6.0 Oceanography

6.1 Physical Oceanography

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6.1.1 Circulation

<u>Observed Currents</u>

The low-frequency water circulation in the Gully region is considered, examining the monthly current maps created from all of the archived data held at Bedford Institute of Oceanography. The majority of these records were collected as a component of the offshore petrochemical exploration activity. Mean current vectors have been constructed from the data regardless of their depth or duration. In the monthly mean current maps that follow, the average duration of a record is 19.4 days with a standard deviation of 10 days. The minimum depth is 2 m, the maximum is 1500 m, the mean 43 m, and the standard deviation is 78 m.

In the northeast portion of the region, currents are generally to the southwest throughout the year with amplitudes of up to 0.15 m/s (Fig. 6.1.1a,b). An exception to this pattern is the east to east-southeast flow seen at the 50 fathom isobath on the eastern flank of the Gully from January to May. At the mouth of the Gully the current appears to be generally towards the southwest from February to August. The instruments there were at depths of 15, 22, 23, 33 and 74 m. The current records from within the Gully show a generally counterclockwise circulation pattern with current speeds generally below 0.1 m/s (see May, June and July in particular). Currents around Sable Island are quite complicated, especially off the eastern tip where the direction of flow changes markedly in a short distance (see March for example). South of Sable Island, the flow is towards the southwest just as it was northeast of the Gully.

The overall picture that emerges for the area is generally a southwestward flow with some counterclockwise circulation along the flanks of the Gully. At the mouth of the Gully there is only a weak inflow indicated by the available data. This inflow is not consistent with the stronger circulation observed within the Gully. However, since the data coverage is sparse, it is possible that, at the mouth of the Gully, a region of stronger inflow was missed.

Modelled Currents

There has been considerable effort in the Coastal Ocean Science section of Bedford Institute of Oceanography (BIO) in the development and application of finite element models (FEM) to circulation problems on the Scotian Shelf. A computational mesh for the eastern half of the Scotian Shelf demonstrates the spatial capabilities of these models, namely, high resolution in areas of rapidly changing depth and of particular concern (Fig. 6.1.2). High vertical resolution is also achieved.

Han *et al.* (1997) have used the measured density structure and the observed wind in a diagnostic FEM model of the baroclinic circulation on the Scotian Shelf for three periods: the long-term mean January-February (winter), April-May (spring), and July-August (summer) (Fig. 6.1.3a,b,c). A diagnostic calculation is strictly constrained by the density structure that is fixed in time, and by the external forcing. Han *et al*. give a full account of the details of their model. They present the near-surface (average from 5 to 25 m) currents for three seasons. Winter near-surface flows over the Gully are generally to the southwest at about 0.1 m/s; in spring the currents show a greater tendency to form a broad scale (over the Gully and the area east of Sable Island) counterclockwise circulation with a typical current speed of about 0.05 m/s; in summer, the counterclockwise flow is confined more tightly to the Gully with characteristic velocities of about 0.1 m/s. An interesting feature crops up in the wintertime bottom circulation in the Gully, namely, a clockwise flow with a representative amplitude of 0.05 m/s.

The gyre-like surface circulation has currents on the outer edge, some 15 km from its centre, of about 0.1 m/s. In geostrophic equilibrium, there will be a surface slope of approximately 0.008 m/15 km (sea level will be lowered at the centre of the gyre) assuming a linear increase of current from the centre of the gyre (zero current) to the edge. Internal mass adjustment will cause the current to decrease to zero at some depth. This will give rise to doming of the isopycnals in a sense opposite to the sea surface (*i.e.*, the isopycnals will be shallower at the centre of the gyre). The magnitude of this effect can be estimated roughly as $(\rho/\Delta\rho)\Delta\varsigma$, where ρ is an average water column density, $\Delta\rho$ represents the vertical density difference (between 0 and 100 m for this example), and $\Delta\varsigma$ is the sea level difference across the gyre. Taking typical density differences for winter and summer, we estimate that the pycnocline would be elevated by 8 and 2 m, respectively, at the centre of the gyre.

Ongoing modelling efforts at BIO have extended the diagnostic calculations of Han *et al.* (1997) to prognostic computations (J. Shore, J. Loder, C. Hannah, pers. comm.). The newer model runs begin with a specified density distribution and external forcing that are maintained until an equilibrium has been established. The rigidly specified density field is then allowed to relax and to evolve away from the initial distribution according to the governing equations. These extended model runs generally do not change the results of Han *et al.* in a major way for the Gully region (see Fig. 6.1.4, spring 30 m currents). The detailed density and current distribution for spring across and along the Gully are shown in Fig. 6.1.5a-c. The density structure indicates that there is significant doming of the isopycnals across the Gully. The currents are asymmetrically distributed across the Gully implying that all of the inflow does not return as part of a gyre. The density slopes and the currents are generally weaker in the along-Gully section.

The model can be used to track the paths particles could take either at fixed depths or when allowed to respond to the vertical as well as the horizontal velocities (Fig. 6.1.6a-e). Particles, whose initial positions are shown in Fig. 6.1.6, are subject to the model's currents. Their positions are displayed every 5 days at 30 m (Fig. 6.1.6b, c). Particles in the western end of the Gully tend to move south of Middle Bank, towards the coast and are carried southwestward. Some particles, caught in the offshore directed flow move around Sable Island Bank and along the outer shelf. Particles whose starting positions lay near the tip of the 200 m isobath in the Gully show the greatest retention. About 11 of the 122 particles used in the calculation remain in the Gully after 40 days. The results are quite similar for the particles that can respond to vertical movement though they seem to experience greater dispersion. After 40 days there are only 4 particles remaining in the Gully.

A line of particles placed across the Scotian Shelf including the Gully shows the larger scale character of the currents in the region (Fig. 6.1.7). Currents near the coast and at the shelf break flow in the same direction for long distances approximately parallel to the bathymetry. The clockwise flow around Middle Bank and the counterclockwise circulation over the Gully indicates the influence of smaller scale topographic features.

Currents from these modelling studies have been compared to in situ current meter data. The statistic used is the sum of the squares of the vector differences between the modelled and observed currents, divided by the sum of the squares of the observed currents. A value of zero indicates perfect agreement; a value of 1 indicates that the sum of the velocities squared of the difference flow is the same as the sum for the observed flow. For spring, the values of this ratio for Western Bank and Browns Bank were 1.53 and 0.40. Both of these values, but particularly the one for Western Bank which is located just west of Sable Island, indicate that we should be cautious about over-interpreting the drifter tracks of Fig. 6.1.6 and 6.1.7.

Other modelling studies recently have shed some light upon the circulation on the eastern Scotian Shelf. Cong *et al.* (1996) modelled the 30 m circulation for an area of the Scotian Shelf defined by a line running offshore from Louisbourg at the coast, cutting Banquereau Bank just east of the Gully, then westward along the shelf break roughly at the 200 m isobath, and finally moving shoreward between Baccaro and Browns Banks to Cape Sable (Fig. 6.1.8a). The model is forced by a time-varying but spatially-uniform windstress (based on Sable Island observations) and inflows through the open boundaries. Sea-level is fixed at zero along the shelf break open boundary where outward propagating gravity waves are allowed to leave the model grid; sea level is linear along the northeastern open boundary and is inferred from Halifax observations at the coast and is zero at the outer boundary. The mean model currents are calculated from the long-term average winter density data and are used as the background flow for all runs. In summary, the circulation consists of a background flow calculated from the winter density field and held fixed, the time varying currents forced by the windstress, and the flow component resulting from the sea level variations at the northeastern open boundary.

The background winter density-forced circulation at 30 m of Cong *et al.* (1996) shows onshelf flow throughout the Gully. However, Sheng and Thompson (1996) have shown that when reasonable long-term contributions of wind and sea level are added, the total circulation features a general counterclockwise surface flow in the region, as is indicated by the current observations. However, the surface flow west of the Gully and south of Sable Island is strongly offshore in their model; moreover, while the modelled flow to the northeast of the Gully is southwestward at the shelf break like the observed currents, the modelled currents on western Banquereau Bank do not indicate the southwestward tendency shown by the observations. Thus, the modelled and observed flows have areas of agreement and disagreement.

Cong *et al.* (1996) seeded their model domain uniformly with particles at the beginning of each March and April for the period 1956 to 1993 (see Fig. 6.1.8 for an example of their model results). They then calculated the distribution of particles until the end of each month and computed retention indices over the model region. The retention index is the ratio of the number of original particles remaining in the specified area at time t, divided by the total number of particles initially in the area under consideration. The Gully was one of the regions that showed marked retention of particles. Cong *et al.* gave indices for the 15th and 30th of March and April after starting from a uniform distribution of particles on March 1 and April 1. The average (1956-1993) maximum values of the retention indices for the Gully were 0.36 (March 15), 0.17 (March 30), 0.40 (April 15), and 0.26 (April 30). These correspond to approximate e-folding times of 16 and 19 days for March and April respectively. The maximum of the retention index is generally located just north of the 200 m isobath in the inner part of the Gully.

There are a couple of caveats to bear in mind with the Cong *et al.* simulations. First, the baroclinic density-forced circulation is fixed in time. This is necessary because of the lack of sufficient observations to model this component of the circulation from year to year; however, this assumption is certainly not true. Secondly, the outer, open boundary of the model is at the outer edge of the Gully. This is also a concern in numerical modelling - usually it is better to have an open boundary far from an area of interest. However, the Cong *et al.* (1996) results do provide some useful insights into the movement of particles in the Gully region.

6.1.2 Low-Frequency Current Variability and Exchange

We have calculated the standard deviation of currents from all of the observed flows shown in Figure 6.1.1a,b. This represents 489 monthly values, with an average depth of 43 m, a standard deviation of 78 m, and a depth range of 2 to 1500 m. The variability represents all of the fluctuations that occur at periods longer than about 1 day, *i.e.*, the semidiurnal and diurnal tides, and inertial oscillations are not included. There is a seasonal variation in the standard deviation with the highest mean values in the winter (0.13 m/s in January) and the lowest values in the summer (0.07 m/s in September, see Fig. 6.1.9). We also have examined the records from within the Gully, defined by the 50 fathom isobath. The values from this more restricted area are very similar to the overall ones. These results are typical for the Scotian Shelf.

The trough between Emerald and LaHave Banks is well known as a pathway for relatively warm and fresh slope water to the inner Scotian Shelf. The Gully is a shallower trough that also connects the continental slope to the inner shelf. It also may serve as a conduit of slope water to the inner half of the shelf (Houghton *et al.* 1978). To address this question, the low frequency current, temperature and salinity from five deep current meter records (sites labelled A and B in Fig. 6.1.1b, July) from the inner part of the Gully have been examined. The current was resolved into an along-Gully component based on the direction of the mean flow over the duration of the mooring. If the Gully is a major pathway for onshelf exchange, then there should be a correlation between temperature (and salinity) and along-Gully current, which was taken as positive in the offshore direction. Temperature and salinity at 100 m increase offshore from Middle Bank to the Gully by 1.4 ^{o}C and 0.54 on average over the year (Petrie *et al.* 1996). Thus, currents out of the Gully (positive direction) should bring relatively cool and fresh shelf waters to the slope, and vice versa. In addition, given the onshore-offshore gradient of temperature and salinity, the current should lag (*i.e.*, current should reach its largest value after T or S) those variables. By correlating the current time series with the T and S series at a later time, we should get a negative correlation at one quarter period offset (assuming sinusoidal variations). The maximum negative correlations shown in the table below indicate that this is generally the case, though the values are not very large. This could be because the A and B sites are on the return side of the gyre-like circulation (see Fig. 6.1.1b, July in particular). Nonetheless, these calculations indicate that low frequency processes contribute to onshore-offshore exchange through the Gully.

Table 6.1.1. Correlations between along-Gully current, temperature and salinity from deep current meter data.

Site	Season	Depth	Correlation, series offset (d) Current, temperature	Current, salinity
A	spring	114	-0.49, 3	-0.41, 3
B	fall	138	-0.22, 0.5	-0.38, 0.5
B	winter	138	-0.60, 0.5	-0.71, 0.5
B	winter	126	-0.40, 0.5	-0.21, 0.5
B	spring	138	-0.35, 0.5	-0.29, 0.5

These current meter data can also be used to estimate the seasonal onshelf transport through the Gully. The data used are presented in detail in the chemical oceanography section (6.2). For the winter season (DJF), the estimated transport is 0.03 Sv (1 Sv=10^6 m^3/s), whereas for the summer (JJA), it is 0.07 S. These transports are very small in comparison to the estimates of outflow from the Gulf of St. Lawrence of 0.52 (El Sabh,

1977) to 1.0 Sv (Han *et al.* 1998) for winter and 0.41 to 0.8 Sv for summer. The outflow from the Gulf is the major source of water for the eastern Scotian Shelf.

6.1.3 Barotropic Tides

The principal semidiurnal and diurnal tidal species have been modelled by de Margerie and Lank (1986). A concise summary of the 3 principal tidal constituents and the residual current generated by the M2 tide, the largest constituent overall, are presented in Fig. 6.1.10 and 6.1.11. The ellipses represent the path a particle of water would take if it experienced the currents at the grid points indicated (Fig. 6.1.10). It is evident that the tidal currents are strongest where the depths are the least, *i.e.*, in the vicinity of Sable Island. Weaker tidal flows occur in the adjacent deeper area of the Gully with the weakest flows found in the adjacent deep ocean. The non-linear M2 residual flows are generally weak throughout the entire area (Fig. 6.1.11). The straight lines of Fig. 6.1.11 indicate the excursion that a water parcel would take if it experienced the mean flow in the local area for one day. The strongest M2 residual flow, 0.042 m/s, occurs just to the northwest of Sable Island.

6.1.4 Internal Waves

The outer portion and flanks of the Gully to approximately the 200 m isobath were indicated by de Margerie and Lank (1986) as regions where internal tide generation was favoured. There is some evidence that this is indeed true. Sandstrom and Elliott (1989) reported the results of extensive Batfish hydrographic surveys of the Gully. A section run on the eastern flank of the mouth of the Gully between the 100 and 200 m isobaths shows large amplitude internal waves (Fig. 6.1.12). The nature of these oscillations - very steep waveforms - indicates that they may be non-linear; that is, they are a group of cnoidal waves generated as the internal tide evolves. Quite often they are called solitary waves or solitons, though in this picture they are certainly not alone. In addition to temperature, salinity and density, the echo-sounder record is also shown Fig. 6.1.12. There were strong reflectors (Sandstrom *et al.* (1989) indicate that this is likely turbulence) at about 25 m that are associated with the density oscillations; moreover, in the shallower region, the reflectors appear to be broken up as if enhanced mixing was generated by the passing wavetrain. This may be evidence of strong vertical mixing in the region and thus could affect the overall productivity (Sandstrom and Elliott, 1984; Sandstrom and Oakey, 1995). This section is perhaps the best example in the Sandstrom-Elliott report. However, very few sites on the Scotian Shelf have received such intensive surveying. Thus, we do not have the database to compare the internal wave activity in the Gully to that elsewhere. However, de Margerie and Lank (1986) indicate that there are other areas of the Scotian Shelf and the Grand Banks that show as much potential for internal tide generation as the Gully. In this respect, the Gully is not a unique region.

From these surveys we cannot say that the activity exhibited in the Gully is average or significantly different from average for the Scotian Shelf. Of the approximately 225 sections displayed by Sandstrom and Elliott, about 40 showed marked internal wave activity. Note though, that some of these sections were very short and were obviously tracking back over the same wave repeatedly in order to determine its history and fate.

Sandstrom and Elliott placed two current meter moorings each with 2 instruments (at 15 and 67 m) on the eastern flank at the mouth of the Gully. They recorded temperature as well as currents. The shallower and deeper instruments had the first and fourth highest temperature variances for the 15 and 9 records respectively collected in the same month from the area defined by Fig. 6.1.1. This indicates that the outer Gully may be a region of enhanced internal wave activity, and thus perhaps of mixing as well.

6.1.5 Monthly Mean Temperature, Salinity and Density

Monthly mean temperature and salinity statistics from Petrie *et al.* (1996) are shown in Fig. 6.1.13 and 6.1.14 for the Gully. The temperature and salinity fields evolve much like the other regions on the Scotian Shelf. Maximum temperatures at the surface occur in the late summer (Fig. 6.1.13). The heat is mixed downward with increasing storm activity in the fall; winter cooling follows. Salinity is strongly influenced by the outflow from the Gulf of St. Lawrence which contributes to the surface minimum in October. The mean, standard deviations and extreme temperatures and salinities, shown in Fig. 6.1.14, emphasize the dominance of the annual cycle at shallow depths. Density reflects the annual variability in the temperature and salinity fields (Fig. 6.1.15).

The question of enhanced mixing in the Gully that was raised above can be addressed through an examination of the density profiles in adjacent areas. This comparison is shown in Fig. 6.1.16 for the Gully and the 4 areas surrounding it as defined by Petrie *et al.* (1996). For this comparison, we have selected only the months (March, July, August and November) that have enough data to give reasonable estimates of the mean density profiles. It is evident from these plots that there is not a marked difference among the 5 regions, except for the deeper portion of the Middle Bank profiles. This could be because Middle Bank is the region closest to the coast and is thus subject to a greater influence of nearshore waters. Hence, it does not appear that there is enhanced mixing in the Gully region.

Mean seasonal bottom salinity distributions show the tendency for saltier and thus generally warmer waters to move onto the shelf via the Gully. The winter distribution of salinity shows this pattern quite distinctly (Fig. 6.1.17). Similar intrusions are evident for the other seasons as well.

6.1.6 Interannual Variability of Temperature and Salinity

The waters of the Scotian Shelf have shown significant interannual and longer-term variability of temperature and salinity (Petrie and Drinkwater, 1993). The variability at the eastern end of the shelf was less than that in the central or western region. The interannual variability found in the Gully at the 0 and 50 m depths resembles the temporal changes Petrie and Drinkwater (1993) found for the Sydney Bight region (Fig. 6.1.18). This indicates the strong influence of Gulf of St. Lawrence outflow. At greater depths, the long-term changes of temperature and salinity in the Gully are similar to (but with smaller amplitudes) those seen at Emerald Bank and Basin, and in the slope area to the west (see Fig. 6.1.18 and Petrie and Drinkwater, 1993).

6.1.7 Ice

The ice charts for the 30 year period from 1964-1993 prepared by the Atmospheric Environment Service have been digitized and analyzed at Bedford Institute of Oceanography (Roger Pettipas, pers. comm.). For this analysis, the ice boundary was defined as the locations where ice covered at least 10% of the ocean surface area. In the table below, we present the mean year day number of first and last appearance of ice, number of years when ice was present at some time, and average duration of ice for five 0.5^{o} latitude by 1^{o} longitude squares that cover the Gully. Ice cover greater than 10% in any part of a 0.5^{o} by 1^{o} polygon counted as an occasion when ice was present. The statistics indicate that ice is present in the Gully region for less than 30% of the years and that when present, its duration is quite short.

Table 6.1.2. Ice Statistics for the Gully for the 30 year period 1964-1993.

Latitude (^{o}N)	Longitude (^{o}W)	Day of 1st Appearance	Day of Last Appearance	Number of Years with Ice	Average Duration of Ice (days)
44-44.5	60-61	58	67	8	<10
44-44.5	59-60	52	66	6	<10
44-44.5	58-59	65	77	5	<10
43.5-44	58-59	79	82	2	<10
43.5-44	59-60	-	-	0	0

6.1.8 Studies of Similar Topographic Features

There have been a number of studies of North American Atlantic coast canyons that could lend some insight into the physical oceanography of the Gully. The common feature each of these canyons has with the Gully, in addition to their morphology, is that the mean flow on the adjacent shelf and slope is in the same sense, *i.e.*, from right to left as you face the canyon from the deep ocean. This external mean flow will play a major role in the determination of the circulation within the canyon.

Hotchkiss and Wunsch (1982) conducted a 15 week observation program in Hudson Canyon. Hydrographic properties, pressure and current were measured from 5 moorings with 10 current meters and 14 temperature-pressure recorders. Hudson Canyon is a steeply sloped feature cutting 30 km into the continental shelf off New York Bight. It is about 13 km wide at the mouth and 3.5 km wide at the head. In these respects, it is similar to the steep outer area of the Gully which intrudes 40 km into the shelf (approximate distance between the 2000 m and 200 m isobaths) and is about 14 km wide at the mouth. The major morphological difference between Hudson Canyon (and the other canyons discussed below) and the Gully is that, in the case of the latter, the 100 m isobath defines a shallower, broad channel-like feature that penetrates deeply onto the shelf and could be considered as part of the overall feature. In fact, the channel defined by the 100 m isobath connects the slope region to the inner Scotian Shelf. Hudson Canyon is confined to the outer shelf. The main result reported by Hotchkiss and Wunsch (1982) was the apparent amplification of the horizontal kinetic energy in the internal wave band near bottom within the canyon and towards the head of the canyon. However, the evidence was not compelling. We do not have a comparable dataset and cannot confirm if the same is true for the Gully. However, in Fig. 6.1.19, we have combined all of the data available to show the distribution of variance along the axis of the Gully, including the inner portion defined by the 50 fathom isobath. The plot indicates that the variance is largest at the mouth of the Gully and decreases shoreward. As pointed out earlier, we have reasons to suspect enhanced internal wave energy there.

Hunkins (1988) maintained 12 moorings in and adjacent to Baltimore Canyon for up to 18 months. The Canyon, defined by the 100 m and 700 m isobath is about 3 km wide at the head, 8 km wide at the shelf break, and is about 13 km long. Thus it is smaller than the Gully. The current pattern within Baltimore Canyon was quite complex making it difficult to determine a well-defined circulation. On the other hand, a number of interesting results emerged: a maximum peak current of 1.06 m/s was observed near-bottom at 275 m (this mooring had instruments at 50, 230 and 275 m); near-bottom amplification of the semidiurnal tidal flows occurred consistently throughout the mooring period. Mean currents shallower than 100 m did not appear to be affected by the canyon. Deeper instruments in the canyon were generally at 2 levels, 50 and 6 m above the bottom. These were strongly affected by the local topography; however, a well-defined circulation pattern did not emerge.

Perhaps the most intensive study of the circulation in an east coast canyon was conducted at Lydonia Canyon, off the southern flank of Georges Bank (Noble and Butman 1989). This feature cuts into the shelf by about 20 km and is about 5 km wide at the mouth. An array of fourteen moorings, three bottom tripod systems and one bottom pressure mooring was deployed for six months. Noble and Butman concluded that mean currents in the Canyon were weaker than those over the adjacent shelf and slope. In addition, the amplitude of subtidal flows was 2 to 6 times higher on the shelf and slope than in the Canyon (see Fig. 6.1.20). An analysis was carried out to determine the circulation patterns within the Canyon. The primary mode of circulation captured only 25% of the along-canyon current variability. This indicates, as was the case for Baltimore Canyon, that the circulation is quite complicated.

6.1.9 Summary

The review of the physical oceanography of the Gully has indicated that it may feature a weak, counterclockwise circulation that could contribute to the retention of particles within it. However, similar patterns are found elsewhere on the Scotian Shelf, for example, the clockwise gyre around Browns Bank, the Western Bank gyre, the retention areas over Emerald and Western Banks (Cong *et al.* 1996). Low-frequency current variability in the Gully is comparable to that observed in nearby regions and for the Scotian Shelf as a whole. Barotropic tides behave regularly. There is some evidence in Batfish surveys and in the temperature variability from fixed sensors that internal tides and internal wave activity at the mouth the Gully may be enhanced. This could lead to greater vertical mixing in the Gully with implications for nutrient exchange and consequently for primary productivity. However, a comparison of the long-term mean profiles of density indicates very little difference among those from the Gully and from four surrounding areas. This may indicate that either the internal wave activity seen in the Gully surveys extends into the adjacent areas, or that enhanced mixing, driven by internal wave breaking and dissipation, is highly localized within the Gully. Thus, our broad averaging of monthly density profiles may have hidden localized mixing hot spots.

6.1.10 Acknowledgments

Helpful suggestions of this report were provided by Peter Smith.

6.1.11 References

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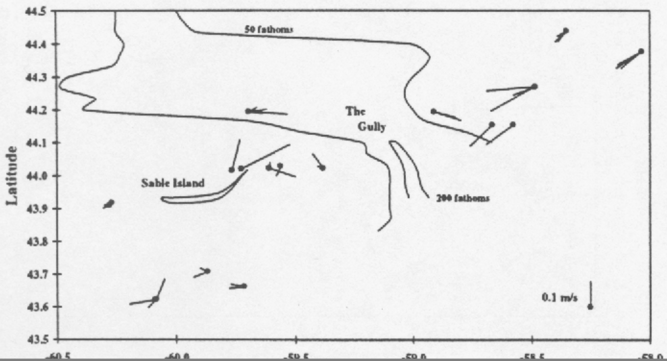
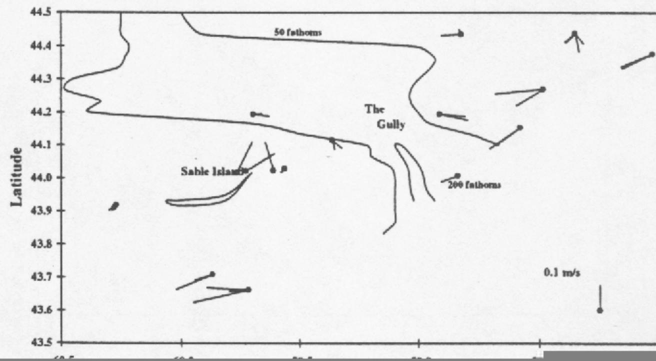
January Mean Currents



February Mean Currents



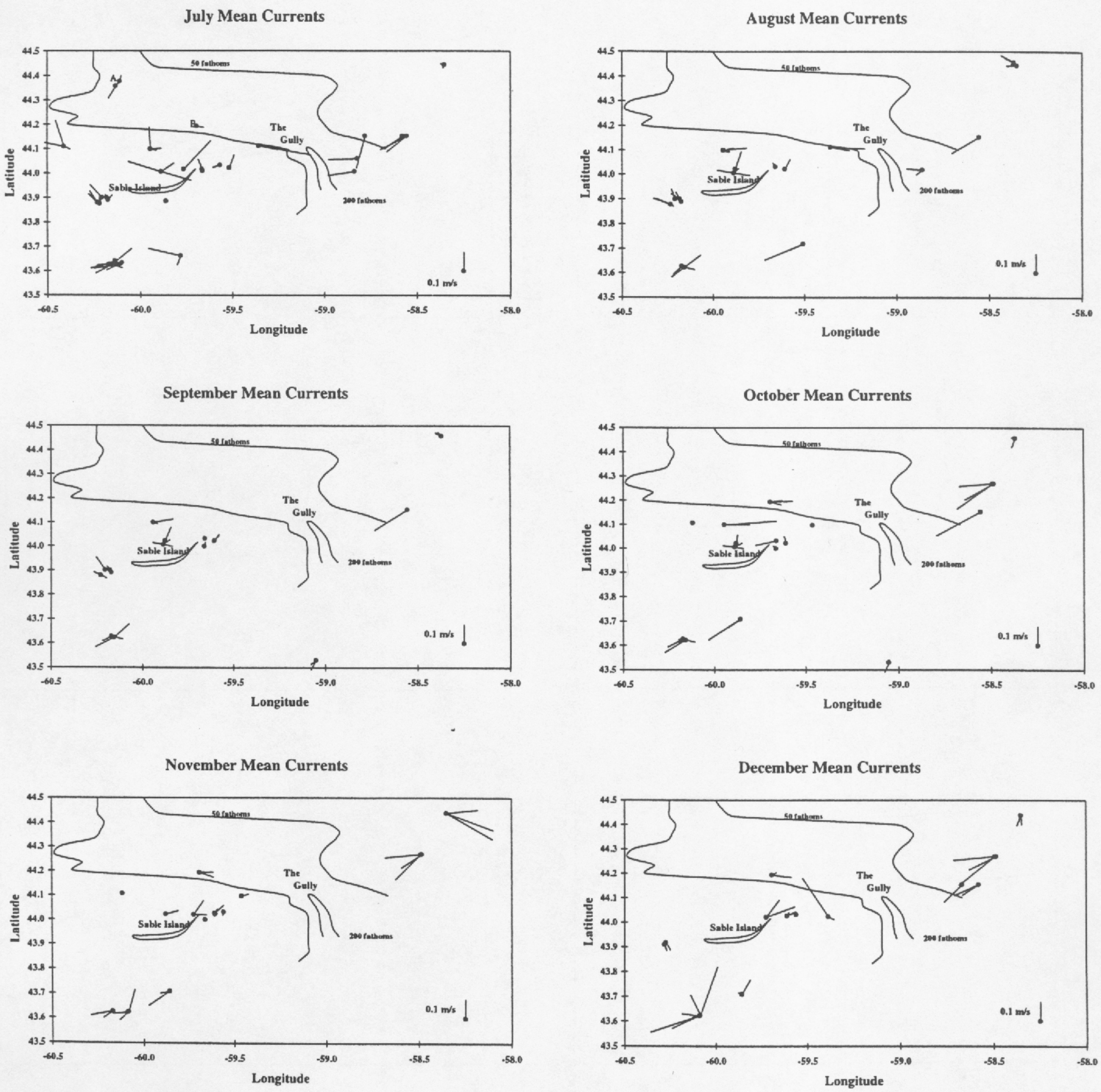


Fig. 6.1.1. (Continued)

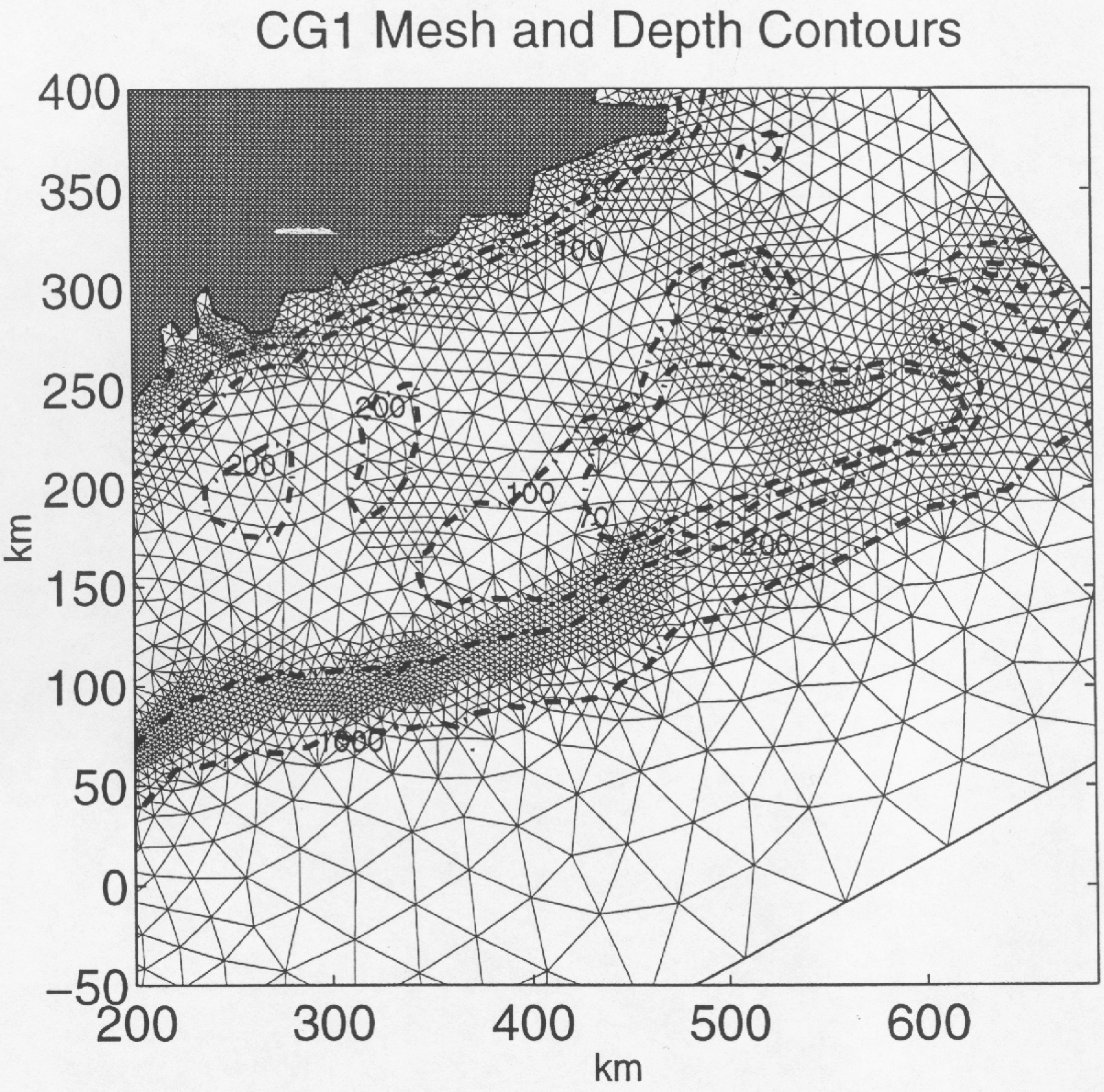


Fig. 6.1.2. Finite element model grid for the Eastern Scotian Shelf. The 100, 200 and 1000 m depth contours are shown.

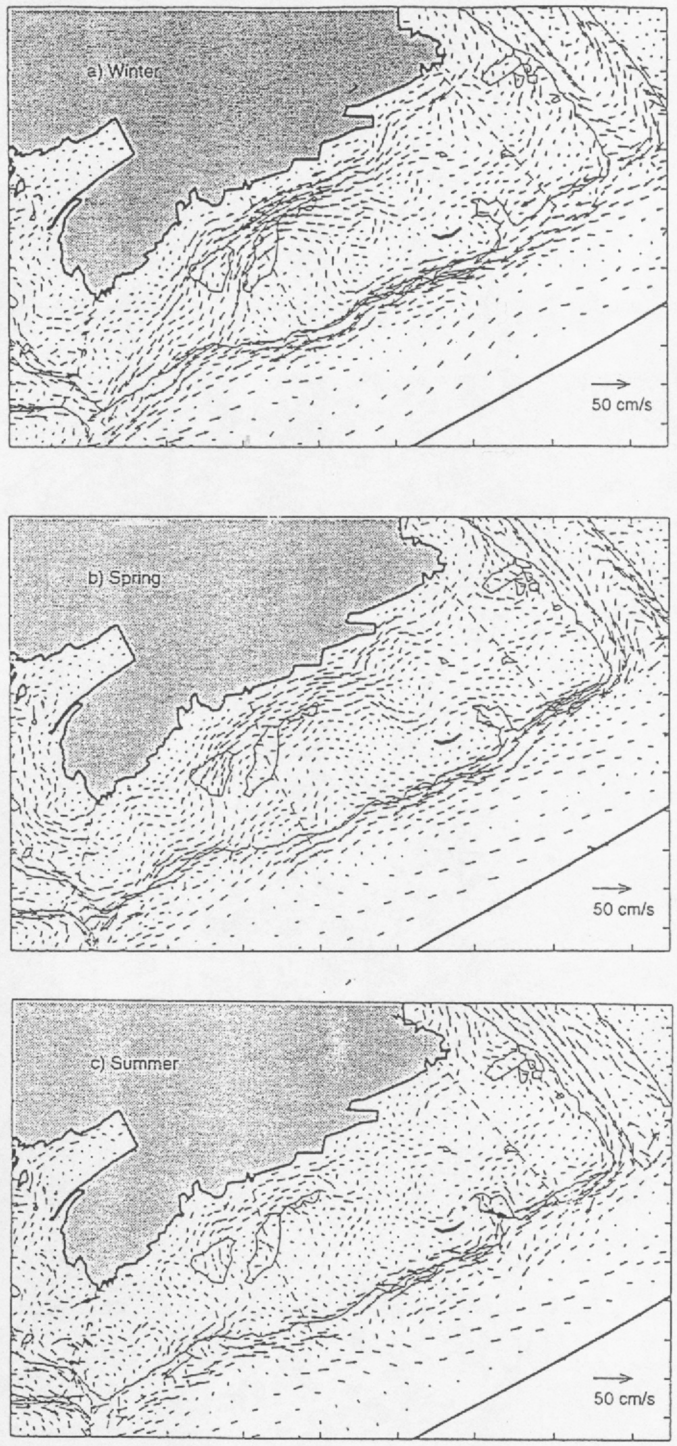


Fig. 6.1.3. Near-surface (averages between 5 and 25 m of the surface) mean currents for (a) winter, (b) spring, and (c) summer from model simulations with full forcing (From Han et al. 1996).

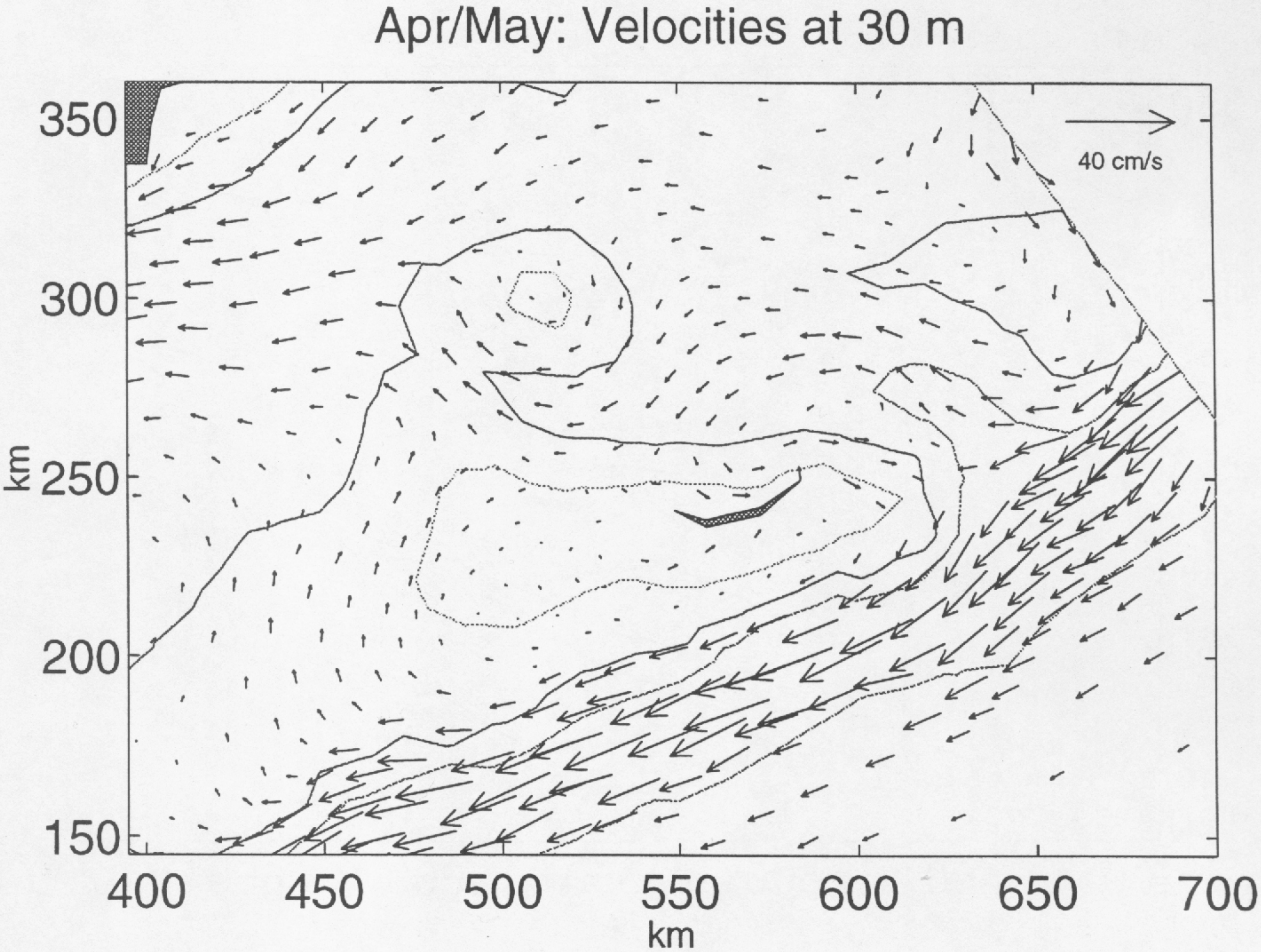


Fig. 6.1.4. Spring circulation at 30 m for the Gully region from Bedford Institute of Oceanography prognostic model.

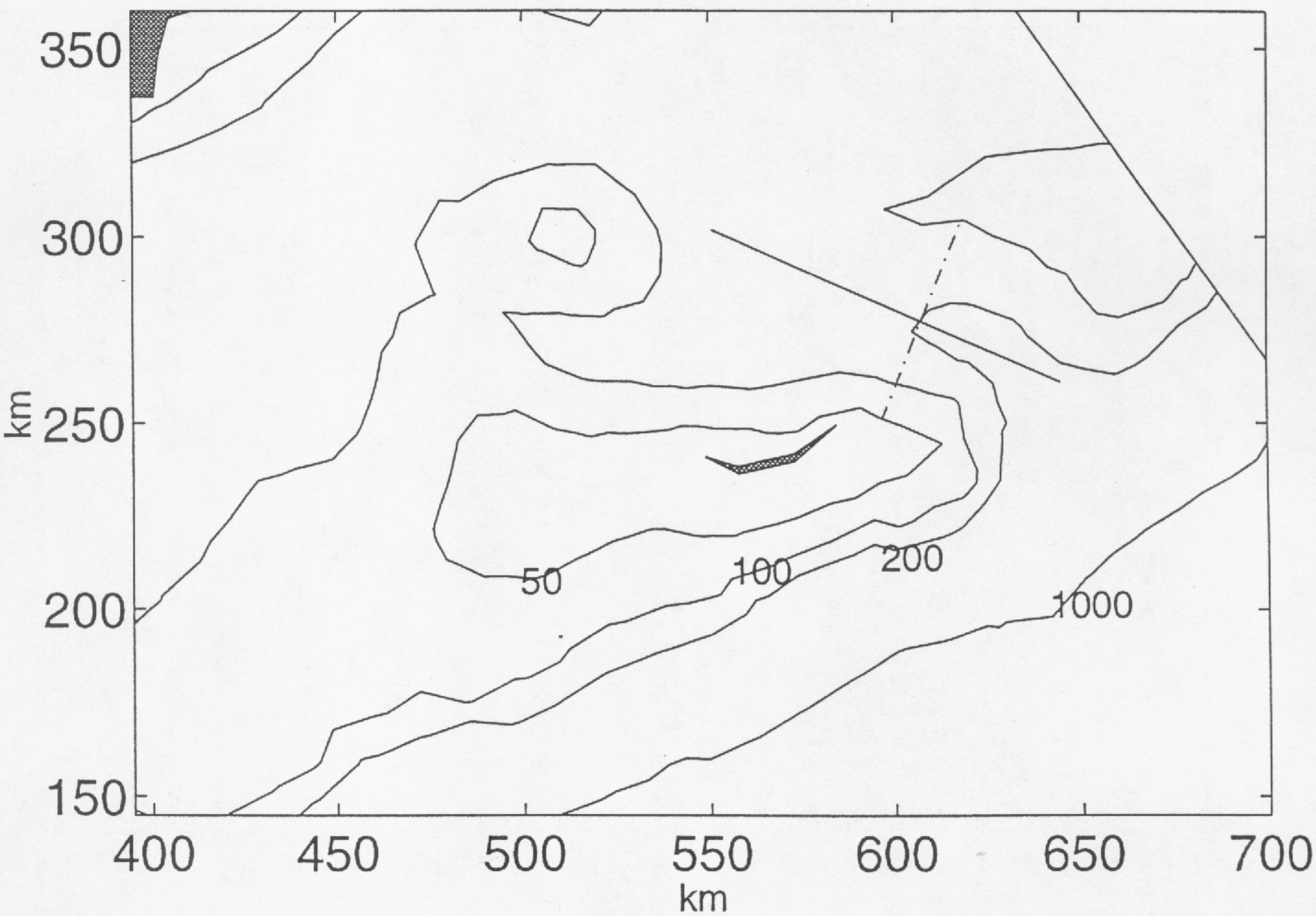


Fig. 6.1.5a. Location of density and current transects along (solid line) and across (broken line) the Gully.

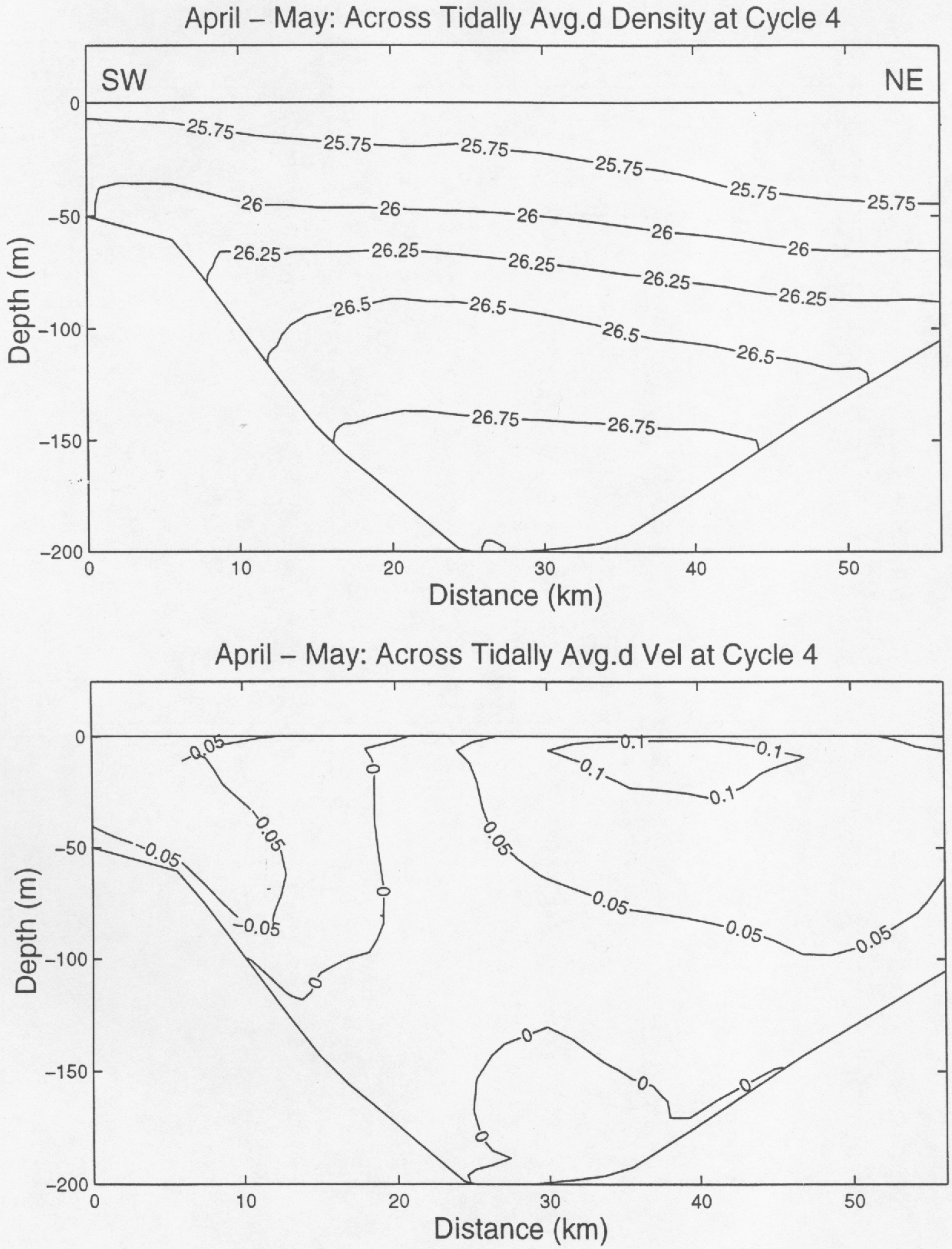


Fig. 6.1.5b. Prognostic calculation of the density and current distributions across the Gully averaged over the fourth M2 tidal cycle. Positive velocities are directed into the page.

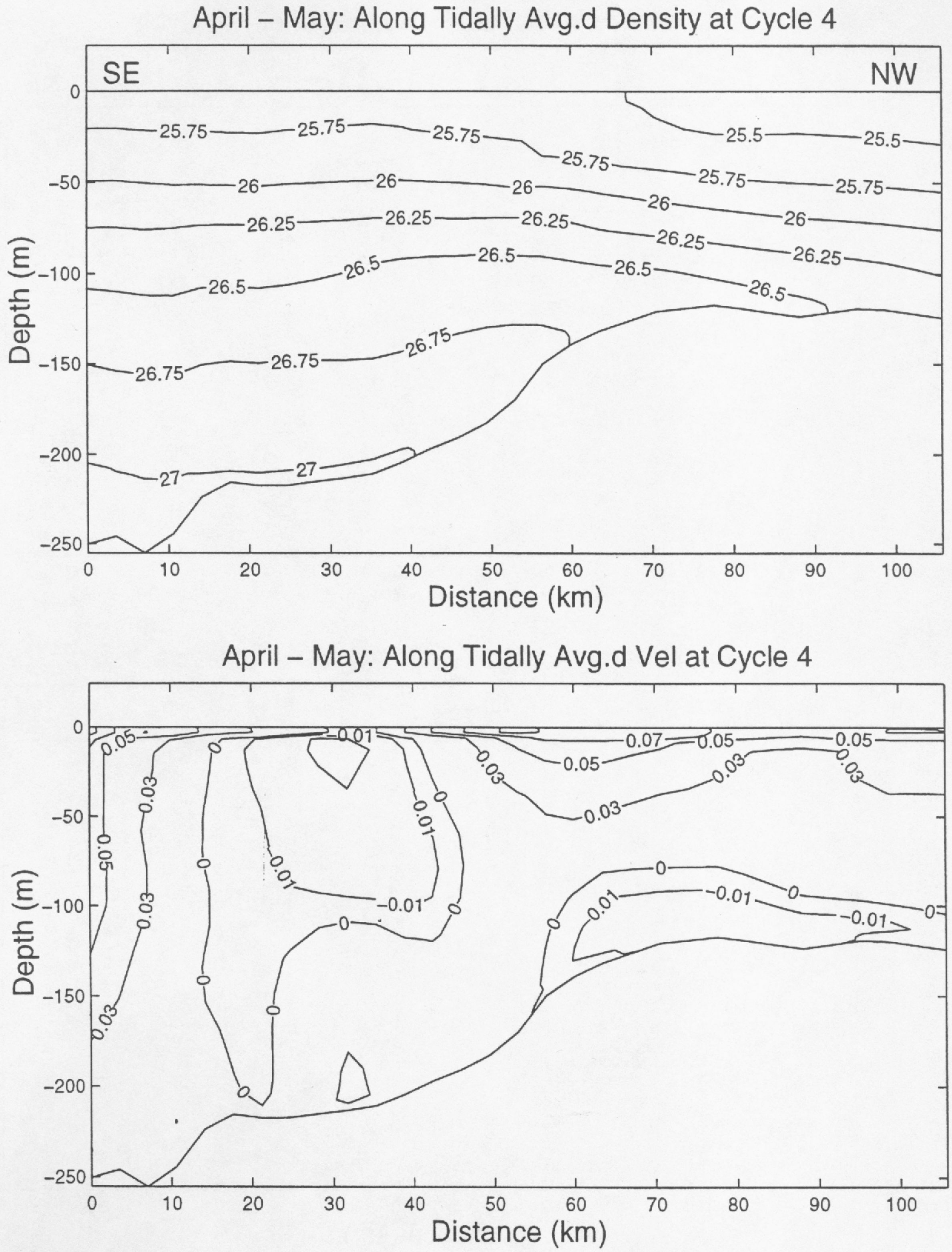


Fig. 6.1.5c. Prognostic calculation of the density and current distributions along the Gully averaged over the fourth M_2 tidal cycle. Positive velocities are directed into the page.

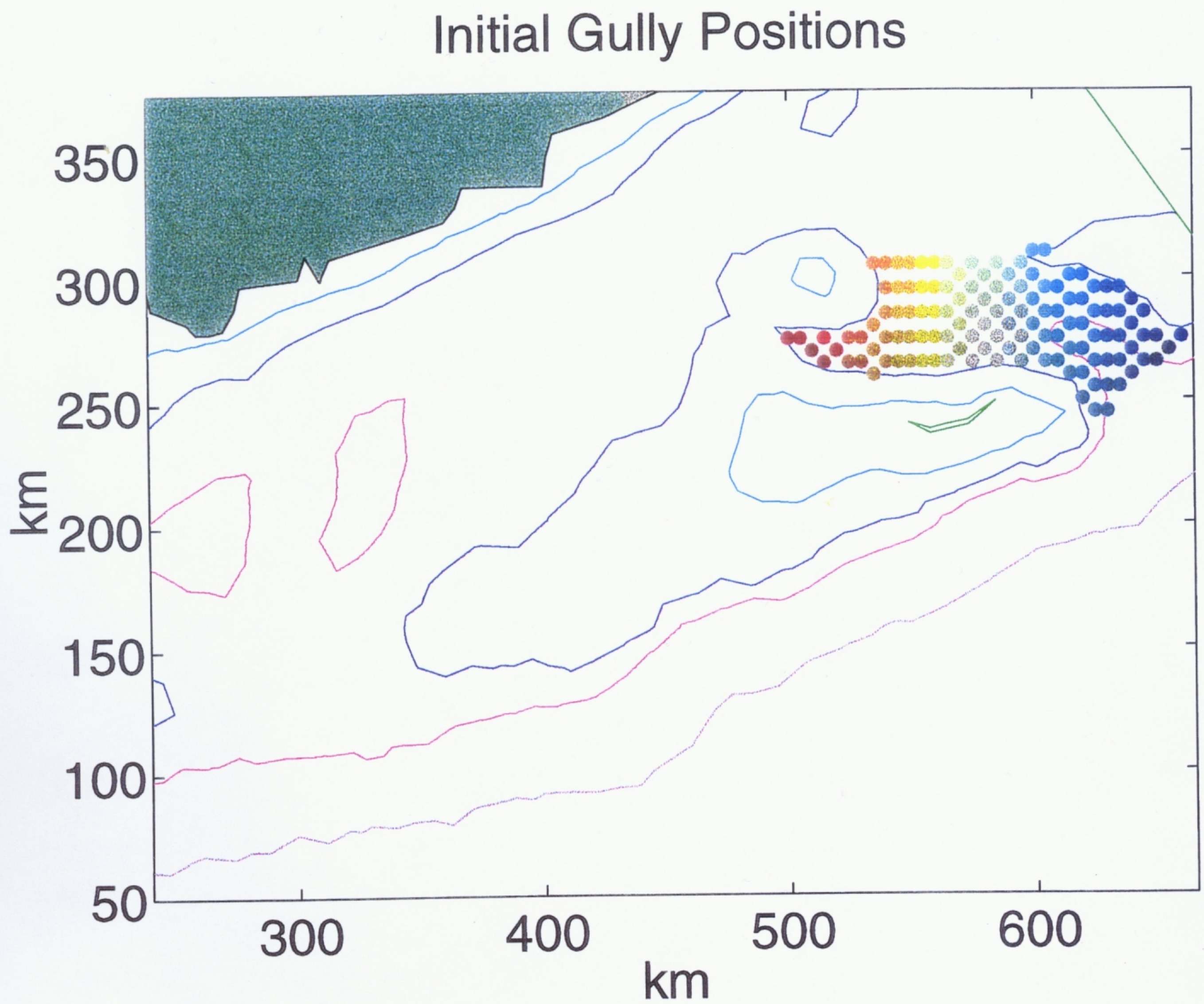


Fig. 6.1.6a. Initial distribution of particles in the Gully.

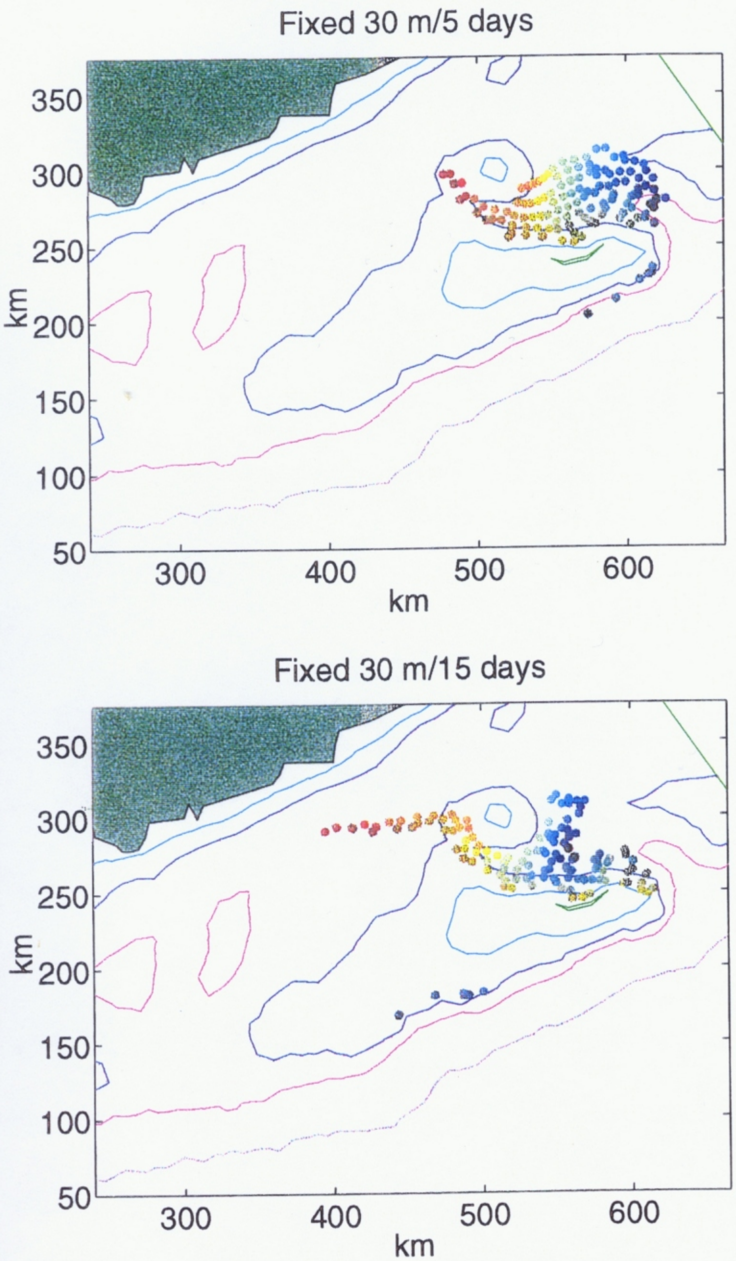


Fig. 6.1.6b. Particle positions every 5 days for days 5 to 20 at the fixed depth of 30 m.

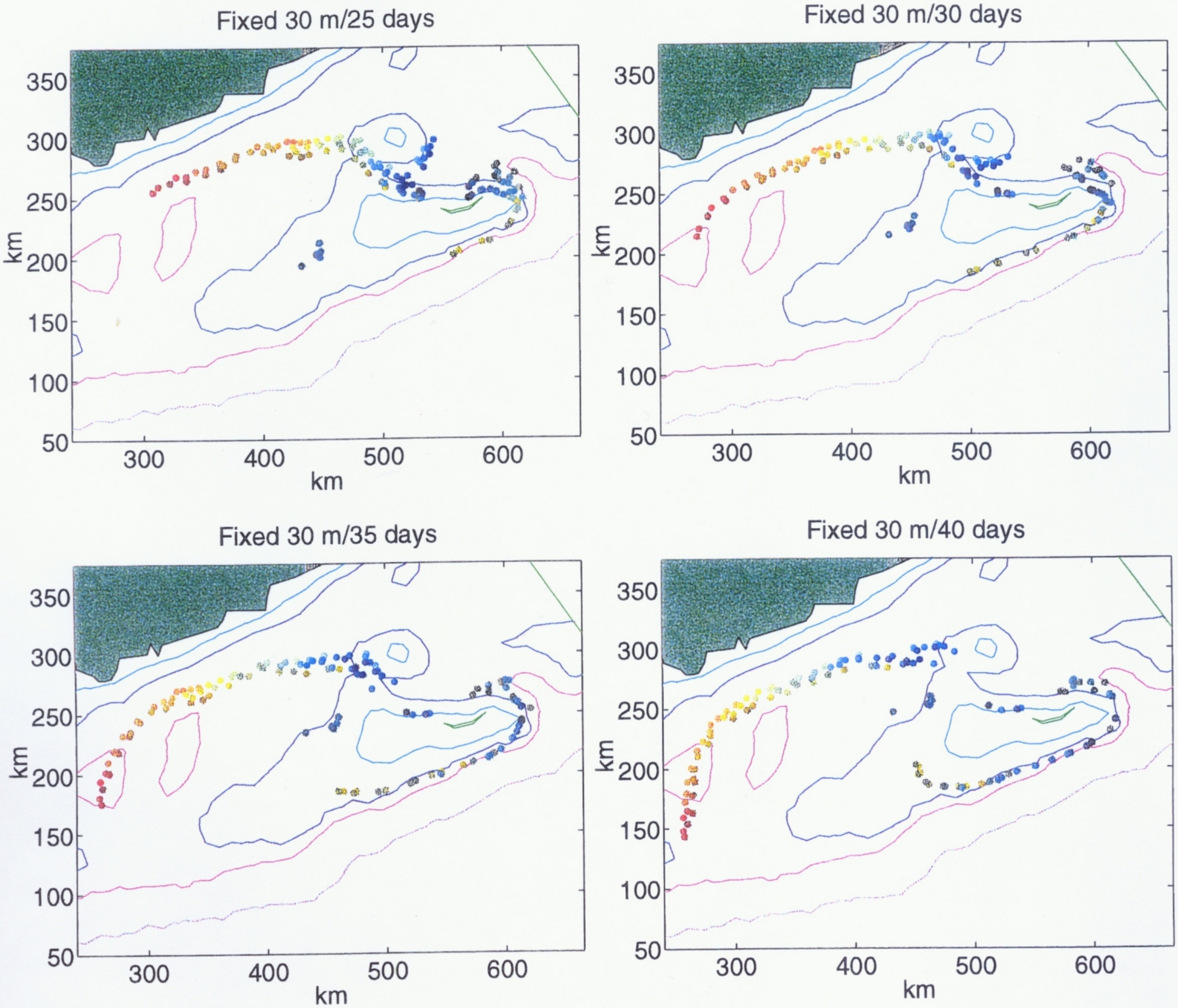


Fig. 6.1.6c. Particle positions every 5 days for days 25 to 40 at the fixed depth of 30 m.

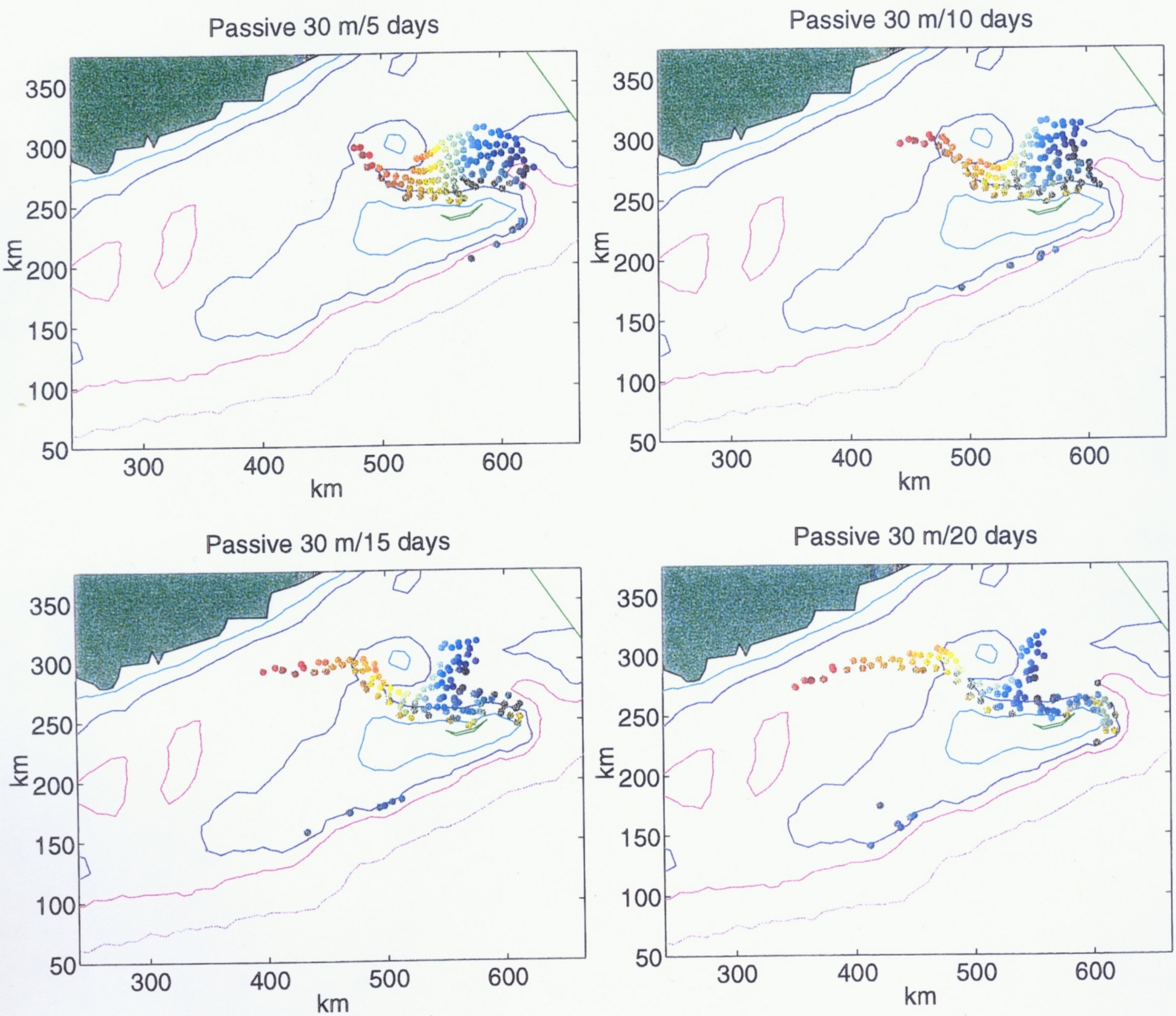


Fig. 6.1.6d. Particle positions every 5 days for days 5 to 20 when allowed to adjust to vertical velocities. Initial depth of particles was 30 m.

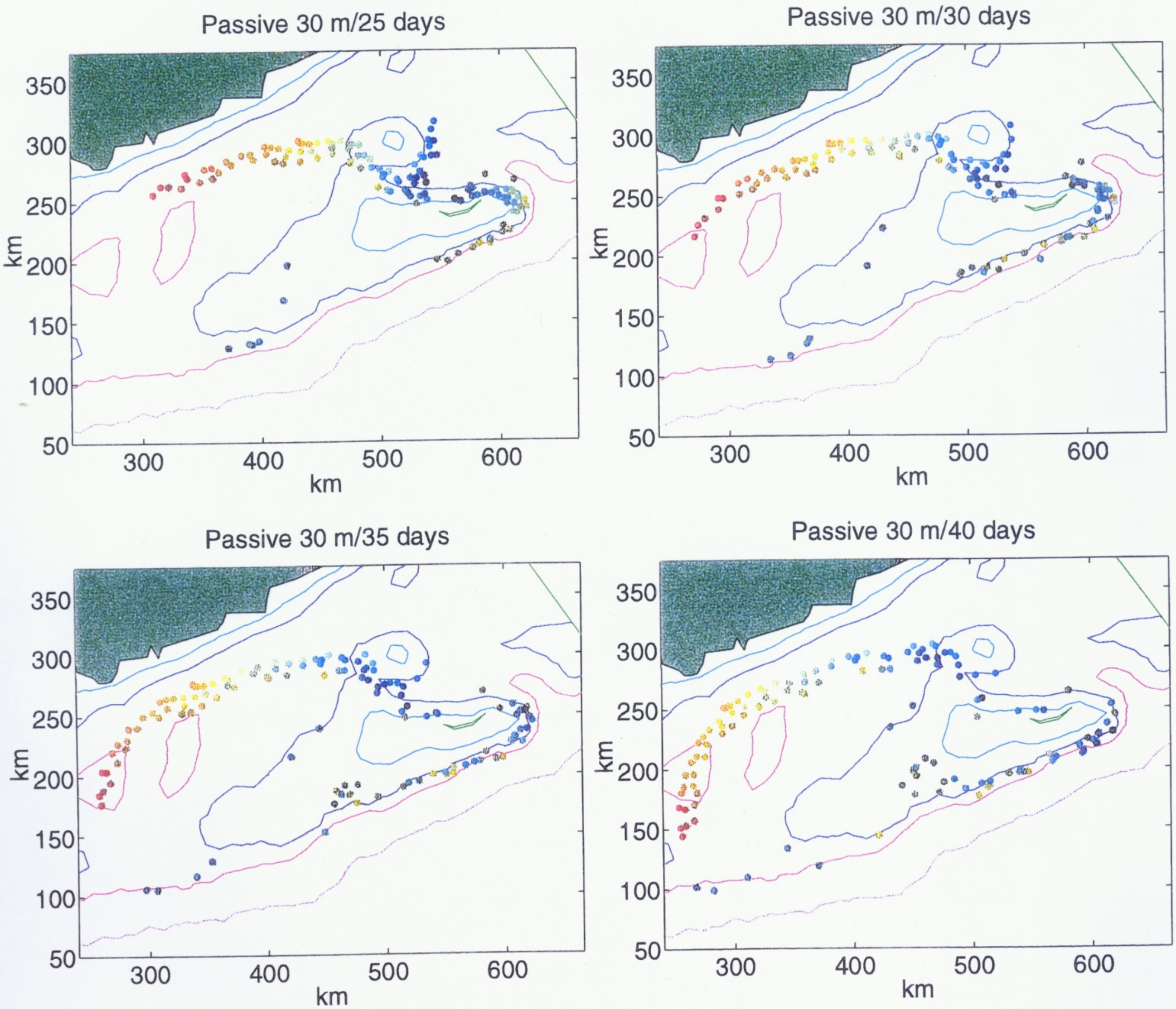


Fig.6.1.6e. Particle positions every 5 days for days 25 to 40 when allowed to adjust to vertical velocities. Initial depth of particles was 30 m.

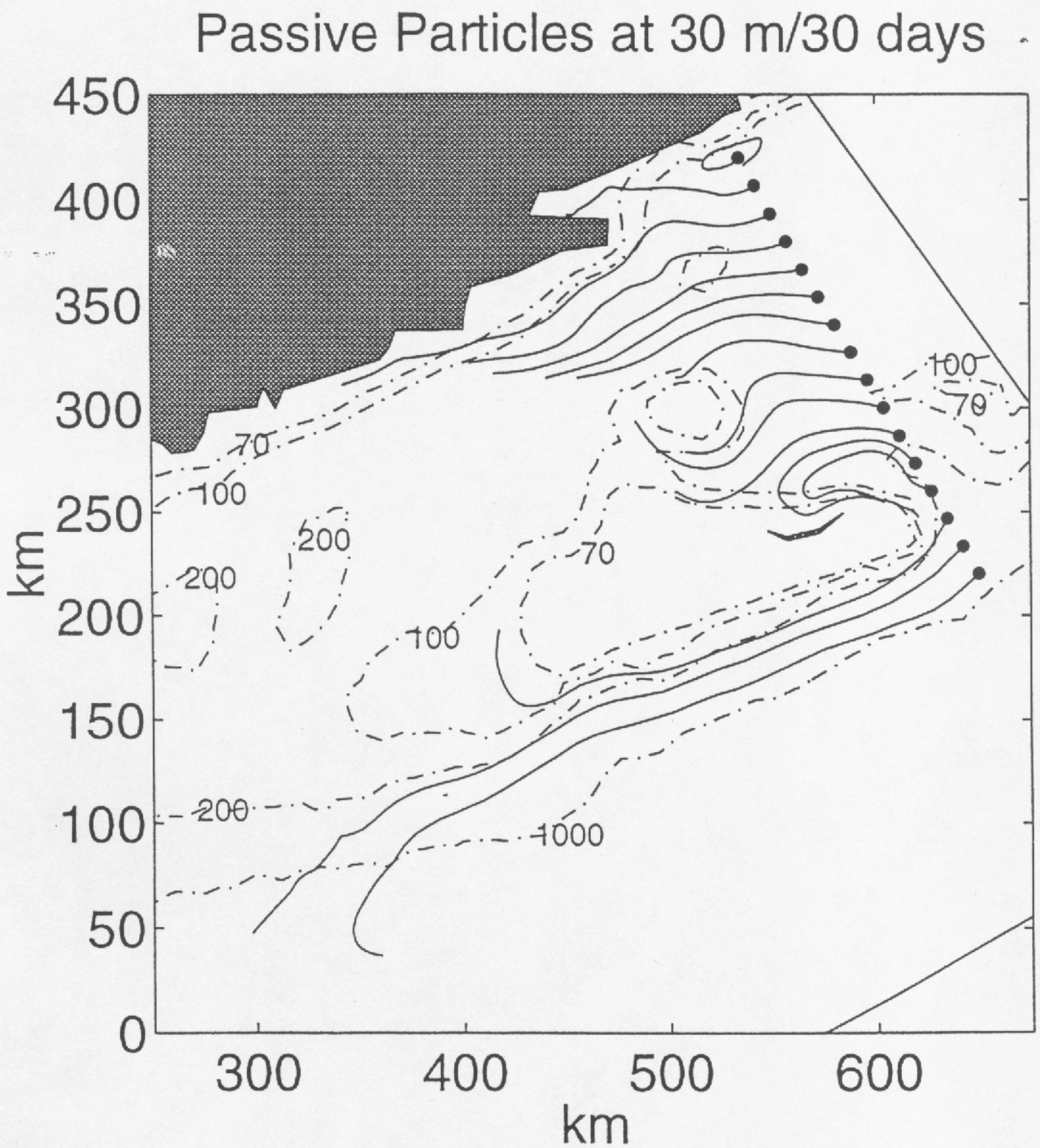


Fig. 6.1.7. **Paths of a line of particles placed initially at 30 m depth across the shelf and allowed to drift for 30 days. The particles could respond to vertical velocities.**

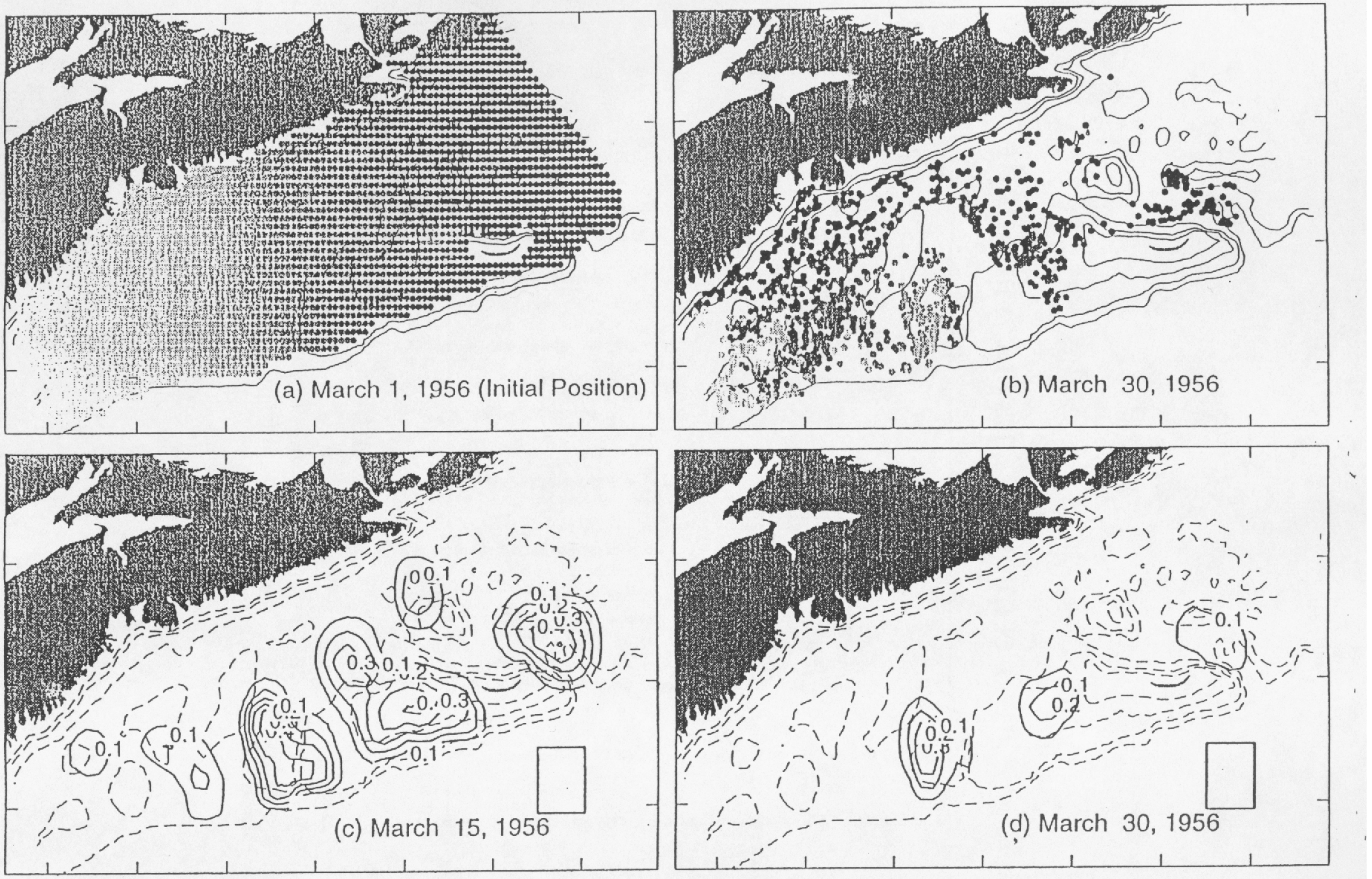


Fig. 6.1.8. (a) Initial positions of particles shaded with different intensities in gray to indicate starting positions; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of a given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days. From Cong et al. (1996).