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Comparison of Northeast Atlantic mackerel (Scomber scombrus) distribution patterns in the Norwegian Sea using lidar, sonar, and trawl

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In July 2002 the Institute of Marine Research (IMR), Bergen mapped the distribution and density of mackerel in the Norwegian Sea using lidar, sonar and trawl. A major objective was to test the efficiency of the lidar as a survey tool. Due to the lack of swim bladder and the fact that mackerel feeds close to the surface, traditional acoustic equipment is inefficient. The airborne NOAA fish lidar covered the same tracks as two commercial trawlers hired by IMR. The trawlers used a Simrad 24-36 kHz sonar to track the speed, volume, direction and depth of mackerel schools and they were trawling close to the surface. Most of the fish caught was mackerel (69% of catch weight) and the majority of the schools (64%) were recorded shallower than 40 meters. The mackerel was mainly distributed in the southern parts, while one of the trawlers also caught a significant amount in the northwest. These are the same areas where we got the strongest lidar return. The southern part of the surveyed area contained rich plankton layers showing up in the lidar return. These layers are easily distinguished from fish as they continue over long distances compared to the size of the schools. Fish data were therefore easily extracted during post-processing. The amount of plankton gradually decreased as we proceeded north giving clearer water and better lidar depth penetration. The lidar seems to be an interesting tool, giving plausible results, but still needs some development. Some aspects of future development are discussed.

Keywords: lidar, trawl, mackerel, plankton

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INTRODUCTION

Mackerel is presently one of the economically most important stocks in the northeast Atlantic Ocean, and through international agreements Norway has got a share of the stock of 31 % (ICES, 2002). Due to the high market prices even small changes in the output or the share of the catch involve great economic consequences. Accurate stock assessment is therefore very important.

From tagging experiments it has been found that Mackerel perform seasonal migrations all the way from Bay of Biscay and up to the very northern parts of the Norwegian Sea (Uriarte and Lucio 2001). Mackerel have no swimbladder and are thus difficult to assess using standard acoustic assessment techniques (MacLennan and Simmonds, 1991). During their summer feeding they are distributed close to the surface, where vessel avoidance is a problem (Aglen, 1994, Misund 1993).

As the migrational and behavioral dynamics of mackerel have changed over the years, Institute of Marine Research (IMR), Bergen has started a program to better understand their behavior (Iversen 2002). This is based on multi-frequency acoustic surveys (Korneliussen and Ona, 2002), and in July 2002 IMR started a lidar-based project called SUrface Monitoring of Marine REsources by Lidar (SUMMAREL). The object of the project is to study the potential of lidar (LIght Detection And Ranging) as assessment tool in collaboration with NTNU University in Trondheim, Norway, and use this in yearly mackerel surveys in the Norwegian Sea.

To evaluate the capabilities of the lidar IMR hired the NOAA fish lidar (see Churnside et al. 2001a) and placed it onboard a Norwegian aircraft in July 2002. The Norwegian Sea was then covered during two weeks of flights. To test the efficiency of the lidar and to validate the lidar returns, two combined purse-seine and mid-water trawlers were hired to trawl in the same area. They were trawling close to the surface where mackerel is found during summer feeding (Godø et al. 2003). These vessels were also using Simrad sonars to look at the schooling and migration dynamics by tracking mackerel schools encountered along the survey track.

MATERIALS AND METHODS

The two vessels, M/S “Trønderbas” and M/S “Endre Dyrøy”, were equipped with large commercial pelagic trawls covering a depth range of 5-40 meters. “Endre Dyrøy” had a 50 m x 108 m square blue whiting trawl while “Trønderbas” had a smaller circular silver smelt trawl. They covered a total of 90 trawl stations in the area between N62°00 and N70°00 during the period of 15-27 July 2002 (see figure 1). “Trønderbas” started in Tromsø following a southbound survey track, whereas “Endre Dyrøy” covered the same area but on different latitude transects, starting in Ålesund and going north. A systematic coverage of trawl stations of 30 minutes duration was used primarily for species identification.

The two vessels used Simrad SP72 sonars, operating at 24-36 kHz, for school tracking. The sonars were connected to a PC for logging of school information such as time, position, volume, depth, speed and direction. Whenever the officer on watch judged a school as mackerel, he activated the built-in tracking routine. In this paper the sonar data are used to find the typical mackerel school depth in the surveyed area. It is important to know whether or not the majority of the schools are within the limited lidar depth (<40 meters).

To relate visual observation depth to lidar depth penetration, the secchi depth was recorded for each trawl station. This is a very simple tool consisting of a white circular disk with a diameter of 40 cm that is lowered to the maximum visible depth, which is then registered.

The NOAA fish lidar was hired and installed onboard a Turbo Commander 690B aircraft from Fjellanger Widerøe. This is a non-scanning, green-laser system, i.e. the angle of incidence relative to the water surface is fixed and that the depth penetration is best in green or close to green waters (Churnside et al. 2001a). The laser and receiver telescope are mounted side by side looking down through a camera port in the bottom of the aircraft. The aircraft was flying at a speed of 180 knots at an altitude of 300 meters when collecting data. To reduce surface reflections, the lidar was tilted forward at a 15 degree angle.

The laser is a Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) with a Q-switch that is opened after the crystal is fully charged, so that all the energy is extracted in a 12 nsec pulse (Churnside et al. 2001b). The light is converted from an infrared wavelength (1064 nm) to visible green (532 nm) through a non-linear optical crystal. The output energy in each pulse is 100 mJ and the pulse repetition rate is 30 Hz. The linearly polarized beam is diverged (62 mrad) through a negative lens in front of the laser producing a disk on the surface having a diameter of approximately 5 m. At 180 knots a new pulse is produced every 3 meter giving an overlap of 2 meters from one pulse to the next.

The receiver optics are comprised of a 17 cm diameter refracting telescope with a polarizing filter in front. The filter was adjusted to only allow for cross-polarized light to pass. This has been found to give the best contrast between fish, water, and other small scatterers in the sea (Churnside et al. 1997). There is also an interference filter only transmitting light in a 1 nm band around the laser wavelength, reducing the impact of other light sources such as direct sunlight and reflections of the sea surface.

The incoming light is converted to an electric signal through a photomultiplier tube (pmt) and digitized at 1 GHz with 8 bits of resolution (256 levels). This gives a depth resolution of 0.11 m. A logarithmic amplifier increases the maximum possible dynamic range from 256 to about 10^4 (Churnside et al. 2001a).

Along with the log-transformed voltage signal, the aircraft's GPS position, GPS time, and aircraft attitude (using tilt sensors) is stored. The computer displays the data in real time. Two different displays are available. One showing the return signal in a similar manner to echograms used for echosounders, and one showing a line plot of the return signal as a function of time for each shot (see figure 5 and 6).

Zorn et al. (2000) found the lidar irradiance to be safe for fish and marine mammals on the sea surface. When vessels were encountered along the survey path the pilot made a short detour to avoid direct illumination. The laser beam can alternatively easily be blocked for safety purposes.

The plan was to cover the same survey tracks as the two vessels, but due to limited fuel capacity, the most western trawl stations were not covered. The flight path is presented in figure 4. There were a total of 11 data-collecting flights starting on 15.07.2002 and continuing through 23.07.2002. The flights started in the city of Bergen, proceeding north to Tromsø and then south, covering some of the tracks twice. Table 1 gives a list of the flights. All flights were done at daytime in mainly overcast weather with some occasional sunshine. Only one day, the flight was cancelled due to poor weather conditions with drizzle and fog. In addition to the scheduled flights, the Hardangerfjord was covered to test the effects of water containing extreme amounts of plankton.

The collected flight data were compared to the trawl data from the two vessels for species identification, and with the sonar data to estimate the efficient vertical coverage of the lidar.

RESULTS

Mackerel were found in 68 out of the 90 trawl hauls covering the whole surveyed area as shown in figure 1. The catches varied from 1 to 1600 kg and the highest concentration was in the southern 2/3 of the surveyed area while “Endre Dyrøy” also got a significant amount in the western part of the 68°45N line. Mackerel was the dominant species in the entire area with 69 % of the total catch weight. Other species encountered were mainly herring and blue whiting. The highest concentration of herring was found in the northeast close to the Lofoten area. As figure 1 shows, this area gave only small catches of mackerel. The hauls on the most southern transect also contained very few mackerel.

The sonar data show that out of the 64 mackerel schools that were tracked only one was recorded deeper than 100 meters, and the majority (64 %) was recorded within the top 40 meters. This is an important result for the reliability of the lidar as a mackerel survey tool. The lidar could typically see down to 25-35 meters during our flights. Figure 7 shows the positions of the 64 sonar tracks included in this paper.

NOAA performed the initial lidar signal processing. First a technique where the background scattering was removed linearly was tried. This technique assumes that plankton and all other small scatterers are uniformly distributed over depth and behave horizontally inhomogeneous. This did not give satisfactorily results for fish abundance because of the large continuous horizontal plankton layers present at this time of year in the Norwegian Sea. A different technique using median background scattering subtraction was used instead. Here we make the assumption that plankton and other small scatterers are relatively homogeneous over distances of 1500 meters and that the fish schools are patchier on this relatively large scale. The median signal for each depth is then found and the median pulse return is subtracted from the return of each pulse in the segment. The difference between the two techniques can be regarded as a measure of the plankton content in the water, but that is beyond the scope of this paper. Figure 8 shows a typical file containing a large continuous plankton layer, while figure 9 shows a dense school where the plankton layer has been removed.

The resulting fish returns were integrated over 1 meter depth bins and averaged along 100 meter segments of the flight path. The geographical distribution is presented in figure 5 and 6. The return is a relative measure of density, but is not calibrated for fish. The stronger the lidar return, the larger the bubbles, while the color indicate the mean depth of the return in the position. The lidar return signal is strong in the southern 2/3 as for the trawl data, and there is also some stronger return in the more western parts further north. These are the same areas as the two trawlers found the greatest concentrations of mackerel, although the aircraft did not cover the most western stations. The most southern transect from Bergen to Shetland show very low return values, which compare to the small trawl catches. However, there is a significant return close to the Lofoten area where herring was dominating the trawl catches.

The color in figure 5 and 6 changes from blue and green to yellow and red as the aircraft proceeds north, indicating that mackerel tend to be at greater depth in the north.

As expected the lidar depth penetration in the Hardangerfjord was very limited due to the large amounts of plankton. We could not observe at depths greater than 10-15 meters. The large plankton layers can be seen in the lidar return in figure 5 and 6. These were not removed with the standard signal post processing due to the large concentrations.

The very limited depth penetration in the Hardanger fjord is also evident in figure 10. This shows the maximum lidar depth penetration in the whole surveyed area and can be compared with the visual secchi observations from M/S “Trønderbas” in Figure 11. The secchi-depths vary quite a lot from station to station, but the overall picture is that the visual depth penetration is better in the north than the south, which agrees with the overall picture from the maximum lidar depth penetration. There were no trawl stations in the Hardanger fjord, so there are no secchi data from this area.

DISCUSSION

The first tests of the lidar as a survey tool for mackerel seem to give plausible and interesting results, although there is some uncertainty around how to handle the backscattering from other scatterers such as plankton layers. As the lidar is airborne and relies on light rather than sound, both ship avoidance and the lack of swimbladder should no longer cause assessment problems. The facts that the majority of the trawl catch is mackerel and that herring is only found in some limited areas around the Lofoten area also go in favor of lidar. If these two species had been more mixed, the need for species identification capabilities would have been more urgent, although this is still one of the lidar’s major limitations. The results are so promising that IMR and NTNU now have started the design process for a new lidar based on the NOAA model.

The sonar data show that the majority of the mackerel schools are within the expected lidar depth penetration of 40 meters. By performing afternoon flights instead of morning flights, the schools will probably be denser and even closer to the surface. The denser the schools are, the easier they are to observe by lidar.

Some interesting new features have been discussed to improve the school-detecting capabilities of the lidar. Adding scanning to the system will add a new dimension to the picture. Calculating school size in 3 dimensions gives more reliable abundance estimates. By adding a second receiver co-polarized with the laser light, we may be able to distinguish between different species as they depolarize the laser light differently. This might also make it easier to distinguish between fish and other scatterers in the sea. The results from reflectivity and target strength measurements on mackerel will be presented in another paper.

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FIGURES AND TABLES

Figure 1. The 90 trawl stations. The size of the bubble indicates the amount of mackerel in each haul, from 0-1600 kg.

Figure 2. The computer real-time display, similar to traditional echograms in acoustics

Figure 3. An alternative computer real-time display that shows a line plot of the return signal as a function of time for each shot.

Figure 4. The flight track of the 11 flights.

Figure 5. The lidar return from the northbound flights (flight 1-6). The stronger the lidar return, the bigger the bubbles. The colour indicates the mean depth of the return.

Figure 6. The lidar return from the southbound flights (flight 7, 8, 10, and 11) and the Hardanger fjord flight (flight 9).

Figure 7. The positions of the 64 sonar tracks. The bubble colour indicates the depth of the tracked school. The majority (64 %) is within the top 40 meters.

Figure 8. File containing a continuous plankton layer.

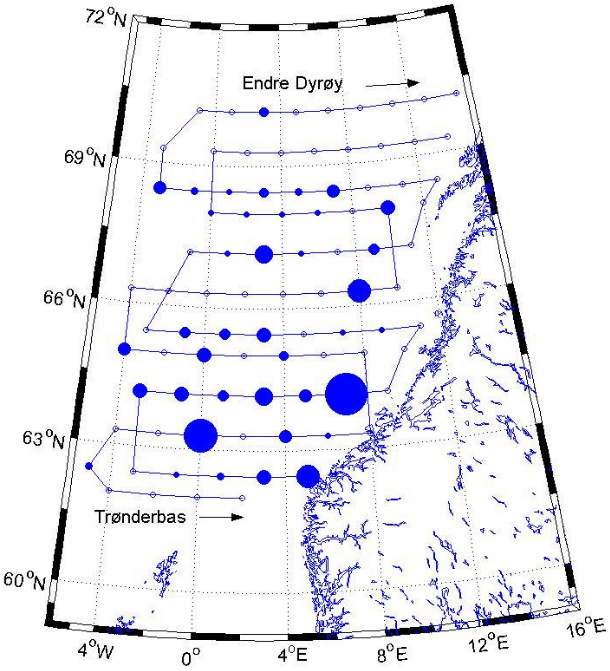
Figure 9. File showing a dense school with the plankton layer removed.

Figure 10. Maximum lidar depth penetration in the surveyed area.

Figure 11. Visual depth observations found with the secchi disk.

Table 1. The 11 flights.

Figure 1.



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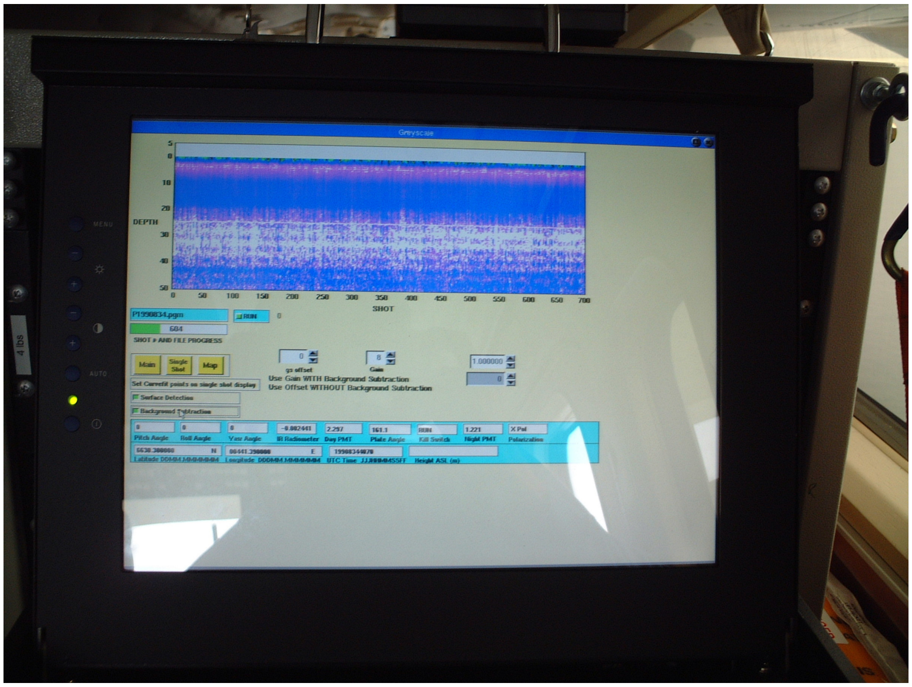

P1990834.pgm

0

684

SHOT # AND FILE PROGRESS

gs offset: 0

Gain: 8

Use Gain WITH Background Subtraction
Use Offset WITHOUT Background Subtraction

1.000000

0

Set Curvefit points on single shot display

Surface Detection

Background Subtraction

Pitch Angle	Roll Angle	Yaw Angle	IR Radiometer	Day PMT	Plate Angle	Kill Switch	Night PMT	Polarization
0	0	0	-0.002441	2.297	161.1	RUN	1.221	X Pol

Latitude DDMM.MMMMMMM	Longitude DDDMM.MMMMMMM	UTC Time JJJHHMMSSFF	Height ASL (m)
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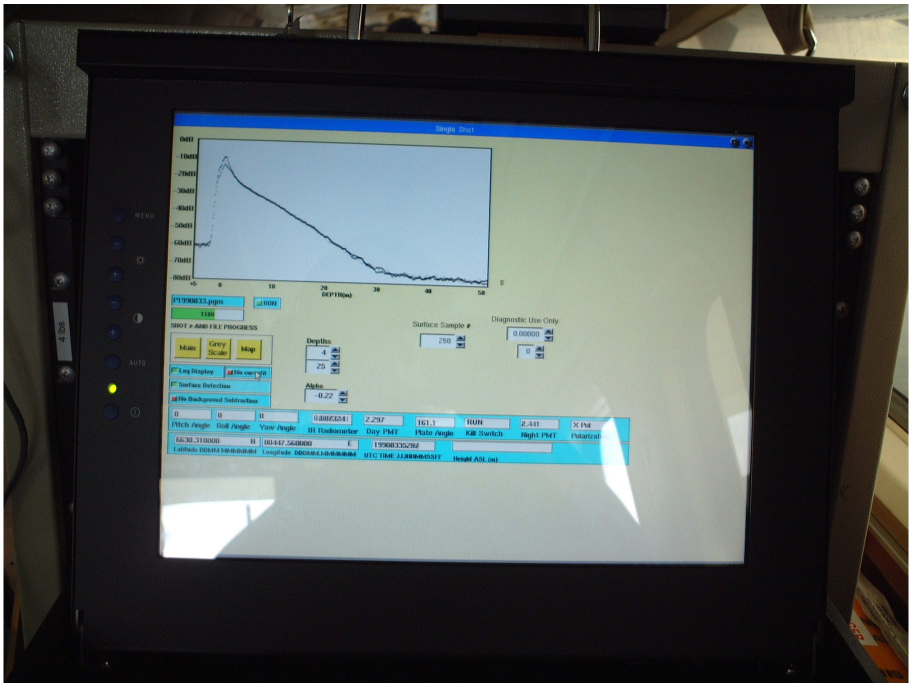
Figure 3.



PT990833.pgm

1188

Depths: 4, 25

Alpha: -0.22

Surface Sample #: 268

Diagnostic Use Only: 0.00000, 0

Pitch Angle	Roll Angle	Yaw Angle	IR Radiometer	Day PMT	Plate Angle	Kill Switch	Night PMT	Polarization
0	0	0	0.0073241	2.297	161.1	RUN	2.441	X Pol

Latitude DDMM.MMMMMM	Longitude DDDMM.MMMMMM	UTC TIME JJJHHMMSSFF	Height ASL (m)
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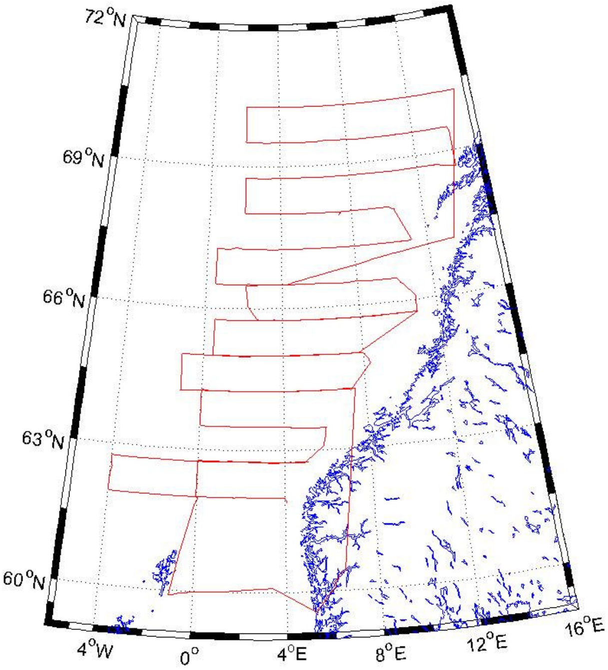
Figure 4.



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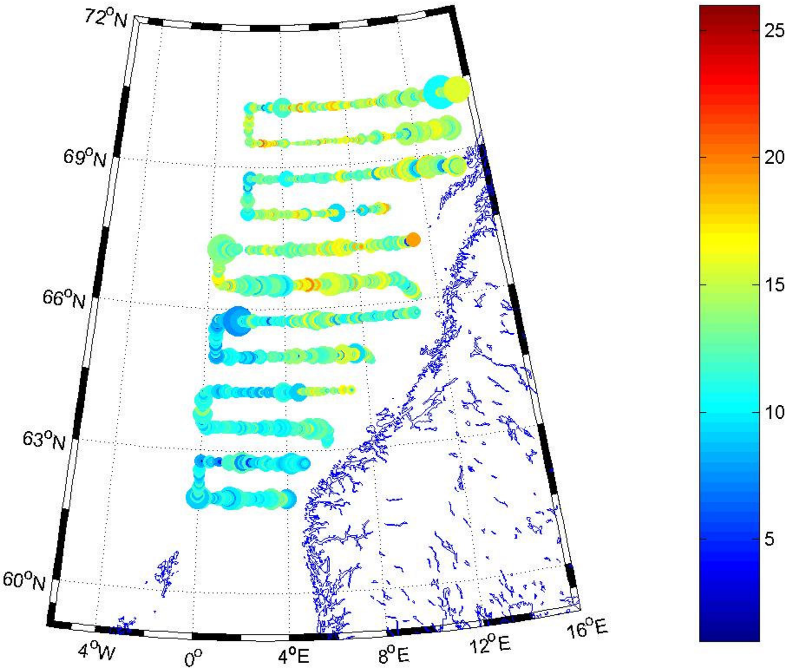

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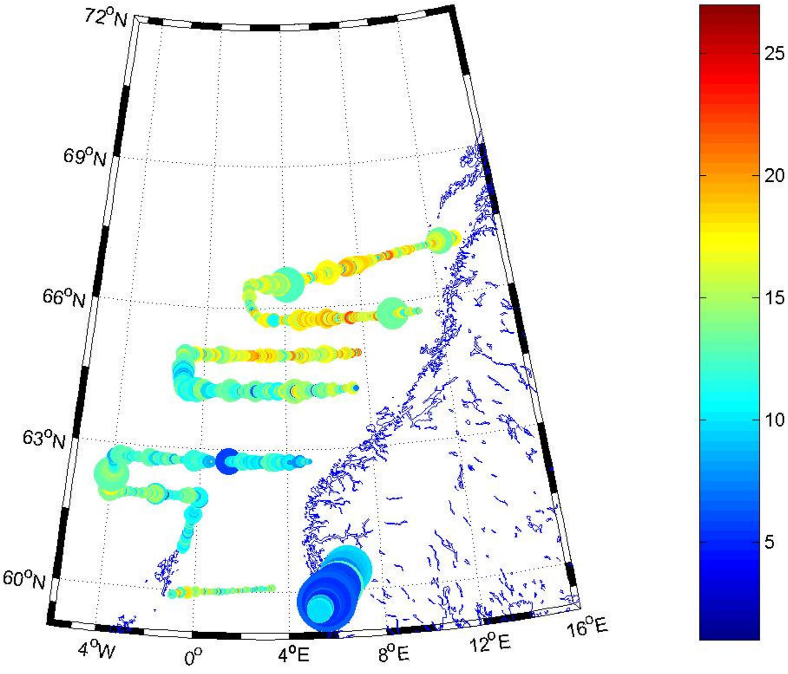

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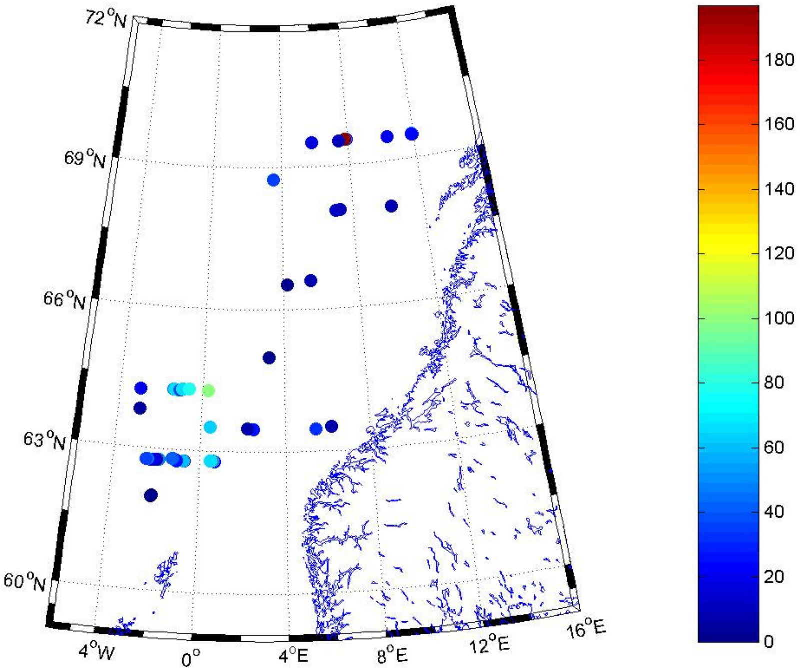

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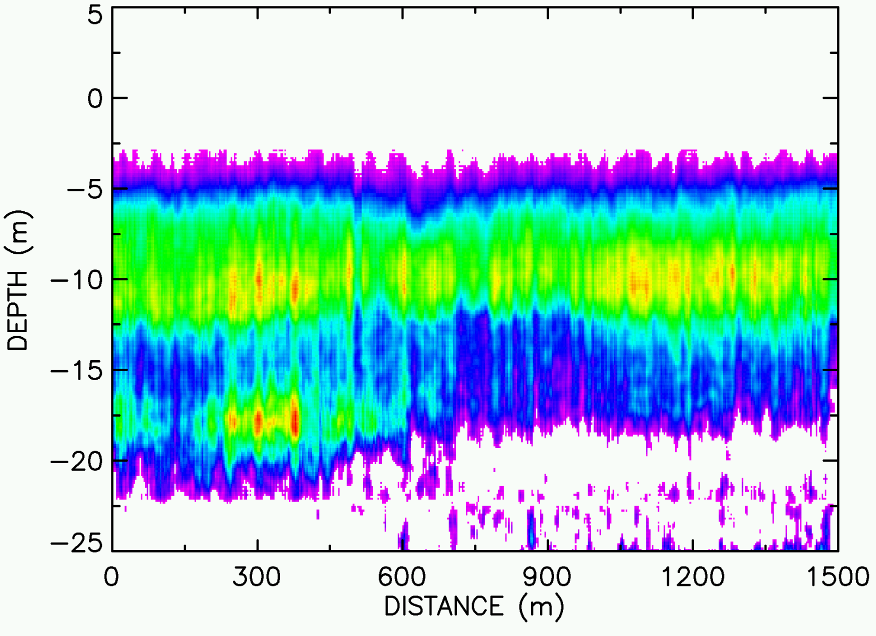

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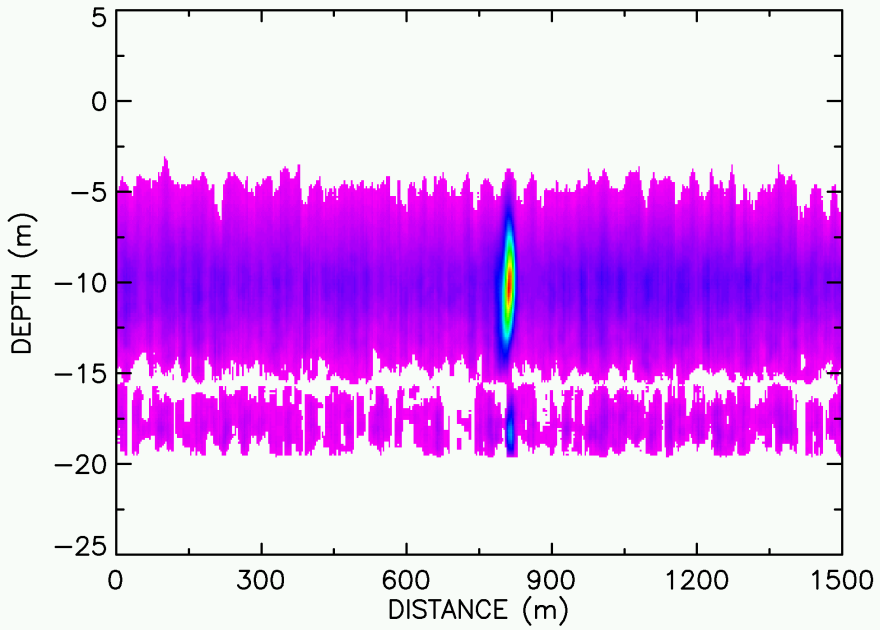
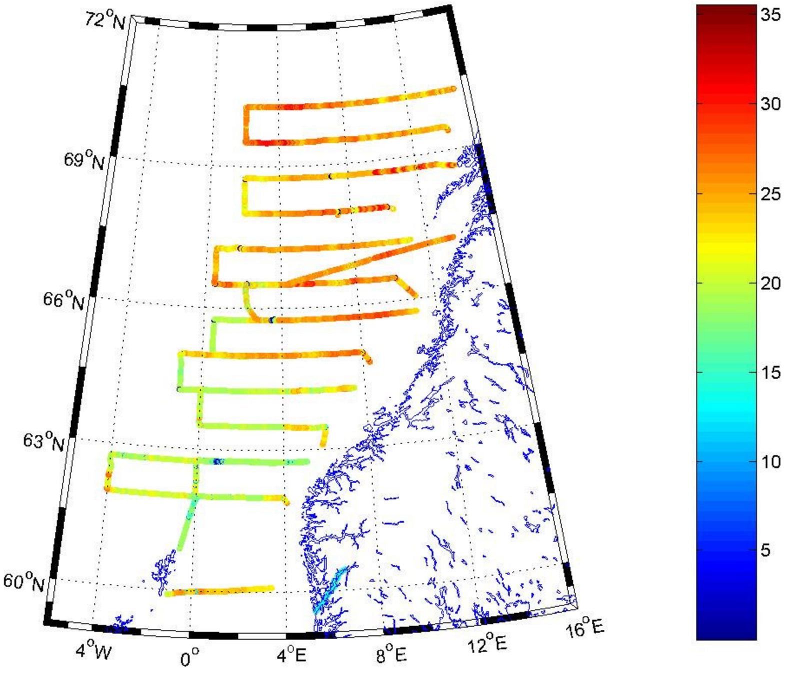


Figure 10.



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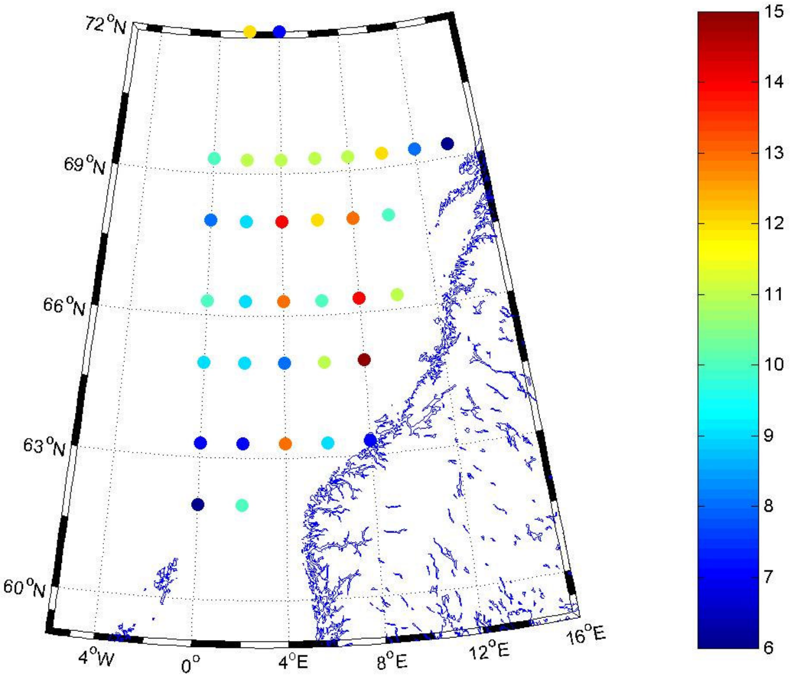

Table 1.

Flight No	Date	Out	Return	Meridian	Comment
1	15.07.02	62°00N	62°45N	00°00	
2	17.07.02	63°30N	64°15N	00°00	
3	17.07.02	65°00N	65°45N	00°30E	
4	18.07.02	66°30N	67°15N	00°30E	
5	18.07.02	68°00N	68°45N	02°00E	
6	19.07.02	69°30N	70°15N	02°00E	
7	20.07.02	66°30N	65°45N	02°00E	
8	21.07.02	65°00N	64°15N	01°00W	
9	21.07.02				Hardanger Fjord
10	23.07.02	60°00N			Bergen-Shetland
11	23.07.02	62°00N	62°45N	04°00W	