Mixed Layer Dynamics in the Caribbean Sea and The Western Tropical Atlantic

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Abstract

Ocean numerical models have become quite realistic over the past several years as a result of improved methods, faster computers, and global data sets. Models now treat basin-scale to global domains while retaining the fine spatial scales that are important for modeling the transport of heat, salt, and other properties over vast distances. Better knowledge of circulation elements in the Caribbean Sea, such as, eddies and recirculating features, dispersal mechanisms, upwelling and downwelling zones and events, retention zones, and space and time scales of mesoscale variability of the Intra-Americas Sea (IAS), is required before attempting to attack research topics in the air-sea exchange of trace gases and dispersion of riverine plumes. The generation of a realistic physical model will improve different studies on this region. Development of a new hydrodynamic-thermodynamic model based on the Thermodynamic Ocean Model System (TOMS) is one of the principal objectives of this project.

1. INTRODUCTION

Several models have been applied to the Caribbean Sea most of them exclusively hydrodynamic. An early numerical model used to study the circulation in the southeastern Caribbean Sea was a version of the Hurlburt and Thompson (1980) Gulf of Mexico model. Contemporaries IAS circulation model are IAS-POM [POM: Princeton Ocean Model (Blumberg and Mellor 1987)] and MICOM [Miami Isopycnic Coordinate Ocean Model, (Smith *et.al.* 1990)].

Luther *et.al.* (1985) programmed a non-linear reduced gravity model, in spherical coordinates for the Arabian Sea. Jensen generalized the model to a multi-layer model to study the seasonal undercurrents in the Somali current system (1991), and the equatorial variability and resonance in a wind-driven Indian Ocean model (1993). Capella added some enhancements and made an 1/6-degree geometry (Barnier *et.al.* 1994). Jensen developed a new thermodynamic version (TOMS) based in the hydrodynamic code. Layer depths in TOMS vary in time and space. For many transient phenomena, such as an internal wave, the layers remain material layers. However, in situations where upwelling or downwelling takes place over a long period, exchange of fluids takes place between layers. For this reason, the uppermost layers are allowed to have variable densities. This in particular allows a realistic ocean-mixed layer.

Recently, Murphy and O'Brien (1999) investigate the connectivity of mesoscale variability in the Atlantic Ocean, the Caribbean, and the Gulf of Mexico by a set of numerical simulations, using three versions of the Naval Research Laboratory (NRL) Layered Ocean Model (NLOM). Two simulations have ¼ degree resolution and include 5.5-layer reduced gravity and 6-layer model with realistic bottom topography. Both are wind forced and include the global thermohaline circulation. The third is a ½ degree linear wind-driven model.

2. TOMS MODEL CHARACTERISTICS

TOMS is a flexible thermodynamic-hydrodynamic model that uses an Arbitrary Lagrangian Eulerian vertical coordinate, which predicts a new Lagrangian layer thickness, each time step. Based on physical and numerical criteria, the layer thickness is adjusted (i.e. remapped) and the associated mass, heat and salt fluxes between layers are computed. This makes it a hybrid between an isopycnal model and a z-coordinate model, see fig. 1. This principal characteristics of TOMS allows faster simulations than other models.

This model may be forced by wind stress, surface heat flux and net precipitation and/or restoring to observations. In addition to prognostic equations for layer thickness and average layer velocities, temperature, salinity and tracers may be included for some or all of the layers. Additionally, bottom topography can be included or the model can be used in a reduced gravity upper ocean mode, which is the case in the project. The mixed layer formulation is of Kraus-Turner type (Kraus and Turner 1967) with added entrainment due to shear.

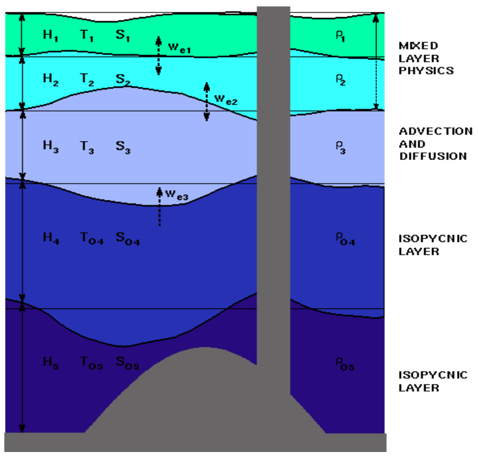

Figure 1 - TOMS vertical structure.

3. NEW MODEL IMPLEMENTATION

Although, the focus is essentially the Caribbean, this study covers the Atlantic Ocean from 16°S to 45°N of latitude and from 100°W to 15°E of longitude, see fig. 2. This area includes principally the Caribbean Sea with the surrounding Atlantic, the Gulf of Mexico, the North Atlantic Mid-Latitude Gyre and the equatorial waveguide due their relevance to Caribbean dynamics. Coastlines are determined from the 200-m isobath, extracted from ETOPO5 topographic database [National Oceanic and Atmospheric Administration (NOAA) 1986]. The north and south boundaries are open using a free slip condition, while no-slip conditions are applied along land boundaries. Orlanski approach is preferred at open boundaries because less instabilities are produced. This condition computes the phase speed of the interior immediately adjacent to the open boundary from the interior solutions.

Implementation of the new model involves modification of several TOMS model routines, adaptation of new boundary geometry, generation of new surface forcing and internal climatological structure data, and porting of the code and compilation in a new system. Furthermore, modification of a set of complementary programs, like preprocessing input data, output analysis and graphic representation, is also required.

Hydrodynamic version has two layers of constant density dynamically active above an infinitely deep, motionless layer. Thus, effects of bottom topography can be neglected. The evolution of the flow on each active layer is governed by an equation for vertically integrated transport and by an equation for the conservation of volume, which includes entrainment to prevent surfacing of the first isopycnal in the event of very strong upwelling.

The climatological monthly mean wind stress of Hellerman and Rosenstein (1983), see fig. 2, and the actualized temperature and salinity data of Levitus (1995) climatology force the model.

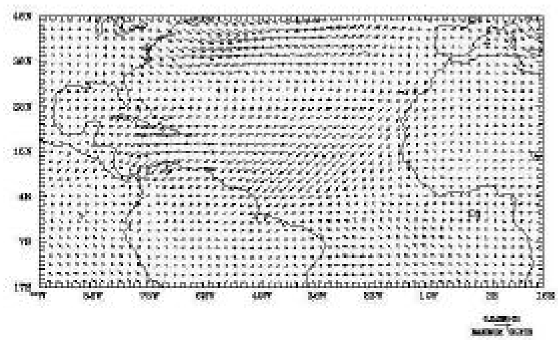

Figure 2 – Hellerman and Rosenstein (1983) climatological mean surface wind stress corresponding to February.

Physical model is represented by a set of main differential equations, which are solved using finite differences. Main variables are staggered arranged in a Arakawa C-grid scheme (Messinger and Arakawa 1976), see fig. 3.

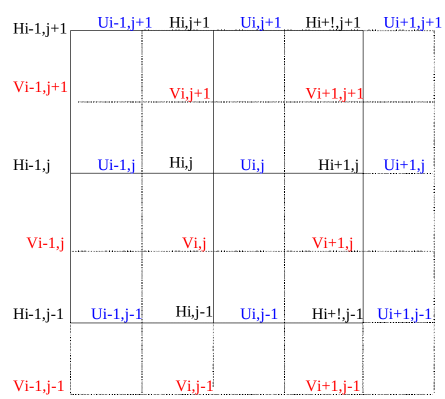

Figure 3 - Arakawa C-grid scheme.

A series of simulations are conducted, starting with the simplest version (coarse grid version) and progressing towards a more realistic model. The model outputs consist of the horizontal transport components, layer-height perturbation field, temperature and salinity, and density of each layer. An example of coarse-resolution result is showed in fig. 4. Preliminary, an Origin 2000 system is been considered for the high-resolution modeling.

This project is supported by the Tropical and Atmospheric Sciences Center (TASC), and is a component of a multi-disciplinary team of researchers from the Mayagüez Campus of the University of Puerto Rico, under the Atmosphere-Ocean Interactions Section. Thus, Dr. Jorge Corredor and Mr. Julio Morell, are studying natural sources of nitrous oxide and its concentration in surface and subsurface waters of the Caribbean Sea, Prof. Aurelio Mercado *et al.* are dedicated to study the ocean-atmosphere interchange of gases, and Dr. Juan Lopez-Garriga *et al.* are quantifying the discharge of volatile halogenated organic compounds from tropical environments. These studies and those of Dr. Lopez on the primary productivity, of the Caribbean Sea oligotrophic waters, are currently providing the algorithms and calibration data to be included in the model once the hydrodynamic/mixed-layer code has been implemented and validated.

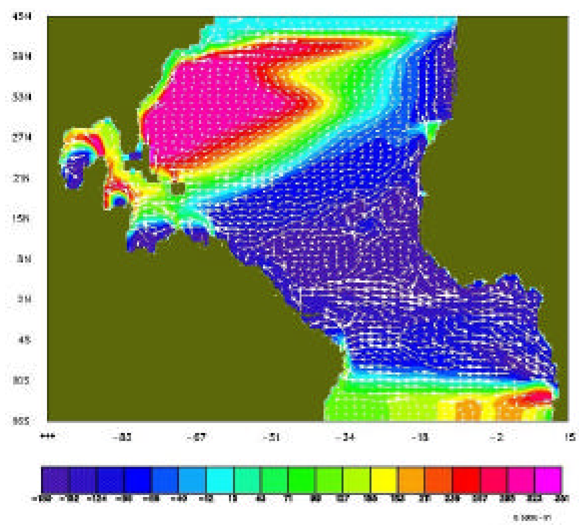

Figure 4 – Mean velocity vectors and first layer height perturbation field, after 30 years of simulation, corresponding to February.

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