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Predicting recruitment of 0-group gadoids in the Barents Sea – critical interaction between models and observations

Johansen G.O., Skogen M.D., Godø O.R., and Torkelsen T.

Abstract

The most important gadoid fish stocks of the Barents Sea spawn along the coast of Norway. The eggs, larvae and juveniles are transported northwards with the oceanic coastal currents from the spawning grounds towards their nursery and feeding areas in the Barents Sea. In this work, we present a conceptual model of the vertical dynamics of 0-group during the transport and settlement phase. Field observations of the vertical distribution and behaviour of 0-group fish recorded by a stationary acoustic system are compared to the conceptual model to validate critical assumptions. They also serve as an example of some critical observations needed to improve hydrodynamic modelling of the transport. We used two different vertical distribution algorithms for particles representing juvenile fish in a Lagrangian particle-tracking model. One is based on the behaviour described in the conceptual model and the other assumes random vertical distribution at a fixed depth range throughout the whole period. The distribution predicted from the vertical behaviour algorithms fits best to observations from surveys. Based on this experience we propose an observation program for collecting the needed observations to obtain a more realistic recruitment prediction model.

Keywords: recruitment, gadoids, hydrodynamic model, observations, fisheries acoustics

Geir Odd Johansen, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway. [tel: +47 55 23 53 78, fax: +47 55 23 85 31, e-mail: geir.odd.johansen@imr.no].

Morten D. Skogen, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway. [tel: +47 55 23 84 61, fax: +47 55 23 85 31, e-mail: morten@imr.no].

Olav Rune Godø, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway. [tel: +47 55 23 86 75, fax: +47 55 23 68 30, e-mail: olav.rune.godoe@imr.no

Terje Torkelsen, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway. [tel: +47 55 23 69 85, fax: +47 55 23 68 30, e-mail: terje.torkelsen@imr.no

Introduction

The Northeast Arctic Cod stock perform long annual spawning migration from the nursery and feeding areas in the Barents Sea – Svalbard region to the spawning grounds at the Norwegian coast (Bergstad *et al.* 1987;Godø 1984). The drift and distribution of eggs and larvae during the first six months and the survival in this period is decisive for the distribution and abundance of the new year class (Ottersen and Sundby 1995; Sundby 2000). Eggs and early larval stages are carried by the large oceanic currents towards the nursery areas (Bergstad *et al.* 1987). After 2-3 weeks a functional swim bladder has been formed (Chu *et al.* 2003) and this gives the larvae a better possibility to regulate its buoyancy and thus its vertical distribution. With increasing size, the ability for horizontal movement improves but remains limited until the time of bottom settlement, which normally takes place from September to January. Distribution of young of the year can thus be considered a result of drift in the water masses. Realistic models of this drift require detailed knowledge of the vertical distribution and migration. Based on the long time series of 0-group surveys in the Barents Sea (Dingsør 2005) and associated studies (Godø *et al.* 1993) we have some information about vertical distribution and migration of age 0 cod in the autumn but lack details throughout the whole recruitment phase. In the following, we propose a conceptual temporal dynamic model that describes the processes we think influence vertical distribution and migration in the period from eggs to larvae and juvenile fish. This model is used for specifying two different scenarios for modelling the transport of 0-group cod into the Barents Sea using a particle-tracking model. We also present observations from a stationary acoustic platform demonstrating how models of juvenile fish transport can be validated and parameterised using new observation technology.

Material and methods

The conceptual model of the drift phase of 0-group cod and its characteristics is described in Table 1 and illustrated in Figure 1. The approach builds partly on knowledge from direct observation during some part of the cycle. This information is expanded throughout the first year of living. The two strong dynamic components of the model is associated with time; i.e. time of the year and time of day. We also present some data used to calibrate these processes. The change in average depth over time is considered a sigmoid curve moving from surface to bottom over a period of 10 months. Two parallel curves indicate the vertical range of the distribution. We also describe six events of importance for the vertical distribution and

migration associated with development and habitat association (surface, midwater and bottom). Vertical migration is modelled as a normal distribution around the average depth as demonstrated in Figure 1. The average depth is the same day and night but the spread is very different, with a wider distribution at night compared to daytime. This captures the situation when the fish is distributed with same distance to surface and bottom. In the cases when fish are associated with surface and bottom only the tail into the free water masses is described by a normal distribution while the portion on the other side will be compressed towards the surface or bottom. Diurnal dynamics follows (Hjellvik *et al.* 2001).

The ocean model used is the Norwegian Meteorological Institute's (http://www.met.no) version of the terrain following ocean model POM (Blumberg and Mellor 1987; Engedahl 1995). The model, MI-POM, is part of the met.no ocean prediction system, and is run operationally with daily forecasts. The model has been run with a horizontal resolution of 20x20 km on an area covering the North Sea, the Nordic Seas, and the Barents Sea (Figure 2). In the vertical 21 sigma-layers, with increased resolution in the upper ocean, are used. Current fields at 0, 3, 10, 30, 50, 100, and 250 m are stored every hour from the model.

Two different simulations have been performed. In both studies, particles simulating cod eggs and larvae have been released on Røstbanken near Lofoten during a 2 months period from 1 March to 1 May 2006. The spawning follows a normal distribution with maximum spawning around 1 April. In total near 32000 particles are released. In the first simulation, the particles are adjusting their vertical position as a function of age and time of day in the following way: The first 45 days after the particles are released their vertical position is random within the upper 30 meters, according to Table1. After that, their vertical position is decided from the model described in Figure 1, with the exception that the relative depth scale is estimated from the minimum of the real depth at point and 250 meters. The night and day distributions are used 12 hours daily each. In the second simulation, the vertical position of each particle is set at random in the upper 30 meters through the whole period. In both simulations, the vertical position is updated every time-step, which is set to 1 hour.

Acoustic observations were done as part of a cruise in the Barents Sea with RV "G.O. Sars" in 1-20 October 2006. The data presented here is from 12-13 October, between 08.00 (UTC) and 07.00 (UTC) the next day, in an area south of Bear Island, at approximately 73°N 18°E. Bottom depth ranged from 104 to 191 m in the whole area. The observations were recorded in a 5x5 nautical mile square with an acoustic Lander at the centre, moored to a bottom anchor with the transducer at 120 m depth (Figure 3). Acoustic observations were taken by

the hull mounted acoustic system on the vessel while surveying the square, and by a 38 kHz split beam GPT and ES38DD transducer mounted on the acoustic Lander, looking upwards in the water column. Fish samples were taken with bottom trawl and pelagic trawl. Details about the experimental setup are given in Johansen *et al.* (2006).

To obtain comparable acoustic data from the Lander and vessel, a survey with 10 kn speed were simulated with the Lander data, to obtain the mean area backscattering coefficient (s_A) per nautical mile for fish above the transducer. The s_A values from vessel and Lander were then aggregated in 10 m depth channels and 1 hour time steps. Corrections were done to invert the acoustic recordings from the upwards looking Lander, so the two data sets were comparable. Acoustic data from the Lander and vessel were compared to evaluate the possibility for using vessel data as a supplement to Lander data, and evaluate the spatial variation in the vertical distribution.

Results and discussion

The results from the simulations of the drift model demonstrated a profound effect of the assumptions about the vertical distribution of the particles. This effect of the different vertical distribution is illustrated in Figure 4. The use of an active vertical migration of the cod larvae in the first simulation clearly give a more northerly and westerly distribution compared to simulation number two where the particles were placed in the upper 30 meters at random. This emphasise the importance of integrating the model and observations to obtain a realistic parameterisation of the vertical dynamics of the simulated particles.

The fish caught by trawl in the area covered by the survey were highly dominated by young-of-the-year cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.), 98% and 84% of total catch by numbers, respectively. Most of the recordings in the echograms were therefore most likely 0-group gadoids. Examples of the vertical distribution of 0-group gadoids as recorded by the Lander are given in Figure 5. Sunrise and sunset are approximately at 06.00 (UTC) and 15.00 (UTC) in this area at this time of the year. Figure panel a, therefore represents daytime, panel b and f represent transition between day and night, and panel c, d, and e represent night time. The general picture of vertical distribution of 0-group is a diurnal cycle of contraction and dispersion instead of a profound vertical migration. The 0-group fish is distributed in dense aggregations during daytime, and disperses throughout the water column during the night. s_A-weighted mean depth and standard deviation of s_A by depth for each hour was calculated for the acoustic data from both

Lander and vessel (Figure 6). The hourly depth profiles of s_A from Lander and vessel are presented in Figures 7 and 8.

The depth profiles seem to be more variable in daytime compared to the smoother profiles in nighttime. This reflects the pattern in the echogram. There are also indications of higher variation in the s_A values in daytime due to the patchy vertical distribution at this time. There seems to be a sudden shift in the vertical distribution around sunrise, accompanied by an increase in the variability. This might be an avoidance reaction to the increasing light level. There are some differences between Lander and vessel in s_A -weighted mean depth, particularly in daytime where the mean depth from the vessel data seems to be higher than for the Lander data. This is probably caused by the better ability of the Lander obtain acoustic recordings in the upper water column. The vessel has a protruding keel where the transducer are mounted, thereby missing the upper 10 m layer. In addition, vessel avoidance might play a role in the upper layers, as the 0-group had reached 10-15 cm length and were capable of vertical movement. Another factor might be a possible difference between acoustic target strength of single fish when it is recorded from above (i.e. the dorsal aspect) by the vessel and from below (i.e. the ventral aspect) by the Lander. Note also that the vessel covered a larger area and that the data are probably influenced by spatial variation in the depth distribution. This is illustrated by the s_A -distribution from the vessel between 23 and 24 differing from the rest. At this time, the vessel was redirected outside the square to pick up an autonomous platform used in another parallel experiment (seen as a loop in the course track towards west in Figure 3). It is important to realise that the acoustic observations are limited in both time and space, only providing an indicative validation of the models. A rigorous test of the models depends on considerable amounts of data on a larger time and space scale. However, the observations shed some light on the largely unknown vertical dynamics of 0-group gadoids in the Barents Sea at this time of the year, and provide valuable insight useful for further validation and parameterisation of the drift models.

The acoustic observations corroborate the general pattern in the vertical distribution depicted by the conceptual model, but the mode of the observed vertical distribution is shifted towards the surface compared to the model, where the distribution is more symmetric.

Based on the indications from the observations, the assumptions about vertical distribution of 0-group in simulation 1 seem to be more realistic than simulation 2. In simulation 1, the 0-group ends up closer to the area around Bear Island, where we observed the high abundances at the cruise, compared to in simulation 2. Simulation 1 results in a geographic distribution of

0-group gadoids corresponding to the distribution observed in the joint Norwegian-Russian ecosystem survey in the period 8 August-5 October 2006 (Anon 2006).

The use of acoustic Landers as stationary platforms for observation of dynamics in marine ecosystems is clearly a step forward in our ability to understand important processes. The use of data from of an acoustic Lander in this study, although limited in time and space, resulted in new and valuable information about vertical structuring of 0-group gadoids in the Barents Sea. It represents a promising approach towards integration of observations and models to improve predictions of ecosystem response to physical variability. This equipment is now operational, and is very compact, durable, and easy to launch. We propose a more thorough observation program to describe and quantify the vertical distribution of 0-group gadoids in the Barents Sea. This should be more extensive in time and space, involving coverage of the whole drift route by moving the Landers according to the geographic distribution of the 0-group. Several Landers should be involved, to evaluate the spatial variation in the vertical dynamics. In addition, the relationship between Lander data and vessel data should be more thoroughly validated. This will explore the possibility of supplying the Lander data with vessel data from both vessels involved directly in the deployment of the Landers and vessels involved in standard surveys covering the distribution of 0-group. This observation program will enable us to collect the needed observations to obtain a more realistic recruitment prediction models.

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Tables

Table 1. Characteristics of the development and behaviour of cod from birth to bottom settlement.

Time / Event	~1 April	~15 April	Mid May- mid September	Mid September- November	December - January	February -
Association	Surface associated	Surface associated	Surface associated	Midwater associated	Bottom associated	Bottom settled
Process / stage	Spawning eggs No active migration	Hatching larvae No active migration	Functional swimbladder Limited migration	Extensive migration	Extensive migration	Limited migration
Model variables	Vertical mixing of water masses	Vertical mixing of water masses	Date, Time of day,	Date, Time of day,	Date, Time of day,	Date, Time of day,
Parameter	From ocean models	From ocean models	Migration range Curvature	Migration range Curvature	Migration range Curvature	Migration range Curvature

Figures
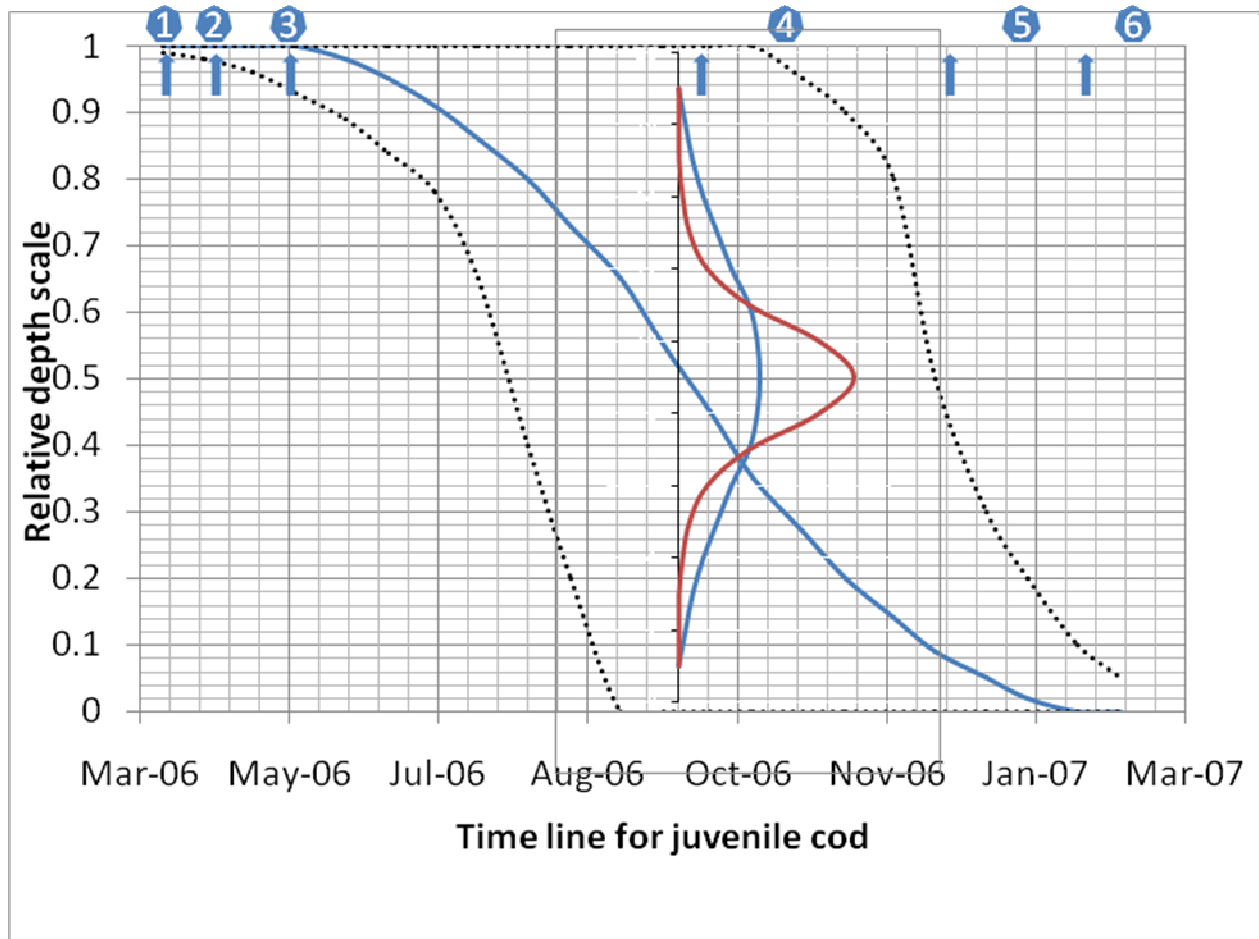
Figure 1. Average relative depth of 0-group cod during the first year of life illustrated by solid line moving from surface (relative depth=1) in April to bottom in January next year. Numbers at top indicate events in the development: 1-spawning, 2-hatching, 3 development of functional swim bladder, 4 changes from surface to mid water association, 5- changes to bottom association, 6- settled. Arrows indicate time of transition between different events. Vertical distribution represented by blue (night) and red (day) normal distributions.
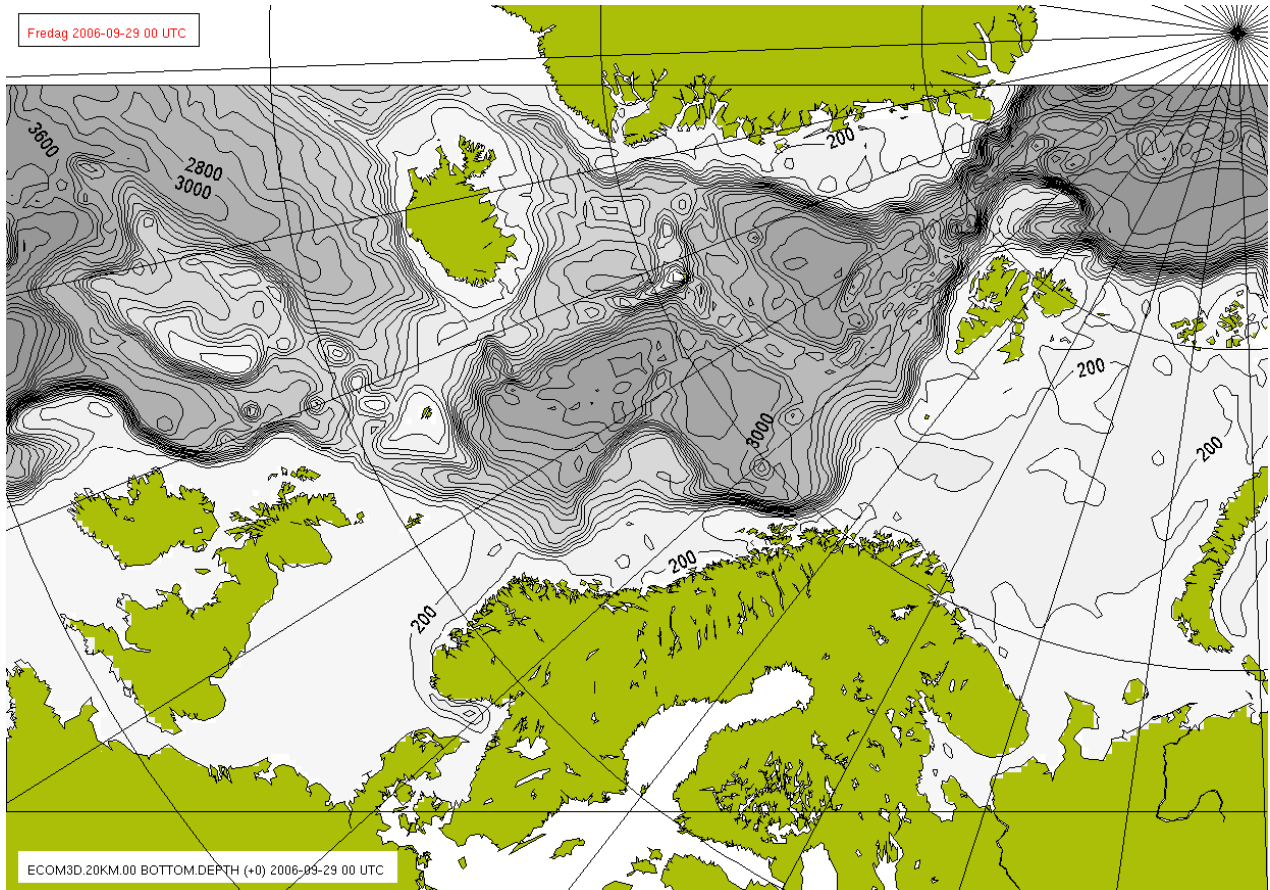
Figure 2. Model domain and bathymetry.
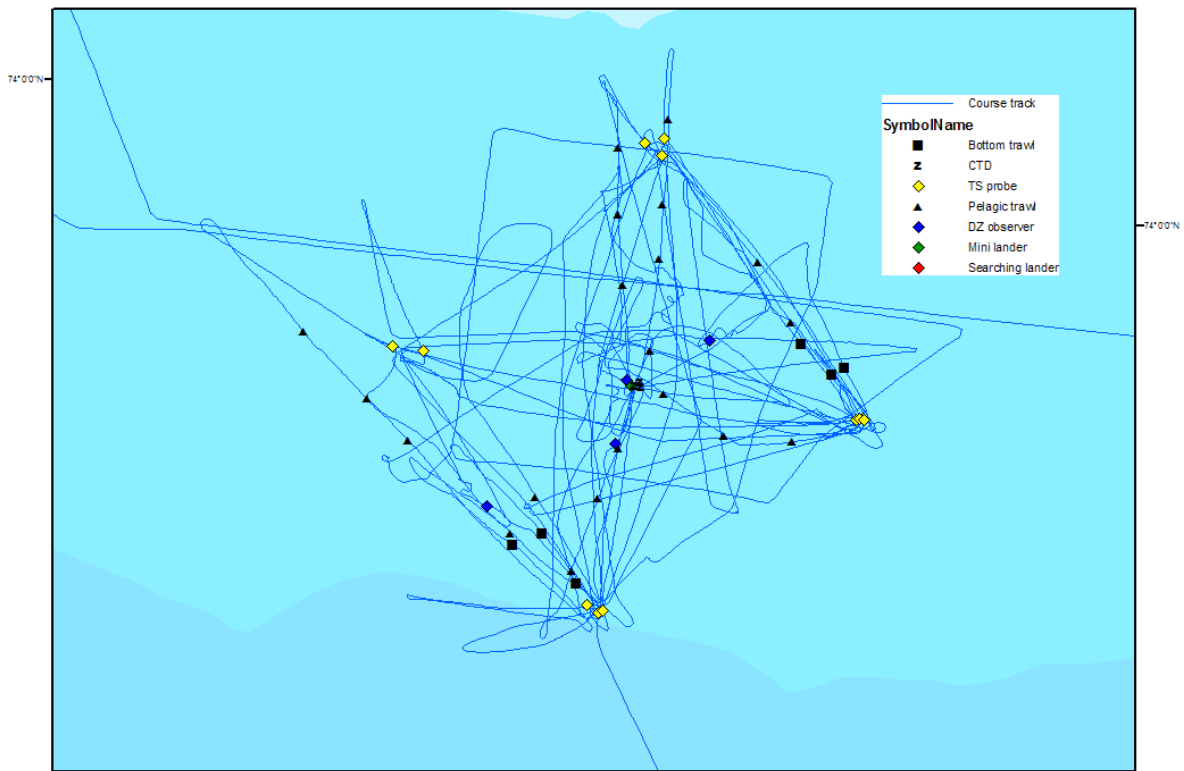
Figure 3. Detailed map showing course tracks and activities for RV "G.O. Sars" in an experiment area south of Bear Island, at approximately 73°N 18°E in 9-13 October 2006. The Lander was placed at the centre of the square formed by the course tracks. Note that only data from 12-13 October were used in the work presented here.
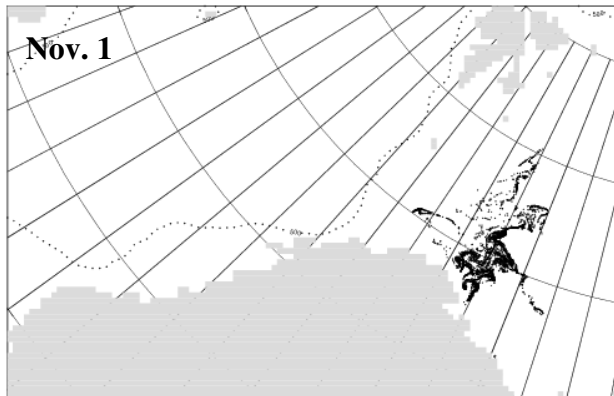
Cod larvae distr. (active) 2006, Day :   180

July 1
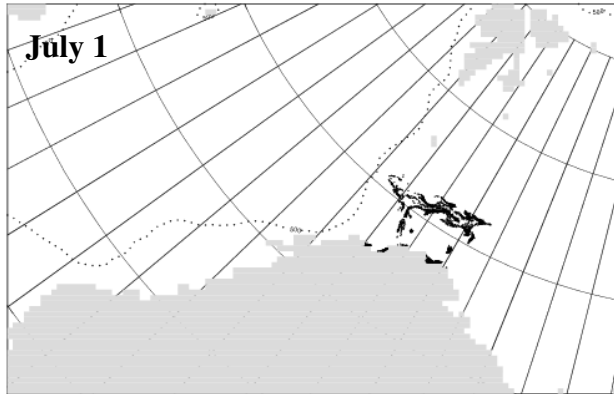
Cod larvae distr. (random) 2006, Day :   180

July 1
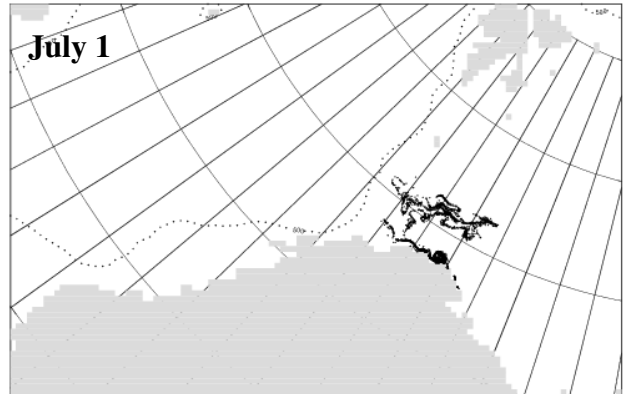
Cod larvae distr. (active) 2006, Day :   300

Nov. 1

Cod larvae distr. (random) 2006, Day :   300

Nov. 1
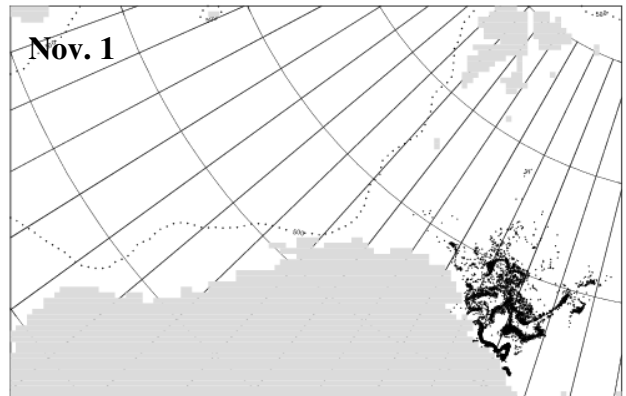
Figure 4. Particle positions on 1 July and 1 November for simulation 1 (left) and simulation 2 (right).
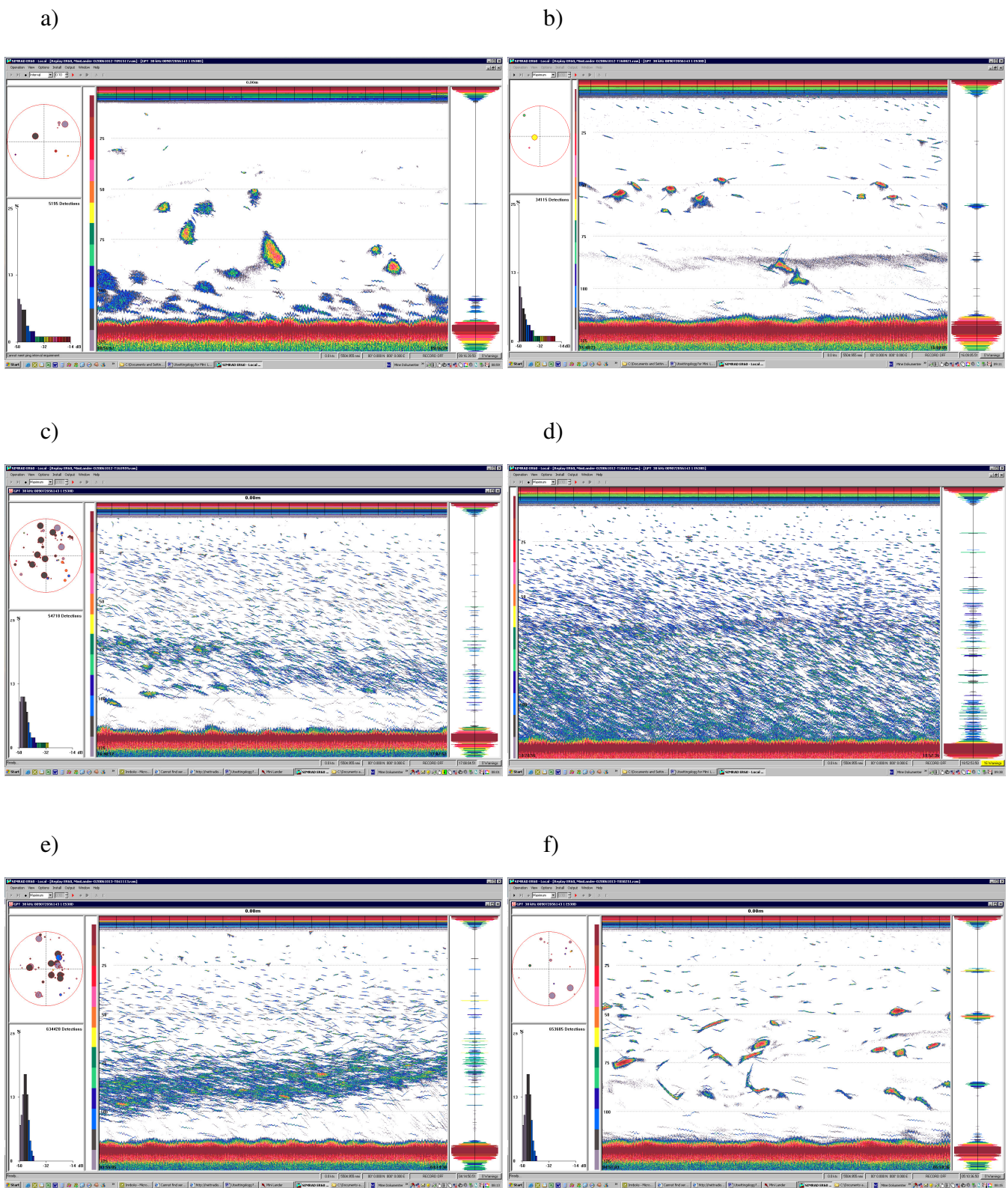
a)

b)

c)

d)

e)

f)

Figure 5. Echograms showing vertical distribution of 0-group in experimental area south of Bear Island 12-13 October. Note that the echograms are from an upwards looking transducer, so the surface is at the bottom of the figures. Different panels are from different times (UTC): a) 09.16, b) 16.09, c) 17.08, d) 18.52, e) 04.14, and f) 05.10.
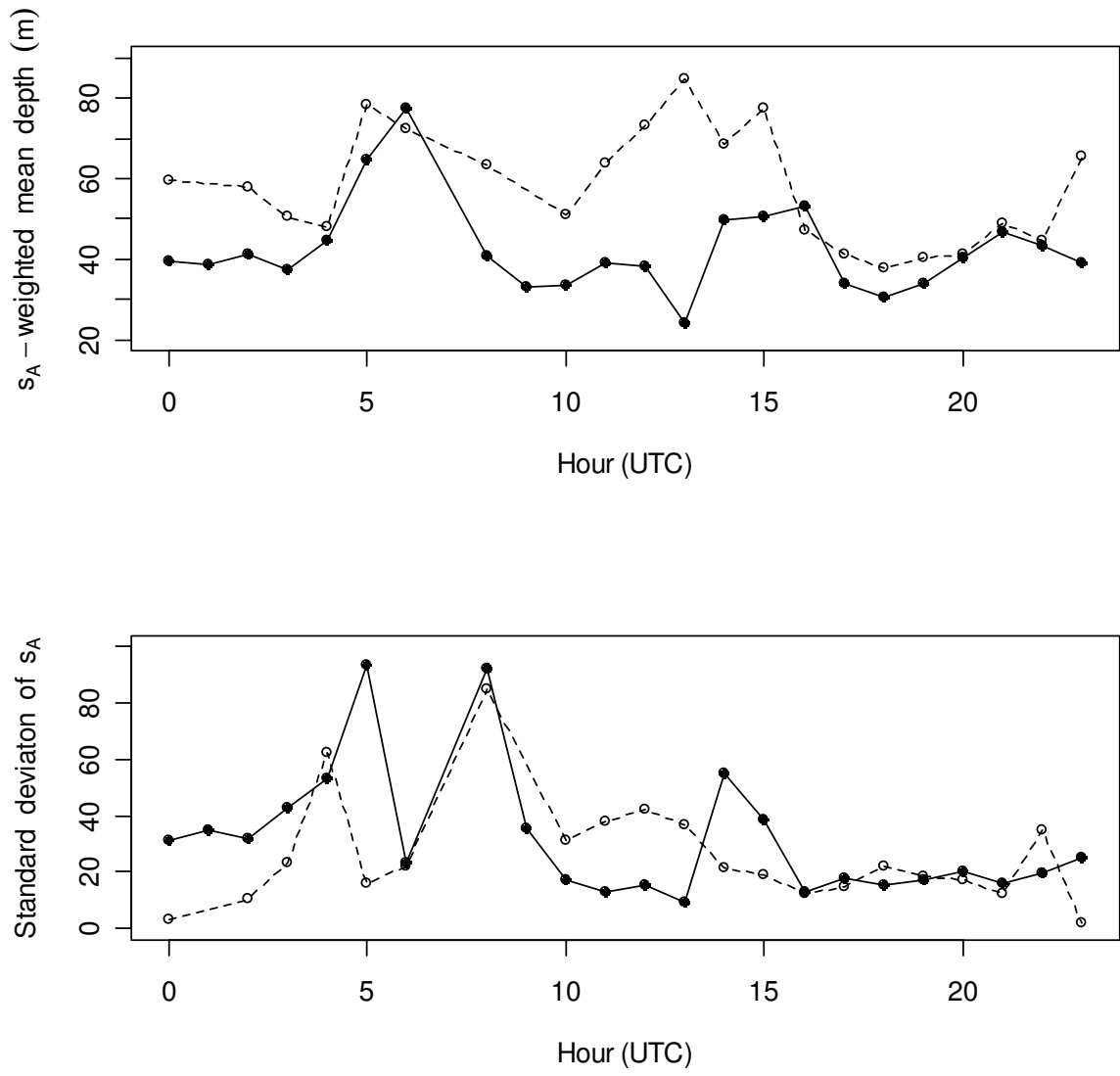
Figure 6. Depth distribution and variation of s_A in the water column by hour. Solid line is data from Lander and dashed line is data from RV "G.O Sars".
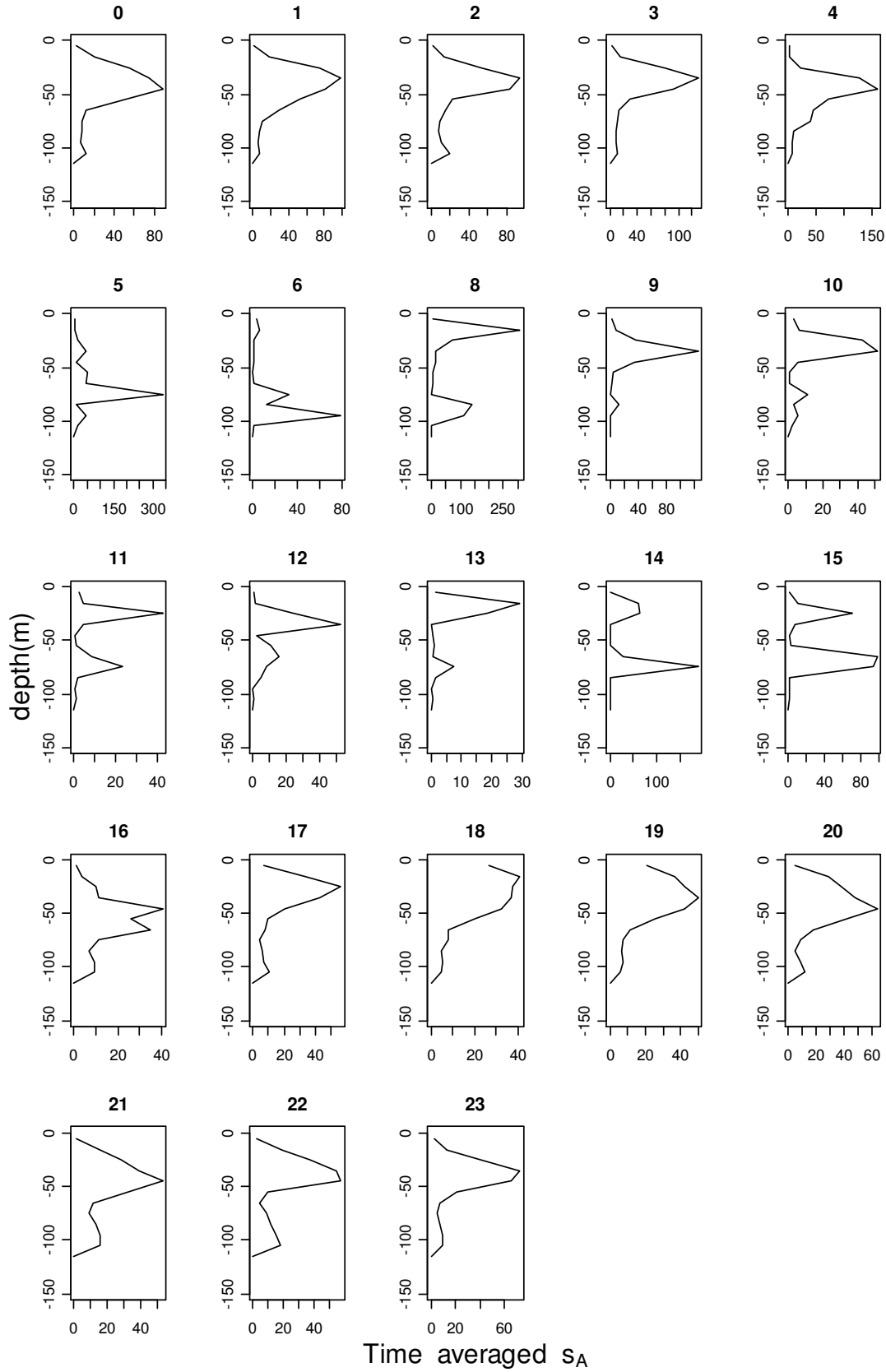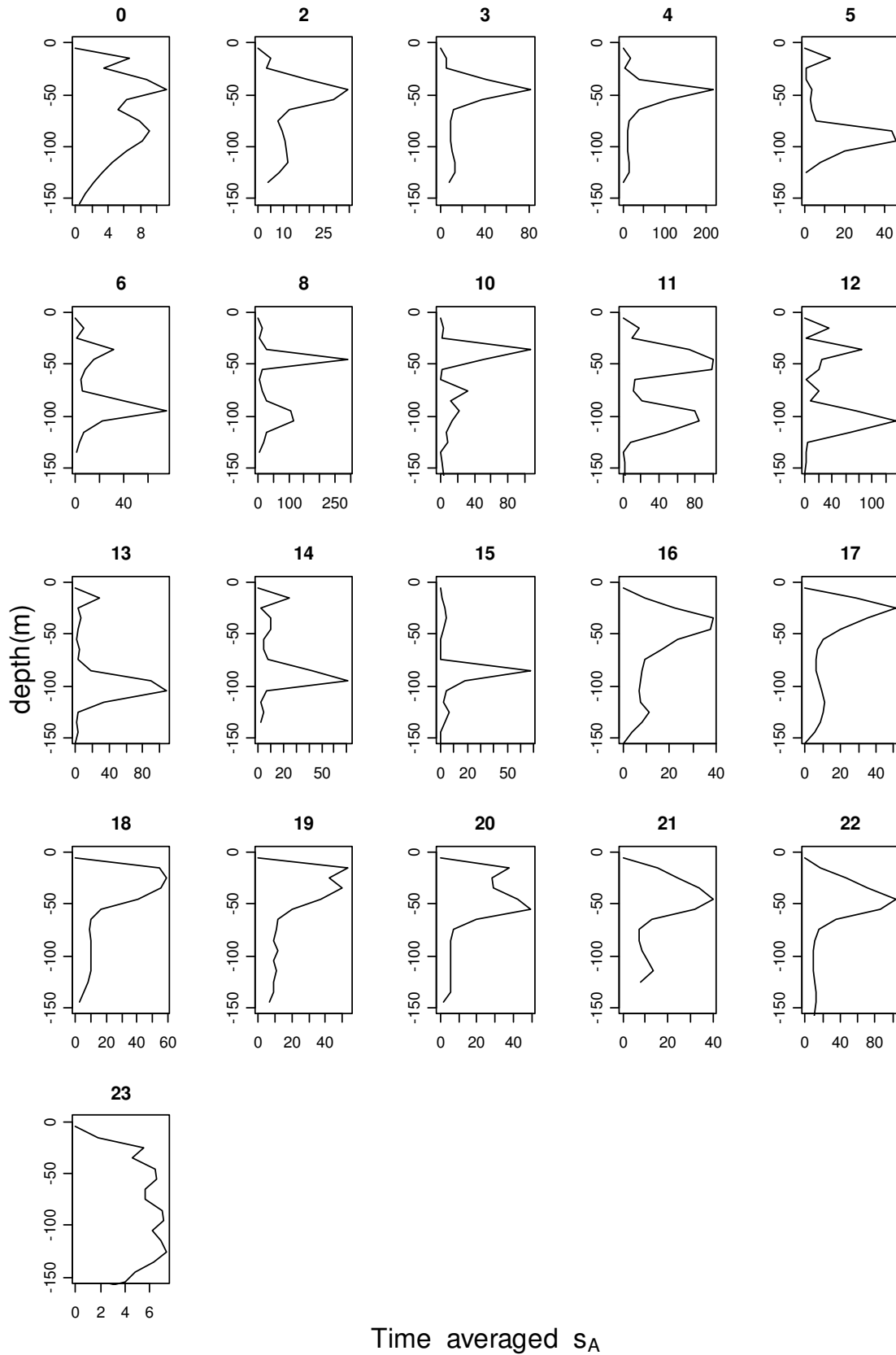
Figure 7. Depth distribution of mean s_A of 0-group gadoids by 10 m depth channels for each hour (UTC) as observed from the Lander.

Vessel observations

Figure 8. Depth distribution of mean s_A of 0-group gadoids by 10 m depth channels for each hour (UTC) as observed from the RV "G.O. Sars".