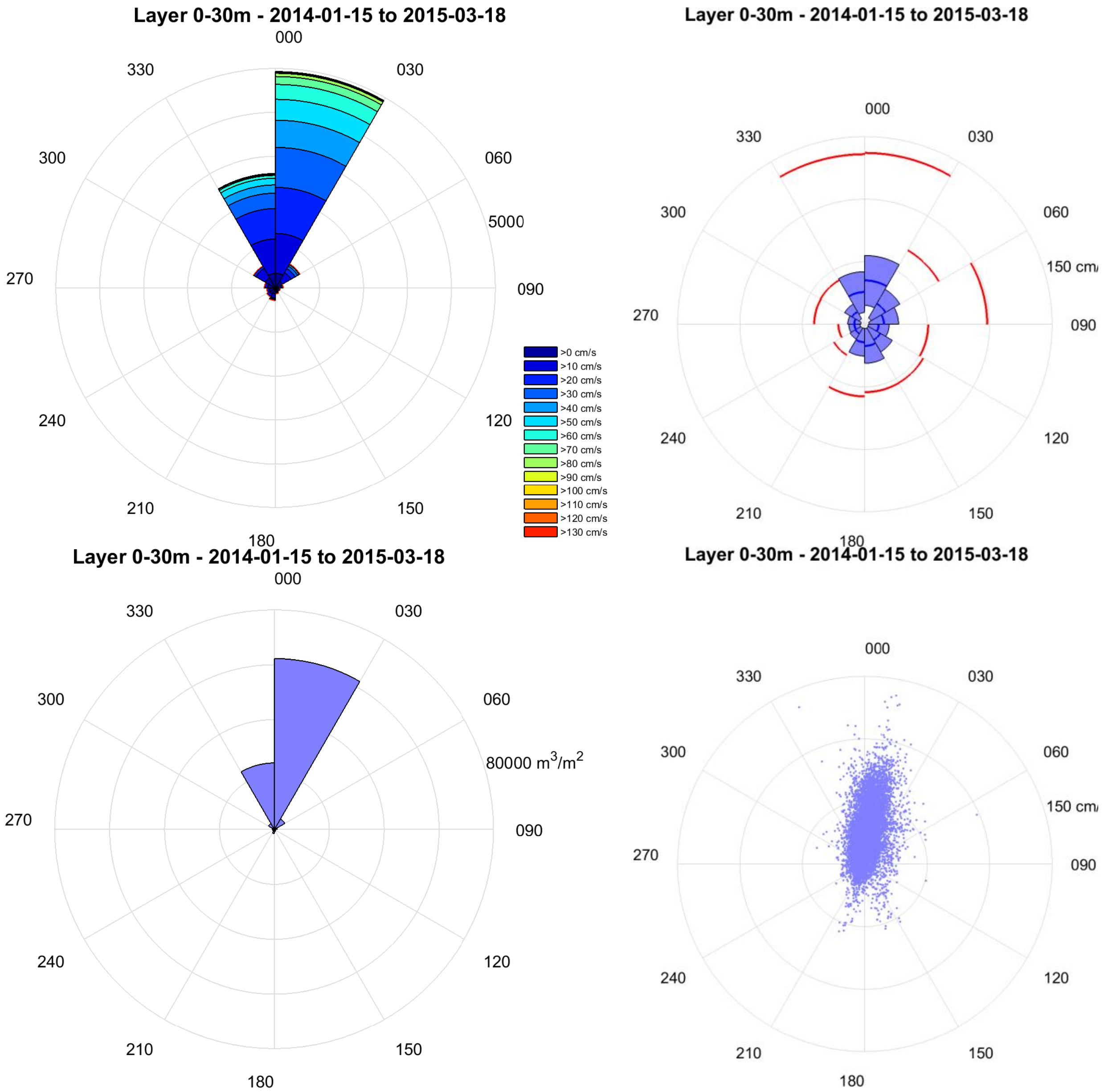

Figure 9 Polar plots of the surface current during the whole deployment period. *Upper left:* current histogram by directions sectors. *Upper right:* blue arcs correspond to the mean current value within the direction sector. Blue areas are standard deviation extending on each side of the mean value. Red arcs are the maximum current value observed. *Lower left:* estimated transport integrated over the deployment period. *Lower right:* scatter plot of all observations.

3.3 Intermediate Layer

Similar tables and figures as those shown for the bottom layer can be found in Table 8, Table 9, Figure 10 and Figure 11. The main flow follows very much the same features than in the surface layer, although variations weaker. This is due to the fact that atmospheric forcing is less influent in this layer.

Table 8 Statistical values for current magnitude in the intermediate layer for the whole deployment period. Units for speed are in cm/s and m^3/m_2 for transport. *Horizontally:* the different direction sectors. *Vertically:* a selection of statistic functions.

	0	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**
(cm/s)	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**
mean	28.9	17	10.4	10.9	9.7	11.7	16.5	10.5	8.3	7.8	11.8	20.9
median	25.8	14.9	7.9	9	8.1	9.1	15.1	9.4	7.6	7.1	10.8	19.3
sdev	14.6	10.8	7	7.2	6.7	8.6	11.5	6	4.2	4	6.4	10.6
max	99.5	116.5	31.9	27.4	21.9	34.2	59.8	32.5	37.7	18.8	43.5	67.6
95%-limit	56.3	36.9	27.3	25.1	20.7	27.5	38	21.3	15.6	15.1	24.5	40.9
transport *(m^3/m^2)*	57414.4	3594.2	503.8	303	254.9	442.3	1191.3	815.6	643.6	673.8	2022.1	17999.5

Table 9 Current histogram values as number of observations for the intermediate layer and the whole deployment period. *Horizontally:* the different direction sectors. *Vertically:* the current magnitude bins in cm/s. Most right column and bottom rows include the corresponding totals

		0	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	
(cm/s)		**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**360**	***Total***
0	**10**	314	152	78	40	42	54	72	115	152	166	200	330	*1715*
10	**20**	1383	258	44	25	25	30	65	85	63	74	226	945	*3223*
20	**30**	1670	115	11	12	6	17	36	14	0	0	44	680	*2605*
30	**40**	949	36	2	0	0	4	19	2	1	0	6	308	*1327*
40	**50**	667	20	0	0	0	0	4	0	0	0	1	99	*791*
50	**60**	359	3	0	0	0	0	4	0	0	0	0	23	*389*
60	**70**	119	1	0	0	0	0	0	0	0	0	0	9	*129*
70	**80**	43	0	0	0	0	0	0	0	0	0	0	0	*43*
80	**90**	15	0	0	0	0	0	0	0	0	0	0	0	*15*
90	**100**	2	0	0	0	0	0	0	0	0	0	0	0	*2*
100	**110**	0	0	0	0	0	0	0	0	0	0	0	0	*0*
110	**120**	0	1	0	0	0	0	0	0	0	0	0	0	*1*
Total		*5521*	*586*	*135*	*77*	*73*	*105*	*200*	*216*	*216*	*240*	*477*	*2394*	*10240*

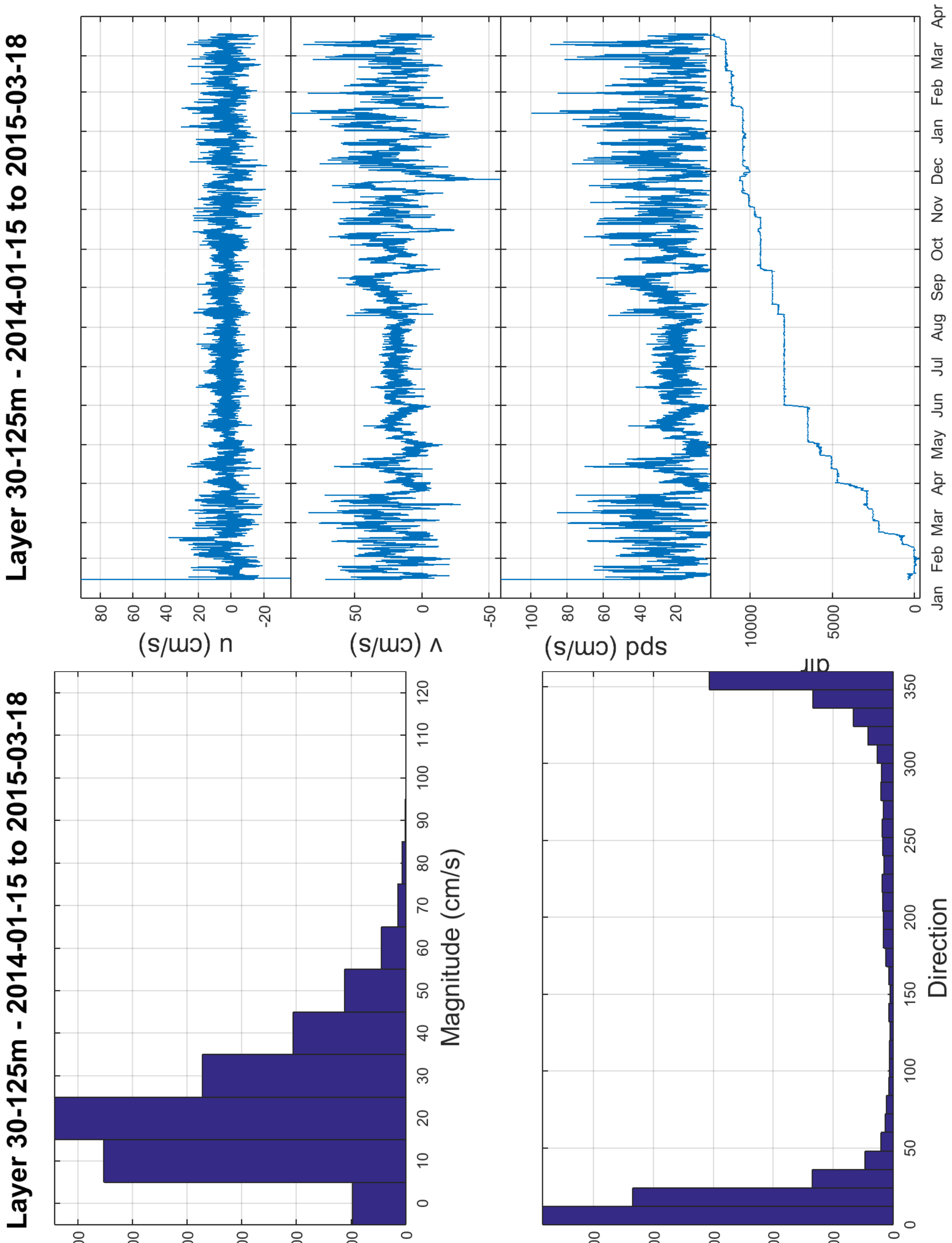

Figure 10 Timeseries and histograms of intermediate layer for the whole deployment period. Note that the direction in the timeseries plot has been unwrapped

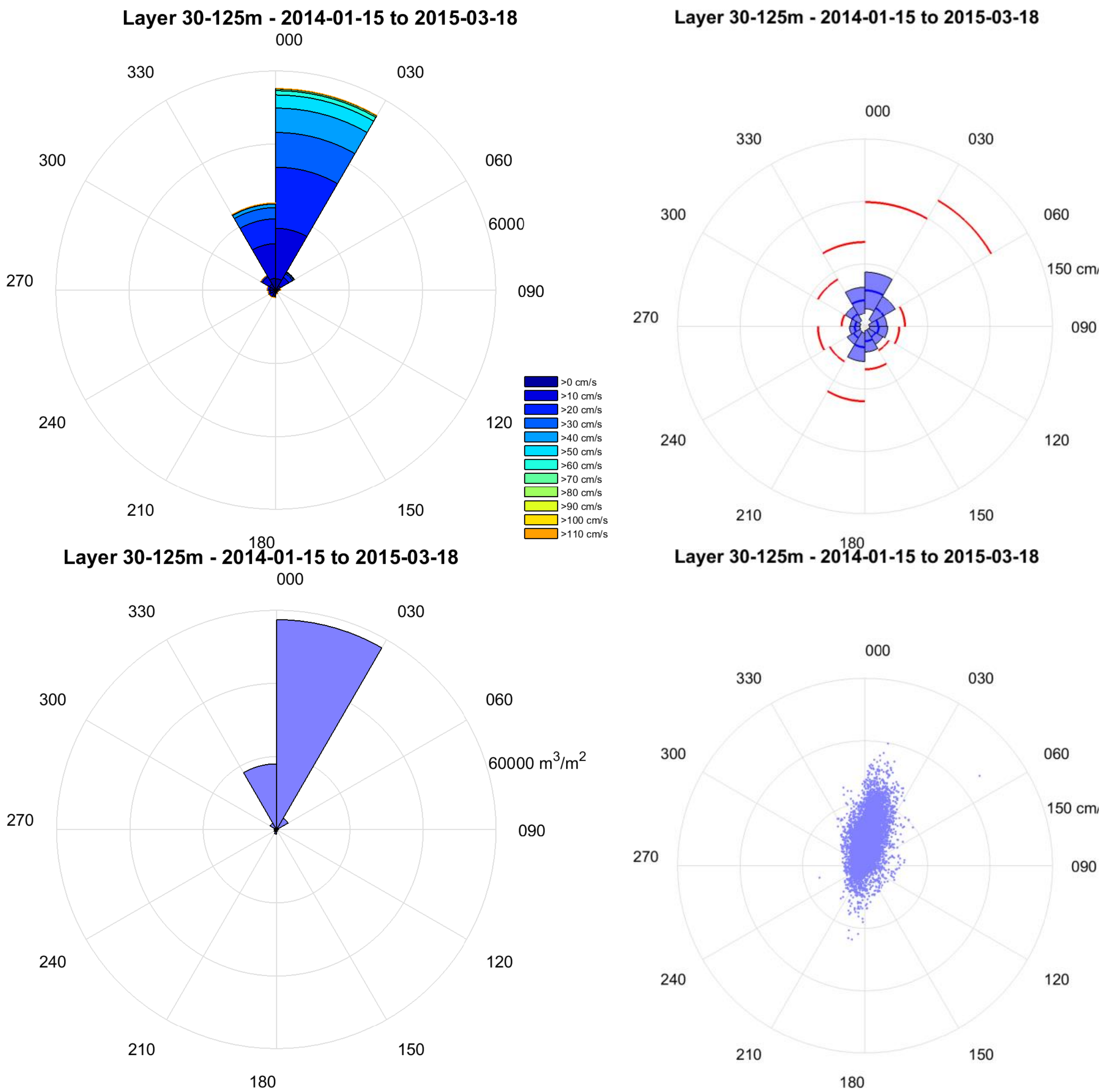

Figure 11 Polar plots of the intermediate current during the whole deployment period. *Upper left:* current histogram by directions sectors. *Upper right:* blue arcs correspond to the mean current value within the direction sector. Blue areas are standard deviation extending on each side of the mean value. Red arcs are the maximum current value observed. *Lower left:* estimated transport integrated over the deployment period. *Lower right:* scatter plot of all observations.

4. Concluding Remarks

From the current measurements, the water column was divided in 3 layers: surface, intermediate and bottom layers. The main flow in the upper layers is confined to the sector N-NE, while it spreads over sector NW-NE in the bottom layer. The latter is due to bottom interferences. The measured current is nearly barotropic (it changes little with depth) and closely related to the Norwegian Coastal current. Typical current values for the main flow directions in these layers are presented in Table 10.

Table 10 Typical current values within the main flow directions in each layer.

	Mean (cm/s)	Max (cm/s)	95%-limit (cm/s)	Direction
Surface Layer 0-30m	35	135	70	0°-30°
Intermediate Layer 30-125m	30	100	55	0°-30°
Bottom Layer 125-150m	16	65	35	330°-30°

It is worth to note that variability and higher current values are seen in all layers and not only on the surface. This can only be due to variations in the Norwegian Coastal current derived from larger scale atmospheric influence. Figure 12 shows the timeseries of wind measurements from meteorological station at Fedje. Events above 95-percentile values have been plotted together with similar events in all 3 layers. This is presented in Figure 13. There is a much closer relation between layers than with wind measurements. Cross covariance of these events between surface and the 2 other layers are also shown in Figure 14. There is a clear correlation maximum when the time lag is zero, supporting the barotropic assumption of the current. If possible, effects of wind should be studied on a much smaller time scale, but are not included in this analysis.

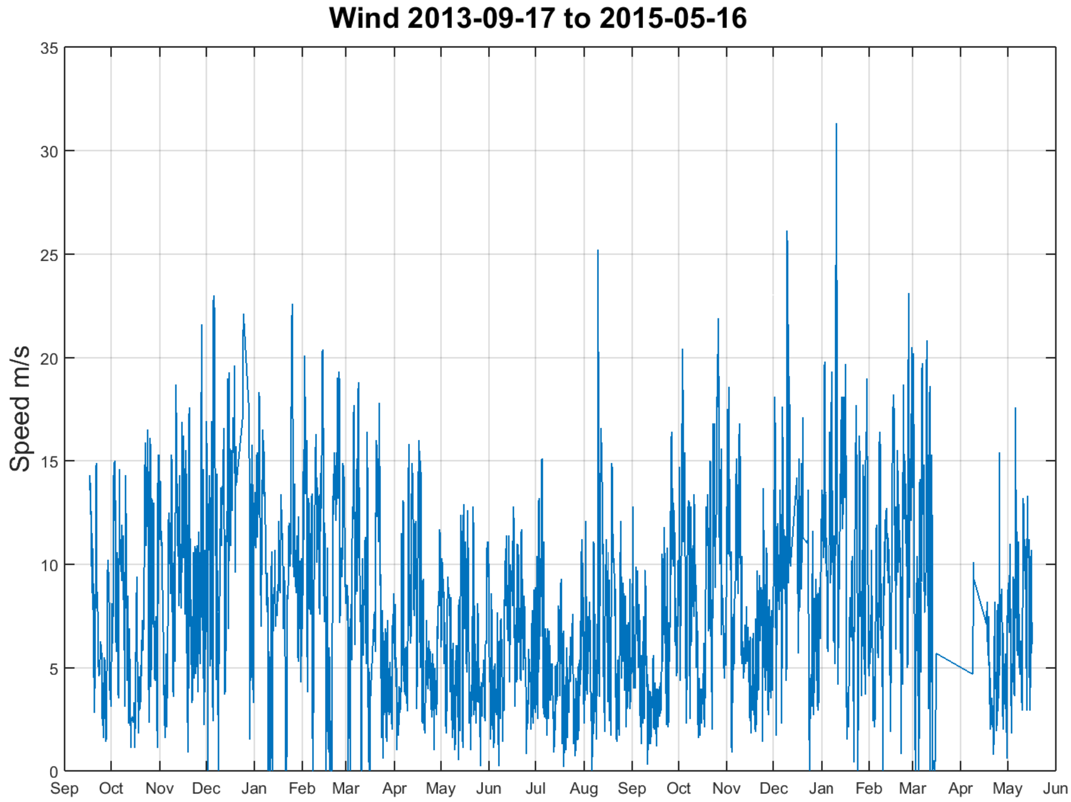

Figure 12 Wind measurements at Fedje station (source: eklima.no).

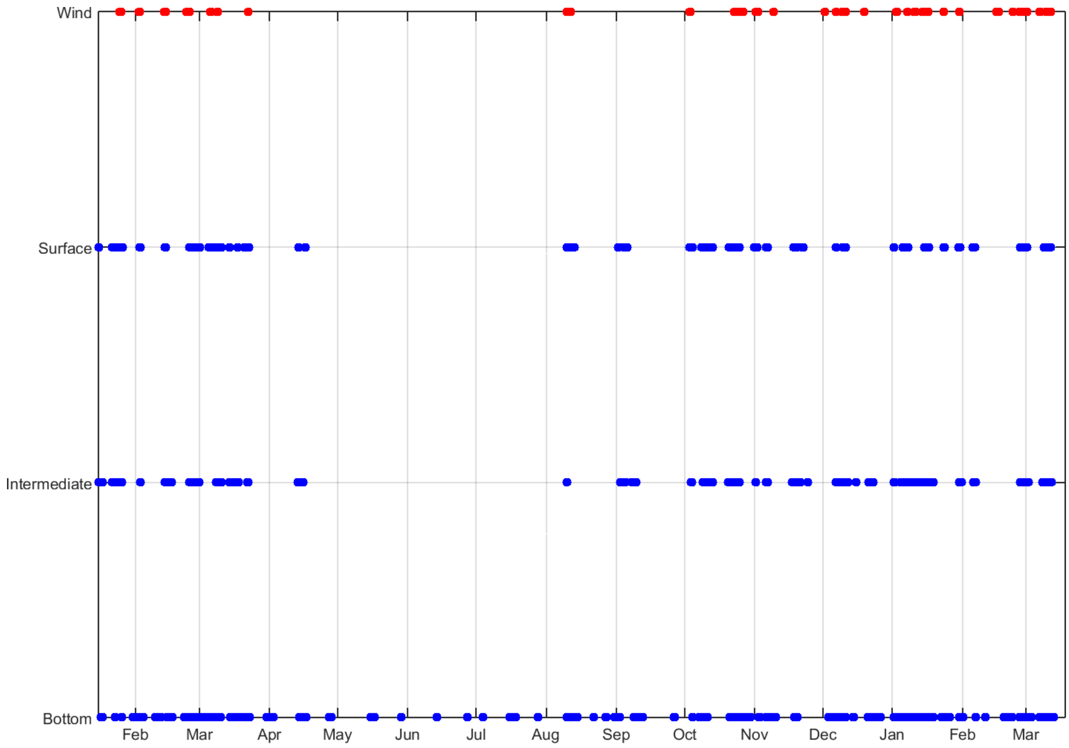

Figure 13 Events of wind and current above 95-percentile value for each layer.

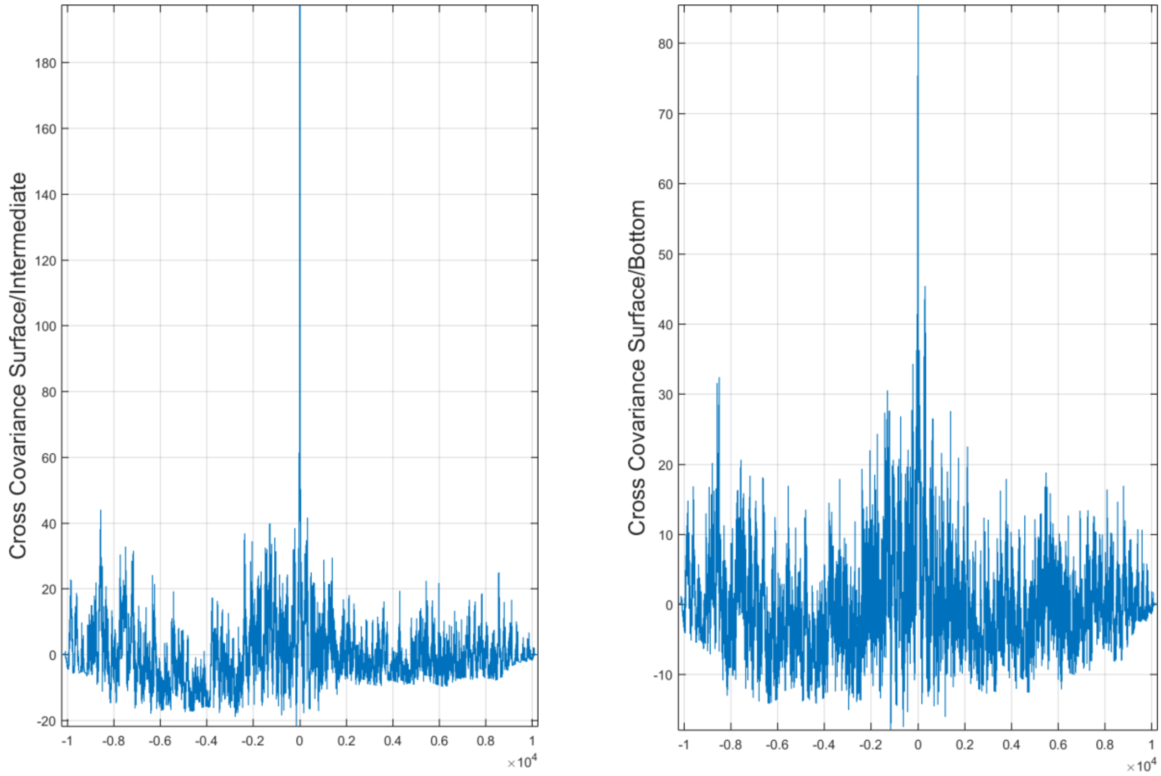

Figure 14 Cross covariance of events above 95-percentile current value. The horizontal axis is a function of the time lag between both datasets. The maximum at zero time lag means that events in both layers are synchronized in time. *Left:* cross covariance between surface and intermediate layer. *Right:* cross covariance between surface and bottom layer.

A comparison with earlier measurements like those carried out by NIVA from September 2 to 16, 2006 was performed (F. Uriansrud 2006).

. The following remarks should be taken into account

- The deployment period in 2006 was 2 weeks, while it was more than 1 year in the present case
- Current was measured at 2.5m above bottom for 3 different locations, 1 of which being very close to the present deployment. Hence only bottom current could be compared.
- A fourth location, also very close to the wrecks, was equipped with a current profiling instrument, but only up 40m above bottom. This extends into the lower part of the intermediate layer and was roughly compared to the present results from this layer.

Results of comparison showed the following

- The mean velocity values correspond to each other.
- Maximum currents in the bottom layer are also similar. However currents in the intermediate layer were higher at that time.
- The measured current directions are very close to those observed here.

Due to the difference between deployment periods, this comparison can only be qualitative.

As a final remark, it must be pointed out that these observations the current profile over 14 months represent at valuable and rare time series of current conditions in the Norwegian coastal current. Further analysis could probably give new insight aboutcoupling between

5. References

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Norwegian Institute for Water Research

Gaustadalléen 21 • NO-0349 Oslo, Norway
Telephone: +47 22 18 51 00 • Fax: 22 18 52 00
www.niva.no • post@niva.no