Final Report

1. **Project Title:** Ferry Based Marine & Atmospheric Observing System
   EPA Grant Number: LI972862050

2. **Grantee Organization:** Marine Sciences Research Center, School of Marine and Atmospheric Sciences, Stony Brook University
   Contact Name: Robert E. Wilson

3. Public Summary: The immediate objectives of this project are the maintenance and refinement of the data acquisition system aboard the passenger ferry P.T. Barnum (Fig. 1) belonging to the Bridgeport-Port Jefferson ferry company which operates along a central Long Island Sound (LIS) transect from Bridgeport, CT to Port Jefferson, NY (Fig. 2).

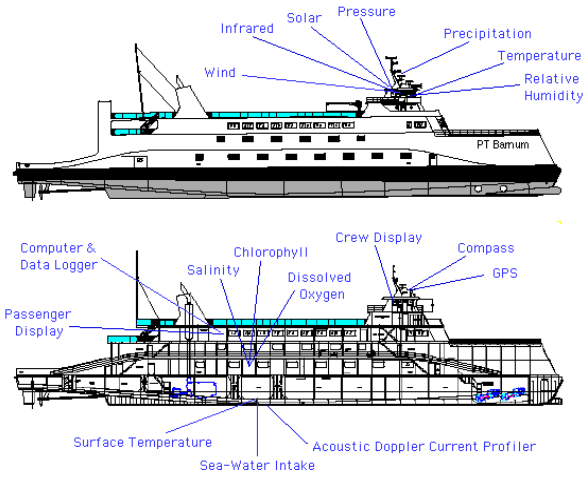


Fig. 1. Instruments aboard the PT Barnum.

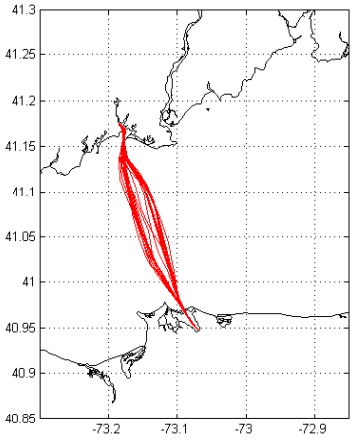


Fig. 2. P.T. Barnum LIS transect.

The environmental variables being collected by the ferry observing system are surface-to-bottom current profiles and quantities necessary to derive research quality estimates of the surface momentum flux, surface mass flux, and all four major components of the surface heat flux (short wave, infrared, latent and sensible). Descriptions of instruments are provided on the project web site: http://www.stonybrook.edu/soundscience.

Funding for the initial development of this system was provided by NOAA through NY Sea Grant. The primary motivation for this project was the continued decline of bottom dissolved oxygen in central and western LIS (Fig. 3), and the necessity of distinguishing the influence anthropogenic and natural climatic factors which contribute to the development of summertime hypoxia. This is especially important in light of the imposition of Total maximum Daily Load (TMDL) nitrogen restrictions for LIS. Results from recent analyses of historical meteorological and water column data have identified a specific scenario of meteorological forcing associated with major summertime hypoxia in western LIS. This scenario is characterized by the early onset of persistent south-westerly winds causing enhanced thermal and haline stratification followed by

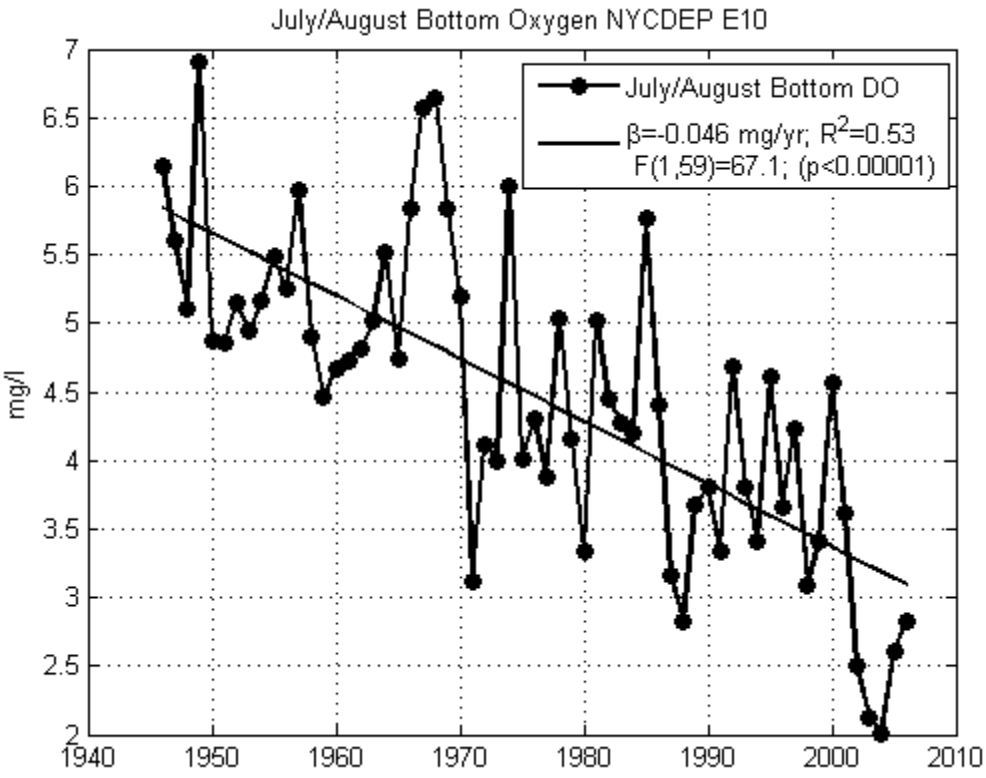


Fig. 3. Inter-annual variations in summertime bottom DO in western LIS

an absence of destratifying north-easterly winds. With reference to Fig. 3, analyses of land-based wind observations, such as those available at Laguardia, point to persistent south-westerly winds during summer months as the prime factor responsible for summertime hypoxia in 1988, 1998, 2003 and 2004. They also point to the sensitivity of density stratification during those years to wind direction and persistence. These findings highlight the importance of obtaining timely high quality over-water meteorological observations, especially winds, to diagnose hypoxia development and to distinguish the effects of climatic and anthropogenic forcing.

The over-water ferry-based observations can be used to make important and critical refinements in LIS surface heat and momentum flux time series developed from land-based observations. These flux time series are appropriate to force regional hydrodynamic and water quality models. The ferry ADCP observations are used to quantify the magnitude and variability in estuarine exchange flow through the ferry transect. This exchange flow contributes to the renewal of bottom waters in central and western LIS. The ferry ADCP observations are also available for use in assimilation and validation in hydrodynamic models. The ferry observing system is highly complementary to other LIS observation programs which include moored buoys and monthly ship surveys; it provides capabilities not offered by either buoys or ship surveys including the support of instruments requiring periodic maintenance.

In addition to maintaining and refining the **BPPJ** ferry observing system, the objectives of the present project include providing both the real-time and archived historical data to the research and management communities via the project's web page. Both of these objectives have been met.

4. Project Period: 10/01/2005 – 07/21/2007

5. Project Description: This has been articulated in previous progress reports for Grants LI972862040 and LI972862050. In eutrophic systems, anthropogenic factors (nitrogen loading) play a direct role in the occurrence and severity of hypoxia events. There is also strong evidence that variations in atmospheric forcing (air-sea heat and momentum fluxes) play a significant role in determining the frequency and severity of hypoxia events in central and western LIS through their effects on both water column stratification and the exchange of bottom waters. Records of over-water parameters necessary to determine the net heat flux (and momentum flux) have not been available for either diagnostic analysis, or for use as surface boundary conditions for LIS modeling efforts. The **primary** goals of this particular project were the development of a ferry-based observing system for LIS and the maintenance of a year-round sampling program along a transect in the central Sound. The main observations considered here include surface meteorology and water column current structure. There are two components of this observation system: the data acquisition system and the data handling system. **Secondary** project goals included: 1) obtaining refined estimates for LIS basin-wide seasonal cycle budgets of heat, mass and salt, 2) development of a multi-decade retrospective time series of LIS surface fluxes that could provide a framework for interpreting modern ferry observations, and 3) obtaining a description of the variability in estuarine exchange flow entering the central Sound.

As discussed in the **Public Summary,** an important outcome with direct management implications is the identification of winds as a factor controlling stratification and the evolution of summertime bottom DO. Earlier analyses, such as those conducted by HydroQual in 1995 for EPA, identified an important relationship between bottom DO and thermal stratification, but factors contributing to anomalies in thermal stratification were not identified. The present project has identified winds and the sensitivity of stratification to *wind direction*. Fig. 4 shows inter-annual variations in July/August wind stress direction (taken here as the direction in which the wind is blowing). This wind direction time series indicates that there may be long term shift in direction towards the north east which is the preferred wind direction for producing a stratified water column. These winds are obtained from NCEP; they serve to emphasize the importance of obtaining high quality over water observations.

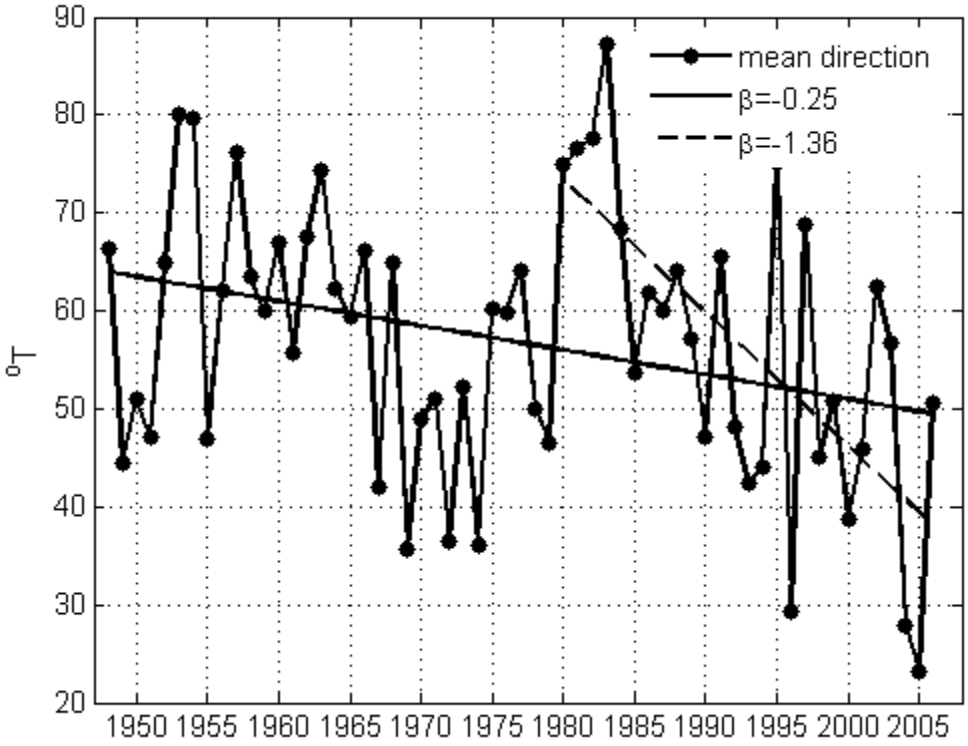


Fig. 4. Inter-annual variations in July/August wind direction over LIS.

6. Activities & Accomplishments: In addition to system maintenance and the regular collection of QA/QC samples, **accomplishments** during the reporting period include the items below:

- We have expended effort working with the ADCP heading error correction. The Barnum is equipped with a 600 kHz broadband ADCP which measures the velocity of the water relative to the ship. In order to convert that information into the absolute velocity of the water over the ground, the speed and direction of the ship needs to be known with some accuracy. The GPS receiver installed on board takes care of the position information yielding speed and course over the ground. The last item needed to complete the calculation is the heading of the ship. On the Barnum this is done using a magnetic compass. The magnetic compass and its deviation, however, introduce a significant problem because the compass is not compensated for the presence of the steel hull. Thus, there is a left deviation when the ship travels north of about 4º and a right deviation of about 2º when the ship travels south. The actual corrections depend upon ship heading which vary somewhat during each cross necessitating a somewhat more complicated correction than these simple deviation errors suggest. This correction has been incorporated into the CODAS processing system which we are using to process and store the data. The CODAS ADCP processing system stores the data in binary block files which are the defacto standard ADCP data base system. Data stored in this manner can be sent to other researchers and is accessible to a web-based server system.

- We have continued the reformatting of archived text files for one-minute data for all meteorological data and hydrological data into well-formed MATLAB-compatible files.
- We have obtained a new server machine for this project. It has disk space to accommodate the ADCP data, it provides more efficient and reliable data preview and data retrieval through our project web page, and it will facilitate data backup. The new server is a Dell PowerEdge 1800, with dual Intel Xeon 3.0GHz processors and 2GB of memory, running Red Hat Enterprise Linux ES v4. It has six 250GB SATA disk drives in a RAID 5 configuration. Backup is via a 200GB/400GB LTO Ultrium II tape drive. The server is now fully functional and Computer Science has transferred their applications to it from the older Windows machine.
- We have acquired a downward looking Heitronics KT15.86 infrared radiation pyrometers for testing against our thermistor measurements of SST.
- We have collaborated with URI in the modification of our web page so that a user is now lead to an entry page that will give access to data from either the SUNY or URI ferry data. The new entry page is shown below. It can still be reached through our original web address http://www.stonybrook.edu/soundscience . Note that meteorological data is available only for the SUNY ferry:

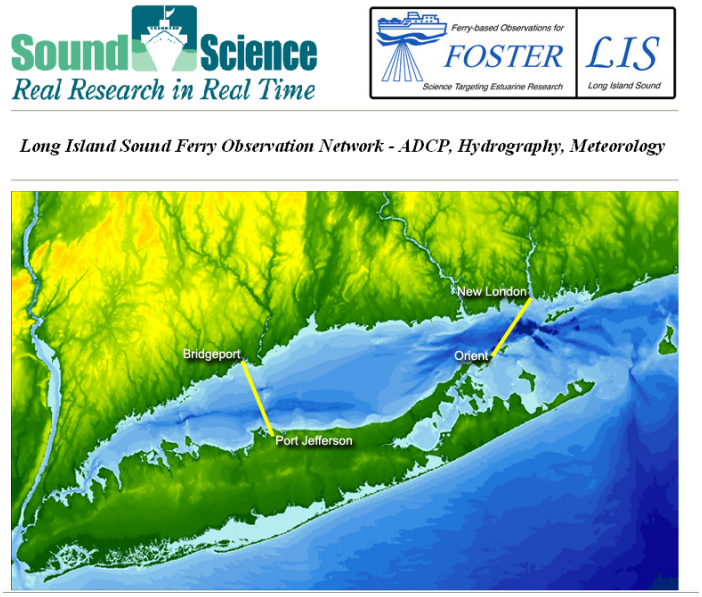


Fig. 5. New entry web page developed in collaboration with URI.

7. Modeling: Numerical modeling was not funded under this project. There is, however, active processes oriented modeling being conducted which contributes to an interpretation of observations. Fig. 6 shows depth versus time plots for vertical current shear, water column stratification, and vertical eddy diffusivity as indicative of the intensity of vertical mixing from Swanson et al. (2008). They show definitively the effects of south-westerly winds: increased current shear, increased stratification, and suppressed vertical mixing for a station in western LIS during summer months.

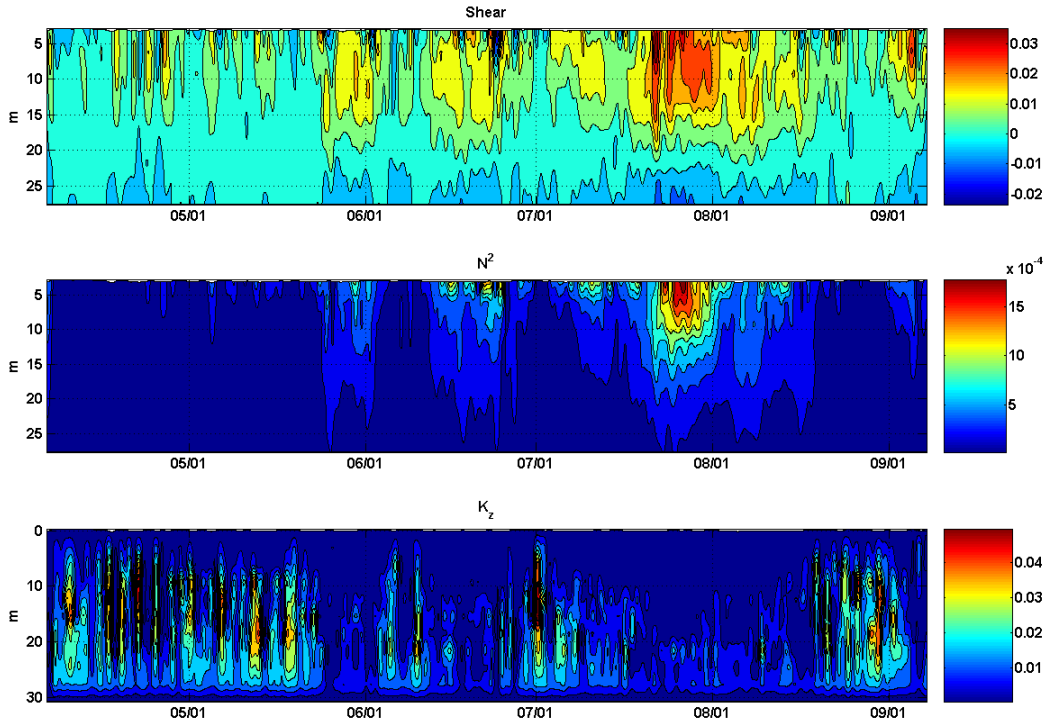


Fig. 6. Low-pass filtered current shear, N^2, and K_z at 40.874^o N, 73.733^o W in wLIS from 05/01/1988 to 09/01/1988 (from Swanson et al.,2008).

In addition, the doctoral dissertation by Hao (2008) includes a comparison between the structure of numerically simulated currents along the ferry transect (Fig. 7) and observed currents derived from ferry ADCP data.

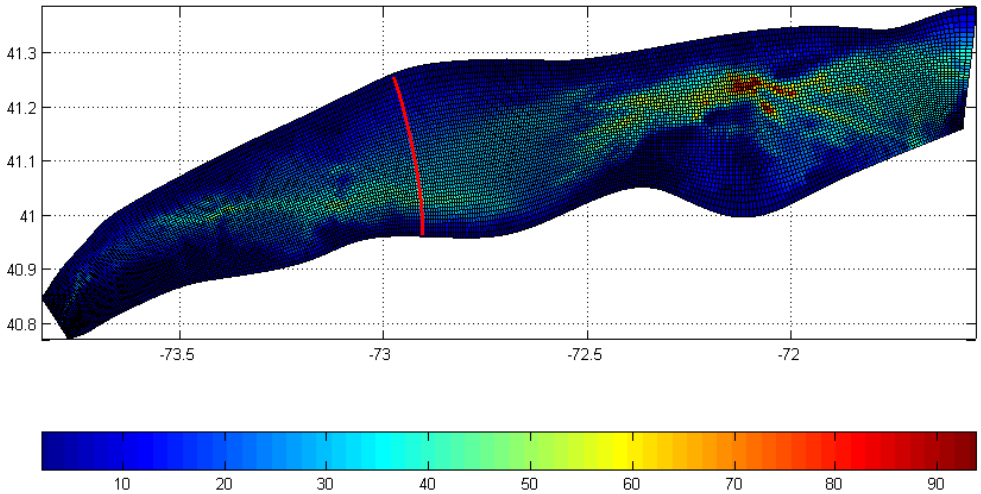


Fig. 7. High resolution ROMS grid for LIS showing ferry transect and model bathymetry. Colorbar refers to bathymetry with units of meters. From Hao (2008); ROMS grid developed by Crowley (2005).

8. Summary of Findings: Technical details related to project instrumentation and data archives are available from the project web site http://www.stonybrook.edu/soundscience. We are finding that we can make good quality over-water meteorological observations including wind speed and direction from a high-speed vessel. We are also finding that we can make acceptable ADCP observations from a high-speed vessel, there was initially skepticism about this. We are also relearning something that has long been known in the oceanographic community, that maintaining continuously flowing sea-water systems is very labor intensive. Time series data from all instruments with the exception of the ADCP are available in **real time** on the project web page. Archived data are also available for graphical previewing and retrieval through the project web site. Data are also transmitted to National Data Buoy Center (NDBC) where they are again range checked and posted as observations at virtual stations in LIS on the NDBC web page http://www.ndbc.noaa.gov.

9. Conclusions: This project, including both the data collection activities and ancillary analyses, is leading us to the conclusion that regional meteorological forcing is extremely important in producing fluctuations in estuarine exchange flows in LIS, in water column stratification, in vertical mixing, and thereby in the extent of summertime hypoxia. Specifically we conclude that wind-controlled stratification controls the evolution of summertime hypoxia, and that inter-annual fluctuations in the stability and directionality of wind forcing affect the severity of hypoxia. The management implication is that the variability in summertime bottom oxygen levels due to wind forcing must be considered when evaluating the response to imposed TMDL measures.

10. Presentations/Publications/Outreach:

Presentations

Robert Wilson and Charles Flagg presented an **invited** talk entitled **"The Bridgeport-Port Jefferson Ferry Observing System: Operational Experience and Scientific Results"** at the 2005 Estuarine Research Federation Conference held October 16-20, 2005 in Norfolk, VA. This talk was part of Special Session SPS-13 Observing and Forecasting Systems for Urban and Coastal Ocean Environments.

Yan Hao and Robert Wilson presented a contributed talk entitled **"Lateral Structure of Tidal and Residual Currents in a Wide Estuary and Effects on Salt Dispersion"** also at the 2005 Estuarine Research Federation Conference to be held October 16-20, 2005 in Norfolk, VA. This talk presented results from analyses of ADCP observations from the Bridgeport-Port Jefferson ferry related to a description of vertical and lateral structure of the tidal and residual currents within the ferry transect.

Robert Wilson was an invited participant at the ***Integrated Sensor Systems for Vessels of Opportunity Workshop***, Southampton, UK, October 10-12, 2006. This workshop was sponsored by ACT (Alliance for Coastal Technologies) http://www.act-us.info/.

Publications

Swanson, R.L., R.E. Wilson and H.A. Crowley. 2008. Perspectives of long-term hypoxic conditions in Long Island Sound. (Submitted to **Journal of Geophysical Research).**

This manuscript was submitted to **JGR** at the end of 2007. It is now under review and it acknowledges support from this grant. The manuscript emphasizes that a major fraction of variance associated with inter-annual fluctuations in summertime bottom dissolved oxygen (DO) in western Long Island Sound is associated with variations in density stratification. It shows that there has been a 60-year (1946-2006) increase in summertime thermal stratification in the western Sound caused largely by a decline in summertime bottom water temperature, and that the divergence between surface and bottom water temperature begins earlier in the year indicating a long term reduction in vertical mixing. Analyses of bottom DO and density stratification point directly to the importance of wind-induced current shear in controlling stratification, vertical mixing, and the ventilation of bottom waters, and more generally to a long term reduction in vertical mixing influenced by changes in wind direction over wLIS. A copy of this manuscript has been supplied to EPA.

Hao, Y. 2008. Three-Dimensional Tidal and Residual Circulation in Long Island Sound. PhD Dissertation, Marine Sciences Research Center, Stony Brook University, Stony Brook, NY.

R.E. Wilson is the advisor. Yan Hao will actually defend here dissertation on03/10/2008. This dissertation includes a comparison between the structure of numerically simulated currents along the ferry transect (see figure below) and observed currents derived from ferry ADCP data. This dissertation acknowledges support from this grant and a copy or pdf file is available upon request. It is important here because it tends to put ferry ADCP observations in the context or regional tidal and residual circulation.

Wilson, R.E., H.A. Crowley and R.L. Swanson. 2008. Circulation and mixing in western Long Island Sound during a major summertime hypoxia event. **(In Preparation).**

This manuscript addresses the effects of wind-induced stratification of vertical mixing and summertime hypoxia in western LIS. It emphasizes, in particular, the importance of surface wind direction on stratification. It acknowledges support from this grant.

Crowley, H.A. and R.E. Wilson 2008. The seasonal evolution of the cold pool in central long island sound. **(In Preparation).**

This manuscript quantifies the relative effects of vertical mixing and longitudinal advection on the seasonal evolution of bottom water temperatures in central and western LIS with direct relevance to hypoxia in western LIS. It acknowledges support from this grant.

Crowley, H., 2005. The seasonal evolution of thermohaline circulation in Long Island Sound. Ph.D. Dissertation, Marine Sciences Research Center, Stony Brook University, Stony Brook, NY, 142 pp.

R.E. Wilson is the advisor. This dissertation provided a description of the seasonal heat and salt budget in LIS, and the seasonal variation in estuarine exchange flux. Ferry based meteorological observations contributed to corrections in surface heat flux inferred from land-based observations. Her numerical simulations of the seasonal evolution of thermohaline circulation focused on 1988 and involved assimilation of LISS hydrographic data and boundary sea level for forcing. The simulations by Yan Hao are based on Crowley's grid and bathymetry..

Baggett, T. 2005. A multi-decade retrospective of regional heat and momentum fluxes for Long Island Sound. Masters Thesis, Institute for Terrestial and Planetary Physics, Stony Brook University, Stony Brook, NY. 87 pp.

Duane Waliser is the advisor. This important thesis provides a climatology of regional meteorological forcing (surface momentum flux and all components of surface heat flux) on LIS, and it discusses certain implications derived from the ferry data related to corrections which should be applied to fluxes inferred from land-based observations.

Bennouna, Y. 2005. Historical Data Base for the Bridgeport-Port Jefferson Ferry Project. **(Unpublished Report).**

A very important product relevant this project. It describes in detail the development of a historical data-base for regional atmospheric observations (primarily Brookhaven National Laboratory) which provide a basis for the interpretation of modern regional observations including ferry observations. The thesis by Baggett (2005) is based on these observations.

Outreach

The project web page has been linked to the MACOORA Sub-Regional Observing Systems web page (http://www.macoora.org/subregional.html).

11. Other Information: As an important recent development, the LIS ferry observing platform developed with EPA support has become part of **An Integrated Network of Ferry-Based Observations for Regional Coastal Ocean Observation Systems (RCOOS) along the Northeast Coastline.** This initiative addresses Funding opportunity FY 2007 Regional Integrated Ocean Observing System Development, NOS-CSC-2007-2000875, from the Coastal Services Center, NOAA. This integrated network of ferry observing platforms involves the collaboration of SUNY, URI, UCONN, UMASS Dartmouth, WHOI, and Bigelow. The Letter of Intent, which is attached below, outlines the objectives. These include the acquisition of over water meteorological observations to support both water quality modeling and regional mesocale modeling for inundation. A complete proposal has been submitted to NOAA Coastal Services Center and reviewed. Reviews were EXCELLENT and the proposal was ranked as eligible for funding, the details of funding decisions will be provided in the Fall of 2008.

Letter of Intent [cover page]

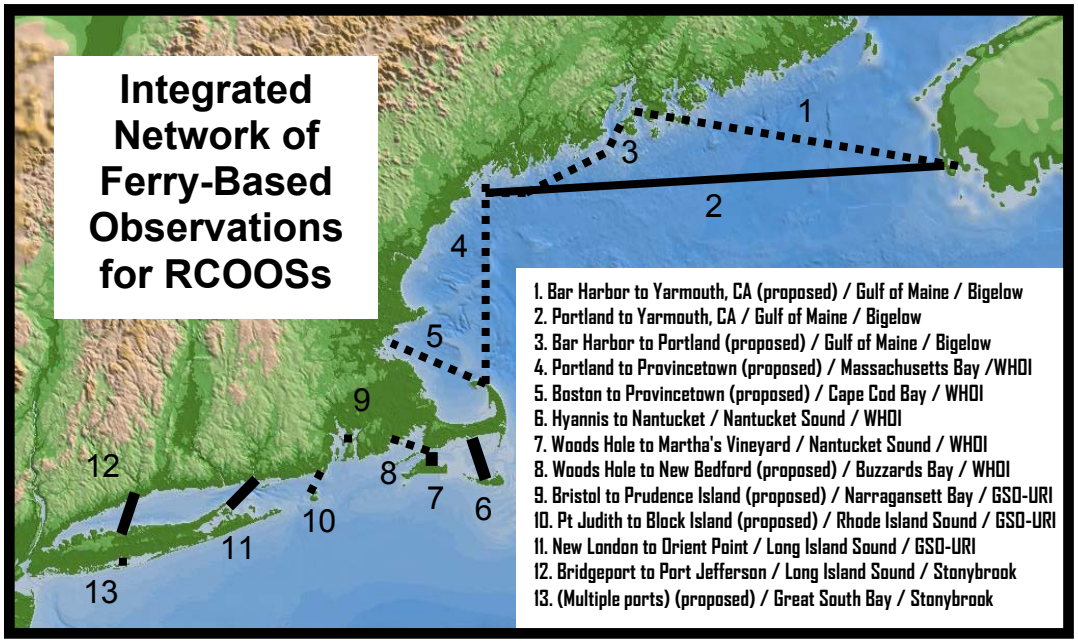
Target of the letter of intent:

Coastal Services Center, National Oceanic and Atmospheric Administration, Department of Commerce

Funding opportunity title and number:

FY 2007 Regional Integrated Ocean Observing System Development, NOS-CSC-2007-2000875

Proposed project title: An Integrated Network of Ferry-Based Observations for Regional Coastal Ocean Observation Systems along the Northeast Coastline



Principal investigators:

Daniel L. Codiga, Lead PI (Graduate School of Oceanography, University of Rhode Island); William M. Balch (Bigelow Laboratory for Ocean Sciences); Scott M. Gallager (Woods Hole Oceanographic Institution); Robert E. Wilson (Marine Sciences Research Center, Stonybrook University)

Contact information for lead principal investigator: Daniel L. Codiga, Graduate School of Oceanography, University of Rhode Island; d.codiga@gso.uri.edu; 401-874-6212

Focus areas: Most relevant focus areas: RCOOS development, observational component (Focus Area #1); and IOOS Application and product development for regional stakeholders (Focus Area #2).

1. Statement of purpose. We propose to augment and integrate a network of university- and private laboratory-operated ferry-based observation programs along the Northeast US coast. Using diverse interdisciplinary (biological/chemical/physical/meteorological) instrumentation sampling at high frequency along track lines in a repeated measures approach, such programs leverage commercial ferry activity to generate uniquely valuable scientific data streams in a highly cost-effective manner, However, they are presently implemented by different institutions with no cohesive intent. With the addition of integrated sensor inter-calibration protocols, quality assurance procedures, data management, and product distribution capabilities in common with other IOOS observatories, ferry data streams will improve end-user products relevant to direct societal needs addressed by public mission agencies. Existing and proposed tracklines span the Gulf of Maine, Massachusetts Bay, Cape Cod Bay, Nantucket Sound, Buzzards Bay, Narragansett Bay, Rhode Island Sound, Long Island Sound, and Great South Bay. Project output will be cost-effective data products from a ferry network forming an essential observational asset, among many, for RCOOSs.

2. Summary of work. (1) Instrumentation of additional ferry lines to enhance natural hazard detection, aid maritime operations, and support ecological decision making. (2) Addition of newly developed sensors for Harmful Algal Blooms (HABs), nutrients and plankton, and a suite of meteorological instruments; interoperability between platforms through centralized and standardized instrument interface design, calibration, and quality control. (3) Implementation of data management, communications infrastructure, and data product distribution under IOOS DMAC guidelines for end users and stakeholders, with a complete cost-benefit analysis of ferry-based sampling. The estimated budget is $500,000 per year for 3 years.

3. Intended benefits and expected use by IOOS community. Ferry-based data streams are uniquely valuable to multiple RCOOS priorities. (a) ***Coastal inundation*** modeling/forecast products stem from

coupled atmospheric-surge models with high sensitivity to mesoscale atmospheric model outputs (wind, pressure, heat flux) that are poorly constrained by data, particularly where influenced by coastal oceanography. Ferries sample over-water parameters in precisely such regions, with spatial coverage unattainable by buoys. (b) Ferries are effective test platforms to develop HAB-sensing instrumentation (e.g. optical, immunological approaches), and the ferry network provides a capability far beyond that of research vessels to ***detect and monitor HABs*** for decision-makers. (c) ***Water quality*** management decisions rely heavily on coupled ecological-hydrodynamic models. Model skill is limited by inadequate water quality, circulation, and surface observations required for forcing and validation. Sustained temporal and spatial coverage of ferry sampling, unattainable by the research fleet, is well-suited for this purpose. (d) Measurements of nutrients, phytoplankton and zooplankton using optical techniques from ferries provide an index to water quality and a link to higher-level ***living marine resources*** including commercially important fish species. (e) Ferry sampling has proven value as ground-truth in algorithm development for ***remote sensing data streams*** to improve their utility to RCOOSs. Utility of ferry sampling to these various goals is demonstrated by existing websites (www.gso.uri.edu/foster, www.sunysb.edu/soundscience, http://sealion.whoi.edu/ferries).

4. Description of partnerships. This project will be coordinated with NERACOOS and MACOORA. University of Rhode Island, Stonybrook University, Woods Hole Oceanographic Institution, and Bigelow Laboratory for Ocean Studies will provide scientific expertise, engineering skills, and computational assets. GoMOOS will provide established relationships with regional stakeholders. The National Marine Fisheries Service will provide requirements related to fisheries management. The United States Geological Survey will provide sediment transport expertise. The NOAA National Weather Office will define use of meteorological data. Ten or more privately owned ferry companies will provide links to the business community.