Section 9

Development of and studies with coupled ocean-atmosphere models

A Unified Dynamical Model for Atmospheric and Oceanic Flows

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The purpose of this study is to test the feasibility of converting an atmosphere model code into an ocean model code, hence producing a single code that is valid for both atmosphere and ocean modelling. There are several motivations for doing this. Recent developments on numerical methods in the atmospheric sciences have permitted the elimination of some approximations that are traditionally applied in the primitive equations (hydrostatic approximation; filtering sound waves). The system of equations used in oceanographic models is a subset of the equations used in atmospheric model codes. The resources available to the Canadian atmospheric and oceanographic scientific community are limited, so sharing the same dynamical core would optimize its development and improvement. There will be increasing use of coupled atmosphere-ocean systems, which could be simplified by using the same code for both fluids. If this preliminary project is successful, a more general project would be conducted using a model with tangent linear and adjoint code for advanced data assimilation, thus facilitating future atmosphere-ocean data assimilation research and development.

Here a semi-implicit, semi-Lagrangian algorithm developed for air flows (Benoit et al., 1997, hereinafter referred to as the RPN code) has been adapted for water. A unified nonhydrostatic and compressible system of equations is used for both fluids. The dynamical kernel (fourth order semi-Lagrangian advection and solver) is shared by both applications. The capability to treat flow around solid objects in the horizontal has been added, together with the ability to handle solid objects using a partial step method with the vertical z-coordinate.

The RPN code has been validated by comparing its performance with that of a well developed ocean model (Saucier et al., 2003, hereinafter referred to as the IML code) on theoretical test cases that are well recognized by the oceanographic community. The IML code is based on hydrostatic and incompressible dynamics, uses second order (flux corrected transport) Eulerian advection, horizontal solid objects, z-coordinate with solid objects in the vertical, has an implicit flexible top, and uses an explicit solver for the remainder of the system of equations.

The first problem examined is that of the overturning of initially adjacent zones of air and water separated by a vertical front of depth H. In the theoretical inviscid solution, in the top half of the domain the vertical front moves into the space formerly occupied by the water, and vice versa in the lower half of the domain. The fronts remain vertical and move with a speed ½ $(gH)^{½}$ in opposite directions, leaving a horizontal interface separating the air in the top from the water in the bottom halves of the domain. Due to the strong vertical shear in velocities across the horizontal interface, it is a dynamically unstable zone and some viscosity has to be introduced in the problem in order for numerical solutions to be obtained. In Eulerian model solutions, the sharp frontal zones give rise to fictitious wave dispersion, whereas the semi-Lagrangian solutions are prone to overshoot / undershoot problems. The presence of diffusion alleviates these difficulties. By using a linear interpolation in the vicinity of the sharp gradients in the RPN code it has been possible to produce very good simulations, with frontal speeds, monotonicity, and conservation that rival those of the IML code.

The second comparison was to test the inclusion of solid objects in the RPN code. Inviscid flow past a square was simulated. The RPN and IML simulations were very similar in their early stages, but an increasingly “noisy” pattern developed around the corners of the object later in the IML simulation. The RPN simulation continued to be well behaved.

Encouraged by these results, simulations of Von Karman vortex streets for flow past a cylinder were also performed with the RPN code and compared with laboratory experiment results. The RPN simulation did very well, quantitatively reproducing details of the boundary layer separation and stagnation points, as well as the turbulent wakes.

These results provide confidence that a unified atmosphere-ocean model is indeed feasible. First comparisons and evaluations using the complete three-dimensional model in a coastal region have begun.

Acknowledgement

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New Sea Surface Salinity Product in the Tropical Indian Ocean

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Abstract

A Sea Surface Salinity (SSS) product derived from satellite measurements would be very welcome by the researchers for assimilation into OGCMs as studies have shown that salinity is important for the simulation of tropical ocean dynamics. The reason for this is that the *in situ* measurements are poorly distributed. We have estimated SSS from satellite measurements of Outgoing Longwave Radiation (OLR) over the tropical oceans during 1979 to present. The algorithms are based on the inter-relationships between OLR, the Effective Oceanic Layer (EOL), climatological SSS (World Ocean Atlas 2001; WOA01) and freshwater flux (P-E). Preliminary results in the tropical Indian Ocean show higher correlation coefficients for the relationships between OLR vs. EOL, EOL vs. WOA98 SSS and OLR vs. P-E. The former relationship couples the atmospheric convection (OLR) and the geopotential thickness of the near-surface stratified layer (EOL). The estimated SSS at 2.5°x2.5° grid on monthly scale is nearer to the WOA98 SSS with lesser differences within ±0.5 psu away from the coastal region. The mixing and advection processes will have to be considered using the Hybrid Coordinate Ocean Model (HYCOM) for the refinement of estimated SSS.

Method

Murty *et al.* [2004] showed the methodology (Figure 1) to estimate the SSS in the tropical Indian Ocean and the statistical relationships (algorithms) between OLR and EOL, between EOL and SSS and between OLR and SSS in the tropical Indian Ocean. The monthly algorithms developed are suitable for both the convection and non-convection regions for the tropical Indian Ocean. After examining the utility of these monthly algorithms for the daily/synoptic scales, the estimation of daily SSS on routine basis are attempted.

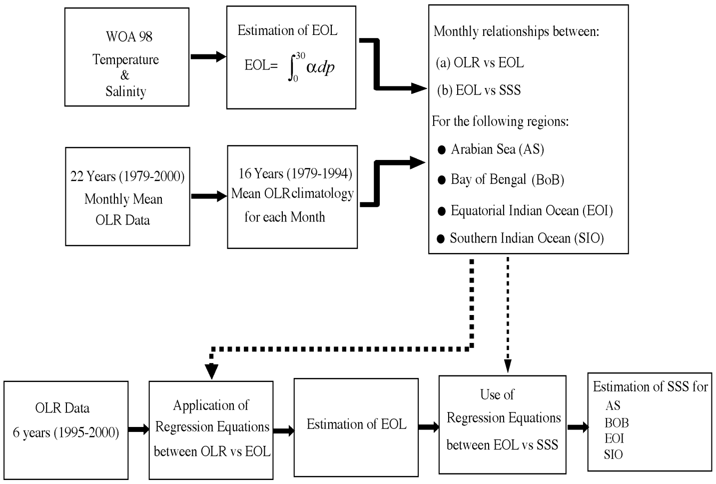

Figure1. Schematic diagram explaining the computational methodology for the estimation of SSS from OLR (taken from Murty et al. 2004).

Subrahmanyam et al. [2004] successfully attempted a case study and estimated the SSS from OLR to understand the air-sea coupling during tropical cyclones in the Arabian Sea and Bay of Bengal.

Results

One important feature of the present algorithms is their ability to simulate the interannual variation of the SSS. The interannual variation of estimated SSS for a 6 year period (1995-2000) is presented for two locations in the EIO (0°N, 55°E and 0°N, 90°E) (Figure 2). The impact of 1997 El Niño signal is evident in the time series of estimated SSS. Higher SSS at the eastern location in 1997 clearly identifies the impact of weaker convection associated with the El Niño. The annual variation of WOA98 SSS is repeated over the 6-year period for a better comparison with the estimated SSS. However, differences in some months are relatively high (0.8 to 1.3) with larger values of estimated SSS than WOA98 in the El Niño period.

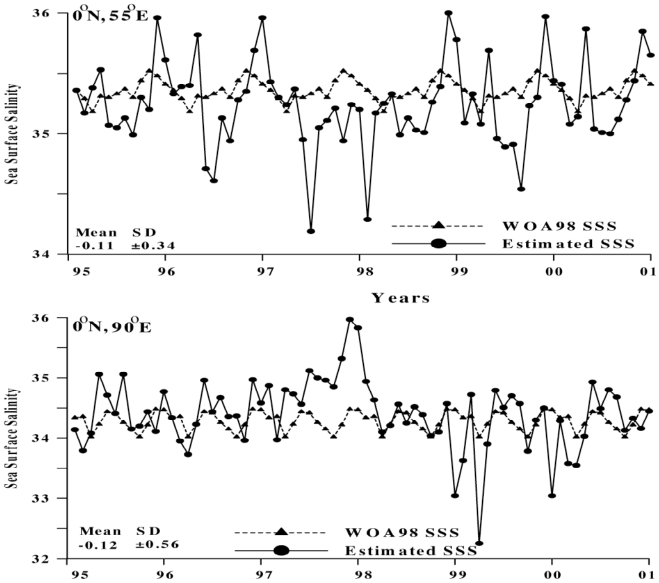

Figure 2. Inter-annual variation of the estimated SSS (solid line) at two selected locations in the equatorial Indian Ocean: 0°, 55°E (top panel) and 0°, 90°E (bottom panel) during 1995-2000. The annual variation of WOA98 SSS (dashed line) at this location is repeated for all the 6 years for easy comparison and to assess the deviation in the estimated SSS from the WOA98 SSS (Taken from Murty et al. 2004)

Conclusions

This new salinity monthly product (2.5°x2.5°) in the tropical Indian Ocean (30°N-30°S, 40°E-100°E) is useful to further studies on coupled models, El Niño-Southern Oscillation forecast models and Ocean Global Circulation Models or regional scale circulation models. In future using 25 years (1979-present) of daily OLR data at 1°x1° grid and the algorithms, the daily SSS will be estimated in the tropical oceans. This method has only been tested in the tropical Indian Ocean; further research is still required to see its applicability to other oceans. We hope that this work will be useful for the validation of the SSS products to be obtained from the two salinity satellite missions – the US 'Aquarius' and the European Space Agency Soil Moisture and Ocean Salinity (SMOS), that are planned for launch in 2008.

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Numerical Experiments of Typhoon Bilis using a non-hydrostatic atmospheric model coupled with a mixed-layer ocean model

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1. Outline of a coupling procedure of a mixed layer model

A non-hydrostatic atmospheric model (NHM), which is the same model as the model running operationally in the Japan Meteorological Agency (JMA), is coupled with the ocean model of which type is a slab-type mixed layer model. Numerical experiments of intensity predictions of tropical cyclones are carried out using the NHM-ocean coupled model with different horizontal resolutions. Vertical configuration of the mixed layer model is comprised of a mixed layer, thermocline, and a bottom layer. Unlike the experiment by a typhoon-ocean coupled model of Wada (2003), initial depths of a mixed layer and a thermocline are simultaneously determined dependent on seasons and areas in the ocean. The mixed layer model consists of equations of motion, continuous equations, equations for sea temperature and salinity, *etc*. Almost all the model specification is the same as that of Wada (2005). However, equations for sea temperature and salinity are applied for Ginis (1995). Moreover, pressure gradient terms in the equations of motion are derived from the formulation of Ginis (1998). ETOPO5 data are used by linear interpolation as model oceanic topography. Map projection of the ocean model is conveniently copied with that of the NHM. Message Passing interface (MPI) is available so that we can run the coupled model more economic. At the initial stage, oceanic currents are assumed to be motionless. At the first step in the computation of the ocean part, a spin up procedure is carried out to estimate the ocean currents until total kinetic energy in the ocean becomes constant.

2. Numerical experiments

Atmospheric initial and lateral conditions are prepared in the following procedure; The JMA global spectral model (GSM of which version is T213L40) is preliminarily carried out to obtain 72-hour predictions every three hours apart. Then, the JMA typhoon model (TYM) with 20km horizontal resolution is also carried out to obtain 72-hour predictions every three hours apart like those of GSM. Atmospheric initial and lateral conditions are obtained from predictions by the TYM. The typhoon bogusing using in the TYM is reflected on the initial field. Initial conditions of sea surface temperature (SST) are obtained by linear interpolation from the JMA daily global analysis data (1x1 degrees). Initial conditions of salinity and sea temperatures except the SST are extracted by linear interpolation from World Ocean Atlas in 1998 (WOA98). Two different horizontal resolutions (6km and 18km in this study) are prepared to evaluate the dependency of tropical cyclones' intensity on the horizontal resolutions. In the NHM, a parameterization of sea spray effect (Bao, 2000) is optionally introduced. The cumulus parameterization by Kain and Fritsch (1990) is used in all numerical experiments although finer horizontal resolution of 6km is applied for the simulations.

3. Results

Numerical experiments in the case of Typhoon Bilis are conducted using the NHM-ocean coupled model. The initial time of the numerical experiment is 1200UTC on August 20 in 2000. Table 1 show results of minimum sea level pressure (MSLP), maximum sustained wind (MSW), and maximum sea surface cooling (SSC) of four kinds of numerical experiments. Finer horizontal resolution, introduction of sea spray effect, and no oceanic mixed layer process, all are factors of intensification of Typhoon Bilis. The numerical experiment with 6km horizontal resolution, sea spray effect, and an oceanic process is the best of all experiments in the light of the prediction of MSLP (920hPa) reported from JMA best track data. Even in the case, maximum SSC is smaller than that of TRMM/TMI SST observation (about 5℃) although the SSC becomes greater than that of previous studies by Wada (2003). Figure 1 shows relationship between MSLP and MSW in the numerical experiments with a sea spray process. The relationship in the NHM experiments agrees well with the JMA best track one. This is also considered to contribute to the production of larger SSC in the ocean model after the passage of Typhoon Bilis due to proper estimation of wind stresses. Figure 2 indicates that the NHM with 6km horizontal resolution and sea spray effect can reproduce more realistic horizontal distribution of cloud and SST of Typhoon Bilis. The NHM-coupled model has been still under development. We will challenge numerical simulations of tropical cyclone in 2004 seasons when ten tropical cyclones were extraordinarily landing on Japan Island.

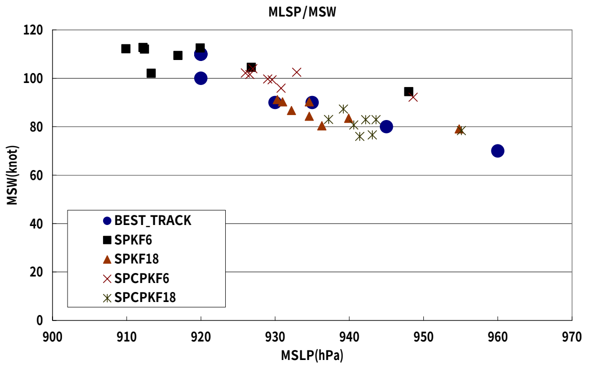

Figure 1 Relationship between MSLP and MSW in numerical experiments with a sea spray process.

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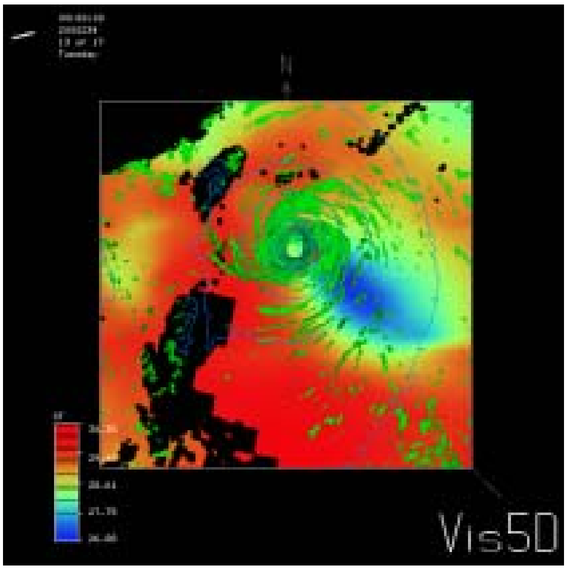

Figure 2. Cloud water content, sea level pressure, and SST at T+36h.

Table 1. Results of numerical experiments of Typhoon Bilis under different specifications.

	No ocean No Sea Spray	No ocean Sea Spray	Ocean No Sea Spray	Ocean Sea Spray
18km				
MSLP(hPa)	941.0	929.5	945.7	934.2
MSW(knot)	82.6	94.3	81.4	87.5
SSC(℃) (T+48h)			2.17	2.66
6km				
MSLP(hPa)	925.4	910.8	939.1	926
MSW(knot)	104.7	117.4	98.6	108.1
SSC(℃) (T+48h)			3.01	3.39