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Chapman Conference on the Circulation of the Intra-Americas Sea

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UNESCO

Forward

Chapman Conference on the Circulation of the Intra-Americas Sea

George A. Maul and Christopher N.K. Mooers

Chapman Conferences are the premier format for scientific symposia organized by the American Geophysical Union (AGU). Based on work of the IOC Subcommission for the Caribbean and Adjacent Regions (IOCARIBE) and the United Nations Environment Programme (UNEP), the AGU also recognized that special attention was warranted for the Gulf of Mexico / Caribbean Sea / Bahamas / Guianas region, the *Intra-Americas Sea*. Accordingly, the AGU agreed to sponsor this Chapman Conference on the Circulation of the Intra-Americas Sea with the express purpose of addressing physical and related issues of the oceanic circulation of these, the headwaters of the Gulf Stream System. The undertaking was supported by the U.S. National Oceanic and Atmospheric Administration, the Intergovernmental Oceanographic Commission (IOC), the University of Puerto Rico Sea Grant Program, the U.S. Minerals Management Service, the U.S. Office of Naval Research, and of course by our home institutions, the Florida Institute of Technology (GAM) and the University of Miami (CNKM). This Conference is one of a series we (GAM & CNKM) envisioned in 1993, the first of which was a special session at the AGU / ASLO Ocean Sciences Meeting in February 1994. Follow-up meetings along these thematic lines are planned for IUGG / IAPSO meetings, other AGU / ASLO Ocean Sciences meetings, and for a follow-up Chapman Conference in 1997. This particular meeting at La Parguera is an extraordinary effort by the AGU to involve Latin American and Caribbean colleagues in the oceanography and marine meteorology of the Intra-Americas Sea, and to address in an interdisciplinary manner, the effects of the ocean and atmosphere on the fisheries, transportation, pollution, climate, socioeconomic and human health issues of the region. Most specifically, oceanographers are on the verge of transition from being observers of the marine environment to becoming forecasters, a metamorphosis our meteorological counterparts accomplished decades ago. This transition was the underlying excitement of this particular Chapman Conference: we will *collectively* be forecasting “ocean weather” before this century is concluded!

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1. Introduction

The Intra-Americas Sea (IAS) is a major semi-enclosed sea and of principal importance to the western Atlantic Ocean. Waters flow into the IAS from the tropical Atlantic and Amazon River; thus the North Brazil Current and the Guianas Coast of South America are included. The Gulf Stream System begins to form in the IAS: first in the Caribbean Sea as the Caribbean Current, which becomes successively the Yucatan Current, the Loop Current (in the Gulf of Mexico), and the Florida Current (which exits the IAS through the Straits of Florida in the offing of Cape Canaveral). The Antilles Current, as a branch of the Gulf Stream System affecting the Windward Islands and the Bahamas, must be considered as well. As is typical of the ocean, there is a great deal of IAS mesoscale eddy activity and seasonal and inter-annual variability in the circulation.

Notable IAS atmospheric phenomena include hurricane and cold front passages and the waters' response to them. In turn, the IAS provides heat and moisture to such weather elements and thus, modifies the marine boundary layer and the lower troposphere. There is also a deep circulation in the IAS associated with flow over sills, ventilation of the deep basins, and water mass formation. These deep flows are connected to important questions concerning the exchange of waters between the North Atlantic, Caribbean, and Gulf on climate time scales. Air-sea interaction over the IAS contributes to the North American Monsoon and its impact on precipitation over the midwestern United States.

The IAS also assimilates runoff from many rivers, most notably the Mississippi, Rio Grande, Magdalena, and Orinoco Rivers. Thus, there are elements of meteorology, and hydrology involved as well as physical and chemical oceanography. The advective and turbulent transports of the IAS affect the distribution and fate of pollutants and the distribution and behavior of fish. Considering the societal importance of pollution abatement and fisheries management for the 33 countries that border and are within the IAS, and that chemical and biological effects on the EEZ of individual countries are linked to the physical transport in the waters, many issues of common interest must be considered.

With these considerations and concerns in mind, we convened an AGU (American Geophysical Union) Chapman Conference on the Circulation of the Intra-Americas Sea. It was held juxtaposed to the University of Puerto Rico's Maine Science Department's laboratory in La Parguera, from 7:30 PM Sunday 22 January to noon, Thursday 26 January 1995. The meeting was co-sponsored by the University of Puerto Rico Sea Grant Program, the Minerals Management Service, the Office of Naval Research, the University of Puerto Rico's Department of Marine Sciences, the National Marine Fisheries Service's Southeast Fisheries Science Center, and the Intergovernmental Oceanographic Commission of UNESCO. The objectives were to:

- increase the exchange of scientific knowledge concerning IAS circulation, and its effect on the North American Monsoon;
- stimulate the development of cooperative and joint research on IAS circulation;

- focus the observational and modeling efforts on developing an IAS nowcast and forecast system for scientific research and societal purposes;
- build stronger bridges between USA and Caribbean and Latin American scientists concerned with the IAS *per se*; and
- build bridges to the marine fisheries and ocean pollution scientists, and to meteorologists and hydrologists for improved circulation understanding.

2. Scientific Presentations

Opening remarks were made by Prof. Christopher N.K. Mooers of the University of Miami, who introduced Dr. Fred Spilhaus, Executive Director of the American Geophysical Union, followed by comments from Prof. George A. Maul of the Florida Institute of Technology. Dr. Javier Velez, University of Puerto Rico Marine Advisory Services, welcomed the 88 people who registered. The speakers and a summary of their contributions follows:

2.1 Sunday Evening

John C. Ogden: *The CARICOMP network of Caribbean marine labs, parks and reserves: connecting coastal and ocean processes*. CARICOMP grew out of the diadema mass mortality in the Caribbean Sea of 1983, which started near the Panama Canal and followed the path of the currents around the basin. CARICOMP is coupled to (1) awareness of the growth of human populations; (2) vectors of natural processes between land-shore-water; (3) riverine influences; (4) the Caribbean as a large marine ecosystem; (5) influence of hurricanes on the biota; and (6) coral bleaching. CARICOMP is a program of the Association of Marine Laboratories of the Caribbean which has 24 labs in 16 countries. It is predicated on the idea of a simple monitoring system using identical equipment, a common manual, and weekly sampling. Dr. Ogden urged a resurrection of the UNEP Regional Seas concept as it was originally conceived.

Jorge E. Corredor: *Temporal trends in mixed layer features of the northeastern Caribbean*. The central question for this research is: does the area function as a carbon sink and does the Orinoco River contribute to this process? Accordingly, the University of Puerto Rico established a monthly serial oceanographic station in 2000 m water depth south of La Parguera. Most of the variability observed there is due to salinity rather than temperature. Low surface salinities are caused by distant riverine effects, which are mirrored in the surface chlorophyll. The general pattern is a shoaling of the chlorophyll maximum with decreasing latitude from about 50 m at 18◦N to about 150 m at 15◦N. Long-term maintenance of the serial station was strongly encouraged by the group.

Elva Escobar-Briones: *Environmental quality: control by circulation and mixing*. Based on several benthic sampling site on IAS continental shelves, the discussion centered on the effect

upon benthic organisms, for example: (1) distribution of species; (2) dispersion span; (3) biodiversty patterns; and (4) pelagic-benthic coupling. A central question is: Are certain species being found further north? The program considers: The effect of circulation in providing very clear waters for photoautotropic systems such as on coral reefs. Chemoautotrophic systems are characterized by seeps along shelves with oil reserves. Eutrophic systems are affected mostly by duration and strength of the bottom currents providing oxygen in shallow reef areas. Mesotropic systems are those between a hypotropic system and an eutropic system. And ogliotropic systems are those with a very small input of organic carbons. Primary factors identified include the availability of oxygen, input of organic matter, and light.

2.2 Monday Morning

William E. Johns: *Modeled inflow variability through the eastern Caribbean passages*. This presentation centered on forcing by the Atlantic and how it affects the Caribbean. Tropical and subtropical gyres split the Caribbean resulting in an expected (from first order Sverdrup theory) outflow from the Caribbean as well as inflow which is most pronounced in summer. A model with thermohaline forcing shows inflow in all passages whereas a wind-forcing only calculation shows outflow in some passages. The macroscale thermohaline forcing increases flow through southern passages. The model results show some nine-month variability in the Windward Passage. Eddy kinetic energy is significantly enhanced by including thermohaline circulation; however there is insufficient current meter data in passages to fully document it. There tends to be a canceling of inflow through Old Bahamas and Windward Passages, which shows up as variability in the annual cycle of the Florida Current (±5 Sv). The annual cycle of the Florida Current is in phase with the cycle in the Lesser Antilles but not in the Greater Antilles passages.

Elizabeth Johns: *Sources of the Florida Current*. Accounting for the thermohaline sources, is cross hemispheric exchange that includes AIW, SEC, and NECC/NEC. CTD & shipboard ADCP data were used (20 CTD cruises, six with ADCP) in the study. The average transport in the Florida Current is balanced by summing the inflows through the Windward (Great Inagua), Anegada, NW Providence, and southern Caribbean Passages. The T-S envelope in the Florida Current is accounted for by the flow through these passages. Temperature-silica plots suggest most water in the main thermocline comes from AIW but may be affected by upwelling in the Caribbean. Much of the western Florida Current surface water is modified by river input from within the IAS.

Roy A. Watlington: *Determining the variability of flow through the Antillean Passages using historical XBT data.* He examined historical XBT data to determine the flow through Antillean Passages. Some drift card studies and satellite-tracked drifters show a northward flow through the Mona Passage from time-to-time. The 15◦C isotherm is typically depressed on the Atlantic side, indicating net flow into the IAS through Mona Passage. The T-S correlation was used to estimate geostrophic flow, and the estimated transports from Kelvin

waves above 15◦C are: 4.9 Sv Anegada; 9.1 Sv Mona; 1.3 Sv Windward. An annual cycle is always found on the Atlantic side but it is obscured on the Caribbean side.

Robert H. Tyler: *Wind-driven pressure and flow fields around Puerto Rico* were studied from two moorings and one wind station on the continental shelf. Near-bottom currents have been observed to flow in the opposite direction from alongshore winds. At zero lag, winds and currents are directly correlated; at greater lags, the bottom flows are out of phase with the winds. Using cylindrical coordinates and the shallow water equations, a linear model shows a low pressure on the windward side of the island and a high on the leeward side that leads to a flow field with phase lags that depend on friction and the Coriolis force. The model best explains the pressure and flow fields when the Coriolis force is significantly larger than friction.

Jorge Capella: *Intra-American response to changes in North Atlantic upper layer transport from a numerical circulation model* (reduced gravity, one active layer, below 200m at rest, 1/12◦ resolution, H&R winds, 200m isobath coastline). He studied various inflow conditions and also found that the South Atlantic cross-equatorial flow influenced the Caribbean inflows. Very small changes in the boundary between the tropical and subtropical gyre cause large changes in the flow behavior of the northern passages. Large anticyclonic eddies off the South American coast reach the Antilles in about 5-6 months, but they do not enter the Caribbean Sea. Eddies carry Amazon River water along their boundary. As an eddy impinges on the Antilles, it impacts the passage flow for about a month pumping water into the Caribbean, affecting the flow around the islands. About three model eddies per year impact the Caribbean.

W. Douglas Wilson: *Measurement of current structure and transport in the Windward Island passages*, using the 1991-1994 series of observations from 10 cruises to date. Historically, 13 Sv from the South Atlantic flow through the southern passages, but this estimate is based on essentially one set of observations. He used a local ship outfitted for observations with self-contained CTD/ADCP combined unit, and accounted for tidal currents from shipboard time- series compared with Barbados sea level. These passages have inflow in part and outflow (usually at depth) in other areas. In the Grenada Passage, the extremes are 11 Sv into the Caribbean, and the extreme outflow case (always at depth along the southern flank) results in a net zero volume transport. Direct measurements give transports that are typically 40-50% lower than those in the literature, most of the discrepancy being in the deeper layers. He achieved better comparisons with the NRL model than with historical data analyses.

2.3 Monday Afternoon

David Neale: *Circulation in the Gulf of Paria: studies on the physical oceanography of a semienclosed sea under the influence of the Orinoco River*. The Gulf of Paria is a shallow (30 m) sea between Trinidad and Venezuela with a net flow from south to north. It is characterized by extreme density fronts due to riverine flow and step-wise vertical

stratification (1013-1027 g/cm^3). He developed a depth averaged 2D finite difference model with tides, wind forcing, and mean flow. Real-time applications have been identified for pollution studies, search and rescue, and research. Future efforts are inhibited by lack of e-mail and Internet connectivity.

Raul Mederos: *Water quality in Cuban Bays.* He examined four bays and modeled the diffusion using classical Fickian equations. He also collected information on chemicals and fecalcoloforms and found a long-term negative trend in petroleum, *i.e.,* the bays' ecological health is improving. Much of the decrease in petroleum pollution is due to a decrease in industrial activity.

Aurelio Mercado: *Nonlinear internal wave forcing of the coastal waters of Puerto Rico*. He discovered coastal seiches of 6 cm in tide gauge records that are in concert with a model of shelf waves for the characteristic depth and width of the shelf off the southwest coast. The seiches seem to be excited by deep-sea tides in the southeast Caribbean; their energy is associated with internal waves that are hypothesized to be caused by flood tide currents entering over the shallow sills of the Lesser Antilles passages. The nonlinear internal wave interaction with the steep island coasts is now being studied with thermistor strings and current meters. The spectrum shows 51-minute periods associated with lunar perigee, *i.e.* with spring tides. They do not seem to be soliton-like events such as have been observed in the Sulu Sea.

Barbara Hickey: *Circulation of water properties of Exuma Sound.* CTD surveys, current meter moorings, and wind sensors were deployed around the Sound to characterize the waters. Effects from density plumes of very saline water from the extensive banks surrounding the Sound have been observed, but the records are quite different in the deep water. Currents on the shelf do not appear to be driven by local winds, perhaps due to the fact that the shelves are "leaky". CTD and current meter moorings suggest that there are several 10-to-20 km diameter eddies that are semi-permanent features of the Sound. Plumes of high salinity and density seem to sink to about 50-to-100 m and spread 10's of kilometers across the Sound. Future efforts will focus on dense saline plumes, eddy generation, generation of shelf flows, and evaporative driving of convection with field studies, plus analytical and numerical models.

Frank E. Muller-Karger*: Availability of synoptic infrared and color satellite data for the Intra-Americas Sea*. Comparisons of in situ and CZCS data show very high correlation between currents and satellite-derived chlorophyll patterns in the retroflection region off the Guianas. In the Caribbean the Orinoco Plume can be traced completely across the Caribbean Basin, with great variability in the patterns. The Amazon Plume surrounds Barbados from time to time. Upwelling along coastal Venezuela is often seen in the CZCS imagery. During the fall, the Orinoco Plume tends northwest but in springtime it surrounds the Lesser Antilles with fresh water. In the Gulf of Mexico, the CZCS supplants the missing (summertime) AVHRR patterns to provide a full year of satellite imagery coverage. Location of ground

stations limits the coverage; a 2000 km radius of coverage is available from a single antenna site. Principal sources of data are JPL, GSFS, U. Miami, and U. South Florida.

Jose M. Lopez: *Bio-optical characteristics of Caribbean waters south of Puerto Rico*. Studied the variability in the influence of the Orinoco Plume around Puerto Rico. PRR, the profiling reflectance radiometer, matches the SeaWIFS sensors at 412, 443, 490, 510, 555, and 665 nm; coupled with ancillary instrumentation, he has the capability to observe *in situ* data at all wavelengths. The "green" water south of Puerto Rico, near 15◦N, has the optical depth for PAR (400-70 nm) of about 15m, whereas it is near 20m in the "blue" water farther north.

George A. Maul: *State-of-the-art sea level and meteorological monitoring systems in the Intra-Americas Sea*. He discussed the new technology of measuring sea level with acoustic tide gauges and the ancillary meteorological information needed to interpret the information. The value of telemetering the data via GOES for early warning of hurricane storm surge, circulation and surface currents, and for tsunamis, as well as for more traditional uses in tides, vertical geodetic datums, and surveying was emphasized.

T.M. Georges: *Capabilities of over-the-horizon radar (OTHR) for monitoring the Intra-Americas Sea*. OTHR looks at the Doppler shift from 20 Mhz radar Bragg scattering of 7.5 m ocean waves; two views resolve the vector wind direction with coverage of almost all the IAS (amongst other areas). The same system also can determine the radial component of surface currents; examples were given showing the Gulf Stream off Cape Hatteras and the Florida Current (*i.e.* the use of two OTHR sites). J.A. Harlan then spoke about comparison of OTHR with geostrophic surface velocities from TOPEX data. He was able to show similar patterns of radial velocities in the Gulf Loop Current and the Florida Current.

2.4 Monday Evening

Doug C. Biggs: *Ship and satellite studies of the Gulf Loop Current (GLC) and "Eddy Yucatan" in the Gulf of Mexico*. He and his colleagues found an especially large GLC eddy in 1994 with transports exceeding 32 Sv and with surface speeds exceeding 1 m/s. The petroleum industry was particularly concerned for their tension-leg drilling rigs. Using satellite altimetry, satellite-tracked drifters and shipboard hydrographic data, the eddy was studied from its separation for half a year. SSH decreased from about 68 dyn-cm at separation to about 37 dyn-cm six months later, and it is expected that it will continue in its westward drift for at least four months more. A video of the SSH history from TOPEX altimetry for 1994 enhanced the description of the this well sampled event.

David E. Dietrich: *High-resolution numerical studies of the Gulf Loop Current, and frontal and parasitic eddies in the Gulf of Mexico*. His group developed a 1/12◦ resolution model showing the GLC, separated eddies, cyclonic / anticyclonic eddy pairs in the western basin, and warm tongues west of the Florida Platform. In the western Gulf, the model and

observations gave similar pictures of eddy interaction with the coast and spin-down; the process seems to involve coalescing of modem pairs giving rise to a westward jet near the latitude of the mouth of the Rio Grande. A video from several years of model run showed some eddy lifetimes of up to two years. The model shows a very rich eddy field throughout the northern and western Gulf.

Luis Zavala: *Eddy-wall interaction on a beta-plane*. Developed a 1 1/2 layer model on a β-plane using the primitive equations, and employing a "particle in cell" method as a tracer. The analytical solution was compared with a numerical solution, which had great similarity. He then applied the boundary conditions of an elastic collision. There was some small growth in energy in the analytic solution, and periodicity in the eddy dynamic height with time. Once the modeled eddy collides with the western boundary, it begins to drift south and to decay in amplitude; the southward speed (v=0.5 km/day) is proportional to the Rossby number (R_o=0.1); the eddy preserves its circular shape.

Leo Oey: *Eddy and wind-forced shelf circulation.* He examined the circulation along the Louisiana-Texas (LATEX) Shelf and approached the question of the cause of the gyres found just offshore and the associated eastward-flowing shelf-break currents. Utilizing a 20-layer 20-km resolution model, the LATEX shelf gyres are seen to be driven by a combination of offshore eddies and a westward wind. Using steady winds, the model shows fluctuating currents along the shelf-break, which can only be attributed to GLC eddies. Then using ECMWF monthly winds and integrating for five years, the Gulf had a maximum western boundary current in July, and a peak in the LATEX shelf transport at the same time. Most of the flow is wind driven, with perhaps half of the remaining forcing split between buoyancy forcing from the Mississippi River and from GLC eddies.

2.5 Poster Sessions

Poster Sessions were held throughout the conference with the following authors and titles:

O'Brien, E., C.N.K. Mooers, and G. Peng: *How does variability in the Intra-Americas Sea affect moisture transport onto surrounding continents?*

Cochrane, J.D., M.K. Howard, and L.L. Lee: *Coastal upwelling and related currents in the western Gulf of Mexico*

Rooth, C.G.H.*: Linear and non-linear Ekman drift effects in cyclonic boundary eddy systems: Physics and potential fisheries recruitment impacts.*

Meza, E., V.M.V. Vidal, F.V. Vidal, A. Hernandez, and L. Zambrano: *Oceanographic atlas of the Gulf of Mexico Volume III*.

Hernandez, A., V.M.V. Vidal, F.V. Vidal, E. Meza, and L. Zambrano: *Cyclonic and anticyclonic rings 3-D distributions in the western Gulf of Mexico*.

Vidal, V.M.V., F.V. Vidal, A. Hernandez, E. Meza, and L. Zambrano: *On the western boundary current in the Gulf of Mexico.*

F.V. Vidal, V.M.V. Vidal, E. Meza, A. Hernandez, L. Zambrano: *On the baroclinic circulation of the Gulf of Mexico.*

Morell, J.M., J.E. Corredor, J. Capella, and J. Lopez: *Density structure oscillations at "El Pichincho": possible implications on pelagic fisheries.*

Sanford, T.M., and W.E. Johns: *Comparison of moored current meter and towed determinations of ocean transport.*

Gallegos, A., I. Victoria, and J. Zavala: *Geostrophic volume, mass, and heat transports through Havana-Key West, Windward, and Yucatan Passages.*

Dietrich, D.E., A. Mestas-Nunez, M. Bowman, and C.A. Lin: *Island wake vortices simulated by the DieCAST ocean model.*

2.6 Tuesday Morning

Richard N. Bohrer: *A comparison of the hydrographic characteristics and circulation of the southern Sargasso Sea and the western Caribbean Sea in winter 1992, 1993, and 1994.* He reported on data acquired by the Sea Education Association along a N-S line from about 28◦N to 11◦N. The 18◦C Water was shown not to penetrate into the Caribbean Sea, but that the other characteristic waters of the region (AAIW, SUW, SAW, *etc.*) are seen along the section. Geostrophic transport between Hispaniola and South America was over 30 Sv in summer, enough to supply all the Florida Current flow, excluding the flow through Windward and Bahamian passages. The coastal upwelling zone of the southern Caribbean was well identified in the surface chlorophyll during 1992, but not in 1993. Was this due to El Niño? Drought in the Caribbean is one of the documented El Niño teleconnections.

Nazario D. Ramirez-Beltran: *A multivariate time series model to predict hurricane tracks.* The data used were the geographical position, wind speed and central pressure for all storms since 1886. Using the historical data, a neural network was trained to produce a vector ARMA model. Typical errors in tracks are less than 100 nautical miles over periods of several weeks. Average errors are ±57 n.mi. compared to ±67 n.mi. in the NHC90 model. The Kalman filter scheme and Vector ARMA model have prediction capabilities similar to the NHC90 model.

Julio Sheinbaum: *Data assimilation experiments with a high-resolution model of the IAS embedded in a low-resolution Atlantic model: some preliminary results.* The objectives are to use a simple 2-layer model with 1/6◦ resolution embedded in an 1/2◦ resolution model to test data-assimilation ideas including winds, heat flux, and salinity for time-dependent

boundary conditions. The techniques of data assimilation used include "nudging", optimal interpolation, and in the future, adjoint models. After four years of integration, the high resolution model shows many of the important features of the IAS including the GLC, the upwelling off South America, and eddies of various types throughout the Caribbean and Gulf of Mexico.

Jorge Zavala: *A numerical study of the circulation and sea surface temperature of the Gulf of Mexico with a 2 1/2 inhomogeneous layers model*. Their modeling approach allows the upper layer thickness to vary with seasons, forced by the Yucatan Current, H&R winds, and COADS temperature values. The model produces GLC eddies every eight months or so either by forcing with currents only or with including winds. Modeled heat fluxes were compared with values calculated from the COADS, but the model had lower values in winter than the observations, and higher values in summer, with discrepancies within ± 1◦C. Most of the differences were explained by entrainment / detrainment in the model being better (because of resolution) than in the areally-averaged dataset.

Y. Peter Sheng: *On modeling of Florida bays*. He considered the response of these shallow bays to forcing from the ocean, winds, rivers, and tides, leading to the result of nutrient loading, dredging, and beach nourishment on fisheries, seagrasses, water quality, and sediments. Navigation channels are the main site of baroclinic flows and must be adequately modeled; hence curvilinear grid systems are employed. Residual flows contrary to the wind direction are caused by the nonlinear response to tidal interaction with the bottom topography. Florida Bay itself is characterized by nonlinear tides, wind mixing, stratification, complex bottom topography, steep slopes, riverine and groundwater supply, vegetation, evaporation, a moving coastal boundary, benthic flux of sediments and nutrients, and oceanic forcing. Tidal dissipation causes a residual flow through the Florida Keys up to 30 cm/s, but a full understanding will require grid sizes of 10-m; a serious challenge for numerical modeling.

Sylvia Murphy: *An investigation of Caribbean mesoscale variability utilizing NRL global ocean model data*. Using the NRL 5.5 layer, 1/4◦ resolution model, numerous anticyclonic eddies are simulated transiting the IAS. Eddies slow down and intensify in the Cayman Sea, taking about one year to transit from the Lesser Antilles to the Yucatan Channel. About three eddies per year form west of the islands, and there is significant interannual variability both in number and intensity of these features. Eddies seem to influence the transport through the Yucatan Channel and the pinching off of GLC eddies.

Tammy Townsend: *Modeling the Intra-Americas Sea*. NRL has several versions of their models with resolution form 1/4◦ to 1/12◦ resolution typically with 5.5 or 6 layers in the vertical, with and without the thermohaline circulation (13 Sv, typically), of various areas including global, North Atlantic, and the IAS, driven by a combination of mean H&R winds and synoptic ECMWF interannual winds. The highest resolution model compares well in amplitude and phase with observations after the bottom topography is adjusted and the thermohaline circulation is included. Important issues are: thermohaline circulation; wind forcing sensitivity; and accurate bottom topography. Most model improvements have come

from improving the accuracy of the depiction of the many passages and banks of the IAS. NRL's latest IAS version is 1/16◦ resolution, but the runs have not as yet been conducted.

2.7 Tuesday Afternoon

Julio Candela: *On the barotropic response of the Gulf of Mexico - Caribbean Sea System: Sensitivity to atmospheric forcings and interactions with the Atlantic Ocean*. The objective is to develop simple spectral models to complement more complex models, investigate how the internal dynamics of the system modifies flow through the passages, develop efficient data assimilation schemes, study the tidal system, and correct altimetry data. The model characteristics are 20 km resolution, bottom topography from ETOPOS, and forcing from ECMWF winds. The application of the model to the Mediterranean (which is about half the area of the IAS) was discussed, elucidating its advantages and disadvantages. A proposal to conduct a multiyear study of the flow in the Yucatan Channel was presented, focusing on hydrographic surveys, with participation form UNAM, CICESE, WHOI, and ICH.

Maria C. Donoso: *Modeling maximum sea states during hurricanes in the Intra-Americas Sea*. This study is motivated by an increase of investments in offshore structures, the length of historical records being in general shorter than the return period of storms, and the need for a simple model for prediction. Parameters considered include the forward velocity of the storm, the pressure difference, and the radius of the maximum winds. Calculation of the characteristic wave height depends on the usage of the information, but can be $H_{1/3}$ or H_{max}. The statistical model compares within 10% in height with more complicated models. Monte Carlo simulations are calculated to estimate the probability of the characteristic wave height and the risk criteria for a given site. Application to a site off southwest Florida and comparison with recent storms demonstrated return periods of characteristic hurricane waves adequate for engineering purposes.

Thomas N. Lee: *Evolution of eddies in the Straits of Florida with implications for larval recruitment*. Eddies up to several 10's of kilometers in diameter are ubiquitous along the cyclonic side of the Florida Current between Dry Tortugas and Cape Hatteras. These features are active upwelling regions that elongate with time and can become >100 km long north of Cape Canaveral, transporting heat and momentum between the coastal and offshore waters. Cyclonic meanders off Dry Tortugas can persist for 100 days and significantly alter the local circulation in the Straits of Florida 2/3 or more of the distance between Florida and Cuba. Satellite-tracked drifters show that some larvae could be retained in the area for as much as eight months; thus some larvae could be of a local origin and others could be from farther upstream in the Caribbean Sea. Observations from shipboard instrumentation, moored current meters and OSCR radar mapping of sea surface current vectors, often show flow patterns that act to bring larvae from offshore into the coastal zone which is a significant recruitment mechanism.

3.0 Interstitial Meeting *Wednesday Morning*

3.1 IOCARIBE Group of Experts on Ocean Processes and Climate

During the Conference field trips on Wednesday, the Group of Experts on Ocean Processes and Climate (GE/OPC) of the Subcommission for the Caribbean and Adjacent Regions of the Intergovernmental Oceanographic Commission (IOCARIBE) met. After receiving informal national reports about activities in Colombia, Cuba, France, Mexico, Panama, United States, and Venezuela, the GE/OPC considered other IOC programs and action items to recommend to the IOCARIBE Secretariat. IOC programs related to ocean processes and climate, such as Ocean Science in relation to Non-Living Resources (OSNLR), Ocean Science in relation to Living Resources (OSLR), GOOS, the Global Ocean Observing System, the Global Sea Level Observing System (GLOSS), and TEMA (Training, Education, and Mutual Assistance) were at the core of the GE/OPC discussions. It was also noted that an important meeting on the fisheries of highly migratory species would be held in Miami, 2-4 March 1995, and that several members of the GE/OPC would attend. A GLOSS tide gauge site at Labidee, Haiti near Cap Hatien, was proposed to solve the void in sea level difference observations across the Windward Passage.

The IOCARIBE GE/OPC focused on the many successes and progress being made particularly with regard to IAS numerical modeling, and urged the IOC to address the following:

- TRMM, SeaWIFS, and TOPEX validation
- Resurrecting time series from colonial records (modeled on the work of the University of East Anglia)
- PACS (the Pan American Climate Study)
- IAI (Inter-American Institute), primary interests for GE/OPC being ENSO and air-sea interactions (ITCZ variability)
- Internet connectivity throughout the region
- NAFTA Institutions; where are the new opportunities?
- Utilize the WWW (Internet World Wide Web) technology to share information: maintain mailing lists and a bibliography; keeping track of instrument deployments such as GLOSS and CARICOMP, satellite ground stations, weather stations; standard data bases such as DBDB-5 bottom topography data and coastlines.
- IOCARIBE home page should incorporate pointers to other institution's home pages showing cruise schedules, programs, lists of experts, *etc*.
- Explore the new ONR interest in "littoral oceanography" and NASA interest in validating other EOS spacecraft.
- Contact PASO (Pan American Space Organization) and determine IOCARIBE role in their interest in conducting remote sensing observations of the 1995 ENSO by means of a multinational project.

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x Specific requests of the IOCARIBE Secretariat are to:

- assess planned satellite remote sensing systems and their contribution to the region;
- improve oceanographic data base coordination;
- assess future opportunities;

- continue experts meetings;
- continue to network people and programs;
- center on coastal circulation around entire IAS boundary;
- build bridges between research science and the socioeconomic concerns of governments;
- assess why the IOCARIBE Secretariat hasn't been more successful with funding of proposals to GEF and other funding agencies;
- encourage bilateral efforts such as the joint coastal influences on fisheries along the Venezuelan-Colombian coast, and the transboundary transport of pollution;
- act on the offer of the Colombian Naval Academy to host a scientific meeting this year in celebration of its 60th anniversary (contact Capt. Carols Andrade, 575-668-4321);
- Commence executing the recommendations of the *Small Island Oceanography* workshop report (IOC Report No. 97) which listed the need for time series and satellite oceanography tools for pelagic fisheries, and more quantitative measures of island circulation for coastal fisheries (mesoscale and small scale variability).

4.0 Continuation of Scientific Presentations

4.1 Wednesday Evening

Christopher N.K. Mooers: *Predictions for sea-air rescue in the Straits of Florida.* POM, the Princeton (University) Ocean Model, with 5 km resolution and 21 sigma-coordinate levels in the vertical is being applied. Model domain is from Dry Tortugas to West Palm Beach, with no inflow from the east. The model is forced by features of the Florida Current on the inflow, and by synoptic operational winds. Comparisons with the STACS data show good correspondence at 27◦N, both in the mean field and in the spectrum of variability. Both the model and the OSCR surface current radar in the Florida Keys show flow reversals during easterly (westward) wind events. Application to the problem of safety at sea for Cuban rafters shows a minimum five day journey under favorable wind conditions. The model automatically acquires data for nowcasts and forecasts, which are being issued as a provisional product for public use.

George A. Maul: *Coastal sea level prediction for climate change* A pragmatic analysis of the various techniques available for predicting probable flood levels as input to coastal design was presented. It was emphasized that the calculation of flooding probabilities is based on a combined use of local data and global climate change, and that the probability depends on: (1) tides; (2) surge; and (3) mean sea level. Anticipating future changes must take into account possible changes in all three variables. Examples were given from Key West, representing the IAS, as well as other sites around the world.

Christopher N.K. Mooers: *A circulation model for the Intra-Americas Sea*. POM is being applied to the IAS using 20 km resolution and 20 sigma-coordinate levels, and exploration of using the NMC Atlantic Ocean Analysis (near real-time) Model to provide the IAS model's open boundary conditions. The Straits of Florida transport in the present version of the model

is only 21 Sv, pointing up the need for reconsideration of the boundary conditions. Ten-year long averages seem to show better comparisons with average surface currents than the detailed cross-sections. Agreement is found in comparisons of SST between the NMC model re-analysis and climatology, but surface salinity comparisons between the NMC model and climatology are less well correlated. These correlation differences are a cause for concern in nesting the IAS-POM into the NMC model.

Raul Mederos: *Assessment and control of marine pollution in the Wider Caribbean Region (CEPPOL).* The three most impacted ecosystems in the region are mangroves, seagrasses, and coral reefs. The CEPPOL program includes study of land sources of pollution; baseline studies on pesticides; monitoring and assessment; impact of oil mitigation strategies; and standard techniques for quantifying the database. Funding for CEPPOL continues to lag behind the requirements, but is expected to reach $800,000 by 1997. Funds for working in CEPPOL must be provided through the government of the country concerned rather than UNEP directly.

4.2 Thursday Morning

Vance Vicente: *Physical processes in relation to: regional extinctions; distribution and management of fisheries resources; and pollution*. Extinctions associated with million-year events, such as the closing of the Panama Isthmus, punctuate the history of die-offs; on shorter time scales, 62% of all extinctions in corals have occurred in the IAS. Commercial sponges were essentially destroyed in the IAS in the 1950's, apparently due to high water temperatures; lower SST's in the 1970's have resulted in a return of these sponges. Land runoff and hurricanes have contributed to the die-off of corals in certain areas near highly populated islands. Pelagic fishes, particularly flying fish, have been impacted by runoff from the Orinoco River. Shelf-based fisheries resources have been depleted throughout the Caribbean, but management measures have been a failure probably because of overfishing but natural effects cannot be ruled out. The IAS produces 170,000,000 tons of oil per year, and most of it is transported by sea. Tar shows up on beaches throughout the region, and when it exceeds a certain value (say 10 g/m^2) it is known to impact fisheries, not to mention the economic impact on tourism, the primary source of revenue to the IAS peoples. Water clarity, whether caused by non-point sources of pollution, point sources such as oil that has sunk to the bottom (which is very common), or re-suspension of sediments, is central to understanding benthic ecology. A shift from mesoscale physical oceanography to kilometer or less scales is essential for predicting the physical impacts. Richard Appeldoorn then spoke on the issue of larvae entrainment around Puerto Rico; needed are the dynamics of the mean flow and its variance, emphasizing the need to connect the dynamics of the IAS to that in the very inshore waters including the reefs.

5.0 Synthesis

The circulation of the IAS is dominated by the origins of the Gulf Stream System and its mesoscale variability. Forcing by inflow, from the North Atlantic subtropical gyre and the

Equatorial Atlantic (including seasonal variability and mesoscale eddy influences), together with regional wind forcing are dominant factors. Observations and numerical models are developing a description rich in detail of the mesoscale variability associated with flow through passages and interactions with other topographic anomalies. The circulation of the Caribbean Sea and the Gulf of Mexico are now known to be strongly linked with time scales of several months being of importance, though such variability is not much understood. The discharge from the Amazon, Orinoco, Magdalena, and Mississippi Rivers play a secondary (but important for ecology) role in forcing the circulation. The societally important concerns with ocean pollution and fisheries issues of this region are strongly influenced by mean and mesoscale advective transports. There is now an increasing demand for, and the technological possibility to provide, synoptic ocean information for practical as well as scientific research purposes. The societal applications are raising concerns with also describing sub-mesoscale processes on continental shelves and around islands throughout the IAS.

The several numerical modeling efforts for the IAS circulation are reaching the point where detailed comparisons with each other and with observations will soon be feasible and productive informationally. Similarly, the observational expertise and resources have grown sufficiently in the region that it is now favorable to conduct multi-national filed studies (for example, on the critical but largely unknown flow and counterflow through the Yucatan Channel), especially in association with the evolution of circulation models. In particular, the study of IAS circulation and ecology will benefit from the use of real-time remote sensing information (thermal, color, radar imagery, radar altimetry, and scatterometry). Conversely, there are rich opportunities to validate the use of multi-sensor multivariate observing systems including Over The Horizon Radar (OTHR) systems.

From another perspective, the IAS is frequently impacted by tropical cyclones (and mid-latitude wintertime cyclones in the northern reaches) and wintertime cold front passages. The mean winds and synoptic disturbances lead to major air-sea transfers of momentum, heat, and moisture and their lateral transport over long disturbances. These ocean-atmosphere transfers and lateral fluxes have yet to be thoroughly studied for their impact on the short term climatic variability of the Americas. With the improved description of the IAS ocean circulation emerging, the possibility for quantitative studies of climatic issues should be significantly improved in the foreseeable future.

6.0 Recommendations

To improve the many modeling efforts and results, several process studies were identified including: the Yucatan Current dynamics (joint Mexican/WHOI 1996-97 plans call for ADCP and CM moorings, hydrographic cruises, and tide gauges); continued Straits of Florida monitoring; western Gulf of Mexico eddy-topography interaction; southwestern Caribbean cyclonic circulation feature variability; propagation and evolution of the cyclonic/anticyclonic circulation; Orinoco Plume behavior with respect to carbon studies; annual cycle in the IAS

region, especially the lack of summertime information; Gulf of Mexico eddy-shedding physics; flow through and around islands and island chains; nearshore/offshore connectivity and transport mechanisms; how the general circulation of the North Atlantic modulates the throughflow; influence of winds on the transport of pathogenic diseases and pollutants in the marine environment.

Observing systems identified and actions proposed were: inaugurate over the horizon radar systems including bringing other OTHR systems on line to provide better coverage, along with validation and verification studies; design and deploy a "roving" CTD/ADCP system as an IAS community resource; install submarine fiber optic cables for monitoring passages in the eastern Caribbean; modernize the sea level / weather network to include GPS and GOES capabilities; create an improved IAS geoid and distribute region-wide maps of SSH variability on the Internet; enhance satellite-tracked drifter studies taking advantage of the many existing opportunities to deploy the instruments without cost.

Modeling systems need to share the same coastline, bottom topography, and forcing for model-model and model-data intercomparisons; the role of model diversity should be recognized; other sets of meteorological data *etc*. need to be made commonly available; model output is required using synoptic forcing for periods when satellite altimetry missions are available; Shuttle flight photograph requests to observe areas where work is being performed should be initiated; the physical oceanography community must demonstrate the ability to describe the circulation sufficiently well for the fisheries community to begin using the ocean forecast data.

7.0 Closure

A follow-on meeting, possibly in Cozumel or Puerto Morelos, Mexico, jointly sponsored by the AGU and the Mexican Geophysical Union in two years has been proposed. A stronger meteorological overtone for that meeting, as well as more hydrological participation, is encouraged.

The meeting was adjourned at noon, 26 January 1995.

ANNEX I

IOCARIBE GROUP OF EXPERTS ON OCEAN PROCESSES AND CLIMATE (GE/OPC)
(held in conjunction with the Chapman Conference on the
Circulation of the Intra-Americas Sea (IAS))
MEETING OF THE GE/OPC AT LA PARGUERA, PUERTO RICO, 25 JANUARY 1995

Agenda:

National Reports on OPC Progress since 1992
Relation of OPC to:
- Ocean Sciences in relation to Non-Living Resources (OSNLR)
- Ocean Sciences in relation to Living Resources (OSLR)
- Caribbean Environment Programme on Pollution (CEPPOL)
- Global Ocean Observing System (GOOS)
- Global Sea Level Observing System (GLOSS)
- Training, Education and Mutual Assistance (TEMA)
- Other

Discussion on New Directions for the OPC
Action items for the Secretariat
Conclusion

OPC National Reports:

USA: WIMP, the joint UM/NOAA Windward Islands Monitoring Program will continue for at least one year, and possibly be enhanced by cooperation with the Eastern Caribbean Fiber System (submarine cables between islands); the suggestion is first to instrument one cable for measuring voltages induced by flow of seawater between islands and then expand the network; reporting every 14 days will suffice for OPC efforts. CARIVENT, the Caribbean ventilation project will be completed this year with no plans for further work. The University of Puerto Rico (UPR) serial oceanographic station off La Parguera has 2 more years of funding, and the plans are to occupy the station indefinitely; two other UPR programs (nonlinear internal waves in the Caribbean and air-sea interaction) are funded for at least the next year. The University of the Virgin Islands (UVI) program in the Anegada Passage is being discussed. The UM/FIT (University of Miami / Florida Institute of Technology) ocean modelling of the IAS program is funded and should be supported for the next two years; other work is planned or proposed including satellite-tracked drifters and surface observations for OTHR (over-the-horizon-radar) validation. The Sea Education Association typically makes two or more voyages into the IAS and often collects CTD and other hydrographic data; this source of information should be included in databases and the cruises made better known to local scientists.

FRANCE: The ETAOMB program off French Guyana will continue to measure the cross-equatorial flow and study of the retroflection region, but USA and German participation has concluded.

MEXICO: A cruise in August 1994 with Cuba to the Yucatan Channel concentrated on chemistry and biology of the Cayman Sea was conducted by UNAM. Numerical modelling of the IAS by CICESE will actively continue for several years. *The Atlas of the Gulf of Mexico* was well received and appreciated, but needs to be put on CD-ROM to enhance its usefulness for the scientific and socioeconomic development communities. The tide gauge system for all of Mexico is under administrative revision. UNAM has acquired an AVHRR antenna. The national GOOS project "Health of the Oceans" is funded by the GEF, and will continue for several years.

CUBA: Most of the work is concentrated on coastal processes and bays, but the bilateral work with Mexico continues to receive high priority.

COLOMBIA: A major effort "Upwelling in Guajira Peninsula" is studying the question "Are the nutrients in tropical upwelling putting greenhouse gases in the atmosphere?"; the program is ongoing. Regular (non-scientific) monthly cruises are being made from Cartagena to San Andres Island and return by the Colombian Navy; XBT's and an ADCP need to be acquired (equipment must be portable), but in the meantime, the Navy is encouraged to collect sea surface temperature, salinity, and chlorophyll to monitor the Colombia-Panama Coastal Current. Also identified were numerous cruise ships such as one that twice weekly travels from Colon to Cartagena. CIOH will begin a remote sensing program. PASO: Pan American Space Organization has been formed. The Navy now expends 80% of its hydrographic effort towards developing nautical charts.

PANAMA: At the presidential level they have approved a national commission on climate change; 4 out of 7 members are scientists. Also created on the national level is a commission on hydrological studies. The first efforts will be to map the coastal areas (Caribbean and Pacific) into a GIS network. CATHALAC, a new center sponsored by the UN and Panama, centered in Panama City has been founded; CATHALAC will center its efforts on hydrological problems of the American humid tropics.

VENEZUELA: US cooperative program in the Cariaco Basin is to be funded; it will consist of a serial oceanographic station in eutrophic waters with extensive geochemical sampling. To help support this and related work, a group resolution on the launch of SeaWIFS will be written and mailed to NASA.

Publications resulting from the combined efforts of the GE/OPC include:

1992 Brown, B.E., W.A. Erb, and G.A. Maul. *Intra-Americas Sea Marine Science Meeting of U.S. Experts*. NOAA Technical Memorandum, NMFS-SEFSC-308, 125 pp.

1993 Maul, G.A. *Ecosystem and Socioeconomic Response to Future Climatic Conditions in the Marine and Coastal Regions of the Caribbean Sea, Gulf of Mexico, Bahamas, and the Northeast Coast of South America*. United Nations Environment Programme, Caribbean Environment Programme, CEP Technical Report No. 22, Kingston, 43 pp.

1993 Maul, G.A. (author/editor). *Climatic Change in the Intra-Americas Sea*: Implications of future climate on the ecosystems and socio-economic structure in the marine and coastal regions of the Caribbean Sea, Gulf of Mexico, Bahamas, and the northeast coast of South America. © United Nations Environment Programme, Edward Arnold Publishers, London, 389 pp.

1994 IOC. *Workshop on Small Island Oceanography in relation to Sustainable Economic Development and Coastal Area Management of Small Island Developing States*, Fort-de-France, Martinique, 8-10 November 1993. Workshop Report No. 97, Intergovernmental Oceanographic Commission of Unesco, Paris, 5 pp + VI Annexes..

Detailed discussion of OPC relationships to OSNLR, OSLR, GOOS, GLOSS, and TEMA were not held as they are considered adequately covered in previous OPC documents. It was noted that an important meeting on the fisheries of highly migratory species will be held in Miami, 2-4 March 1995, and that several members of the GE/OPC will attend. A GLOSS site at Labidee Haiti near Cap Hatien was suggested by Doug Wilson, who will research the suitability of the location for OPC purposes.

OPC Activities in the future:

The following group activities for future consideration were discussed:

- TRMM validation
- SeaWIFS validation
- Resurrecting time series form colonial records (modelled on the work of the University of East Anglia)
- PACS the Pan American Climate Study
- IAI (will be accepting consortia pre-proposals until March 31 for large program efforts; primary interests for GE/OPC are ENSO and air-sea interactions (ITCZ variability)
- Internet throughout the region; what happened to the NOAA money for this purpose?
- NAFTA Institutions; where are the new opportunities?
- Utilize the www (Internet world wide web) technology to share information: maintain mailing lists and a bibliography; keeping track of instrument deployments such as GLOSS and CARICOMP, satellite ground stations, weather stations; standard data bases such as DBD-5 bottom topography data and coastlines.
- IOCARIBE home page should put pointers to other institution's home pages showing cruise schedules, programs, lists of experts, *etc*.
- Explore new ONR interest in "littoral oceanography" and NASA interest in validating SeaWIFS, TRMM, TOPEX, and other EOS spacecraft.

x Specific requests of the IOCARIBE Secretariat are to;
- assess planned satellite remote sensing systems and their contribution to the region;
- oceanographic data base coordination;
- assessment of future opportunities;
- continue experts meetings;
- continue to network people and programs;
- center on coastal circulation around entire boundary;
- build bridges between research science and the socioeconomic concerns of governments;
- assess why the IOCARIBE Secretariat hasn't been more successful with funding of proposals to GEF and other funding;
- encourage bilateral efforts such as the joint coastal influences on fisheries along the Venezuelan-Colombian coast., and the transboundary transport of pollution.

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ANNEX III

ABSTRACTS OF PAPERS

The Wind-Driven Pressure and Flow Fields Around the Island of Puerto Rico □

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Observations on the south-western shelf of the island of Puerto Rico indicate that alongshore flows near the surface and on the shallow part of the insular shelf are primarily driven by the alongshore trade winds. The above flow has the tendency to reverse when the wind stress drops and observations of near-bottom currents on the deep outer shelf indicate flow counter to the wind stress. These observations indicate an alongshore pressure gradient that tends to oppose the wind stress.

An analytical reduced-gravity model is presented describing the idealized wind-driven pressure and flow fields around a cylindrical island under low-frequency wind stress. The model shows that the offshore wind-driven flow around the island sets up pressure gradients in the same direction as observed at the study site. We calculate pressure gradients from a wind-driven reduced-gravity model of the offshore flow. Using these as a boundary condition for a barotropic model of wind-driven flow on the shallow shelf, we obtain steady-state pressure gradients on the insular shelf that are comparable to those found from observations. Evidence for other possible effects of large-scale flow on the island records are explored and presented.

COMAR: Computing System for the Processing of Marine Current Time Series

A. B. Bango Sotolongo, J. Talavera Hurtado (Both at: Computing Department, Instituto Cubano de Hidrografía, Calle 4 No 304 Playa. Aptdo 606 Marianao 13 CP 11300, La Habana, Cuba), **A. L. Chirino, L. Fernandez Vila, S. T. Alvarez Delgado, R. Arcis Soriano** (Research Department for Physical and Chemical Oceanography, Instituto Cubano de Hidrografía, Calle 4 No 304 Playa, Aptdo 606 Marianao 13 CP 11300, La Habana, Cuba)

A computing system for the analysis, validation, graphic representation, organization and processing of marine current information is presented. The information were obtained using the Eulerian method. The system is programmed for IBM compatible PC in Borland C++ for Windows version 3.1. The system has powerful mathematical tools like on the implementation of six mathematical filters, for example Doodson, Bartlett, Tukey, Gauss, Smooth, etc., and the spectral analysis. Twenty-seven statistical parameters of current series and the frequency distribution are calculated.

Hydrodynamical Model for the Circulation in Shallow Water

R. Vega Puente (Research Department for Physical and Chemical Oceanography, Instituto Cubano de Hidrografía, Calle 4 No 304 Playa, Aptdo 606 Marianao 13 CP 11300, La Habana, Cuba)

A finite difference model for application to the circulation in shallow water is presented. The numerical model is developed using the 2-dimensional shallow water equations and following a semi-implicit scheme. The gradient of the water surface elevation and the Coriolis term in the momentum equation and the velocity divergence in the continuity equation are discretized implicitly. The horizontal viscosity term and the convective terms are discretized explicitly. The latter terms are discretized using a simple upwind differencing approximation. An ADI technique is introduced in order to simplify the solution algorithm. The model has been successfully applied in the Bay of Cárdenas.

Physical Oceanography Along the Southeastern Boundary of the Caribbean Sea: Applications to Fisheries Management in Venezuela

Rubén Aparicio Castro (Universidad de Oriente, Instituto Oceanografico de Venezuela, Depto. de Oceanografia, Comana Edo. Sucre Venezuela)

In this paper, an effort is made for identifying linkages among the driving physical forces that control population dynamic of small pelagic fish stocks of high socio-economical interest for Venezuela. In particular, for the northeastern continental shelf of Venezuela, site of the Sarinella Aurita fishery, one of the most remarkable national marine resource, the seasonal migration of the intertropical convergence zone of the trade winds is identified as the most important atmospheric forcing governing the local coastal ocean circulation which exhibits wind induced upwelling and seasonal discharge of the Orinoco River water inflow as main regional hydrodynamical properties.

An attempt is made for qualifying the regional pattern of coastal upwelling by using the Ekman Theory methodology in the generation of wind induced coastal upwelling indices that can be incorporated in the modeling efforts made by local scientist dealing with fisheries management. Indices of coastal upwelling coming from in situ continuous records of sea surface temperature collected on key coastal locations during the period 1993-1994 are presented and compared with those derived from the Ekman Theory.

Some Oceanographic Considerations about the Recent Floods in the Littoral of Havana City

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We analyze the principals meteorological and oceanographic parameters characterizing the recent floods at Havana City's levee in order to discern which of them had the greatest incidence. We analyze the sea level surge as a result of the wind set-up, waves and atmospheric pressure, acting together with the astronomical tide. We conclude that the wave's characteristics are not the same at different spots of the levee, and they can be forecasted. We obtained maps of sensibility, in order to establish which places will be more affected by the flood, starting from the wind and wave directions of propagation. We studied the transformation of the waves, which is decisive in the occurrence of floods.

We calculate the external regimens of wind and swell in deep waters, employing a statistical analysis method, new in our country.

Capabilities of Over-the Horizon Radar for Monitoring the Intra-Americas Sea

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Ground-based over-the-horizon (OTH) radars have demonstrated an ability to map ocean surface winds, waves, and currents over ocean areas the size of the Intra-Americas Sea. We show examples of ocean surface products produced by the U. S. Air Force OTH-B radars on the U. S. East and West Coasts, as well as by the southward-looking U. S. Navy ROTHR in Virginia.

By early 1995, two ROTHR radars will provide overlapping coverage of the entire Caribbean Sea and the southern part of the Gulf of Mexico, permitting for the first time extraction of unambiguous surface wind directions and surface currents with resolution of the order of 10 km. Wave height, wind speed, and ocean wave spectral information have been extracted on an experimental basis, and these products require further development.

The Physical Oceanographic Approach to the CHIBCHA Languages Spatial and Temporal Spreading

Javier Bonatti (Escuela de Fisica, Universidad de Costa Rica); **Alejandro Gutierrez** (Laboratorio de Oceanografia, Universidad Nacional)

A hypothesis about the existence of a maritime communication between the present South-East of Costa Rica and North-East of Colombia during the Little Ice Age is established in Section I. Section II is devoted to the review of the linguistic studies on the so called proto-chibcha. In Section III a review of historical data available is performed. Section IV includes archaeological data. Section V considers the extrapolated pre-Colombian coastal current system by using historical, paleoceanograhical and numerical modeling data. Conclusive remarks and discussion of results are included in section VI.

On Modeling of Florida Bay Circulation

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Florida Bay is a shallow hypersaline estuary which boarders the Gulf of Mexico on the west and Florida Strait on the south. Over the past decades, there have been significant changes in the quantity and quality of water which the Florida Bay receives from the Everglades. This change in water quantity and quality is believed to have contributed to the recent major seagrass dieoffs and massive algal blooms in the Florida Bay. As a part of a multi agency effort to develop understanding and solution of this problem, a circulation model of Florida Bay is being developed. The modeling effort starts with an analysis of the measured wind and tide response in Florida Bay. Results of the tidal analysis indicated that tides are significantly damped due to the bottom friction and obstruction to flow from numerous submerged mudbanks and chained islands. The tidal damping cannot be simulated with 2-D vertically-averaged tidal circulation model. In order to simulate the complex tidal circulation, a three-dimensional boundary-fitted-grid hydrodynamic model is used. In addition to allowing forcing of tide, wind and density gradient, the model incorporates the following features:

(1) effects of vegetation (seagrass, mangrove, etc.) on flow,
(2) wetting and drying of the Bay,
(3) heating/cooling and evaporation at the air-sea interface, and
(4) coupling with Straits of Florida and Gulf of Mexico.

These model features and some model results of tidal simulation will be presented.

Coastal Upwelling and Related Current in the Western Gulf of Mexico

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Monthly climatic means of wind stress are favorable to upwelling along much of the western boundary of the Gulf of Mexico from 20◦ to 28◦N from March to September, particularly between 26◦ and 27◦N in June. However, NOAA-NOS analyses of infrared imagery, the surface temperatures of the GUS III cruises (1963-1965) and the Brazos Santiago Tide Station (means for 1958-1971) all indicate little upwelling in April, May, and June, but marked upwelling in July and August; a secondary minimum mean temperature (~25 to 27°C) appears in the July means for the direct measurements.

The early August hydrographic observations made by the LATEX Shelf Programs in 1993 and 1994 showed a coastal cool band between 26◦ and 28◦N as well as northward flow in that zone. Current measurements from ~12 m depth at three LATEX moorings along 27◦20' N out to 75 km from the coast are available for 1992, 1993, and 1994 to 29 July. The mean alongshore currents for April, May, and June were never significantly upcoast, but changed to upcoast for July and early August. This is consistent with marked upwelling only in the latter months.

For the coastal mooring at 27◦20'N, the temperature and alongshore current showed very short upwelling episodes in response to wind during April, May, and early June of 1992, 1993, and 1994. However, in later June or July of all the above years after an upcoast wind episode, the temperature quickly fell by 4-5°C and then remained reduced for days, exceeding a month in 1992 and 1993.

This study was supported by the Minerals Management Service.

Sources of the Florida Current: Results From NOAA's Subtropical Atlantic Climate Study

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The Florida Current is a major component of the Atlantic's thermohaline circulation, which is believed to play a significant role in controlling the global climate. To quantify the net heat flux of the Florida Current, recirculating flow, which would not lead to a net heat flux, must be distinguished from cross-equatorial flow which carries significant interhemispheric exchanges of mass, heat and salt. Previous studies using historical data have indicated that some 45% of the transport of the Florida Current, primarily in the <24◦C and 7-12◦C temperature ranges, originates in the southern hemisphere (Schmitz and Richardson, DSR, vol. 38 suppl., 1991). However, the available historical data are somewhat limited in space and time. Herein we examine the transport and water masses of the Florida Current and surrounding inflows to the Caribbean Sea using more recent data, in an effort to further refine and quantify our understanding of its source waters.

Using shipboard hydrographic and direct velocity data collected as part of NOAA's Subtropical Atlantic Climate Study between 1984 and 1991 we have examined the volume

transport and water mass properties of the Florida Current, the northern passages into the Caribbean Sea (Windward, Mona and Anegada) and across the Caribbean Sea along 63◦30'W. The transport analysis suggests that the circulation into the Caribbean Sea is different than reported in earlier studies, with a greater proportion of the flow entering through the northern passages (Windward, Mona, and Anegada) and a smaller amount through the more southern passages of the Lesser Antilles. Distributions of salinity, oxygen, and silica indicate that the conclusions of earlier studies about the sources of the Florida Current are generally correct. However, there are indications in our more recent data that the freshest waters of the Florida Current in the 17-24◦C range do not enter the Caribbean through any of the passages but rather are formed in the Gulf of Mexico by mixing and freshwater input. In addition, the silica distributions suggest that the main thermocline waters of the Florida Current, which in the earlier studies were considered to be primarily of northern origin, may also include a significant component from the south.

Measurements of Current Structure and Transport in the Windward Islands Passages: 1991-1993

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The Windward Islands Passages Monitoring Program has been designed to obtain inexpensive regular measurement of transport and water mass characteristics in the major southern passages to the Caribbean towards the goal of understanding the interhemispheric exchange of upper ocean waters in the western tropical Atlantic. Many present theories of North Atlantic circulation have the southward cross-equatorial Deep Western Boundary Current flow compensated by a northward transport of upper ocean South Atlantic water. This scenario is supported by the work of Schmitz and Richardson (1991, hereafter SR91) which contains a re-analysis of hydrographic and current measurements made in the southern passages in March and April of 1970 (Stalcup and Metcalf, 1972). Their analysis indicated that of 19×10^6 m^3/s (1×10^6 m^3/s =1 Sv) entering the Caribbean through the three southernmost passages, 13 Sv were of South Atlantic origin.

To better resolve the mean flow and the percentage of waters of South Atlantic origin, a Barbados Coast Guard vessel, the ***HMBS Trident***, which makes regular patrols through the islands, has been equipped to collect standard hydrographic measurements (CTD and water samples) and velocity profiles using a lowered ADCP. Since the program's inception in December, 1991, a total of ten cruises have been made, with repeat section occupations in Grenada, St. Vincent, St. Lucia, and Dominica Passages. Whenever possible, geostrophic velocity estimates have been referenced with upper layer measured currents to estimate full passage transports. The structure of the observed velocity and transport fields is similar to

that described by SR91, however, mean transports are significantly smaller. Total westward transport through the three southernmost passages ranges from approximately 3 to 17 Sv with a mean value of 10 Sv, with no clear annual cycle apparent as yet in the data. Time series of current profiles collected in July 1994 in the Grenada and St. Vincent passages have been analyzed and used to predict and remove the barotropic tidal component from the transport data in these two passages, which account for 85% of the transport.

The transports and their vertical structure are also consistent with recent results from a high-resolution numerical model of the North Atlantic which includes forcing by a simulated thermohaline circulation at the northern and southern boundaries (Johns, Fratantoni, and Townsend, 1995). Salinity and dissolved oxygen measurements are presently being analyzed to determine water mass origins. Without the benefit of this analysis, exact estimates of the transport of South Atlantic water are impossible, but the low mean total transport numbers strongly suggest that significantly less than 13 Sv of upper ocean South Atlantic transport is occurring at the western boundary south of 15◦N.

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Ship and Satellite Studies of the Loop Current and Eddy Yucatan in the Gulf of Mexico, 1994

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In late summer 1994, the Loop Current (LC) shed a new anticyclonic eddy. Known as "Eddy Yucatan," this is the 25th LC feature which has been tracked since 1975. From ship of opportunity XBT + CTD transits of the LC in May, 1994 and July, 1994, it was expected that the anticyclonic circulation around the periphery of this eddy would be quite intense, i.e. similar to that reported for "Nelson Eddy" which separated from the LC in 1991 (a.k.a. The Once in a Hundred Years Eddy) and for "Eddy Whopper," which separated from the LC in summer 1993. Depth of 15°C and 8°C isotherms exceeded 450 m and 850 m respectively, and LC geopotential anomaly relative to 800 db exceeded 70 dyn cm shortly before Eddy Yucatan separated from the main LC. Such a 2/3 dyn meter sea surface height (SSH) gradient is capable of sustaining anticyclonic near surface currents > 3 knots around an eddy of diameter 200-300 km and, in fact, strong anticyclonic surface currents were evident in the underway ADCP records in both May and July, particularly along the eastern wall of the LC.

The magnitude of the SSH gradient from the center to periphery of LC eddies is of strategic interest to petroleum exploration rigs prospecting for oil and gas along the continental margin of the northern Gulf of Mexico, since the strong currents inherent to high gradients may exceed operational limits for some tension leg exploration platforms. However, within just a few weeks of its separation from the LC, both remote sensing and sea truth data showed (rather surprisingly!) that the geopotential anomaly of Eddy Yucatan decreased rapidly. Interpolation of SSH using Topex Cycles 72-76 combined with ERS-1 data show a 30 cm drop in SSH anomaly from early September to mid-October. XBTs deployed during a ship of opportunity survey of Eddy Yucatan in mid-October 1994 confirmed the altimeter data, documenting relatively shallow depths for the 15°C and 8°C isotherms (< 380 m and < 680 m, respectively), and a geopotential anomaly of 48 cm between center and periphery of Eddy Yucatan, relative to 800 db. While a 48 dyn cm gradient in SSH equates to average geostrophic surface current < 2 knots, these currents in Eddy Yucatan may intensify as this LC eddy drifts west and interacts frictionally with the continental margin.

The CARICOMP Network of Caribbean Marine Labs, Parks, and Reserves: Connecting Coastal and Ocean Processes

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The coastal zone of the tropical western Atlantic, an ecologically coherent region interconnected by ocean currents, is threatened by the relentless growth of human populations. Deforestation and poor land-use practices, leading to increased runoff, sedimentation, and elevated nutrients, as well as over-fishing, oil pollution, and dredging, have all been cited as major impacts. The ecological structure and function of the coastal zone in any particular location will be the result of the long-term interplay between natural and human factors. Inter-disciplinary studies conducted over the full range of regional development of the coastal zone and encompassing the time scale of ocean processes will provide the best opportunity to discriminate thresholds and rates of responses of ecosystems to global change and to evaluate the success of our attempts to manage the coastal zone for sustainable use. The CARICOMP (Caribbean Coastal Marine Productivity) network consists of 24 sites in 16 countries which represent the range of regional coastal environmental settings and which are carrying out a synoptic, standardized protocol of observations on the structure and function of the principal ecosystems: coral reefs, seagrasses, and mangroves. Data are archived and accessed through a Data Management Center at the University of the West Indies, Jamaica, which also serves as a communications and coordination center. The network is a powerful tool for the development of meso-scale remote sensing of the coastal zone, particularly land-sea interactions, interplay of coastal and oceanic processes, and regional patterns of marine biological diversity.

Temporal Trends in Mixed Layer Features of the Northeastern Caribbean

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With financial assistance from NASA, we have established a serial station at 17◦ 35'N, 67◦ 00'W about 30 nautical miles south of Puerto Rico. The station is occupied monthly for physical, chemical and biological characterization to 200 m.

Initial results show marked seasonality in the mixed layer characterized by alternation of high salinity waters (up to 35.88) during the early part of the year and lower salinities (down to 34.50) between August and November. Temperature variations are more gradual throughout the course of the year. Mixed layer depths varied from 35 to 75 m and temperatures varied less than 1◦C. Surface layers are well mixed during most of the year but intrusion of low-salinity waters during August 1994 resulted in a gradient varying from 34.75 at 5 m to 35.52 at 57 m. Density profiles closely mirrored salinity variations.

While the chlorophyll *a* maxima during June and July were located at *ca*. 100 m, the maximum in August was located in the low salinity surface waters with only a small intermediate peak observable at 100 m. Nevertheless, chlorophyll *a* concentration, when integrated throughout the euphotic zone, was not significantly greater in August than in the previous months.

Values for silicate concentration are not available for August 1994. Vertical profiles show surface silicate enrichment with values of 1.4 µM at the surface descending to 0.4 µM at 173 m. This pattern suggests that the low salinity waters are the result of continental runoff.

Environmental Quality: Control by Circulation and Mixing

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The hypothesis is presented that "environmental quality" (assessed from biotic indices and geochemical fluxes) is dependent on circulation and vertical stratification, in addition to organic loading. Hypertrophic systems are associated with rivers where sediment accumulation buries carbon rapidly and metabolic consumption is dominated by anaerobic pathways. Eutrophic systems have appreciable inputs of organic matter, but sustain high secondary production because oxygen is maintained through physical mixing and photosynthesis. The mesotrophic state is an intermediate which can evolve to the eu- or hypertrophic condition, depending eddy kinetic energy. Extensive carbonate sediments are examples of photoautotrophic sediment systems typified by the Flower Gardens off Texas. Chemoautotropic systems sustained by oil seeps on the upper slope in the NW Gulf will be found in the "salt deposits" of the Gulf of Campeche, since these deposits have similar geologic origins.

Modeled Inflow Variability through the Eastern Caribbean Passages

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Inflow from the Atlantic Ocean to the Caribbean Sea between South America and Cuba is studied using a 6-layer version of the NRL Atlantic Basin Model. A purely wind-driven version of the model exhibits a total Caribbean inflow of 17 Sv, compared to approximately 10 Sv expected from steady, non-topographic Sverdrup theory. Nearly all of this inflow occurs north of Martinique. The net transport through Grenada, St. Vincent, and St. Lucia passages is nearly zero when the model is forced by winds alone. The addition of a 14 Sv meridional cell in the model increases the net Caribbean inflow to 28 Sv, with nearly all of the additional 11 Sv of inflow entering through the above three southern passages.

Variability of the modeled inflow shows a dramatic change in character moving northward along the Antilles arc. The southern passages are dominated by large fluctuations on 40-70 day time scales while north of Dominica the variability is confined mainly to annual and interannual time scales. The seasonal cycle of the total inflow has a mixed annual/semiannual character with maxima in winter/summer and minima in spring/fall, with a total range of about 5 Sv. The seasonal ranges for the southern and northern passages separately are larger, of 0 (8 Sv), but are largely out of phase at the annual period leading to the smaller net inflow variation. These predicted seasonal cycles are roughly consistent with the seasonal variations in non-topographic Sverdrup flow incident from the Atlantic, but appear to lag by 2-3 months. Observations are presently insufficient to confirm the seasonal cycles and variability spectra in the passages predicted by the model.

Determining the Variability of Flow through the Antillean Passages Using Historical XBT Data

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The possibility of using temperature alone to calculate dynamic height in that portion of the water column where temperature and salinity track linearly was suggested by a work of Nof and Olson (1983). Using such a technique on an available extensive time series composed of expendable bathythermograph (XBT) data has allowed an expeditious examination of the spatial and temporal trends in the variability of the depth of any particular isotherm. In this study, charting the variability of the topography of the 15°C isotherm has provided a description of the changes in the conditions that induce inflow through the deep passages connecting the Caribbean Sea to the Atlantic Ocean. This has also provided estimates of the periodicities with which these changes occur.

Interesting findings resulted from focusing on the inclination of the 15°C isotherm across the Greater Antillean island arc and by seeking out the most prominent periodicities in its vertical displacement. Among these findings is a strong indication that the east-to-west diminishing tilt of the isothermal surface - and, therefore, of the forcing of inflow - is explainable in terms of Kelvin wave dynamics. In addition, interesting periodicities appear in the spectral analysis of the XBT data sets for the several passages. The frequencies of some spectral peaks in isotherm depth variability are suggestive of large scale oceanic and atmospheric phenomena. Further, the range of periodicities of flow variability across the Greater Antilles differs noticeably from the range of periodicities in the Lesser Antilles.

Geostrophic Volume, Mass, and Heat Transports through Havana-Key West, Windward, and Yucatan Passages

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Hydrographic data from eight cruises, the first one in may, 1968 and the last one in July, 1994, are used to calculate geostrophic transports of volume, mass, and heat through the Havana-Key West, Windward, and Yucatan passages. The aim of this study is to provide useful numbers (open boundary conditions, model calibration, etc.) for modellers of the ocean circulation of the IAS.

Calculated flows for a densely sampled transect across the Yucatan Channel (July, 1994) are used as a reference for the assessment of results from other transects across this channel. Transports computed for the other two passages are examined with as much rigor as allowed by the limitations of the sampling scheme applied in each cruise.

Intra-Americas Sea Response to Changes in North Atlantic Upper Layer Transport

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Changes to the circulation of the Intra-Americas Sea due to changes in the intensity of the conveyor belt circulation in the North Atlantic are explored by manipulating the northwards upper layer transport from the South Atlantic in an island-resolving numerical model. South Atlantic waters that cross the Equator into the North Atlantic contribute to upper layer transports along the northeast coast of South America and the Caribbean Sea, therefore, affecting the field of anticyclonic eddies in the Western Tropical Atlantic and the partitioning of Caribbean inflow through the various island passages.

The reduced gravity model covers the Atlantic Ocean from 16◦S to 45◦N and 15◦W to 100◦W at a resolution of 5 minutes between equal points in the staggered grid. Coastlines

are determined from 200 m isobath. The north and south boundaries are open, while the no-slip condition is applied along the north and land boundaries. The model is forced by the climatological monthly mean wind stress of Hellerman and Rosenstein.

Island Wake Vortices Simulated by the DieCAST Ocean Model

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The DieCAST ocean model is applied to the flow around islands patterned after Barbados. Von-Karman-like vortices occur in the wake. These are strongly three-dimensional. The model is validated by comparison with laboratory wake vortex experiments and by resolution sensitivity tests. Vorticity separation is an important part of the island wake problem and is of more general interest in coastal region oceanography. Animated results are shown.

Circulation in the Gulf of Paria: On-Going Studies on the Physical Oceanography of a Semi-Enclosed Sea Under the Influence of the Orinoco River

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The Gulf of Paria is a shallow semi-enclosed sea that lies at the southern end of the Caribbean Sea between the South American mainland and the island of Trinidad. The Gulf is under the direct influence of an arm of the Guiana Current which imposes a background flow northwards through the Gulf and delivers, during the local wet season, relatively large volumes of fresh water from the Orinoco River. The tides are mixed semi-diurnal in nature with a maximum range of about 1 meter. Stratification during the wet season may induce internal tides and through interaction with steep, non-linear topography at the northern and southern openings may result in the generation of solitary internal waves. On-going field studies, numerical models and satellite imagery (CZCS) are used in the investigation of older theories about the variability of the Gulf's circulation, the hydrography and its influence on the Caribbean Sea.

Water Quality in Cuban Bays

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The water quality of a ten-year of monitoring program which includes physical, chemical, and biological measurements as well as a mathematical model for Havana Bay are shown. The conclusions obtained reflect the different levels of pollution in the analyzed bays, its causes, and the alternative ways to reduce them.

Non-Linear Internal Wave Forcing of the Coastal Waters of Puerto Rico

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Seiching motion of the shelf waters of Puerto Rico, with a periodicity of the order of an hour, has been observed along the south, southeast, and southwest coasts. Giese et al. (1982, 1990) have found evidence that the large-amplitude seiching is excited by solitary-type internal waves. We will present preliminary results of an Office of Naval Research sponsored study started in September of 1994 whose aim is to better document the arrival of the internal waves, and the factors determining their arrival. A 100 m long thermistor string, together with two S4 current meters will be deployed for two months along a transect perpendicular to the shelf break off La Parguera, PR for this purpose.

Circulation and Water Properties of Exuma Sound

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A variety of measurement techniques, such as moored current meters, hydrographic surveys and Lagrangian drifters are being used to examine the temporal and spatial variability of circulation and water properties in Exuma Sound, Bahamas, with an emphasis on the upper water column. The focus of this interdisciplinary study, which is an element of the FORECAST program within the Caribbean Marine Research Center, is larval transport mechanisms. The initial field studies (1993-1994) included an array of moored current/temperature/wind sensors and two spatially comprehensive CTD surveys. The moored consisted of year-long current measurements at five shallow (~30 m) sites on the narrow shelf that surrounds the Sound, and 7-month measurements at three sites in the deep (~2000 m) Sound. The deep Sound measurements included two vertically profiling Acoustic Doppler current meters and wind sensors as well as conventional current meters.

Subtidal scale currents measured at the various sites are poorly correlated with each other. The magnitudes of these currents are reasonably large (~20 cm s^{-1}) suggesting that they are not merely the result of random noise. Moreover, similar time scales (~3-5 days) at the various sites suggest a common origin. These currents do not appear to be wind-driven. The currents over the deep Sound differ significantly from those over the shelves. Time scales are longer (10 d vs. 3-5 d) and the amplitude of the fluctuations is a factor of two or more larger than those over the adjacent shelves. Results from the water property surveys indicate that circulation patterns over the deep Sound are large-scale and relatively complex.

In both surveys, geostrophic velocities calculated relative to 500 db (the 'level of no motion') suggest the existence of two mesoscale gyres in Exuma Sound, one in the northern Sound, and one in the southern Sound. These features extend well past the surface layers, to depths of at least 200 m from the surface. Both these data and water property data suggest that the Sound is not closed: it exchanges water with the open ocean at both the shallow entrance on the eastern side of the Sound and the deeper entrance on the southeastern end of the Sound.

Availability of Synoptic Infrared and Color Satellite Data for the Intra-Americas Sea

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The Intra-Americas Sea (IAS) have been routinely covered by environmental satellites for over a decade. These satellites have provided frequent and synoptic images showing the sea-surface temperature (SST) and phytoplankton pigment concentration in the region, and can provide information on the surface circulation including major currents, eddies, the dispersal of riverine or upwelling plumes, and the distribution of phytoplankton. Of particular interest are data from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA Polar Orbiting Satellites, and ocean color data from NASA's Coastal Zone Color Scanner (CZCS) on Nimbus-7 and the future SeaWiFS (Sea-viewing Wide Field-of-view Sensor). AVHRR imagery shows that upwelling in the southern Caribbean is a year-round phenomenon. Such images also show the Loop Current and its associated eddies in the Gulf of Mexico between October and May. During summer, the Loop Current features are less clear in the AVHRR data because gradients in SST are less pronounced. Ocean color imagery shows the dispersal of the Amazon, Orinoco, and smaller rivers in the IAS, as well as the location and magnitude of seasonal blooming of phytoplankton. CZCS data clearly show how the Orinoco plume occupies much of the eastern Caribbean between September and November, reaching Puerto Rico approximately every October. The infrared and visible data complement each other. Ocean color data provides information on circulation features during times of the year when infrared data show homogeneous fields, and vice-versa. The University of South Florida routinely collects and maintains an active archive of these satellite data.

Bio-optical Characteristics of Caribbean Waters South of Puerto Rico

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We discussed bio-optical observations conducted north of the 15 degree parallel in the northeastern Caribbean Sea. These measurements are part of a program aimed at understanding the influence of massive fresh water inputs from the Orinoco River on the physics, chemistry and biology of these waters. In situ as well as satellite remote sensing observations have established the occurrence of strong seasonal changes in bio-optical properties in this region. Significant variations in near-surface phytoplankton biomass (a ten-fold change in chlorophyll fluorescence) were determined by continuous flow fluorometry in a north-south transect along the 67 degree meridian.

Natural fluorescence (Lu 683) profiles revealed a primary phytoplankton biomass maximum at 35 m and a secondary peak at 70 m. Concurrent vertical profiles of PAR, upwelling radiance and downwelling irradiance at six of the SeaWiFS bands (412, 443, 490, 510, 555, 665 nm) were measured using a Biospherical Instruments PRR-660 PRR-660 Profiling Reflectance Radiometer. Remote sensing reflectance (water-leaving radiance) between 400 and 1100 nm was measured at five stations using a Spectron SE590 spectroradiometer. Variability in bio-optical properties of the underwater field were associated with the occurrence of high chlorophyll-low salinity water (amidst low chlorophyll-high salinity water) presumed to originate from the Orinoco River discharge.

State-of-the Art Sea Level and Meteorological Monitoring Systems in the Intra-Americas Sea

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State-of-the-art technology is presently being used for the acquisition for water level and meteorological data in the Intra-Americas Sea to support the Global Sea Level Observing System (GLOSS) network of sea level monitoring stations. GLOSS stations provide data to support the investigation of regional relative sea level changes in areas of complex tectonic motion, near real-time data for input to climatic diagnostic numerical models, calibration of satellite altimetry and scatterometer data, and the evaluation of the feasibility of producing synoptic mean sea level charts for the prediction of climatic trends, long-range weather forecasts and ocean processes. Sea level and weather stations are being added to the GLOSS

network each year, however, critical areas such as the Windward Passage are still without monitoring stations.

Oceanographic Atlas of the Gulf of Mexico -- Volume III

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We have recently published Volume III of the Oceanographic Atlas of the Gulf of Mexico. The hydrographic data base used in the preparation and edition of this volume was conformed during the July - August 85-2 Argos Cruise in the Gulf of Mexico aboard the R/V Justo Sierra. This volume describes in full detail the baroclinic circulation and transports; hydrography, water masses' distribution; kinematic properties of cyclonic-anticyclonic ring pairs; the formation of a north flowing western boundary current jet parallel to the continental shelf slope of the western Gulf of Mexico; the spatial distribution of temperature, salinity, dissolved oxygen, pressure, micronutrients and surface chlorophyll; interaction between oceanic and coastal circulation; cyclonic-anticyclonic-cyclonic ring interactions; and the collision of anticyclonic Loop Current rings against the western boundary of the Gulf.

Comparison of Moored Current Meter and Towed Transport Determinations of Ocean Transport

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The structure of the meridional east of Abaco, the Bahamas, was simultaneously observed with moored current meters and a towed electric field sensor. Important currents in this region include the northward flowing Antilles Current near the surface and the Deep Western Boundary Current flowing southward at depth. Both methods observed a change in the vertically averaged north velocity component of more than -0.25 m s^{-1} over less than 20 km. The cumulative northward transport reached almost 10 Sv 70 km east of Abaco, and by 130 km offshore it had decreased to -8 Sv. The velocity and transport structure measured by the two techniques was very similar, supporting the accuracy of the towed measurements as well as the transport estimates from the moored array.

The towed measurements of vertically averaged velocity were obtained with the TTM2 (Towed Transport Meter) based on the observation of motionally induced electric fields. The electric field observed by electrodes spaced along a line behind a ship is equal to the vertical component of the Earth's magnetic field times the cross-track velocity difference between that of the ship and electrical conductivity-weighted, vertically-averaged horizontal velocity (denoted as $\bar{v}^*$) of the ocean. The velocity of the ship normal to its track was determined from radio navigation methods (e.g., LORAN-C) and the ship's gyrocompass.

The difference between the ship's velocity normal to its track and the TTM2 observed velocity was □*. □The difference between □* and the conventional v indicated that the conductivity weighting and the effect of bottom electrical conductances were small, of the order of 5%. The comparison with the moored current meter array revealed gyrocompass errors of up to 2.5◦. Such errors will be reduced with the application of GPS heading sensors in the near future.

The lateral distribution of transport was also observed on several TTM2 transects of the Florida Current. TTM2 transects between Miami and Bimini and between Jupiter Inlet FL and Settlement Pt GBI are presented.

High Resolution Numerical Studies of Loop Current, Frontal, and Parasitic Eddies in the Gulf of Mexico

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Modeled large-scale Loop Current eddies and small-scale frontal and parasitic eddies are compared with GOM observations. Major general circulation features, including mean thermocline structure and vertical EOF's are also compared with model results. Resolution and dissipation effects are explored. The most realistic results are obtained using very small horizontal eddy viscosity and diffusivity. Frontal eddies intensify and appear much more like observations as resolution increases. Animated results are shown.

Eddy-Wall Interaction on a Beta-Plane

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We present the preliminary results of a numerical study on the collision of a warm eddy with a meridional vertical wall. A particle-in-cell model is used to solve the shallow-water primitive equations (PE) on a beta plane. To perform the numerical experiments, we investigate first the proper form of the boundary condition at the wall. In the analytical part, we obtain an exact solution of the PE by setting the beta term equal to a constant of the same order of magnitude in the v-momentum equation. This solution corresponds to a vortex with a North-South asymmetry which propagates westward. The asymmetric vortex is

reproduced by the model, with the above-mentioned restriction, as proof of reliability of the numerical integration. Otherwise the model is initialized with the exact solution on the *f*-plane (the axisymmetric eddy called rodon) which, after some time, adjusts to the numerical solution. We investigate whether it is preferable to initialize the model with the rodon or the asymmetric vortex in order to minimize the effect of adjustment. In general, the numerical experiments show the formation of a coastal front due to the expulsion of mass toward the South at the moment of the impingement. Afterwards the entire eddy also moves to the South.

Eddy and Wind-Forced Shelf Circulation

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Cochrane and Kelly (1986; *J. Geophys. Res., 91*: 10,645-10,659) proposed a cyclonic gyre as the large-scale mean circulation on the Louisiana-Texas (LATEX) shelf, produced by convergence of coastal current in the west and divergence in the east. While currents near the coast are wind and buoyancy driven, the origin of the eastward flow on the outer shelf and shelfbreak, which forms the seaward limb of the gyre, as well as the near-shore divergence in the east, are not known. A numerical model is used to show that the shelfbreak current is driven by collision and stalling of westward-propagating Loop Current eddies in the northwest Gulf, and divergence in the east is caused by shoreward intrusions along the Mississippi canyon. On the other hand, alongshelf transport with magnitudes of $O(1.5x10^5\ m^3s^{-1})$ is primarily due to wind. Model results also show that, in the absence of westward wind, the less-saline water from the Mississippi does not spread onto the LATEX shelf.

A Comparison of the Hydrographic Characteristics and Circulation of the Southern Sargasso Sea and the Western Caribbean Sea in the Winter 1992, 1993, and 1994

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A hydrographic transect (to 1000m) and surface samples were taken from the southern Sargasso Sea (25-27◦N) to the coast of Colombia (11◦N) in February-March 1992 and 1993 and across the Cayman basin in 1994. Temperature, salinity, oxygen, phosphate, and chlorophyll a were measured. Water mass distributions (Subtropical Underwater, 18° Water, Tropical Atlantic Central Water, and Antarctic Intermediate Water) showed distinct differences between the southern Sargasso Sea, the northern Caribbean Sea, and the southern Caribbean Sea. Only the southern Caribbean was truly tropical with TACW and AAIW showing transitional characteristics in the northern Caribbean. Surface chlorophyll abundance was lower in the Sargasso Sea (0.05 mg m^{-3}) than in the Caribbean Sea (0.05-0.15), and lower in 1993 and 1994 in the Caribbean Sea than in 1992. Geostrophic transport

of the Caribbean Current south of Jamaica was 31.5 Sv and 32.2 Sv in 1992 and 1993 suggesting little inflow through the Windward Passage in winter.

1992 differed from 1993 in the presence of a strong divergence between 12 and 14°N characterized by low temperature, high salinity, and high chlorophyll indicating upwelling of SUW. This feature also affected the structure of the Caribbean Current. In 1992 the current was fast (0.5 m sec^{-1}) and narrow whereas in 1993 it was slow (0.3 m sec^{-1}) and broad (with a consequent narrowing of the Panama-Colombian countercurrent near the coast). Although it is impossible to say whether this is an example of interannual variability, it is interesting to speculate that the 1992 pattern represents a teleconnection to the 91/92 El Niño. Easterly winds from the southern Caribbean in 1985-1991 were anomalously strong for fall 1986 and 1991. I will be interested to hear if other conference participants have data which would bear on this issue.

A Multivariate Time Series Model to Predict Hurricane Tracks

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The stochastic behavior of hurricane tracks are expressed by a vector autoregressive time series model. Historical data and correlation analysis were used to identify the structure of a typical hurricane track. Parameter estimation schema is based on recursive and iterative algorithms. Recursive approach is used when small number of points have been collected from a hurricane. On the other hand, iterative algorithms are used when enough information for optimal estimation is available. The multivariate time series model was used to predict hurricane tracks during the 1990 hurricane season in the North Atlantic ocean. Prediction errors from the vector autoregressive model are compared with errors from the NHC90 model.

Data Assimilation Experiments with a High Resolution Model of the IAS Embedded in a Low Resolution Atlantic Model: Some Preliminary Results

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Sea surface temperature observations are assimilated into a high resolution (one sixth of a degree) two and a half layer model with thermodynamics of the Intra-Americas Sea, embedded in a similar but low resolution (half of degree) model of the Atlantic. Both models are forced by the Hellerman-Rosenstein climatological wind stresses with a Haney-type thermal forcing at the surface. Simple parameterizations of entrainment-detrainment are employed. The impact of data assimilation is measured comparing the analyses to data

not assimilated by the model. Hindcast experiments to measure the models' ability to retain the information provided by the data are also discussed.

A Numerical Study of the Circulation and Sea Surface Temperature of the Gulf of Mexico with a 2½ Inhomogeneous Layers Model

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The circulation of the Gulf of México is simulated with a 2½ inhomogeneous-layers numerical model. The most complete experiment includes the influence of climatic winds, heat fluxes at the surface and between layers, entrainment and boundary conditions which produce the Loop Current (LC).

Experiments removing some of these inputs clarify their relevance respect to observed features of the Western Boundary Current (WBC), the predominant cyclonic circulation in the southwest region and the sea surface temperature (SST).

The WBC is mostly due to the wind but also to the rings shed by the LC. Removing the wind the WBC transport is reduced by more than half. There is a weaker reduction when the LC rings are removed. Since a fraction of the entrainment is directly related to the heat flux, there is a seasonal thickening of the surface layer reaching its maximum by August. The WBC seasonal cycle intensity is influenced by both, the surface heat flux and the variation of surface layer thickness.

The positive wind stress curl in the southwest is the main contributor that produces the cyclonic circulation there. Minimal effects arise from the LC rings. Only when the heat fluxes are included the simulation shows the observed permanence of relatively warm waters. Without the surface heat flux, the dome associated with the cyclonic circulation induces colder waters than the observed ones.

In the northern region the seasonal SST variation is smaller than the observations, while in the southern part they are in agreement. The phase of the SST variation is well reproduced in all the domain.

The simulations show a faster decay of detached rings when the entrainment is included.

An Investigation of Caribbean Mesoscale Variability Utilizing NRL Global Ocean Model Data

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A quarter degree, 5.5 layer, thermodynamic global ocean model experiment with daily ECMWF 1000 MB winds has been run by the Naval Research Laboratory. This model has been used in numerous model-data comparisons.

This research utilizes model data to focus on the Caribbean and Gulf of Mexico regions covering the years 1981-1993. Transport and sea surface height deviation time series have been extracted for all passages in the Antilles from the Yucatan Channel to Grenada Passage. In addition, time series of net transport and sea surface height deviation have been obtained for slices bisecting the region at various longitudes.

Analysis of the advection of potential vorticity through St. Vincent passage indicates that some mesoscale features observed west of the passage originate outside the Caribbean. These features cross the Caribbean basin in a northwesterly direction towards the Yucatan channel.

Time variations in net transport through the Yucatan Straits are related to similar variability in the transport of the Florida Current at 27°N STACS. This variability is also influenced to a lesser extent by the eddy shedding of the Loop Current in the Gulf of Mexico.

Modeling the Intra-Americas Sea

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Several versions of the Navy layered ocean model encompass the Intra-Americas Sea (IAS) region. These include a 1/8°, 6-layer North Atlantic model north of 20°S, a 1/4°, 5.5-layer, thermodynamic global model and a 1/8°, 6-layer global model. All have realistic coastline geometry and the finite depth versions have realistic bottom topography.

In the global thermodynamic model, the thermohaline circulation at 20°S in the Atlantic is consistent with Schmitz and Richardson's (DSR, 1991) estimate of the northward transport in the upper layers. The horizontal and vertical distribution of this transport from the global model are used to specify the inflow at the southern boundary of the basin-scale model. Model simulations which do not include the thermohaline circulation give unrealistically low eddy variability in the IAS.

Consistent with Schmitz and Richardson's analysis (DSR, 1991) there is an absence of South Atlantic water at the depth of the undercurrent in the Straits of Florida. Associated with the EUC is strong upwelling along the equator such that the net northward transport switches from the undercurrent layer south of the equator to the first layer north of the equator. Corrections to the ETOPOS5 topographic dataset, especially in the southeast Bahamas were critical for simulating realistic transport through the Straits of Florida and east of the Bahamas.

Simulations forced by the Hellerman-Rosenstein (JPO, 1983) monthly mean wind stress climatology and by ECMWF 1000 mb winds have been performed and comparison of results reveals significant differences in the IAS and adjacent waters.

On the Baroclinic Circulation of the Gulf of Mexico During June-July 1989

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The baroclinic circulation of the Gulf of Mexico during June-July of 1989 is described. Hydrographic data were collected aboard the R/V Justo Sierra between 26°N and 18°N latitude, and 98°W and 85°W longitude, from the surface to 3000 m. The data allow us to characterize the surface (0-500 m), mid-depth (500-1000 m), and deep circulation (1000-3000 m) of the entire Gulf of Mexico with the exception of the North and Northeastern portion of the Gulf and the Yucatan Channel. During this time the most energetic baroclinic circulation of the Gulf of Mexico was dominated by an anticyclonic ring centered at ~ 23°N, 95°W and flanked to the north and south by two cyclones centered at ~ 25°N, 95.5°W and ~ 20.5°N, 93°W, respectively. The northernmost cyclone was flanked to the east by an anticyclone centered at ~ 25°N, 91°W, thus forming an anticyclone-cyclone pair. The most energetic anticyclone is observed beginning to interact with the westernmost boundary of the Gulf of Mexico, giving rise to a north flowing western boundary current jet parallel to the continental shelf break between ~21°N and 24°N. The entire hydrography, vertical and horizontal distribution of temperature, salinity, dissolved oxygen and micronutrients in the Gulf is controlled by the coupled interaction of cyclonic-anticyclonic ring pairs. The rings control the upwelling and downwelling of the water masses and thus constitute a natural pumping mechanism responsible for the formation of Gulf Common Water.

Cyclonic and Anticyclonic Rings' 3-D Distribution in the Western Gulf of Mexico

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During March 1985 hydrographic measurements were taken aboard Justo Sierra vessel during Argos 85-1 cruise. The study area included the western Gulf of Mexico - between 18°-26°N latitudes and 92°-98°W longitudes. Geostrophic velocities were calculated from the density distribution measured from 3000 db up to the sea surface. Baroclinic velocities were estimated at different depths by choosing different levels of no motion. Horizontal velocity gradients were also computed to eventually determine rings kinematic properties.

The horizontal velocity field at sea surface reveals several cyclonic and anticyclonic circulation features within the area of study. A big cyclonic ring, located at 24°N, 95°W dominates the western gulf circulation together with a strong western boundary current. The cyclonic ring is being flanked by a long, elongated anticyclonic ring which is enduring a subdivision process. Other important anticyclonic and cyclonic circulations are also found within the area of study. Tridimensional views of the volumetric surfaces defined by relative vorticity isolevels show the extent and configuration with depth of these cyclonic and anticyclonic features.

On the Western Boundary Current of the Gulf of Mexico

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Analysis of hydrographic data from the Argos cruises conducted between 1984 and 1989 in the Gulf of Mexico reveals the existence of a north flowing western boundary current jet along the continental shelf slope of the western Gulf of Mexico between ~ 20°N and ~ 25°N latitude. The current is formed by the collision of anticyclonic Loop Current rings against the western margin of the Gulf and not by the annual wind stress curl cycle as proposed by, for example, Sturges, (1993). The average speed of the current and the average mass transport between 95°-96°W at 25°N is estimated at 25 cm s^{-1} and 4 Sv, respectively. The current extends from the surface to a depth of ~ 500 m, with its core at ~ 100 m.

Reference: Sturges, W., The Annual Cycle of the Western Boundary Current in the Gulf of Mexico, *J. Geophys. Res.*, 98, No. C10, pp. 18,053-18,068, October 15, 1993.

On the Barotropic Response of the Gulf of Mexico-Caribbean Sea System: Sensitivity to Atmospheric Forcings and Interactions with the Atlantic Ocean

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An assessment of the barotropic response to local atmospheric forcings and the exchanges through the multiple channels and passages connecting the Gulf of Mexico-Caribbean Sea with the Atlantic Ocean is carried out in the linear and non-linear regimes. The sensitivity study is based on simulations generated by a spectral shallow water equation model (Lozano and Candela, 1994). The atmospheric forcings are derived from ECMWF twice daily analysis. Comparison of the model generated fields with observations are carried out using two years (1985-86) of sea level observations at 14 locations and five years (1985-90) of daily transport fluxes of the Florida Current at 27°N derived from cross-stream voltages and profiling data (J. C. Larsen, Trans. Royal Soc., A, 1991).

Modeling Maximum Sea States During Hurricanes in the Intra-Americas Sea

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A simple model is developed to evaluate the sea state at a given location in deep water under severe storm conditions, especially hurricanes. The model is based on the statistics of hurricane parameters (radius of maximum wind, central pressure deficit, forward velocity, and track location with respect to the selected site) registered within 100 nautical miles of the prespecified location. A parameterized time- and space-dependent wind wave model is used to calculate the maximum sea state during hurricanes. Multiple hurricane occurrences are generated through a Monte Carlo simulation. The corresponding sea state is calculated for each synthetic storm. Then the cumulative probability distribution of sea state is defined.

The second stage of the analysis consists in defining a stochastic model for hurricane occurrences. Finally, the probability of hurricane occurrences is related to the derived distribution of sea state to yield the probability that the sea state will not exceed a given value within a prespecified time interval, at a previously ascribed site. Statistical risk criteria, such as the return interval, the probability of exceeding and the nonencounter probability, are then derived.

Evolution of Eddies in the Straits of Florida with Implications for Larval Recruitment

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Recent and historical measurements of flow variability, water mass distribution and satellite derived surface thermal fields are used to describe the formation and evolution of cyclonic eddies along the Florida Current front from the Gulf of Mexico to the southeast U. S. continental shelf. Eddies with spatial scales of 200, 100 and 20 km have been identified. The larger eddies form off the Dry Tortugas associated with the turning of the Loop Current into the Straits of Florida and later evolve into 100 km scale eddies off the lower Keys. Further disintegration of these features coupled with flow instability appears to result in smaller 20 km scale vortices in the middle to upper Keys and extending to the northern exit of the Straits. Gyre formation provides enhanced food supply, retention and shoreward transports for successful recruitment in the western and lower Florida Keys of locally spawned snapper and grouper larvae. A previously unknown retention area for spiny lobster larvae on the southwest Florida shelf has been identified from satellite tracked drifter trajectories, and a local lobster recruitment pathway combining advective influences from the Tortugas gyre, Loop Current and shelf circulation is proposed.

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The Intra-Americas Sea (IAS) has a great scientific, technological, economical, social, and political importance and require the cooperation at global, regional and multinational levels. Several countries share the IAS requiring for the improvement of the knowledge of oceanographic processes a spirit of international cooperation. The Gulf of Mexico (GOM) as the northern part of the IAS has been thoroughly studied by Cuba, Mexico and the U. S. Forecast of the resources production (fisheries, oil exploitation, coastal development), effects of storm events and pollution in management are urgently needed for which a shared vision within the context of academic interdisciplinary collaboration is envisaged. Bilateral partnership between ICMyL-UNAM and TAMU has been casual and continues for a long time. Since 1992 a new partnership was formally started in the framework of a MOA between the two institutions. It has started as a bilateral agreement for benthic research with a number of cruises and studies. Resulting information is integrated in publications on the processes occurring in the western GOM. This new partnership includes "rules of the game" with mature and adequate attitudes in academic collaboration: initial bilateral phases of planning, trust between partners, continuous dialogue, and development of programs that include the sharing of human resources and equipment, with the joint presentation of results. Commitments and rights in this new partnership are based in the mutual respect, trust, goodwill and solidarity representing a promising future. Main result of this collaborative effort is the understanding of benthic processes in the western GOM.

Density Structure Oscillations at "El Pichincho": Possible Implications on Pelagic Fisheries

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Initial interest in the possibility of unusual physical phenomena occurring at the area known as "El Pichincho" in the Mona channel was fueled by anecdotal observation by fishermen of surface slicks, turbulence and unusually high fisheries yield. This area, with an accented bottom topography, occupies a boundary between the Atlantic Ocean and the Caribbean Sea. The most significant feature of the bottom topography is a ridge which extends from the northeast of Hispaniola to Puerto Rico. Its shallowest depth aside from insular platforms is of approximately 250 meters. To the north, on the Atlantic side, there is pronounced slope towards the Puerto Rico Trench. To the south, the slope in the Caribbean is significantly less abrupt.

In our first survey a CTD was used to characterize the salinity-temperature structure at 17 stations in two transects, one across and one along the bottom ridge. We found substantial

variability of the density structure from station to station. A time vs. depth plot of the Sigma-t=24 isopycnal for all stations indicated the temporal and cyclic nature of the phenomenon. On a second cruise, this was verified by performing consecutive hourly CTD casts at a central station. CTD casts on all side of the minimum depth zone indicate that the phenomena occurs at all stations.

We hypothesize that the physical disturbance results in an upward displacement of the deep scattering layer into the euphotic zone therefore causing aggregation of predators.

How Does Variability in the Intra-Americas Sea Affect Moisture Transport Onto Surrounding Continents?

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The Intra-Americas Sea (IAS) is the principal pathway and a source region for water transport to all the land masses surrounding it. While the gross features of the transport are controlled by the large-scale dynamics (e.g., the Bermuda High in summer; mid-latitude planetary waves in winter), the details of the transport are presumably sensitive to variability in the IAS itself. Moreover, very complicated tropical-extratropical interaction dynamics affect the moisture flux over the southern U.S.

A project is described which combines the available data and model resources in an attempt to identify preferred patterns of air-sea interaction over the IAS, and to determine how much of the variability in oceanic and atmospheric fields (especially in moisture and heat fluxes) is due to these interactions. Moisture transport sensitivity is investigated in the first instance using NMC-reanalyzed atmospheric and oceanic data sets. These data sets allow identification of large-scale atmospheric and oceanic conditions under which the flux is enhanced or inhibited. Regional-scale numerical models (the NMC ETA atmospheric model and the Mellor-Blumberg ocean model, both configured for the IAS region), with mesoscale resolution, are being deployed to compensate for the coarse data resolution over the region of interest and to allow perturbed experiments to be conducted.

One of the aims is to determine and quantify the influence of SST perturbations associated with the IAS jets, eddies, and fronts on the atmospheric transport of heat and moisture.

Non Linear Drift Effects in Cyclonic Boundary Eddy System Along the Florida Keys Physics, and Potential Impacts on Fisheries Recruitment

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Under the dominant easterly wind climate in the Straits of Florida, surface wind stress induces an onshore Ekman drift and coastal downwelling. The resulting onshore transport is substantially increased by Ekman drift enhancement due to the surface current which opposes the surface wind, and modified in its alongshore structure by cyclonic eddies in the boundary region between the Florida Current and the Florida Keys.

A significant effect of the Ekman drift modification by currents is that cyclonic coastal eddies can capture and for some time retain biota carried by the Florida Current, and also allow the effective local retention of fish larvae and weakly swimming juveniles.

This effect is not dependent on the Florida Current, per se. It is thus likely to have ramifications also for dispersal of planktonic eggs and larvae along the southern coasts of Cuba, Hispaniola, and Puerto Rico.

A Circulation Model for the Intra-Americas Sea (IAS)

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The Mellor-Blumberg Princeton Ocean Model (free surface, split mode, sigma coordinate) is being implemented for the Intra-Americas Sea (IAS). The aim is to evolve the model for use in process studies (e.g., air-sea interaction related to short-term climate variability) and for use as an experimental nowcast/forecast system. The initial domain extends from 6 to 30°N and from 55 to 98°W; thus, it includes the Caribbean Sea, Gulf of Mexico, Straits of Florida, and a sizable portion of the western North Atlantic. The model's grid is ca. 20 x 20 km in the horizontal, and it has 15 levels in the vertical. The time step is 15 minutes for the external mode and is 25 seconds for the internal mode. The DBDB5 digital database is used for the bottom topography, as edited with the assistance of a standard chart. The Levitus climatology is used to initialize the temperature and salinity fields. Climatology is used to specify open boundary conditions. The Hellerman-Rosenstein winds are used for spinning-up the model.

In preparation for the model runs, five years of monthly MCSST data were analyzed. Anomalies relative to the five-year annual cycle have maximum variance over the continental margin of the northern and eastern Gulf. The first three EOFs account for 94% of the variance; the predominant time scale is several months. The NMC reanalysis for the North Atlantic will be used to determine other properties of the mean and variance.

Initial spin-up studies demonstrate the major circulation features of the IAS, including the Caribbean, Yucatan, Loop, Florida, and Antilles Currents, plus mesoscale eddies. Observing system requirements for model validation, initialization, assimilation, and verification are outlined.

Predictions for Sea-Air Rescue in the Straits of Florida

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A continuing exodus of economic and political refugees from various Caribbean nations in small craft is taxing the ability to perform air-sea rescue at several points in the basin. One of the most pressing areas of concern is the Straits of Florida between Cuba and Florida where thousands of people have attempted to cross the 168 km on rafts, some consisting of nothing more than a set of inner tubes. A set of model simulations based on a primitive equation model of the Florida Current in the Straits and a sub-grid stochastic turbulence code to estimate Lagrangian trajectories is applied to the problem of predicting rafter positions given various weather conditions and raft characteristics. The basic characteristics of the Florida Current model and the particle based turbulence simulation are presented. This is followed by a discussion of the problem of predicting raft leeway, i.e., how a raft will respond to the combination of currents and wind in the Straits. Finally, simulations are inter-compared with observed trajectories of actual rafts and surface drifters. The model set is shown to have reasonable capabilities to recreate the basic drift pattern in the central Straits, but has some problems with the drift along the coast of Cuba. More needs to be known on the range of characteristics of air-sea rescue targets to improve these types of models.

Stochastic Prediction of Coastal Sea Level Change in the Intra-Americas Sea

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Predicting probable coastal flood levels is critical as input to the design of coastal structures and defenses. We develop statistical tools to make the best use of local data and global climate change predictions. We emphasize that flooding probabilities depend on tidal and surge influences as well as on the change in mean sea level. Changes, taking into account all three variables, may be estimated by extrapolating present trends plus scientific interpretation of future climate. Uncertainties in predicting climatic change are difficult to assess, but uncertainties associated with trend extrapolation can be estimated statistically and reduced by planned observation programs such as the Intergovernmental Oceanographic Commission's GLOSS (Global Sea Level Observing System) regional effort in the Intra-Americas Sea.

Assessment and Control of Marine Pollution

in the Wider Caribbean Region (CEPPOL)

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The Regional Programme for the Assessment and Control of Marine Pollution in the Wider Caribbean Region (CEPPOL) was formulated in cooperation with UNEP-OCA/PAC, UNEP-CAR/RCU and the Intergovernmental Oceanographic Commission of UNESCO (IOC), with the participation of the IOC Sub-Commission for the Caribbean and Adjacent Regions (IOCARIBE).

The long-term objective of the program is to provide governments of the region with the guidelines and information required for the establishment and enforcement of the necessary measures to control and reduce marine pollution. The following activities are being developed: Assessment of Landbased Sources of Pollution; Baseline Studies on Pesticide Contamination; Monitoring and Assessment of the Sanitary Quality of Bathing and Shellfish-Growing Waters; Monitoring and Control of Oil Pollution; Monitoring and Control of Pollution by Marine Debris; Site Specific Studies in Damaged Ecosystems; Development of Pollution Control Measures and Environmental Quality Criteria and Research on the Significance of Eutrophication in the Wider Caribbean Region.

The Importance of Circulation Modeling in the Intra-Americas Sea to Fisheries Management

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There are several fundamental questions that fisheries managers ask fisheries scientists for which improved understanding of circulation and the ability to predict circulation are critical. One set of questions relates to distribution and the second set to transport. The former includes questions when certain species (e.g. *coryphaenses sp.*) appear in a fishery. The latter involves source and fate such as sources of larval recruitment to adult populations. This is important in establishing conservation regulations to protect spawning stocks. Impacts of pollution events involve both concepts. Evaluation requires knowledge of where vulnerable living marine organisms are (often larvae are the most vulnerable) and where the pollutants will go. The multitude of local area interests in the Intra-Americas Sea make these questions particularly critical to fisheries managers in this region.

Long and Short Term Effects of Oceanographic Variables on Marine Resources within the Intra-Americas Sea

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Biological processes are often major structuring forces in the maintenance, organization and evolution of tropical systems. Changes in the physical environment have transformed ecosystems, caused extinctions, and significantly disrupt biological distributional patterns over geological time scales. However, physical processes within the IAS have been directly and indirectly involved in changes in the distribution of fisheries resources and their habitats within ecological time scales. These are discussed in this paper.

Regional population extinctions of components which structure reef fisheries habitat were mediated by surface currents. For example, the pathogens responsible for the massive dieoffs of Diadema antillarum throughout the tropical and subtropical western Atlantic was dispersed throughout the region by surface currents. Commercial sponge extinctions throughout the IAS have been attributed to changes in the oceanic conditions including positive thermal anomalies. Regional coral bleaching events which affected coral reefs within the IAS were attributed to changes in sea surface temperatures and UV radiation. Regional decline of coral populations throughout the IAS during the last few decades have been attributed to hurricanes, sea surface temperature changes, and transport of disease by surface currents. Changes in the physicochemical water quality parameters have been implied in massive fish kills within and beyond the IAS. Upwelling, fronts, eddies, gyres, surface currents and other mesoscale phenomena have been associated with migration and with the seasonal distribution of offshore and shelf based fisheries resources within the IAS.

Physical oceanographic variables determine to a large extent the dispersal and recruitment mechanisms of eggs, larvae and of other propagules throughout the IAS. The dispersion pattern of pollutants from point and non-point sources are often dictated by hydrological conditions within a given area. The overall productivity of coastal ecosystems within the IAS is largely determined by sea water quality parameters within the water column. Proper management of marine resources within the IAS require large scale oceanographic studies if a regional approach is taken. However, small scale oceanographic studies are urgently needed to explain local variations in the spatial pattern of biotic and abiotic components of near shore and offshore resources.