Decadal prediction of physical and biogeochemical processes in the Gulf of Mexico and US Caribbean Sea, with impacts on new gear-restricted areas for Atlantic bluefin tuna

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Principal Investigator Institution: Southeast Fisheries Science Center

Associated NMFS Fisheries Science Center: Southeast Fisheries Science Center

Research Priority (#) for this Proposal: 4) and 5)

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Year 1 Request (all institutions): $80,376

Year 2 Request (all institutions): $59,378

Lead NMFS Investigator: John Lamkin

Lead NMFS Investigator organization: NMFS/SEFSC/Protected Resources/Early Life History

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List institutional breakdown of Year 1 budget (institution: funding request for year 1):

- University of Miami CIMAS: $80,376

List institutional breakdown of Year 2 budget (institution: funding request for year 2):

- University of Miami CIMAS: $59,378

Background

A large body of recent research has examined the potential impacts of climate change on marine species (Hollowed et al., 2013). As ocean temperatures have risen in recent decades, evidence of associated shifts in distributions of marine populations has increased (Nye et al., 2009; Pinsky and Fogarty, 2012). A common approach is to first define responses of species to current environmental conditions, and then estimate future impacts by applying present-day habitat models to predictions of future conditions, from global or downscaled climate models. However, these models typically do not consider decadal-scale natural variability, such as from the Atlantic Multidecadal Oscillation (AMO). At time scales relevant to management (years to decades), natural variability can significantly enhance, or nearly nullify temperature increases from climate change (Enfield and Cid-Serrano, 2006), and subsequent species responses. This decadal-scale variability has important management implications for fisheries resources. Inter-annual environmental shifts can impact recruitment, competition among species, and overlap between fishermen and targeted populations. To quantify these impacts in the short-medium term, which is the management timescale for most fisheries, a decadal-scale predictive model is much more appropriate and useful than a climate model. However, the success of a decadal model will depend on the predictability of the region in question.

Sea Surface Temperatures (SSTs) in the Gulf of Mexico (GoM) and Caribbean Sea (CBN) are strongly affected by the AMO; a long-term (30-70 year period) oscillation of North Atlantic SSTs (Enfield et al. 2001). This means that, at decadal to multi-decadal time scales, the effects of climate change on the GoM and CBN can be significantly enhanced or suppressed depending on the phase of the AMO (Enfield and Cid-Serrano 2006). Thus, for skillful predictions of the upper ocean temperatures in the GoM and CBN for the coming decades, future phase shifts in the AMO must be considered.

Studies have shown that upper ocean temperatures in the Pacific basin are not predictable beyond two years, as they are largely determined by the foot-prints of the atmospheric bridge from the tropical Pacific associated with the El Niño – Southern Oscillation (Newman 2007). In contrast, Coupled General Circulation Models (CGCMs) have repeatedly demonstrated that the warm (cold) phase of the AMO occurs in concert with increases (decreases) in the Atlantic Meridional Overturning Circulation (AMOC), which is the Atlantic branch of a slowly varying thermohaline and partly wind-driven global circulation system (e.g., Delworth and Mann 2000; Knight et al. 2005). This coherent relationship may allow us to predict the AMO, and thus regional SSTs, on a decadal time scale (e.g., Griffies and Bryan 1997; Collins and Sinha, 2003; Keenlyside et al. 2008). In fact, the decadal hindcasts/forecasts by CGCMs participating in the Coupled Model Intercomparison Project phase-5 (CMIP5) showed that a large portion of the North Atlantic SSTs north of ~ 20°N are predictable with up to 6 ~ 9 years forecast lead (Kim et al. 2012).

Given the relatively high decadal prediction skills for the North Atlantic SSTs, we can explore the upper ocean temperature changes in the GoM and CBN for the coming decade using the CMIP5 decadal forecast simulations. However, prediction skills in climate models are still subject to structural and parametric imperfections and many degrees of uncertainty (Collins et al., 2006; Meehl et al., 2009). In particular, as shown in our earlier FATE-supported work, CGCMs fail to simulate important regional-scale features, such as the projected weakening of the Loop Current in the 21st century (Liu et al. 2012). Therefore, for skillful predictions of the upper ocean changes in the GoM and CBN, we need to downscale the CMIP5 decadal forecasts using a high-resolution regional ocean model. In our earlier work, the concept of using a high-resolution regional ocean model to downscale global CGCMs for the GoM and CBN was successfully tested and showed great improvements in simulating features that are important in the region, such as the annual cycle of heat and volume transport across the Yucatan Channel, and projected changes in the 21st century under various emission scenarios (Liu et al. 2012).

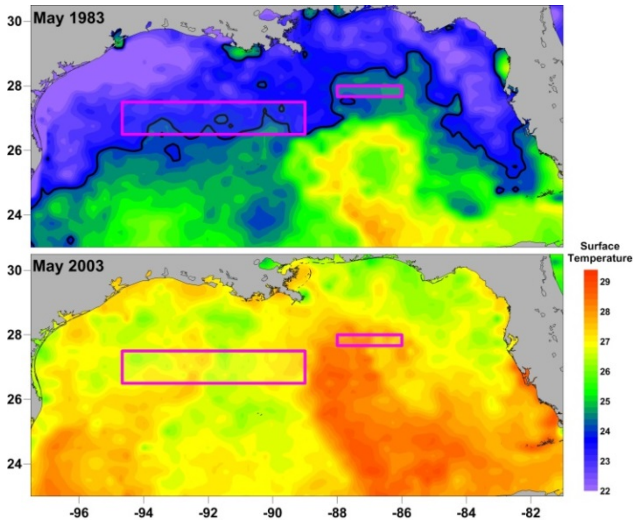

Figure 1: New gear-restricted closed areas for the GoM (pink), overlaid on mean May SST for a cold year (1983, top), and a warm year (2003, bottom). The 24°C isotherm represents the lower limit for BFT spawning (Muhling et al., 2010), and is shown in black for 1983. In 2003, the entire GOM was >24°C.

Decadal forecasts are fundamentally different from climate projections. While the latter are designed to project centennial time-scale trends, the former are designed to forecast decadal time-scale variations, which are subject to both anthropogenic climate change and natural variability. Therefore, while climate projections are largely determined by the external forcing (i.e., greenhouse warming), decadal forecasts rely on ocean initializations, which are usually derived from *in situ* observations or data-assimilated ocean reanalysis products.

Given our experience with projecting climate impacts on Atlantic bluefin tuna (BFT) spawning habitat in the GoM (Muhling et al., 2011), we propose to build and evaluate a decadal forecast system for physical and biogeochemical processes in the GoM and CBN. We will achieve this by downscaling the existing CMIP5 decadal forecast simulations to a regional scale, using the framework described in Liu et al. (2012, 2014). Results from the regional forecast system will provide insight into habitat conditions including estimates of uncertainty for the next decade (2015 - 2023).

The decadal forecast model could be applied to multiple research questions in the GoM and CBN. For this project, we propose to use a case study to demonstrate the utility of the model: namely an assessment of the impact of two new closed areas in the GoM on BFT. Like most Atlantic highly migratory species, BFT are managed under the dual authority of the Magnuson-Stevens Fishery Conservation and Management Act, and the Atlantic Tunas Convention Act (ATCA). Under the former, NMFS must manage fisheries to maintain optimum yield by rebuilding overfished fisheries and preventing overfishing. BFT are currently overfished, and undergoing overfishing, and consequently are managed under a rebuilding plan through to 2019.

The US is assigned an annual BFT quota, of which the pelagic longline fishery is assigned 8.1%. However, catches (landings plus dead discards) have been significantly over that sub-quota in recent years. As a result, two new restricted areas closed to longline fishing will be implemented in the GoM from 2015 (NMFS, 2014a). These will be enforced from April - May, the months when the highest numbers of interactions have historically occurred. The GoM is the primary spawning ground for the western Atlantic BFT stock, and spawning activity is concentrated from April to early June (Muhling et al., 2010). The closed areas will therefore reduce interactions between pelagic longline gear and large, mature BFT with high spawning potential. NMFS estimates that the new GoM closed areas would reduce dead discards by ~58% (NMFS, 2014a).

However, this estimate clearly depends on the degree of spatiotemporal overlap between BFT and the closed areas. In addition, the impact of this new measure on the protection of actively spawning fish is not clear. Distributions of both adult and larval BFT are known to be strongly determined by their oceanographic environment, and subject to high interannual variability (e.g. Teo et al., 2007; Muhling et al., 2010). The degree of spawning activity within the closed areas during April – May could vary substantially, depending on environmental conditions (Fig. 1). We therefore propose to:

1. Use historical biological and environmental data to build habitat models predicting interactions with:

a. All BFT

b. BFT discarded dead

c. BFT with a high probability of spawning

2. Apply these habitat models to spring environmental conditions from 2015 – 2023, derived from the decadal forecast model

3. Provide estimates of future variability in fishing mortality in the GoM to stock assessment scientists. This will allow the calculation of an environmental error term to be applied to future stock projections.

Approach

<u>Decadal Forecast Model</u>

The decadal forecasts will be based on the GFDL_CM2.1 10 member ensemble CGCM, and will be downscaled to a regional level using the Modular Ocean Model version 5 (MOM5, Griffies et al., 2004). The GFDL_CM2.1 hindcasts/forecasts are initialized by the GFDL ensemble coupled data assimilation (ECDA) system on January 1 every year from 1981 - 2012, and integrated for 10 years with temporarily varying anthropogenic and natural forcing (Yang et al. 2013). The hindcast skill score of GFDL_CM2.1 for the AMO is > 0.6, which is the threshold value typically used in operational forecast models (i.e. < 0.6 ~ 0.5 means "no-skill") (Fig. 2). However, hindcast skill for SSTs in the GoM/CBN is barely > 0.6. Regional forecasts from the downscaling model will likely improve this skill because unlike GFDL_CM2.1 (low-resolution global model), the downscaled model from this project will resolve regional ocean features.

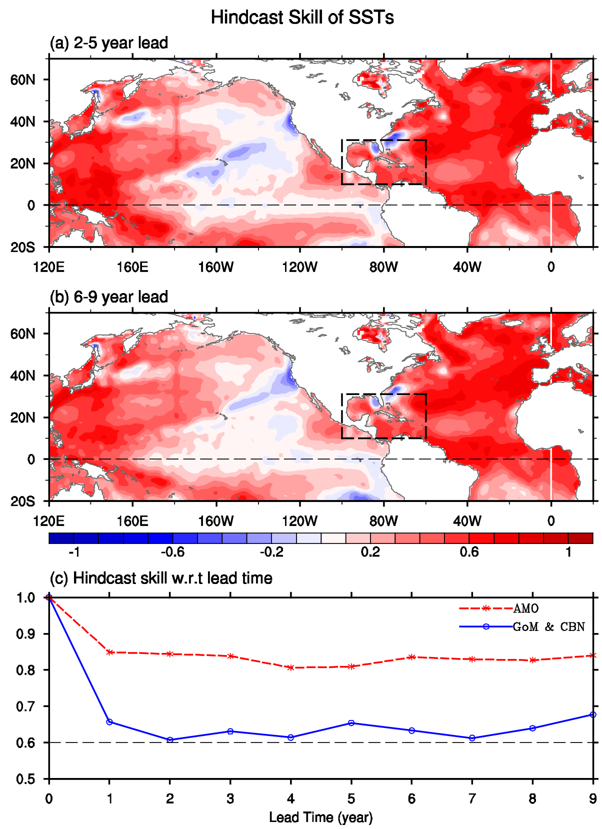

Figure 2. Hindcast skill of GFDL_CM2.1 for global SSTs, and AMO and SSTs in the GoM and CBN.

The downscaling model (MOM5) will be coupled to the TOPAZ (Tracers of Phytoplankton with Allometric Zooplankton; Dunne et al., 2005) biogeochemical model. TOPAZ includes all major nutrient elements, and 25 tracers describing cycles of carbon, nitrogen, phosphorus, silicate, iron, oxygen and lithogenic material (Dunne et al., 2012). It includes three explicit phytoplankton groups ("small", "large", and diazotrophic), and it traces dissolved oxygen, dissolved inorganic carbon and alkalinity, and includes highly flexible phytoplankton stoichiometry and variable chl:C ratios (Polovina et al., 2011; Dunne et al., 2012). The downscaling model domain will contain the Atlantic Ocean from 100°W to 20°E, and 65°N to 20°S, and will have a fully eddy-resolving horizontal resolution of 0.1° over the GoM and CBN region, decreasing linearly to

0.25° in the rest of the model domain. The initial and boundary conditions for the downscaling model will be obtained from the GFDL_CM2.1 decadal hindcasts/forecasts.

Our first task will be to understand and quantify the prediction skill of the regional forecast system. This will be achieved by downscaling the GFDL_CM2.1 decadal hindcasts. The downscaling model will be initialized on January 1 every year from 1981 to 2003 and integrated for 10 years using the initial and boundary conditions obtained from the GFDL_CM2.1 decadal hindcasts. Results from the regional hindcasts will be compared with available observations (i.e. World Ocean Atlas, SeaWiFS ocean color and historical CTD cast data) to understand and quantify the prediction skill of the regional decadal forecast system.

Once the regional hindcasts are completed, we will perform regional forecasts. For this, the downscaling model (MOM5-TOPAZ) will be initialized on January 1 of 2015 and integrated until December 31 of 2023. The regional forecasts will be performed for each of the 10 ensemble members to obtain the ensemble mean forecasts and their statistical significance.

Habitat Modeling

Habitat models for larval and adult BFT have been completed in the GoM previously (FATE projects 10-07, 12-05 & 07-03, Muhling et al., 2010, 2012), and so the strong influence of the oceanographic environment on spatiotemporal distributions is well known. For this project, we will modify existing models in several ways. Adult predictive models will run on data from the NMFS Pelagic Observer Program, and will predict both total catch rates of BFT (/1000 hooks), as well as catch rates of dead discards. It has been suggested that BFT die quickly when hooked in the GoM, due to thermal and hypoxic stress (Block et al., 2005), and so catch rates of dead discards may differ from total catch rates. Larval models will include only small, pre-flexion larvae (<4mm length), in order to better define spawning habitats. Areas with high predicted habitat suitability for both adult BFT and small larvae will be designated as spawning habitats.

Environmental variables will be extracted for the date and location of each biological data-point. We will consider surface temperature (NOAA Pathfinder, MODIS Aqua, HYCOM GOM Expt), temperature at 200m depth (HYCOM), surface current velocities (HYCOM, AVISO MADT), surface height (AVISO MADT), surface chlorophyll (MODIS Aqua, SeaWiFS) and water depth (NOAA GEODAS). The HYCOM GOM experiment is only available since 2003, and so habitat models will be trained using data from 2003 – 2013.

Habitat models will be completed using machine learning models, primarily artificial neural networks and boosted regression trees, in DTREG software. These are suitable for modeling multivariate, non-parametric relationships, and have been used with success previously for BFT (e.g. Muhling et al., 2010, 2012, 2014). Once models are complete, they will be applied to spring environmental fields from the decadal forecast model for years 2015 – 2023. The same variables used for model training (temperature at 0 and 200m, surface current velocities, surface chlorophyll) will be extracted from the decadal forecast model, and used for future projections. The proportions of adult habitat and spawning habitat protected by the closed areas in each year will be calculated, and the reductions in mortality (fish kept and discarded dead) will be quantified. As adult BFT migrate into the GoM as early as November-December each year, but do not start spawning until temperatures warm sufficiently April-May, adult habitat and spawning habitat are distinct, and will therefore be modeled separately. Reductions in interactions and mortality will be calculated based on a reduction of fishing effort, and a redistribution of effort outside the closed area, as described in Amendment 7 to the 2006 Fishery Management Plan (NMFS, 2014a).

We have every confidence that the decadal forecast model will be useful for predicting the GoM spring environment. However, if model accuracies are unacceptably low, habitat models will instead be applied to historical environmental fields derived from *in situ*, satellite and ocean model observations. The mean and variance of habitat protected and changes in mortality will instead be provided to stock assessment scientists.

Benefits

This project will directly address FATE Research Priority 5): "Evaluate the feasibility of forecasting oceanographic and climate processes and improving forecast skills for these processes and their ecosystem impacts over short (1-10 years) time periods." It will also be applicable to FATE Research Priority 4) "Examine the potential effects of climate variability, climate change, and fishing on managed species, protected resources, and ecosystems". Results will also directly address the high priority research objective from the NMFS Atlantic HMS management-based research needs and priorities report (NMFS, 2014b) of "Assessing the long-term ecological and socioeconomic impacts of closed areas for highly migratory species".

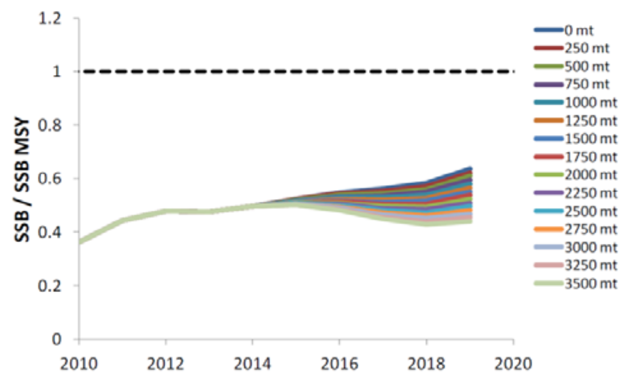

Figure 3: Spawning biomass for western Atlantic BFT as a proportion of biomass at Maximum Sustainable Yield, for a range of constant catches (Lauretta et al., 2014)

The most recent assessment for western Atlantic BFT shows the rebuilding potential of the stock across a range of catches and mortalities (Fig. 3). Results from this project will be provided to stock assessment scientists as future estimates of changes in mortality in the GoM, thus quantifying environmental effects on factors contributing to rebuilding potential. NOAA intends to review the effectiveness of the new closed areas in 2017 (NMFS, 2014a). Our results will be provided directly to that meeting, allowing stock managers to assess the effectiveness of this management measure.

Previous experience with the downscaled climate model from the 2010-11 FATE project also suggests that many other fisheries and management applications will be possible, highlighting the advantage of building a widely applicable product for multiple uses. Outcomes from the proposed work will add value to ongoing multidisciplinary projects, and will be of substantial benefit to fisheries managers and the scientific community.

Deliverables

Deliverables from this project will include:

1) High-resolution decadal forecasts for the GoM and US CBN for 2015-2023, including biogeochemical outputs such as chlorophyll and dissolved oxygen at multiple depths
2) Estimates of adult habitat and spawning habitat protected by new GoM closed areas, and estimates of interannual reductions in BFT mortality for 2015 - 2023
3) Analysis of effectiveness of this management measure in protected BFT spawning grounds, and reducing dead discards
4) Publication of results in scientific literature, and in ICCAT reports, which will be presented to the ICCAT Standing Committee on Research and Statistics (SCRS)
5) Formal presentation of results to stock assessment scientists and resource managers

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Budget

1) Personnel	Year 1		Year 2	
Yanyun Liu	6 months salary	$27,054	3 months salary	$13,527
Barbara Muhling	1 months salary	$6,375	3 months salary	$19,125
Sang-Ki Lee	1 months salary	$7,782		
Research Associate	1 months salary	$3,500		
Total Salaries		$44,711		$32,652
2) UM Fringe Benefits (38.2%)		$17,080		$12,473
3) Travel	FATE Meeting	$2,000		$2,000
8) Total Direct Charges		$63,791		$47,125
9) UM Indirect Charges (26%)		$16,586		$12,253
10) Total		$80,376		$59,378
Total project costs				$139,754

Budget Justification and Statements of Work

Year 1

The first year of the project will be primarily devoted to the initialization of the decadal forecasting model. Six months of salary is requested for Year 1 for Yanyun Liu, who will build and evaluate the downscaled decadal forecast system, supported by a research associate (1 month salary). The GFDL_CM2.1 decadal hindcasts will be run from January 1st each year from 1981 – 2003, and integrated for 10 years. One month salary is also requested for Sang-Ki Lee, who will work with Dr. Liu to design and test the forecast system.

Barbara Muhling will be tasked with developing habitat models, and applying these to environmental fields from the decadal forecast model. During the first year of the project, three months of salary is requested, to allow the collation of fisheries data, and larval survey data, and the extraction of environmental variables for catch locations. Dr. Muhling has several years experience with developing habitat models for Atlantic Highly Migratory Species. As the habitat models for this project will build on those developed in previous projects, 3 month salary will be sufficient for this portion of the project.

Year 2

The second year of the project will be devoted to the validation of the decadal forecast model, and the application of environmental fields to the predictive habitat models. Three months of salary is requested for Y. Liu, who will work to quantify to predictive skill of the decadal model compared to available observations. Final environmental fields will then be provided to Dr.

Muhling, who will use these to forecast overlap between BFT habitats and closed areas in the GOM on an annual basis through to 2023. Results will be summarized into an ICCAT report, and at least one manuscript for submission to a peer-reviewed journal.

In-kind support and collaboration

John Lamkin will be the NOAA-NMFS lead on the project, and will serve as the link between the other investigators and the SEFSC. He will contribute 3 months/year to the project as in-kind support.

David Enfield is the leading expert on the mechanisms of the AMO, and will provide valuable insight into the predictability of ocean conditions based on AMO cycles. John Dunne is an internationally regarded expert on biogeochemical processes and climate change, working at NOAA GFDL. He will assist with incorporating biogeochemical modules into the decadal forecasts. Rik Wanninkhof works with the NOAA Ocean Acidification (OA) program. He will be involved with the carbon and biogeochemical parameters in the decadal forecast experiments. Once the model is completed, Dr. Wanninkhof will also use output fields to explore the past and future ocean acidification (OA) along the east and gulf coast of the U.S.

Funding Mechanism

Funds will be transferred to the University of Miami through an existing cooperative agreement: the Cooperative Institute for Marine and Atmospheric Studies (CIMAS).

Project Timeline

The timeline for the proposed work is summarized below:

	Year 1				**Year 2**			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Downscale GFDL_CM2.1 decadal hindcasts								
Quantify the prediction skill of the decadal forecast system								
Collate fisheries and larval survey data, extract environmental variables								
Perform regional forecasts: 2015 - 2023								
Apply decadal forecast fields to habitat models								
Complete data analyses, prepare ICCAT and peer-reviewed publications								

Statement of Previous Results

The proposed project will continue our close collaborations between ocean modelers, ecologists and stock assessment scientists. B. Muhling was involved in a 2007 FATE project (07-03: Richards, Bakun and Muhling, "Decadal and basin scale oceanographic variability and pelagic fishery production in the Gulf of Mexico"), which linked larval fish communities and oceanographic variability in the GoM. Results from this project were incorporated into the larval bluefin tuna index, which is a direct input to the western Atlantic stock assessment. Results relating to this project were published in Muhling et al. (2012).

Initial work investigating climate change impacts on highly migratory fish species was funded through a 2010 FATE proposal involving B. Muhling, Y. Liu, S.-K. Lee and J. Lamkin (10-07: Muhling, Lee, Schirripa, Ingram and Lamkin, "Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning in the Gulf of Mexico using downscaled climate models"). This work provided the first downscaled climate model for the Gulf of Mexico. Model outputs have since been requested and used by scientists from the NOAA Southeast Fisheries Science Center, NOAA Protected Resources Division (Corals), Florida Fish and Wildlife Conservation Commission, Gulf of Mexico Fisheries Management Council and University of Miami. This previous project therefore demonstrates the high demand for products of this type, and the wide variety of uses for regional-scale, predictive environmental models. Results have been published in Muhling et al. (2011) and Liu et al. (2012).

B. Muhling also received additional FATE funding in 2012 (Muhling, Ingram, Cass-Calay and Walter: Incorporating indicators of environmental suitability and catchability into existing Atlantic bluefin tuna abundance indices from the Gulf of Mexico). This project used habitat models to investigate sources of variability in indices of abundance for adult bluefin tuna caught on longlines in the GoM. In addition, B. Muhling was a collaborator on a 2013 FATE project (Nero, Ingram and Muhling: Lagrangian based habitat assessment for bluefin tuna (*Thunnus thynnus*) spawning in the Gulf of Mexico"). This work used particle back-tracking techniques to investigate transport, growth and ecology of larval bluefin tuna, and provide further inputs to the larval bluefin tuna index. A spawning habitat model was developed using backtracked larval locations, and this model will be investigated for application to the project proposed here.

The investigators on this project therefore have extensive experience with the development of cutting-edge predictive models, and construction of environmental and oceanographic indices of direct relevance to stock assessment.

Curriculum Vitae: Barbara Muhling

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Education

2003 -2006: PhD: Marine Science, Murdoch University, Australia, Awarded October 2006
1998 – 2002: BSc with 1st Class Honors: Marine Science, Murdoch University, Australia

Professional Experience

July 2012 – Present: Associate Scientist, University of Miami: Cooperative Institute for Marine and Atmospheric Science (CIMAS)

September 2009 – July 2012: Assistant Scientist, University of Miami: Cooperative Institute for Marine and Atmospheric Science (CIMAS)

September 2007 – September 2009: Post-doctoral Research Scientist, National Research Council

October 2006 – September 2007: Research Scientist, Department of Fisheries, Western Australia

Recent Publications

Muhling, B.A., Smith, R.H., Vasquez, L., Lamkin, J.T., Johns, E.M., Carrillo, L., Sosa-Cordero, E., Malca, E. (2013) “Larval fish assemblages and mesoscale oceanographic structure along the Mesoamerican Barrier Reef System”. Fisheries Oceanography 22: 409-428.

Muhling, B.A., Reglero, P., Ciannelli, L., Alvarez-Berastegui, D., Alemany, F., Lamkin, J.T., Roffer, M.A. (2013) Comparison between environmental characteristics of larval bluefin tuna *Thunnus thynnus* habitat in the Gulf of Mexico and western Mediterranean Sea. Marine Ecology Progress Series 486: 257–276.

Liu, Y., Lee, S.K., Muhling, B.A., Lamkin, J.T., Enfield, D.B. (2012) Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. Journal of Geophysical Research 117: C05039, doi:10.1029/2011JC007555.

Muhling, B.A., Lamkin, J.T., Richards, W.J. (2012) Decadal-scale responses of larval fish assemblages to multiple ecosystem processes in the northern Gulf of Mexico. Marine Ecology Progress Series 450:37-53.

Lindo-Atichati, D., Bringas, F., Goni, G., Muhling, B., Muller-Karger, F.E., Habtes, S. (2012) Varying mesoscale structures influence larval fish distribution in the northern Gulf of Mexico. Marine Ecology Progress Series 463: 245-257.

Muhling, B.A., Roffer, M.A., Lamkin, J.T., Ingram, G.W. Jr., Upton, M.A., Gawlikowski, G., Muller-Karger, F., Habtes, S., Richards, W.J. (2012) Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bulletin 64:679-687.

Muhling, B.A., Lamkin, J.T., Quattro, J.M., Smith, R.A., Roberts, M.A., Roffer, M.A., Ramirez, K.A. (2011) Collection of larval bluefin tuna (*Thunnus thynnus*) outside documented western Atlantic spawning grounds. Bulletin of Marine Science 87: 687-694.

Muhling, B.A., Lee, S-K, Lamkin, J.T. (2011) Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. ICES Journal of Marine Science 68: 1051-1062.

Muhling, B.A., Lamkin, J.T., Roffer, M.A. (2010) Predicting the occurrence of bluefin tuna (*Thunnus thynnus*) larvae in the northern Gulf of Mexico: Building a classification model from archival data Fisheries Oceanography 19: 526-539.

Ingram, G.W., Jr., Richards, W.J., Lamkin, J.T., Muhling, B. (2010) Annual indices of Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico developed using delta-lognormal and multivariate models. Aquatic Living Resources 23: 35-47.

Funded Research

Principal Investigator: "Accounting for the Influence of Feeding Success on the Growth and Survival of Bluefin Tuna Larvae in Stock Assessment Efforts", NOAA-NMFS Bluefin Tuna Research Program, September 2013 – September 2014.

Principal Investigator: "Incorporating indicators of environmental suitability and catchability into existing Atlantic bluefin tuna abundance indices from the Gulf of Mexico", NOAA Fisheries and the Environment (FATE) Program, September 2011 – September 2012

Principal Investigator: "Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning in the Gulf of Mexico using downscaled climate models", NOAA Fisheries and the Environment (FATE) Program, September 2010 – September 2011

Co-investigator: "Management and Conservation Of Atlantic Bluefin Tuna (*Thunnus Thynnus*) And Other Highly Migratory Fish In The Gulf Of Mexico Under IPCC Climate Change Scenarios: A Study Using Regional Climate And Habitat Models", NASA Grant #NNH10ZDA001N-BIOCLIM, September 2011 – September 2014

Co-investigator: "Improving the NOAA NMFS and ICCAT Atlantic Bluefin Tuna Fisheries Management Decision Support System" NASA Ecological Forecasting Program, Grant # NNX08AL06G, March 2008 – March 2011

Co-investigator: "Decadal and basin scale oceanographic variability and pelagic fishery production in the Gulf of Mexico – a synthesis of 30-years of data for management applications" NOAA Fisheries and the Environment (FATE) Program, September 2007 – September 2009

Co-investigator: "Developing downscaled climate models for coral reef management into the 21st century". Coral Reef Conservation Program: January 2011 – January 2014

Co-investigator: "Coordinated Monitoring, Prediction and Assessment to Support Decision-Makers Needs for Coastal and Ocean Data and Tools" Southeast Coastal Ocean Observing Regional Association (SECOORA): Coordinated Monitoring, Prediction and Assessment to Support Decision-Makers Needs for Coastal and Ocean Data and Tools, June 2011–May 2016

Research Interests

Development of spawning habitat models for highly migratory Atlantic fish species
Multivariate statistical analyses of long-term datasets in relation to environmental trends
Climate change impacts on fish spawning and coral reef bleaching in the western Atlantic Ocean

Collaborators over past 48 months

F. Muller-Karger, S. Habtes (University of South Florida)
M. Roffer, M. Upton, G. Gawlikowski (ROFFS)
W. Ingram (NOAA-NMFS Pascagoula)
J. Franks, B. Comyns (University of Southern Mississippi)
J. Walter, S. Cass-Calay, G. Diaz, M. Schirripa, T. Gerard (NOAA-NMFS Miami)
E. Johns, R. Smith (NOAA-AOML Miami), S-K Lee, Y. Liu (University of Miami)
J. Quattro, R. Smith (University of South Carolina)
K. Ramirez (INAPESCA Mexico) A. Garcia, F. Alemany, R. Laiz (IEO, Spain)
J. Llopiz (Woods Hole Oceanographic Institution)

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Present Position
Scientist, with University of Miami, Cooperative Institute for Marine and Atmospheric Studies

Education

PhD, Old Dominion University, Norfolk, Va (Oceanography)	1995
MSc, Old Dominion University, Norfolk, Va (Oceanography)	1993
BSc, Inha University, Incheon, South Korea (Oceanography)	1991

Professional Service

Scientist, CIMAS, University of Miami	2011 - Present
Associate Scientist, CIMAS, University of Miami	2007 - 2010
Assistant Scientist, CIMAS, University of Miami	2005 - 2007
Postdoctoral Associate, CIMAS, University of Miami	2002 - 2004
Associate Scientist: Maritime Research Institute, Samsung Heavy Industries	1996 - 2001
Graduate Research Assistant, Old Dominion University	1991 - 1995

Refereed publications (last three years)

Ji, X., J. D. Neelin, **S.-K. Lee** and C. R. Mechoso, 2013. Interhemispheric teleconnections from tropical heat sources in intermediate and simple models. J. Climate, In-press.

Lee, S.-K., C. R. Mechoso, C. Wang and J. D. Neelin, 2013: Interhemispheric influence of the northern summer monsoons on the southern subtropical anticyclone. J. Climate, In-press.

Lee, S.-K., R. Atlas, D. B. Enfield, C. Wang and H. Liu, 2013: Is there an optimal ENSO pattern that enhances large-scale atmospheric processes conducive to major tornado outbreaks in the U.S.? J. Climate, 26, 1626-1642. doi:http://dx.doi.org/10.1175/JCLI-D-12-00128.1.

Liu, H., C. Wang, **S.-K. Lee** and D. B. Enfield, 2013: Atlantic warm pool variability in the CMIP5 simulations. J. Climate, 26, 5315-5336, doi: http://dx.doi.org/10.1175/JCLI-D-12-00556.1.

Menary M. B, C. D. Roberts, M. D. Palmer, P. R. Halloran, L. Jackson, R. A. Wood, W. A. Mueller, D. Matei and **S.-K. Lee**, 2013: Mechanisms of aerosol-forced AMOC variability in a state of the art climate model. J. Geophys. Res., 118, 2087-2096, doi:10.1002/jgrc.20178.

Wang, C., L. Zhang, **S.-K. Lee**, 2013: Response of freshwater and sea surface salinity to variability of the Atlantic warm pool. J. Climate, 26, 1249-1267, doi:10.1175/JCLI-D-12-00284.1.

DiNezio, P. N., B. P. Kirtman, A. C. Clement, **S.-K. Lee**, G. A. Vecchi and A. Wittenberg, 2012: Mean climate controls on the simulated response of ENSO to increasing greenhouse gases. J. Climate, 25, 7399-7420, doi: http://dx.doi.org/10.1175/JCLI-D-11-00494.1.

Larson, S., **S.-K. Lee**, C. Wang, E.-S. Chung, and D. Enfield, 2012. Impacts of non-canonical El Nino patterns on Atlantic hurricane activity. Geophys. Res. Lett., 39, L14706, doi:10.1029/2012GL052595.

Lee S.-K., W. Park, E. van Sebille, M. O. Baringer, C. Wang, D. B. Enfield, S. Yeager, and B. P. Kirtman, 2011. What caused the significant increase in Atlantic Ocean heat content since the mid-20th century? Geophys. Res. Lett., doi:10.1029/2011GL048856.

Lee, S.-K., D. B. Enfield and C. Wang, 2011. Future impact of differential inter-basin ocean warming on Atlantic hurricanes. J. Climate, 24, 1264-1275.

Liu, H., C. Wang, **S.-K. Lee** and D. B. Enfield, 2012. Atlantic warm pool variability in the IPCC twentieth-century climate simulations. J. Climate, 25, 5612-5628, doi:10.1175/JCLI-D-11-00376.1.

Liu Y., **S.-K. Lee**, B. A. Muhling, J. T. Lamkin and D. B. Enfield, 2012. Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. J. Geophys. Res, 117, C05039, doi:10.1029/2011JC007555.

Wang, C., S. Dong, A. T. Evan, G. R. Foltz, and **S.-K. Lee**, 2012. Multidecadal co-variability of North Atlantic sea surface temperature, African dust, Sahel rainfall and Atlantic hurricanes. J. Climate, 25, 5404-5415, doi:10.1175/JCLI-D-11-00413.1.

Wang, C., L. Zhang, **S.-K. Lee**, 2012. Response of freshwater and sea surface salinity to variability of the Atlantic warm pool. J. Climate, In-press.

Muhling, B. A., **S.-K. Lee**, J. T. Lamkin, and Y. Liu, 2011. Predicting the effects of climate change on Bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. ICES J. Mar. Sci., doi:10.1093/icesjms/fsr008.

Wang, C., H. Liu, **S.-K. Lee**, and R. Atlas 2011. Impact of the Atlantic warm pool on United States landfalling hurricanes, Geophys. Res. Lett., doi:10.1029/2011GL049265.

<u>Current projects</u>

NOAA/CPO/MAPP: Toward Developing a Seasonal Outlook for the Occurrence of Major U.S. Tornado Outbreaks, PIs: **S.-K. Lee**, R. Atlas, Chunzai Wang, 2012 - 2015.

NSF: The Southern Subtropical Anticyclones, PIs: **S.-K Lee**, and C. Wang 2011 - 2013.

NASA: Management and Conservation of Atlantic Bluefin Tuna (Thunnus Thynnus) and Other Highly Migratory Fish in the Gulf Of Mexico under IPCC Climate Change Scenarios: A Study using Regional Climate and Habitat Models, PIs: M. A. Roffer, J. T. Lamkin, F. E. Muller-Karger, **S.-K. Lee**, B. A. Muhling, and G. J. Goni, 2011 – 2015.

NOAA/CPO/MAPP: Variability and Predictability of the Atlantic Warm Pool and Its Impacts on Extreme Events in North America, PIs: C. Wang, **S.-K. Lee**, and D. B. Enfield, 2012 - 2015.

<u>Collaborators over past 48 months</u>

C. Wang, D. Enfield, S. Dong, L. Zhang, H. Liu, Y. Liu, G. Foltz (NOAA-AOML and CIMAS-Univ. of Miami)
R. Mechoso, D. Neelin and X. Ji (UCLA)
P. DiNezio (Univ. of Hawaii)
F. Muller-Kargers (University of South Florida)
M. Roffer (ROFFS)
B. Muhling, and J. Lamkin (NOAA-NMFS Miami)

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Current position

Postdoctoral Associate, CIMAS, University of Miami and NOAA/AOML 2010/08 - present

Education

PhD, North Carolina State University, Raleigh, NC (Marine Science) 2010
MS, Ocean University of China, Qingdao, P.R. China (Marine Meteorology) 2005
Dual BS, Ocean University of China, (Meteorology & Computer Science) 2002

Professional experiences

Graduate Research Assistant, North Carolina State University 2005/08 - 2010/07
Graduate Research Assistant, Ocean University of China 2002/01 - 2005/07

Publications

Liu, Y., S.-K. Lee, D. B. Enfield, B. A. Muhling, J. T. Lamkin, F. Muller-Karger, and M. A. Roffer, 2014. Potential impact of climate change on the Intra-Americas Sea: Part-1. A dynamic downscaling of the CMIP5 model projections. Submitted.

Muhling B. A., Y. Liu, S.-K. Lee, J. T. Lamkin, M. A. Roffer, and F. Muller-Karger, 2014. Potential impact of climate change on the Intra-Americas Sea: Part-2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. Submitted

Liu, Y., S.-K. Lee, C. Wang, D. B. Enfield, B. A. Muhling and J. T. Lamkin, 2014, Impact of the Atlantic multidecadal oscillation on North Atlantic Ocean circulation variability. Submitted.

Liu Y., L. Xie, J. M. Morrison, D. L. Kamykowski, W.V. Sweet, 2014, Ocean circulation and water mass characteristics around the Galápagos Archipelago simulated by a multi-scale nested ocean circulation model. International Journal of Oceanography, doi:10.1155/2014/198686..

Liu, Y., L. Xie, J. M. Morrison, and D. Kamykowski., 2013. Dynamic downscaling of the impact of climate change on the ocean circulation in the Galapagos Archipelago. Advances in Meteorology, 2013:837432, doi:10.1155/2013/837432, 18 pp.

Liu Y., S.-K. Lee, B. A. Muhling, J. T. Lamkin and D.B. Enfield, 2012. Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. J. Geophys. Res, 117, C05039, doi:10.1029/2011JC007555

Muhling, B. A., S.-K. Lee, J. T. Lamkin, and Y. Liu, 2011. Predicting the effects of climate change on Bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. ICES J. Mar. Sci., doi:10.1093/icesjms/fsr008.

Sweet W. V., J. M. Morrison, Y. Liu, D. L. Kamykowski, B. A. Schaeffer, L. Xie, S. Banks, 2009. Tropical instability wave interactions within the Galápagos Archipelago, Deep Sea Research, Part I, 56 (8), pp 1217-1229.

Schaeffer B. A., J. M. Morrison, D. Kamykowski, G. Feldman, L. Xie, Y. Liu, W.V. Sweet, A. McCulloch, 2009. Phytoplankton biomass distribution and identification of productive

habitats within the Galapagos Marine Reserve by MODIS, a surface acquisition system, and in-situ measurements Journal of Remote Sensing of Environment, 112(6), pp. 3044-3054.
Liu Q. Y., Y. Liu, F. Huang, 2008. A study of the response of ENSO phenomena to external forcing in the tropical west Pacific Ocean, Journal of Ocean University of China, 38, (3), 345-351.
Liu Q. Y., Y. Liu, 2008. An ability testing of experiment scheme for response of the intermediate ocean-atmosphere model to external forcing, Journal of Ocean University of China, 38, (1), 001-006.
Liu Y., Q. Liu, A. Pan, 2004. Seasonal-interannual and decadal variations of air-sea heat fluxes in the northern Pacific Ocean, Journal of Ocean University of China. 34 (3), 341-350.

Fields of interest

Biogeochemical ocean modelling, climate variability and climate changes, regional ocean modeling, ocean circulation dynamics, ocean-atmosphere interaction

Collaborators over past 48 months

S. K. Lee, C. Wang, D. B. Enfield, G.J. Goni (NOAA-AOML/PHOD)
J. T. Lamkin, B. A. Muhling (NOAA-NMFS/SWFSC)
M. Roffer (ROFFS)
F. Muller-Karger (University of South Florida)
R. Wanninkhof, R. van Hooidonk (NOAA-AOML/OCD)
J. M. Morrison (University of North Carolina, Wilmington)
L. Xie, D. L. Kamykowski, F. Semazzi (North Carolina State University)

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Education:
University of Miami, Rosenstiel School of Marine & Atmospheric Science - 1995 - Ph.D. Biological Oceanography
Texas A&M University - 1983 - M.S. Fisheries Science
Texas A&M University - 1976 - B.S. Wildlife & Fisheries Science

Employment History:
Larval and Juvenile Fish Ecology Team Leader, SEFSC 2004-
Lead Scientist, Fisheries Oceanography, SEFSC 2008-
Florida Bay Project Manager, Southeast Science Fisheries Center 2000 -2010
Commanding Officer, NOAA ship TOWNSEND CROMWELL 1997-1999
Southeast Fisheries Science Center, Resource Program Coordinator 1994 - 1997

Professional Activities

NASA Biodiversity and Ecology Forecasting Team
Federal Co-Chair, Interagency Florida Bay Program Management Committee (PMC).
South Florida Water Resources Advisory Committee
Fisheries and the Environment Steering committee
NASA Climate Change and Forecasting Team
DWH Damage Assessment and Restoration working groups

Selected Recent Publications

Lamkin, John T., Richards, W.J., Brown C., and Brinn, R. 2009. Seasonal and Spatial abundance and assemblages of Ichthyoplankton, Kuwait Waters 2002-2005. NOAA Tech Memo. 59pp.

Lamkin, John T, T. Gerard, E. Malca, A. Shiroza, B. Muhling, N. Davis, F. Fuenmayor, S. Whitcraft, L. Johns, R. Smith, N. Melo, G. Rawson, N. Idrisi, T. Smith, K. Brown. 2009. US Virgin Islands Larval reef fish supply study: 2007-2008 report. PRB-08-09-12

Muhling, B.A., Reglero, P., Ciannelli, L., Alvarez-Berastegui, D., Alemany, F., Lamkin, J.T., Roffer, M.A. (2013) Comparison between environmental characteristics of larval bluefin tuna *Thunnus thynnus* habitat in the Gulf of Mexico and western Mediterranean Sea. Marine Ecology Progress Series 486: 257–276.

Liu, Y., Lee, S.K., Muhling, B.A., Lamkin, J.T., Enfield, D.B. (2012) Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. Journal of Geophysical Research 117: C05039, doi:10.1029/2011JC007555.

Muhling, B.A., Lamkin, J.T., Richards, W.J. (2012) Decadal-scale responses of larval fish assemblages to multiple ecosystem processes in the northern Gulf of Mexico. Marine Ecology Progress Series 450:37-53Muhling, B.A., Lamkin, J.T., Quattro, J.M., Smith, R.A., Roberts, M.A., Roffer, M.A., Ramirez, K.A. (2011) Collection of larval bluefin tuna (Thunnus thynnus) outside documented western Atlantic spawning grounds. Bulletin of Marine Science 87: 687-694.

Lamkin, John T. 2005 Chapter 195. Suborder Stromateoidei. In: W. J. Richards, Ed. Laboratory guide for the identification of the early life history stages of fishes from the western central Atlantic. Lawrence, Kansas, Allen Press, Inc.

Muhling, B., J. T. Lamkin, M. Roffer 2010. Predicting the occurrence of bluefin tuna (Thunnus thynnus) larvae in the northern Gulf of Mexico: Building a classification model from archival data. Fish. Ocean. 19:6, pp 526-539.

Muhling, B., S. Lee, J. T. Lamkin Yanyun Liu 2011. Predicting the effects of climate change on bluefin tuna (Thunnus thynnus) spawning habitat in the Gulf of Mexico. ICES. doi:10.1093/icesjms/fsr008

Ingram, G. Walter, W. Richards, C. Porch, V. Restrepo, J. Lamkin, B. Muhling, G. Scott, and S. Turner. 2008. Annual indices of bluefin tuna (Thunnus Thynnus) Spawning biomass in the Gulf of Mexico developed using delta-lognormal and multivariate models. SCRS/2008/086

Lamkin, J. T. & W. J. Richards. 2000. A brief review and current status of bluefin tuna larval ecology. In Proceedings of a workshop on the biology of bluefin tuna in the mid-Atlantic. M. Lutcavage & B. E. Luckhurst, Convenors. Department of Agriculture and Fisheries.

Collaborators over the past 48 months

F. Muller-Karger, S. Habtes (University of South Florida)
M. Roffer, M. Upton, G. Gawlikowski (ROFFS)
W. Ingram (NOAA-NMFS Pascagoula)
J. Franks, B. Comyns (University of Southern Mississippi)
B. Muhling, J. Walter, M. Schirripa, T. Gerard (NOAA-NMFS Miami)
E. Johns, R. Smith, S-K Lee, Y. Liu (NOAA-AOML Miami)
J. Quattro, R. Smith (University of South Carolina)
K. Ramirez (INAPESCA Mexico) A. Garcia, F. Alemany, R. Laiz (IEO, Spain)
J. Llopiz (Woods Hole Oceanographic Institution)
B. Block and C. Reeb Stanford

Curriculum Vitae: David B. Enfield

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Education:

A.B., University of California, Berkeley (Geophysics/Physics)	1965
M.S., Oregon State University (Physical Oceanography)	1970
Ph.D., Oregon State University (Physical Oceanography)	1973

Professional Service:

UNESCO Phys. Oceanog. expert at the Naval Oceanogr. Inst. of Ecuador.	1973-1975
Science Liaison Officer for the IDOE JOINT-II Upwelling experi ment in Peru.	1975-1977
Research Associate, School of Oceanography, Oregon State University	1977-1981
Assistant Professor (Sr. Research), School of Oceanography, Ore. St. Univ.	1981-1983
Assistant Professor (tenure track), School of Oceanography, Ore. St. Univ.	1983-1987
Associate Professor (tenure track), College of Oceanography, Ore. St. Univ.	1987
Research Oceanographer, NOAA Atlantic Oceanog. and Met. Lab. (AOML)	1987-2008
Scientist, Cooperative Institute for Marine & Atmospheric Science (U of M)	2009-

Career refereed publications: 67 **h-index** = 28

ResearcherID: www.researcherid.com/rid/I-2112-2013

Refereed publications (last 10 years):

Lee, S.-K., B. E. Mapes, C. Wang, **D. B. Enfield** and S. J. Weaver, 2014: Springtime ENSO phase evolution and its relation to rainfall in the continental U.S. Geophys. Res. Lett., 41, doi: 10.1002/2013GL059137.

Lee, S.-k., R. Atlas, **D. B. Enfield**, C. Wang, and H. Liu, 2013: Is there an optimal ENSO pattern that enhances large-scale processes conducive to tornado outbreaks in the U.S.? J. Climate, 26, 1626-1642.

Liu, H., S.-k. Lee, C. Wang, and **D. B. Enfield**, 2012: Atlantic warm pool variability in the IPCC AR4 CGCM simulations. J. Climate, 25, 5612-5628.

Larson, S., S.-K. Lee, C. Wang, E.-S. Chung, and **D. B. Enfield**, 2012: Impacts of non-canonical El Niño patterns on Atlantic hurricane activity. Geophys. Res. Lett., doi:10.1029/2012GL052595.

Liu, Y., S.-k. Lee, B. A. Muhling, J. T. Lamkin, and **D. B. Enfield**, 2012: Significant Reduction of the Loop Current in the 21st Century and Its Impact on the Gulf of Mexico, *J. Geophys. Res.*, **117**, C05039.

Lee, S.-k., **D. B. Enfield,** and C. Wang, 2011: Future impact of differential inter-basin ocean warming on Atlantic hurricanes, *J. Climate*, **24**(4):1264-1275.

Lee S.-k., W. Park, E. van Sebille, M.O. Baringer, C. Wang, **D. B. Enfield**, S. Yeager, and B.P. Kirtman, 2011: What Caused the Significant Increase in Atlantic Ocean Heat Content Since the mid-20th Century? *Geophys. Res. Lett.*, L17607, doi:10.1029/2011GL048856.

Rauscher, S. A., F. Kucharski, and **D.B. Enfield**, 2011: The role of regional SST warming variations in the drying of Meso-America in future climate projections, *J. Climate*, **24**, 2003-2016, doi: 10.1175/2010JCLI3536.1.

Munoz, E., and **D. B. Enfield**, 2011: The boreal spring variability of the Intra-Americas low-level jet and its relation with precipitation and tornadoes in the eastern United States. *Climate Dynamics*, **36**, DOI 10.1007/s00382-009-0688-3.

Enfield, D.B., and L. Cid-Serrano, 2010: Secular and multidecadal warmings in the North Atlantic and their relationship with major hurricanes. *Int'l J. Clim.*, **28**, DOI: 10.1002/joc.1881

Lee, S.-k., C. Wang and **D. B. Enfield**, 2010: On the impacts of central Pacific warming events on Atlantic tropical storm activity. *Geophys. Res. Lett.*, **37**, L17702, doi:10.1029/2010GL044459

Jury, M.R., and **D. B. Enfield**, 2010: Environmental patterns associated with active and inactive Caribbean hurricane seasons. *J. Climate*, **23**, 2146-2160.

Muñoz, E., C. Wang, **D.B. Enfield**, 2010: The Intra-Americas Sea springtime surface temperature anomaly dipole as fingerprint of remote influences. *J. Climate*, **23**, 43-56.

Lee, S.-K., **D.B. Enfield** and C. Wang, 2008. Why do some El Ninos have no impact on tropical North Atlantic SST? *Geophys.l Res. Lett.*, doi:10.1029/2008GL034734.

Wang, C., S.-K. Lee, and **D.B. Enfield**, 2008: Climate response to anomalously large and small Atlantic warm pools during the summer. *J. Climate*, **21**, 2437–2450.

Lee, S.-K., **D. B. Enfield**, and C. Wang, 2007: What drives the seasonal onset and decay of the Western Hemisphere Warm Pool? *J. Climate*, **, 20**, 2133-2146*.*

Wang, C., S.-K. Lee, and **D.B. Enfield**, 2007: Impact of the Atlantic warm pool on the summer climate of the Western Hemisphere. *J. Climate*, **20**, 5021-5040.

Enfield, D.B., and L. Cid-Serrano, 2006: Projecting the risk of future climate shifts. *Int'l J. of Climatology*, **26**(7):885-895.

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Enfield D.B., S.-K. Lee, and C. Wang, 2006: How are large Western Hemisphere Warm Pools formed? *Progress in Oceanography*, **70**(2-4), 346-365.

Enfield D. B., and S.-K. Lee, 2005: The Heat Balance of the Western Hemisphere Warm Pool. *J. Climate*, **18**, No. 14, 2662–2681.

Collaborators over the past 48 months

C. Wang, R. Atlas, M. Baringer (NOAA Atlantic Oceanographic & Meteorological Laboratory)
F. Muller-Karger (University of South Florida)
M. Karnauskas, B. Muhling, J. Lamkin (NMFS Southeast Fisheries Science center)
Lee, S-K, Y. Liu, H.Liu (Cooperative Institute for Marine and Atmospheric Studies, University of Miami)
S. Larson, B. Mapes, B. Kirtman (Rosenstiel School of Marine and Atmospheric Science, University of Miami)
E. Muñoz (National Center for Atmospheric Research)
M. Jury (University of Puerto Rico - Mayaguez PR))
S. Rauscher (Los Alamos National Laboratory, NM)
S. Weaver (NOAA Climate Prediction Center)
L. Cid-Serrano (University of Concepción, Chile)

Curriculum Vitae: Richard H. Wanninkhof

Professional Preparation:

Berea College Ky	Chemistry B.A.	1980
Columbia University	Geology M.A.	1983
Columbia University	Geology Ph.D.	1986
Columbia University Ocean carbon and tracer studies		1986-1989 (post-doc)

Appointments:

Oceanographer at the Atlantic Oceanographic and Atmospheric Laboratory (AOML) of the National Oceanographic and Atmospheric Administration (NOAA) in Miami. 1991-present
Adjunct professor of the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. 1993-present
Research Associate LDGO, Columbia University 1989-1991

Synergistic Activities:

Co-chair GO-SHIP: Global Ocean Shipbased hydrographic investigations program: 2014-current
NOAA Ocean Acidification Steering Group; 2011 -current
Member IOC Deep Ocean Observing System scoping group; 2010- current
CLIVAR Southern Ocean CO_2 Climate Process Team member ;2012- current
Contributing author IPCC AR5 Chapter 3 Ocean Observations; 2013
Member U.S. Government Review Team for IPCC Chapters 6 and 30; 2013
SOLAS implementation plan working group 2 writing team member; 2006-2008
SOLAS implementation plan working group 2 data liaison; 2004-2008
Interim US SOLAS chair; 2002-2004
Co-chairperson of the CLIVAR/CO_2 repeat hydrography working group; 2000-2002
Member of the US JGOFS Steering Committee; 1998-2003
Member of the Steering committee of the Carbon Cycle Science Program; 2000-2003
Member of the Carbon Modeling Consortium; 1996-2002
Member of the planning committee for the North American Carbon Plan Data Management meeting 2004
Member of the organizing committee for the International Gas Transfer at water surfaces (ITWG) symposia in 1995, 2000, 2005, 2010, 2015
Fellow of the CIMAS Cooperative Institute. 1994-2010

Awards and Recognition:

ASLO John Martin Award (2012)
Excellence in refereeing for Journal of Geophysical Research Oceans (2011)
AGU Fellow [Biogeosciences section] (2009)
Excellence in reviewing for Geophysical Research Letters (2009)
Dept of Commerce group Silver Medal (remote environmental obs. with NESDIS) (2009)
Dept of Commerce group Gold Medal (ocean carbon group effort with PMEL) (2006)
NOAA Administrator's award (2002)
NOAA/OAR best paper award (1999, 2000, 2002)

Publication statistics (Web of Knowledge/WOS March 2014)

Total articles	160	(136 indexed WOS)
Citations	8981	
H-index	42	

Selected recent Publications:

Bakker, D. C. E. et al. (40 authors including Wanninkhof, R.), 2014: An update to the Surface Ocean CO2 Atlas (SOCAT version 2), Earth Syst. Sci. Data, 6, 69-90, 10.5194/essd-6-69-2014.

Ishii, M. et al. (23 authors including Wanninkhof, R.), 2014: Air-sea CO2 flux in the Pacific Ocean for the period 1990-2009, Biogeosciences, 11, 709-734, 10.5194/bg-11-709-2014.

Le Quéré, C. et al. (39 authors including Wanninkhof, R.), 2014: Global Carbon Budget 2013, Earth Syst. Sci. Data, 6, 1-29, doi:10.5194/essd-6-1-2014.

Rodgers, K.B. et al. (12 authors including Wanninkhof, R.) 2014: Strong sensitivity of Southern Ocean carbon uptake and nutrient cycling to wind stirring. Biogeosciences 11, 4077-4098.

Wang, Z. A., Wanninkhof, R., Peng, T.-H., Cai, W.-J., Hu, X., Huang, W.-J., and Byrne, R., 2013: The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a transregional coastal carbon study, Limnol and Oceanogr., 58, 325-342, DOI: 10.4319/lo.2013.58.1.0325.

Wanninkhof, R., 2014. Relationship between wind speed and gas exchange over the ocean revisited. Limnol and Oceanogr: Methods 12, 351-362.

Wanninkhof, R., Park, G.-H., Takahashi, T., Feely, R. A., Bullister, J. L., and Doney, S. C., 2013: Changes in deep-water CO_2 concentrations over the last several decades determined from discrete pCO_2 measurements, Deep-Sea Res I., 74, 48-63, http://dx.doi.org/10.1016/j.dsr.2012.12.005.

Wanninkhof, R., Park, G.-H., Takahashi, T., Sweeney, C., Feely, R., Nojiri, Y., Gruber, N., Doney, S. C., McKinley, G. A., Lenton, A., Le Quéré, C., Heinze, C., Schwinger, J., Graven, H., and Khatiwala, S., 2013: Global ocean carbon uptake: magnitude, variability and trends, Biogeosciences, 10, 1983-2000, doi:10.5194/bg-10-1983-2013.

Collaborators over the past 48 months

W. Asher	U Washington
D. Bender	Princteon U.
W.-J. Cai	U Delaware
S. Doney	Woods Hole
R. Feely	NOAA PMEL
D. Gledhill	NOAA Ocean Acidification program office
D. Glover	Woods Hole
B. E. Hales	U. Oregon
F. Millero	U. Miami
K. B. Rodgers	Princeton U.
C. Sabine	NOAA PMEL
J. Salisbury	U. New Hampshire
C. Sweeney	NOAA ESRL
T. Takahashi	Columbia U.

CV: John P. Dunne

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Education:

Ph.D. March 1999, University of Washington, Seattle, WA; Field: Oceanography; Dissertation: Measured and Modeled Particle export in the equatorial and coastal oceans.

M.S. June 1996, University of Washington, Seattle, WA; Field: Oceanography; Thesis: ^{234}Th and particle cycling in the central equatorial Pacific.

B.S. June 1993, the University of California at San Diego; Major: Chemistry; Minor: Writing.

Recent Professional Experience:

Research Oceanographer, National Oceanic and Atmospheric Administration / Geophysical Fluid Dynamics Laboratory, Princeton, NJ. Dec. 2002-present.

Research Associate (Postdoctoral), Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ. Apr. 2001-Nov. 2002.

Research Associate (Postdoctoral), Oceanography, University of Washington, Seattle, WA; Apr. 1999-Mar. 2001.

Recent Publications:

Stock, C. A., J. P. Dunne, and Jasmin John, in press: Drivers of trophic amplification of ocean productivity trends in a changing climate. Biogeosciences Discussions. DOI:10.5194/bgd-11-11331-2014. 7/14.

Nevison, C. D., and J. P. Dunne, et al., in press: Evaluating the ocean biogeochemical components of earth system models using atmospheric potential oxygen (APO) and ocean color data. Biogeosciences Discussions. DOI:10.5194/bgd-11-8485-2014. 6/14.

de Souza, G. F., R. D. Slater, J. P. Dunne, and J. L Sarmiento, 2014: Deconvolving the controls on the deep ocean's silicon stable isotope distribution. Earth and Planetary Science Letters, 398, DOI:10.1016/j.epsl.2014.04.040.

Gehlen, M, and J. P. Dunne, et al., in press: Projected pH reductions by 2100 might put deep North Atlantic biodiversity at risk. Biogeosciences Discussions. DOI:10.5194/bgd-11-8607-2014. 6/14.

Gnanadesikan, A., J. P. Dunne, and R. Msadek, .2014: Connecting Atlantic Temperature Variability and Biological Cycling in two Earth System Models. Journal of Marine Systems, 133, DOI:10.1016/j.jmarsys.2013.10.003.

Ishii, M, and J. P. Dunne, et al., 2014: Air–sea CO2 flux in the Pacific Ocean for the period 1990–2009. Biogeosciences, 11(3), DOI:10.5194/bg-11-709-2014.

Krasting, John P., J. P. Dunne, E. Shevliakova, and R. J. Stouffer, 2014: Trajectory sensitivity of the transient climate response to cumulative carbon emissions. Geophysical Research Letters, 41(7), DOI:10.1002/2013GL059141.

Logan, C. A., J. P. Dunne, C. M. Eakin, and S. D. Donner, 2014: Incorporating adaptive responses into future projections of coral bleaching. Global Change Biology, 20(1), DOI:10.1111/gcb.12390.

Stock, C. A., John P Dunne, and J. John, 2014: Global-scale carbon and energy flows through the marine food web: an analysis with a coupled physical-biological mode. Progress in Oceanography, 120, DOI:10.1016/j.pocean.2013.07.001.

Beaulieu, C, S. A. Henson, J. L Sarmiento, and J. P. Dunne, et al., 2013: Factors challenging our ability to detect long-term trends in ocean chlorophyll. Biogeosciences, 10(4), DOI:10.5194/bg-10-2711-2013.

Bopp, L, and J. P. Dunne, et al., 2013: Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. Biogeosciences, 10(10), DOI:10.5194/bg-10-6225-2013.
Woodworth, P. A., J. J. Polovina, J. P. Dunne, J. L. Blanchard, 2013: Ecosystem size structure response to 21st century climate projection: large fish abundance decreases in the central North Pacific and increases in the California Current. Global Change Biology, 19(3), DOI:10.1111/gcb.12076.
Dunne, J. P., J. John, A. Adcroft, S. M. Griffies, R. W. Hallberg, E. Shevliakova, R. J. Stouffer, W. F. Cooke et al. 2012: GFDL's ESM2 global coupled climate-carbon Earth System Models Part I: Physical formulation and baseline simulation characteristics. Journal of Climate, 25(19), DOI:10.1175/JCLI-D-11-00560.1.
Dunne, J. P., B. Hales, J. R. Toggweiler, 2012: Global calcite cycling constrained by sediment preservation controls. Global Biogeochemical Cycles, 26, GB3023, DOI:10.1029/2010GB003935.
Dunne, J. P., J. John, E. Shevliakova, R. J. Stouffer, J. P. Krasting, S. Malyshev, P. C. D. Milly, et al., 2013: GFDL's ESM2 global coupled climate-carbon Earth System Models Part II: Carbon system formulation and baseline simulation characteristics. Journal of Climate. DOI:10.1175/JCLI-D-12-00150.1. 10/12.
Hazen, E. L., R. Rykaczewski, J. P. Dunne, et al., 2012: Predicted habitat shifts of Pacific top predators in a changing climate. Nature Climate Change. DOI:10.1038/nclimate1686. 9/12.

Collaborators Past 48 Months

Brooklyn College of the City University of New York	Marine Ecosystem Modeling & Monitoring by Satellites	Tokyo University of Information Sciences
Bermuda Institute of Ocean Sciences	Massachusetts Institute of Technology	University of Bergen
Albert Ludwigs University	Max Planck Institut for Meteorologie	Universidade Estadual Paulista
California Institute of Technology	McGill University	Université Pierre et Marie Curie
California State University	Meteorological Research Institute	UN Environmental Program
College of William and Mary	Middle East Technical Institute	University of British Columbia
Columbia University	Nagoya University	University of California
CSIC, Instituto de Investigacións	NASA-Goddard	University of Colorado-Boulder
University of Miami	Duke University	University of East Anglia
Environmental Protection Agency	University of Hawaii	University of Florida
Fisheries and Oceans Canada	NOAA/CSC	Hawaii Pacific University
Freshwater Institute	University of Rome	University of Maine
GEOMAR - Helmholtz Centre for Ocean Research Kiel	Instituto Nazionale di Geofisica e Vulcanologia	National Research Institute of Far Seas Fisheries
NOAA/AOML	NOAA/NESDIS	NOAA/GFDL
Hellenic Centre for Marine Science	HPTi	University of South Florida
NOAA/NMFS	NOAA/ORR	NOAA/ESRL
Ifremer	Oregon State University	University of Texas at Arlington
University of Southampton	Plymouth Marine Laboratory	University of Victoria
Joint Research Center	Princeton University	University of Washington
Johns Hopkins University	Rutgers University	University of Wisconsin-Madison
Japan Agency for Marine-Earth Science and Technology	Sir Alistair Hardy Foundation for Ocean Science, Plymouth, UK	Laboratoire des Sciences du Climat et de l'Environnement
University Pierre and Marie Curie	Southampton University	US Geological Survey
Louisiana State University	SUNY-StonyBrook	Vrje University of Amsterdam
Marine Conservation Biology Institute	Technical University of Denmark	Woods Hole