# A New Two-Way Nested-Grid Ocean Modelling Technique Applied to the Scotian Shelf and Slope

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Circulation, semi-prognostic method, two-way nesting, three-dimensional model, one-way nesting, Scotian Shelf, Slope Water.

# A New Two-Way Nested-Grid Ocean Modelling Technique Applied to the Scotian Shelf and Slope

Xiaoming Zhai[1], Jinyu Sheng[1], and Richard Greatbatch[1]

**Abstract**

A nested-grid ocean circulation model is developed for the Scotian Shelf and adjacent slope. The nested model consists of a fine-resolution inner model embedded inside a coarse-resolution outer model. The inner model covers the Scotian Shelf and slope, with a resolution of approximate 7 km. The outer model is the northwest Atlantic Ocean model developed by Sheng et al. (2001), with a horizontal resolution of approximate 25 km. The unique feature of the nested-grid model is its use of the semi-prognostic method to exchange information between the two different grids. The nested-grid ocean model is forced by the monthly mean COADS (Comprehensive Ocean-Atmosphere Data Set) wind stress and surface heat flux. The model sea surface salinity is restored to the monthly mean climatology. The nested-grid model is integrated for two years and the model results in the second year are presented in this paper. The inner model produces not only large-scale circulation features which are consistent with observations and those produced by the outer model, but also more meso-scale features than those in the outer model.

**Introduction**

The Scotian Shelf (SS) and adjacent Slope Water (SW) are bounded by the Laurentian Channel to the east, the Northeast Channel to the west, and deep waters to the south (Figure 1). The Scotian Shelf is about 700 km long and 200 km wide, with an average depth of approximate 90 m. The bottom topography is characterized by deep basins and marginal troughs of greater than 150 m depth over the inner shelf and long chains of shallow banks over the outer shelf. The offshore banks on the SS form a natural barrier to exchange between oceanic and coastal waters. Water

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mass distributions on the SS are affected primarily by seasonally varying air-sea heat and freshwater fluxes, the Cabot Strait outflow from the Gulf of St. Lawrence, and the shelf-break current that is the continuation of the Labrador Current from the Newfoundland Shelf. The Gulf Stream also influences the Scotian Shelf indirectly via Slope Water and transient rings. In addition, the SS and SW are frequently affected by storms, especially during the winter months. It follows that the ocean circulation and temperature/salinity distributions on the SS and SW have significant spatial and temporal variability at various time and length scales.

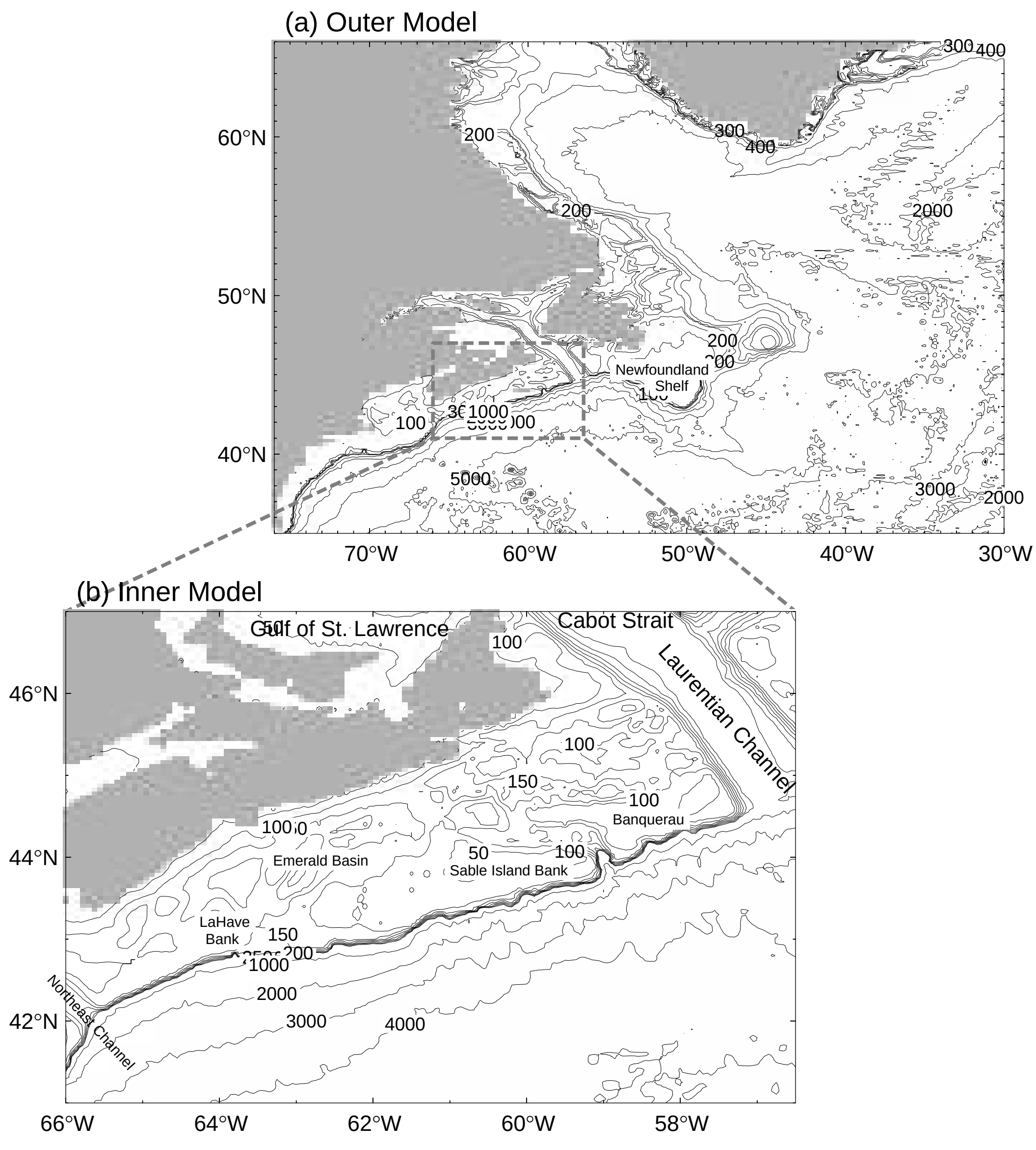


Figure 1: Bathymetric features within (a) the outer model domain of the northwest Atlantic Ocean, and (b) the inner model domain of the Scotian Shelf and Slope Water.

Ocean circulation models are useful tools for understanding and eventually predicting circulation over the shelf seas. Significant effort has been made over the last twenty years in developing numerical shelf circulation models for the SS and SW, ranging from two-dimensional barotropic models to sophisticated three-dimensional models (Greenberg, 1983; Wright et al., 1986; Hannah et al., 1996; Han et al., 1997; Thompson and Sheng, 1997; Sheng et al., 2001). Most of these models have a regional shelf domain with a specification of the transport and water mass distribution at the model open boundaries. Since the physical processes affecting circulation on the SS and SW operate over a wide range of temporal and spatial scales, to fully resolve all these different scales using a single-grid model is a formidable task. For any single-grid numerical model, one is usually faced with a choice between a large-scale simulation at a relatively coarse resolution, or a limited-area simulation with a very high resolution in which a prior knowledge is required for physical processes at work along the model open boundaries (Ginis et al., 1998). Furthermore, in limited-area simulations, the large-scale circulation features must be specified, and interactions between the large and small scales are prohibited.

The main advantage of a nested-grid model is that it allows the large-scale flow over a large domain to be simulated by a coarse resolution model, while circulation over a small domain is simulated at a higher resolution by a submodel that has essentially the same physics and numerical structure as the coarse-resolution model. The two-way interaction between two different model grids can be achieved in many ways. A fairly common nesting technique is to exchange information between the two grids in a narrow zone (dynamic interface) near the grid interface (e.g., Kurihara et al., 1979). The coarse grid model variables, such as velocity, temperature, salinity and associated fluxes, are interpolated at the dynamic interface onto the fine grid to provides the time-dependent boundary conditions for the fine-grid model. The fine-grid model variables are interpolated back onto the coarse grid to update the coincident coarse-grid values in the narrow zone. The main difficulty of this nesting scheme is a compatibility problem (e.g., mass conservation) at the grid interface (Ginis et al., 1998). Furthermore, there is undesirable numerical noise resulting from the change of the grid resolution at the grid interface and additional damping is required (Fox and Maskell, 1995). It should be noted that the dynamic interface of this nesting scheme can be considered as an internal boundary of the coarse-grid model, and the coarse-grid integration is not necessary over the subregion covered by the fine-grid domain.

An alternative nesting technique developed by Oey and Chen (1992) is to embed a fine grid (inner model) inside a coarse grid (outer model) and use the inner model variables to replace the outer model variables over the subregion where the two grids overlap. In comparison with other schemes, Oey and Chen's nesting scheme has the advantage of allowing a two-way interaction not only at the grid interface but also directly inside the common subregion where the two grids overlap. In this study, we follow Oey and Chen (1992) and embed a fine-grid model inside a coarse-grid model. Different from Oey and Chen's nesting technique, we use the semi-prognostic method (Sheng et al., 2001; Eden et al., 2004; Greatbatch et al., 2004) to exchange information between the two grids over the common subregion. (A detailed discussion of the new nesting technique can be found in Sheng et al. (2004).) The main objective of this study is to demonstrate the advantage of the new nesting technique in simulating the mean and seasonal circulation and temperature/salinity distributions on the Scotian Shelf and adjacent Slope Water.

The arrangement of this paper is as follows. The next section briefly reviews the ocean circulation model. This is followed by a presentation of the new two-way nesting technique based on the semi-prognostic method. We discuss the nested grid model results and compare them with results produced by other nesting techniques. The final section is a summary and conclusion.

## Ocean Circulation Model

The ocean circulation model used in this study is the three-dimensional primitive equation z-level model known as CANDIE (Sheng et al., 1998). This model has been successfully used to study various physical processes on the shelf, including wind-driven circulation over an idealized coastal canyon (Sheng et al., 1998), nonlinear dynamics of a density-driven coastal current (Sheng, 2001), tidal circulation in the Gulf of St. Lawrence (Lu et al., 2001) and wind-driven circulation over a stratified coastal embayment (Davidson et al., 2001). Most recently, CANDIE has been applied to the western Caribbean Sea by Sheng and Tang (2003). The governing equations of the model can be written in spherical coordinates as

$$\frac{\partial u}{\partial t} + \mathcal{L}u - \left(f + \frac{u\tan\phi}{R}\right)v = -\frac{1}{\rho_o R\cos\phi}\frac{\partial p}{\partial\lambda} + \mathcal{D}_m u + \frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right), \quad (1)$$

$$\frac{\partial v}{\partial t} + \mathcal{L}v + \left(f + \frac{u\tan\phi}{R}\right)u = -\frac{1}{\rho_o R}\frac{\partial p}{\partial\phi} + \mathcal{D}_m v + \frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right), \quad (2)$$

$$\frac{1}{R\cos\phi}\left(\frac{\partial u}{\partial\lambda} + \frac{\partial(v\cos\phi)}{\partial\phi}\right) = -\frac{\partial w}{\partial z}, \quad (3)$$

$$\frac{\partial p}{\partial z} = -\rho g, \quad (4)$$

$$\frac{\partial T}{\partial t} + \mathcal{L}T = \mathcal{D}_h T + \frac{\partial}{\partial z}\left(K_h\frac{\partial T}{\partial z}\right), \quad (5)$$

$$\frac{\partial S}{\partial t} + \mathcal{L}S = \mathcal{D}_h S + \frac{\partial}{\partial z}\left(K_h\frac{\partial S}{\partial z}\right) \quad (6)$$

where $u, v$ and $w$ are the east ($\lambda$), north ($\phi$) and vertical ($z$) components of the velocity vector $\vec{u}$, $p$ is pressure (see below), and $\rho$ is the density. Here $K_m$ and $K_h$

are vertical eddy viscosity and diffusivity coefficients, $f$ is the Coriolis parameter, $\rho_o$ is a reference density, $R$ and $g$ are the Earth's radius and gravitational acceleration, $\mathcal{L}$ is an advection operator defined as

$$\mathcal{L}q = \frac{1}{R\cos\phi}\frac{\partial(uq)}{\partial\lambda} + \frac{1}{R\cos\phi}\frac{\partial(vq\cos\phi)}{\partial\phi} + \frac{\partial(wq)}{\partial z} \tag{7}$$

and $\mathcal{D}_m$ and $\mathcal{D}_h$ are diffusion operators defined as

$$\mathcal{D}_{(m,h)}q = \frac{1}{R^2}\left[\frac{1}{\cos^2\phi}\frac{\partial}{\partial\lambda}\left(A_{(m,h)}\frac{\partial q}{\partial\lambda}\right) + \frac{\partial q}{\partial\phi}\left(\cos\phi A_{(m,h)}\frac{\partial q}{\partial\phi}\right)\right] \tag{8}$$

where $A_m$ and $A_h$ are horizontal eddy viscosity and diffusivity coefficients, respectively. The model uses the subgrid-scale mixing parameterization of Smagorinsky (1963) for the horizontal eddy viscosity ($A_m$) and diffusivity ($A_h$), and the schemes proposed by Large et al. (1994) for the vertical mixing coefficients $K_m$ and $K_h$.

As mentioned in the introduction, the nested-grid modelling system has a fine-resolution inner model embedded inside a coarse-resolution outer model (Figure 1). The fine-resolution inner model covers the Scotian Shelf and slope between 54°W and 66°W and between 39°N and 47°N, with a horizontal resolution of one eleventh degree in longitude (about 7 km). The coarse-resolution outer model is the northwest Atlantic Ocean model developed by Sheng et al. (2001) which covers the areas between 30°W and 76°W and between 35°N and 66°N, with a horizontal resolution of one third degree in longitude (about 25 km). There are 31 unevenly spaced z levels in both the outer and inner models with the centers of each level located at 5, 16, 29, 44, 61, 80, 102, 128, 157, 191, 229, 273, 324, 383, 450, 527, 615, 717, 833, 967, 1121, 1297, 1500, 1733, 2000, 2307, 2659, 3063, 3528, 4061, and 4673 m, respectively. Both the outer and inner models are initialized with the January mean temperature and salinity and forced by the monthly mean COADS (Comprehensive Ocean-Atmosphere Data Set) wind stress and surface heat flux. The model sea surface salinity is restored to the monthly mean climatology at every time step. In addition, at the inner model open boundaries, the temperature and salinity fields are first radiated from the inner model using an explicit Orlanski radiation condition (Orlanski, 1976) and then restored to the outer model values at each z-level with the time scale of 2 days.

## A New Nesting Technique Based on the Semi-Prognostic Method

The semi-prognostic method was introduced originally by Sheng et al. (2001), for the purpose of adjusting model momentum equations to correct for model systematic errors (see Greatbatch et al., 2004 for an overview). The adjustment is accomplished by replacing the density variable $\rho$ in the hydrostatic equation (4) by a linear combination of the model-computed density $\rho_m$ and an input density $\rho_c$:

$$\rho = \alpha\rho_m + (1-\alpha)\rho_c \equiv \rho_m + (1-\alpha)(\rho_c - \rho_m) \tag{9}$$

where $\rho_m = \rho(T, S, p_{ref})$ is the density calculated from the model potential temperature $T$ and salinity $S$ described in (5) and (6), and $p_{ref}$ is the reference pressure at the center of each z level, and $\alpha$ is the linear combination coefficient with a value between 0 and 1. In Sheng et al. (2001), the input density $\rho_c$ is computed from a climatology of hydrographic data, but it might also be density from another model, as in the nesting technique to be described. Using (9), the hydrostatic equation can be rewritten as:

$$\frac{\partial p}{\partial z} = -g\rho_m - g(1-\alpha)(\rho_c - \rho_m), \tag{10}$$

where the second term on the RHS of (10) is the correction term used to correct for model systematic error and unresolved processes. As stated in Sheng et al. (2001), the above procedure is equivalent to adding a forcing term to the horizontal momentum equations. To demonstrate this, we decompose the model pressure variable $p$ into two terms:

$$p = p^* + \hat{p} \tag{11}$$

where $p^*$ is the traditional pressure variable satisfying

$$\frac{\partial p^*}{\partial z} = -g\rho_m \tag{12}$$

with $p^* = g\rho_0\eta$ at the sea surface, and $\hat{p}$ is a correction term satisfying

$$\frac{\partial \hat{p}}{\partial z} = -g(1-\alpha)(\rho_c - \rho_m) \tag{13}$$

with $\hat{p} = 0$ at the sea surface. Using (11), the horizontal momentum equations can be rewritten as:

$$\frac{\partial \vec{u}}{\partial t} = -\frac{1}{\rho_o}\nabla_h p^* - \frac{1}{\rho_o}\nabla_h \hat{p} + \ldots \tag{14}$$

where $\vec{u}$ is the horizontal velocity vector and $\nabla_h$ is the horizontal Laplacian operator. Therefore, the semi-prognostic method is equivalent to adding a forcing term $(-\frac{1}{\rho_o}\nabla_h \hat{p}\ )$ to the model horizontal momentum equations. It is important to note that the semi-prognostic method is adiabatic, leaving the temperature and salinity equations unchanged, i.e. as in (5) and (6) (Greatbatch et al., 2004).

The original semi-prognostic method (OSP hereinafter) introduced by Sheng et al. has drawbacks of damping the mesoscale eddy field and reducing wave propagation speeds. Eden et al. (2004) recently introduced the smoothed semi-prognostic method (SSP hereinafter) by applying the correction term only on large spatial scales:

$$\frac{\partial p}{\partial z} = -g\rho_m - g(1-\alpha) < \rho_c - \rho_m > \tag{15}$$

where <> represents spatial averaging. Eden et al. (2004) demonstrated that the SSP method effectively reduces the damping effect of the OSP method on the mesoscale eddy field.

In this study, we use a new two-way nesting technique based on the smoothed semi-prognostic method (referred to as the SSP nesting technique; Sheng et al., 2004). First, the outer model variables are interpolated onto the fine grid. The interpolated fields are then used to provide boundary conditions for the inner model. Second, the outer model density is used to adjust the inner model in the region where the domains of the two models overlap based on

$$\frac{\partial p}{\partial z} = -g\rho_{inner} - g(1-\beta_i) < \hat{\rho}_{outer} - \rho_{inner} > \quad \text{(for the inner model)} \tag{16}$$

where $p$ is the pressure variable carried by the inner model, $\rho_{inner}$ is the inner model density, $\hat{\rho}_{outer}$ is the density computed from the outer model $T$ and $S$ fields after interpolation to the fine grid, and $\beta_i$ is a linear combination coefficient with a value between 0 and 1, and $<>$ is the smoothing operator (for the results shown here, the correction term is smoothed over 16 grid points; that is, 112 km).

In the same way, the inner model density is used to adjust the outer model in the overlapping subregion based on

$$\frac{\partial p}{\partial z} = -g\rho_{outer} - g(1-\beta_o) < \hat{\rho}_{inner} - \rho_{outer} > \quad \text{(for the outer model)} \tag{17}$$

where $p$ is the pressure variable of the outer model, $\hat{\rho}_{inner}$ is the density calculated from the inner model $T$ and $S$ fields after interpolation to the coarse grid, and $\beta_o$ is a linear combination coefficient with a value between 0 and 1, and $<>$ is a smoothing operator (usually different from that used in (16)). For the present application, this second smoothing operation is not applied. (A complication in the present application is that the outer model is also being corrected using climatological data. Details of how to apply these two corrections simultaneously are given in Sheng et al. (2004).)

The above two-way interaction can be applied at each outer model time step. However, since the present nested-grid model is driven by monthly forcings, it is sufficient for the correction term to be updated once per day. Also, for simplicity, $\beta_i$ and $\beta_o$ are set to be 0.5.

It should be noted that Sheng and Tang (2004) used the original semi-prognostic method in the development of a two-way nested-grid model for the Meso-American Barrier Reef System of the Caribbean Sea. Their nesting technique (referred as to the OSP nesting technique) differs from the above SSP technique only in that the correction terms used to exchange information between the two grids are not spatially smoothed. We show a comparison between the SSP and OSP methods below. We also compare the SSP method with what we call "conventional one-way" nesting (COW for short). In the COW method, the boundary conditions for the inner model are taken from the outer model exactly as in the SSP method. The difference is that the inner model only knows about the outer model through the boundary conditions. In particular, there is no transfer of information into the interior of the inner model domain, and there is also no transfer of information back from the inner model to the outer model.

## Model Results

The ocean circulation models are integrated for two years. The model results in the second year are used to calculate the annual mean volume transport streamfunctions over the outer and inner model domains, respectively, for the SSP and COW methods (Figure 2). Since there is no influence from the inner to the outer model in the COW case, the field shown for the outer model in Figure 2d is the same as that in Sheng et al. (2001). In the SSP case, the annual mean streamfunctions produced by inner and outer models are very similar over their common domain, and also very similar to the outer model when run on its own, without feedback from the inner model (see Figure 2d). The annual mean volume transport produced by the outer model is about 50 Sverdrup (Sv) for the subpolar circulation of the North Atlantic, 90 Sv for the Gulf Stream, and 10 Sv for the recirculation in the Slope Water region between the Scotian Shelf and the Gulf Stream, comparable to estimates found in diagnostic modelling studies and in observations (see Mellor et al., 1982; Greatbatch et al., 1991). Over the Slope Water region, offshore from the Scotian Shelf, the two-way nested-grid outer model produces a slightly stronger recirculation in comparison with Sheng et al. (2001) (Figures 2b,d), indicating the effect of the feedback from the inner model to the outer model in the two-way nested modelling system.

In the COW method, the inner model is constrained by the outer model only along the boundary of its domain, and the interior of the inner model domain is not constrained directly by the outer model. The result is that the inner model can drift away from the outer model, as is evident here. The one-way nested inner model generates an unrealistically large and broad eastward transport over the SW and adjacent deep water regions and fails to produce the widely recognized recirculation in the SW region (Figure 2c).

The model results in the second year are also used to calculate the annual mean near-surface currents at 16 m depth in the SSP, OSP and COW cases (Figure 3). Figure 3a, for the outer model, shows a southwestward coastal flow known as the Scotian Current over the coastal region, a narrow current known as the shelf break jet over the outer SS, and a narrow jet over the SW that first flows northeastward over the SW region off the southwestern SS and then turns eastward to the deep water off the southeastern SS. Further south of the SW, there is a strong and broad eastward flow as part of the Gulf stream. The nested-grid inner model using the SSP nesting technique reproduces the large-scale features of the near-surface currents produced by the outer model in the overlapping region (Figures 3a,b), but with much better resolution.

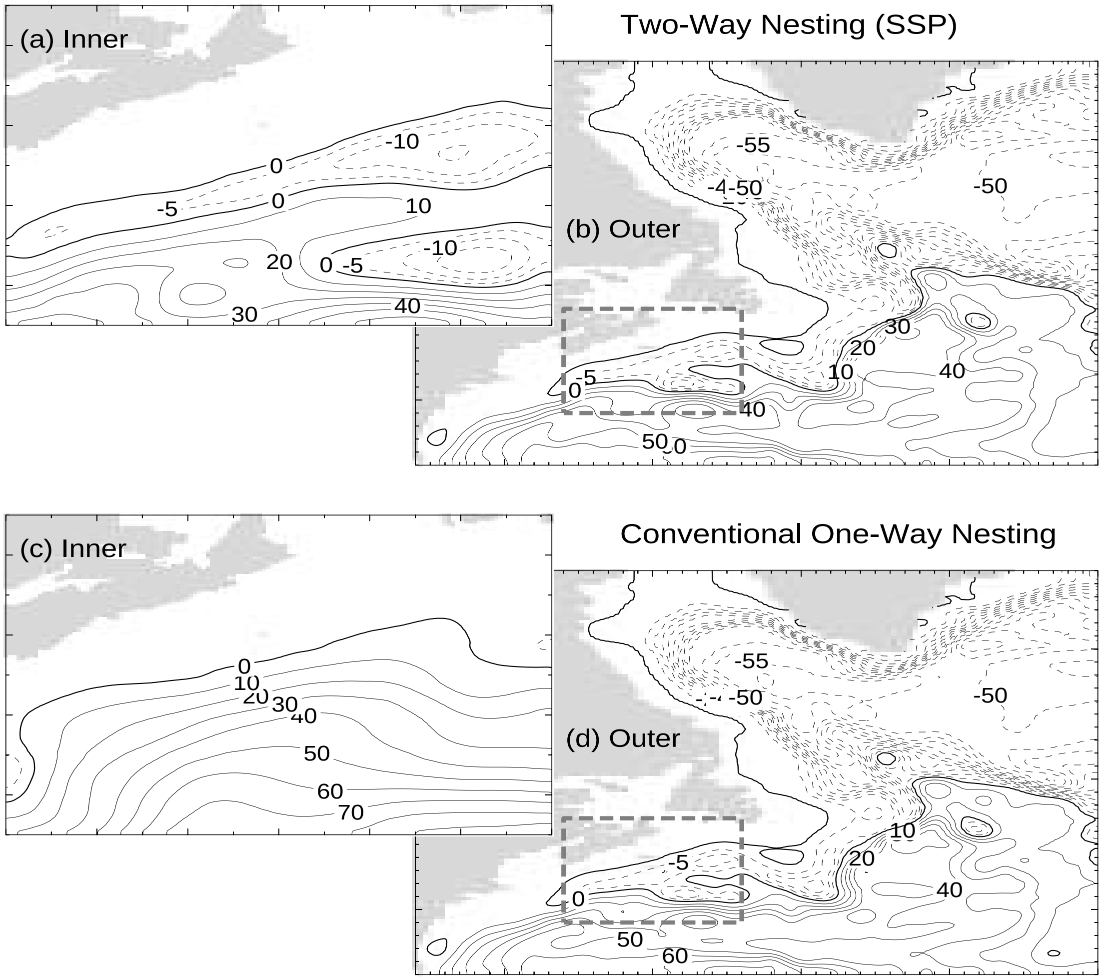


Figure 2: Annual mean volume transport streamfunctions computed from the second year model results produced by (a) the inner and (b) outer model of the two-way nested grid modelling system using the smoothed semi-prognostic nesting technique and by (c) the inner and (d) outer model using the conventional one-way nesting technique. The streamfunction shown in (d) is the same as that produced by the single-domain Northwest Atlantic Ocean model of Sheng et al. (2001). Contours are labeled in units of Sv (= $10^6$ $m^3$ $s^{-1}$).

To assess the performance of the nested-grid model, we compare the model calculated annual mean near-surface currents with the time mean currents inferred from the observed trajectories of near-surface drifters by Fratantoni (2001) over the SS and SW region. Overall, the model calculated currents in the SSP case agree with the observed currents (Figures 3a,b). To further quantify the misfit between the observed and model-calculated near-surface currents, we follow Sheng and Tang (2003)

Table 1: The $\gamma^2$-values that measure the misfit between the observed and the model simulated near-surface currents at 15 m in terms of different nesting techniques.

| Technique | $\gamma^2$ |
|---|---|
| Outer (SSP) | 0.73 |
| SSP | 0.62 |
| OSP | 0.65 |
| COW | 1.01 |

and define $\gamma^2$ as

$$\gamma^2 = \frac{\sum_k{}^N[({u_k}^o - {u_k}^s)^2 + ({v_k}^o - {v_k}^s)^2]}{\sum_k{}^N[({u_k}^o)^2 + ({v_k}^o)^2]} \tag{18}$$

where $({u_k}^o, {v_k}^o)$ are the horizontal components of the observed near-surface currents at the $k$th location estimated by Fratantoni (2001), $({u_k}^s, {v_k}^s)$ are the horizontal components of the simulated near-surface currents at the same location as the observations, and $N$ is the total number of locations where observed estimates are available. Clearly, the smaller $\gamma^2$, the better the model results fit the observations. For the two-way nested-grid modelling system using the SSP nesting technique, the value of $\gamma^2$ is about 0.73 for the outer model and 0.62 for the inner model (Table 1), indicating that the inner model performs better than the outer model in reproducing Fratantoni's observed currents.

The overall distributions of the annual mean near-surface currents produced by the inner model using the OSP technique agree with those produced by the inner model using the SSP technique, with some differences in the small-scale features (Figure 3c). The inner model using the OSP technique generates relatively weaker southwestward currents over the western Scotian Shelf and relatively weaker eastward currents in the deep water off the SW region, in comparison with those using the SSP technique (Figures 3b,c). The inner model using the OSP nesting technique also reproduces Fratantoni's time-mean observed currents in the SS and SW region reasonably well, with the $\gamma^2$ value of about 0.65 (Table 1), which is slightly larger than the value for the SSP technique.

The annual mean near-surface currents at 16 m produced by the inner model using the COW nesting technique differ significantly from the inner model results using the OPS and SSP nesting techniques (Figure 3d). In addition, the inner model results using the COW technique agree poorly with Fratantoni's time-mean observed near-surface currents, with the $\gamma^2$ value of about 1.01, which is about 60% larger than that of the inner model results using the SSP or OSP nesting techniques.

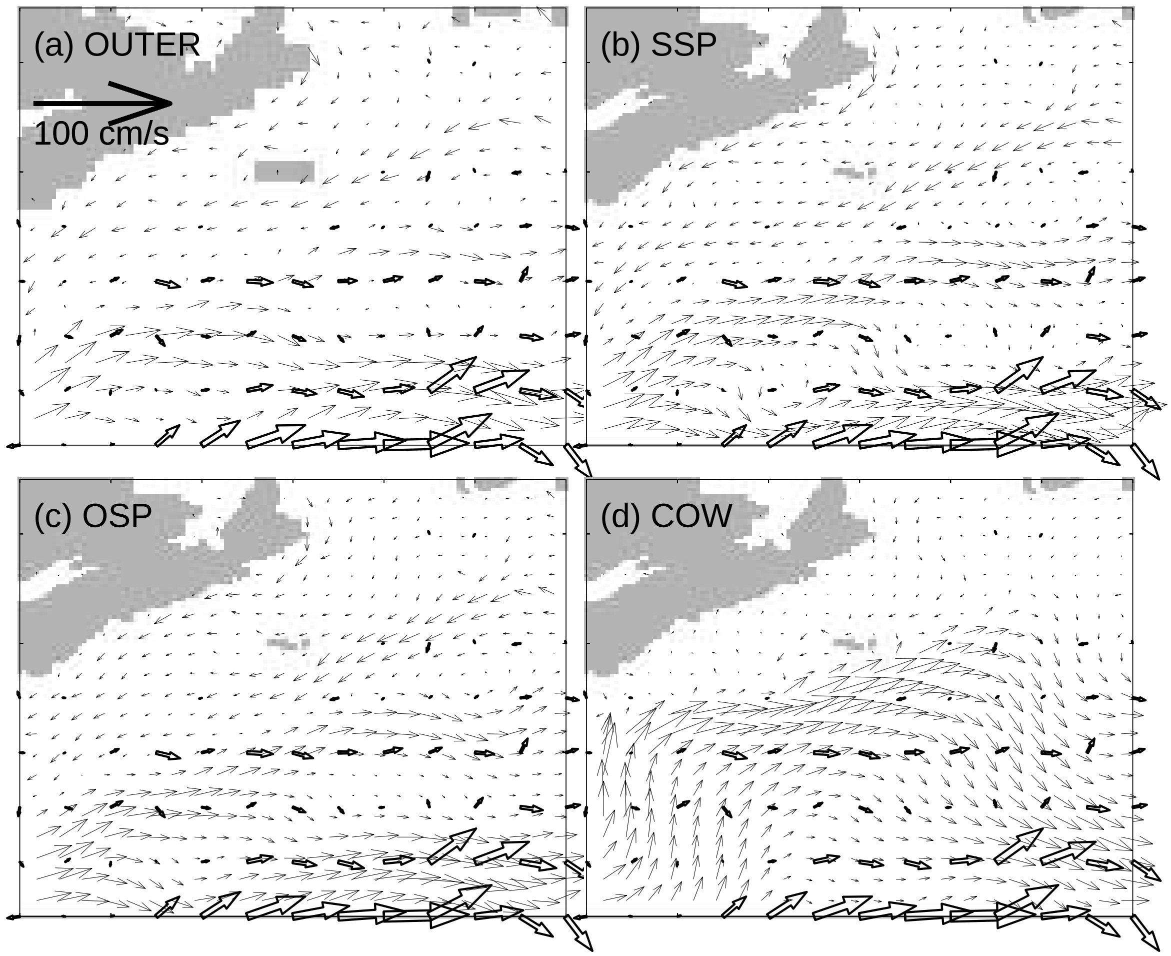


Figure 3: Comparison of modeled (solid arrows) and observed (open arrows) near-surface currents over the SS and SW region. The observed currents are the gridded time-mean near-surface currents during the 1990s inferred from trajectories of 15 m-drogued satellite-tracked drifters by Fratantoni (2001) on a 1° grid. The modeled currents are the annual mean currents at 16 m computed from the second year model results generated by (a) the outer model and (b) inner model of the two-way nested-grid modelling system using the smoothed semi-prognostic (SSP) nesting technique; (c) the two-way nested-grid inner model using the original semi-prognostic (OSP) nesting technique; and (d) the conventional one-way (COW) nested-grid inner model.

We next compare the instantaneous sub-surface currents and temperatures at 50 m at day 690 (end of November of the second model year) produced by the outer and inner models using the SSP, OSP and COW nesting techniques (Figure 4). In the SSP and OSP cases, the large-scale features of the sub-surface currents and temperature produced by the inner model compare well with those produced by the outer model, except that the inner model produces more meso-scale eddies over the SW region, especially in the SSP case (Figures 4a,b). Both the circulation and the temperature field in the COW case are quite unrealistic. In particular, the COW nested inner model fails to generate the well-known Scotian Current near the coast and the shelf-break jet over the outer SS. Instead, the model generates unrealistically large and broad northeastward flow over the SW region. The inner model using the COW nesting technique also overestimates the sub-surface SW temperature significantly (Figure 4d).

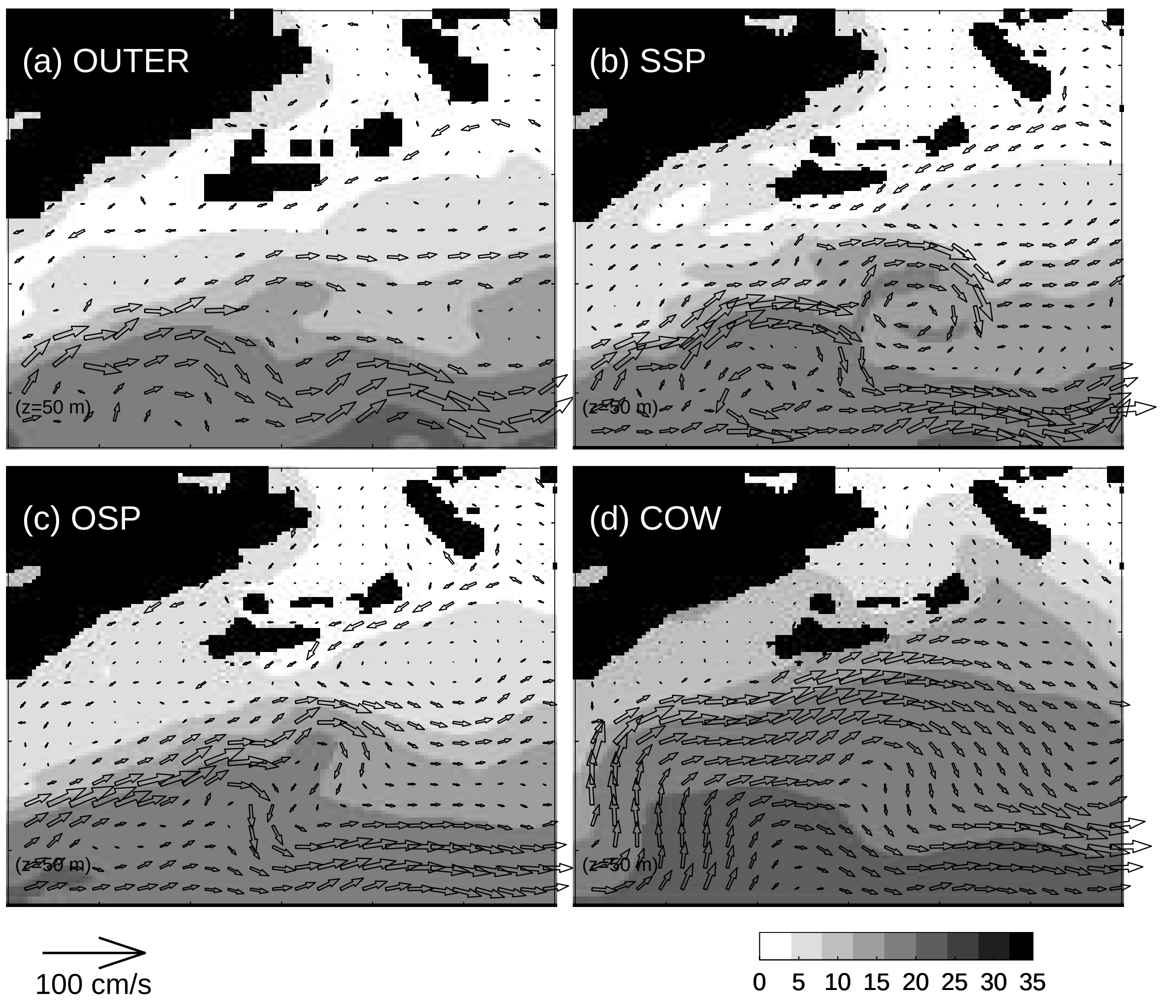


Figure 4: Simulated sub-surface temperature (gray image) and currents (arrows) at 50 m over the SS and SW region at day 690 produced by (a) the outer model and (b) the inner model of the nested system using the SSP nesting technique; (c) the nested-grid inner model using the OSP nesting technique (d) the conventional one-way nested inner model. Velocity vectors are plotted at every four model grid points for the inner model and every two model grid points for the outer model.

As mentioned above, one of the most important circulation features over the SS and SW region is the spreading of the Labrador Current from the Grand Banks to the outer Scotian Shelf. The inner model using the SSP nesting technique successfully reproduces the cold tongue associated with the Labrador Current along the shelf-break (Figure 4b), indicating that advection is important for the presence of the cold intermediate layer on the shelf (Hachey, 1938).

## Summary and conclusion

We have described a new two-way interactive nesting technique based on the smoothed semi-prognostic (SSP) method suggested by Eden et al. (2004) (see also Greatbatch et al., 2004). In this paper we demonstrated that both the SSP and OSP methods can be used to exchange information between the sub-components of a nested-grid modelling system by adding a two-way interaction term to the horizontal momentum equations of each sub-model. The main difference between these two nesting techniques is that the SSP nesting technique uses a spatially smoothed (large-scale) interaction term, while the OSP nesting technique uses an unsmoothed interaction term. Therefore, the SSP nesting technique reduces the damping effect of the OSP nesting technique on the mesoscale eddy field.

The two-way nesting technique based on the SSP method was used in the development of a two-way nested-grid ocean circulation model for the Scotian Shelf and Slope Water, with a high-resolution inner model embedded inside a coarse-resolution outer model. The inner model covers the Scotian Shelf (SS) and Slope Water (SW), with a resolution of approximate 7 km. The outer model is the northwest Atlantic Ocean model developed earlier by Sheng et al. (2001), with a horizontal resolution of approximate 25 km. The nested-grid inner model using the SSP nesting technique reproduces many well-known large-scale circulation features over the SS and SW region and is fully compatible with the outer model. In addition, the fine-grid inner model using the SSP technique produces more small-scale features (e.g., meanderings, warm rings etc.) than those produced by the coarse-grid outer model. In comparison with the time mean near-surface currents inferred from the observed trajectories of near-surface drifters at 16 m by Fratantoni (2001), both the SSP and OSP nesting techniques perform much better than the conventional one-way nested inner model over the SS and SW region. Comparison of the instantaneous sub-surface circulation and temperature field produced by the inner models demonstrates that the SSP nesting technique performs better than the OPS and much better than the COW nesting techniques.

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