LISICOS: The Long Island Sound Integrated Coastal Observing System

Interim Report, August, 2005- January 2006

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Brief Project Summary: With more than eight million people living in its watershed, Long Island Sound (LIS) is the nation's preeminent urban estuary. LIS provides the region with natural resources, including oysters, clams, lobsters, and bluefish, and both commercial and sport fishing are important to the regional economy. Unfortunately, LIS has also served as the region's sewer, resulting in water quality degradation and critical habitat loss. Extensive wastewater treatment plant upgrades have been mandated to rectify these problems. The high concentration of development along the surrounding coastline has also prompted increased dredging for navigation, electric power transmission, and gas pipelines. The goal of the Long Island Sound Integrated Coastal Observing System is the development of a sustained capability to observe the Long Island Sound ecosystem and an adequate capability to understand and predict its response to natural and anthropogenic changes.

Current Year Objectives:
- Measure carbon flux and benthic oxygen demand during the spring bloom and during the summer hypoxia season in western LIS.
- Measure and monitor fluxes of salt and carbon through the East River
- Provide operational surface current predictions in LIS and adjacent shelf
- Maintain moored instruments,
- Develop data archiving and distribution system for LIS

Accomplishments to Date:
- Deployment and maintenance of five buoys that monitor salinity, temperature, and dissolved oxygen throughout the sound.
- Three of the above buoys provide over-water meteorological observations. One includes a surface wave sensor, and one includes PAR and chlorophyll sensors.
- Deployment and maintenance of three additional buoys that monitor salinity, temperature, and dissolved oxygen in the area of the LISICOS process studies.
- Conducted two major interdisciplinary process studies
- Development of a three-dimensional circulation model.
- Development and testing of a primary-production respiration model.
- Coupling of the circulation and ecosystem models
- Development of simple models of the salinity, temperature and oxygen dynamics of Western LIS.
- Implementation of data-base a internet distribution system
- Analysis of existing hydrography to infer exchange between LIS, the Hudson River, and the shelf waters
- Supported the CODAR infrastructure for the forecasting of surface currents for the USCG

Task 1. Program Management

During this contract period we continued the modeling, data center development, and maintenance of the observation array. In addition, we completed the sample analysis and much of the data processing for the two intensive field campaigns that occurred in the spring and summer of 2005. The LISICOS support boat remains under construction, still delayed by fiscal difficulties in the shipyard. After the exploration of multiple options, Mr. Turner Cabaniss and the UConn purchasing office have decided to allow the completion

of the hull and engine installation in the yard and continue to monitor progress. Delivery is now expected in March, 2006. On the positive side, we have received a pledge from a program supporter for a major gift to the University to be used to support the operation of the vessel.

Task 2. Observational Array

We have maintained three moorings in LIS from the beginning of the present contract and added a fourth in western LIS in January, 2005. In June 2005 we deployed an additional three buoys and five acoustic Doppler current profilers (ADCPs) in the western Sound in support of the process studies. Figure 1 shows their locations. The ADCPs were located at the five western most stations. In October, 2005 the buoys deployed to support the process studies were recovered. The instrument deployment details are summarized in Table 1.
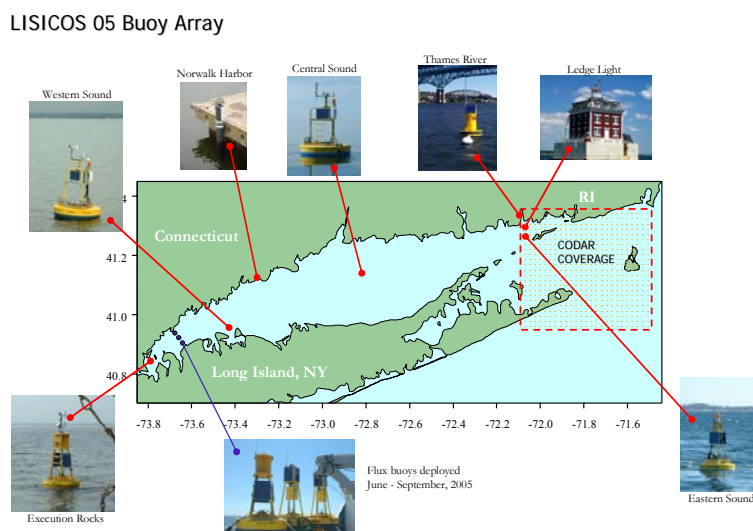
Figure 1. **Location of the LISICOS buoys during 2005. The blue line in the western Sound indicates the location of the buoys deployed in June 2005 in the area of the process studies.**

Each of the buoys is equipped with three YSI 6920 Sondes connected to cellular phone telemetry system. The instruments measure salinity, temperature, pressure, dissolved oxygen concentration, chlorophyll fluorescence, and light level. Data is stored locally every 15 minutes and transmitted to the LISICOS data center every hour. Figure 2 shows a schematic of the buoy design and a photograph of the four buoys being prepared for deployment in support of the process studies. Table 1 summarizes the buoy location and sensor depths for the western Sound array during the summer of 2005.
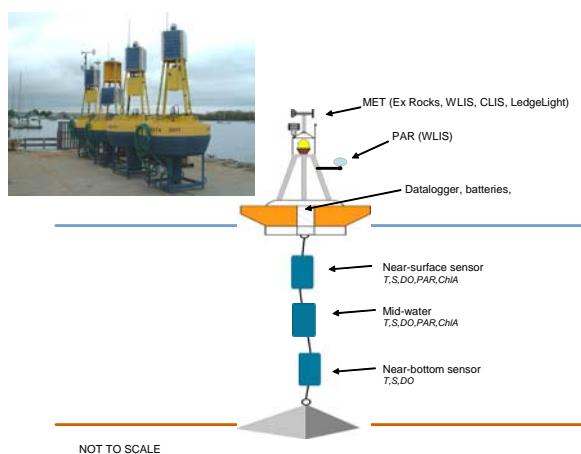
Figure 2. A schematic of the instruments on the LISICOS buoys. A photograph of three buoys on the UConn Avery Point Dock prior to deployment is inset at the top-left side of the figure

Table 1. Summary of the LISICOS Western Sound Buoy Locations and sensors and instrument depths during the summer of 2005

Station Name Deployment period	Depth (m)	Lat	Lon	Sensors		
				SFC 1m	MID 7m	BTM 2m above bottom
Western Sound 27 May – 8 November 2005	19.8	40.9561	73.5809	T,C,DO,F	T,C,DO,F	T,C,DO
Execution Rocks 27 May 2005 – Dec 31, 2005	22.6	40.8833	73.7283	T,C,DO	T,C,DO	T,C,DO
Flux Buoy 1 27 May – 29 September 2005	12.8	40.8437	73.6799	T,C,DO,F	T,C,DO,F	T,C,DO
Flux Buoy 2 27 May – 29 September 2005	16.5	40.9234	73.65827	T,C,DO,F	T,C,DO,F	T,C,DO
Flux Buoy 3 27 May – 29 September 2005	11.9	40.9023	73.6406	T,C,DO,F	T,C,DO,F	T,C,DO

T=temperature, C=Conductivity, DO=Dissolved Oxygen Saturation and Concentration, F=% fluorescence

The moored array in the western Sound also included five bottom mounted, upward looking RD Instruments acoustic Doppler current meters. These were deployed on aluminum frames within 100m of the 5 western Sound buoys. Unfortunately, the power supply on the eastern-most buoy failed and no data was recovered. Figure 3 shows the mean circulation approximately 3m below the mean surface level. The mean is typically ~3cm/s towards the eastern Sound, but is substantially intensified on the southern side of the Sound ~10 cm/s.
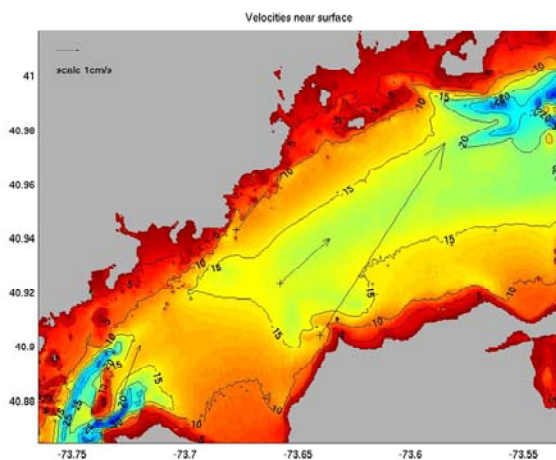

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Figure 3. Mean near surface current vectors during the summer of 2005. The scale vector (1 cm/s) is shown at the top-left side of the figure.

The vertical structure of the circulation has now been quality controlled and processed and the 2004 array observations have been analyzed in conjunction with the array dissolved oxygen (DO), salinity and temperature records. The observations were presented at the Estuarine Research Federation meeting in Norfolk, Virginia in October 2005. The most significant finding is the discovery that the onset of hypoxia in western Long Island Sound is characterized by a series of intervals rapidly increasing DO and rapidly decreasing DO. Figure 4 shows (a) the tine series of dissolved oxygen from the Execution Rocks buoy (see Figure 1) with the near surface record in blue, the mid depth record in green and the near bottom record in red. Some of the intervals during which the near bottom DO increased are highlighted by arrows.
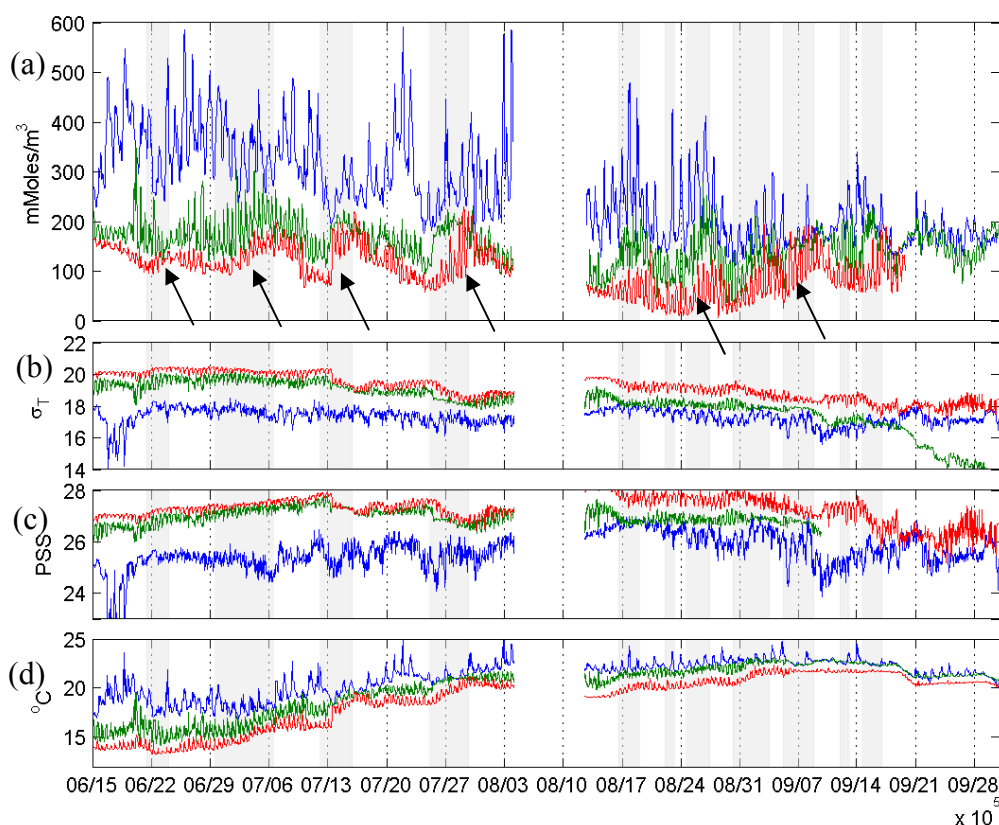
Figure 4. Time series of (a) disolved oxxygen, (b) density, (c) salinity and (d) temperatute at the Execution Rocks Buoy in 2004. The blue, green and red lines show the observations at 1m, 7m and 15m respectively. The arrows show intervals during which the near bottom DO was increasing.

That the near bottom waters in the area of western LIS that is prone to hypoxia every year are intermittently ventilated by higher dissolved oxygen is an entirely new perspective that could only be obtained by high temporal resolution sampling. Correlation of the occurrence of the ventilation events with the observations of salinity, temperature, current and wind to identify mechanisms that could be responsible is underway.

The LISICOS observation program was complemented by the CTDEP survey program (see Kaputo and Olsen, 2000). This program has been underway since 1991 and completes Sound-wide surveys of water quality parameters each month and bi-weekly during the summer. The data is shared with the LISICOS program via the data base. The most frequently occupied Station locations are shown in Figure 4. We have acquired the dataset from our collaborators at the CT DEP and have incorporated it in the LISICOS database so that it will be available to the LISICOS investigators. We are currently building an interface to allow records to be downloaded via the internet. Figure 5 shows the station locations and Table 2 lists the parameters that are measured with the units and detection thresholds.
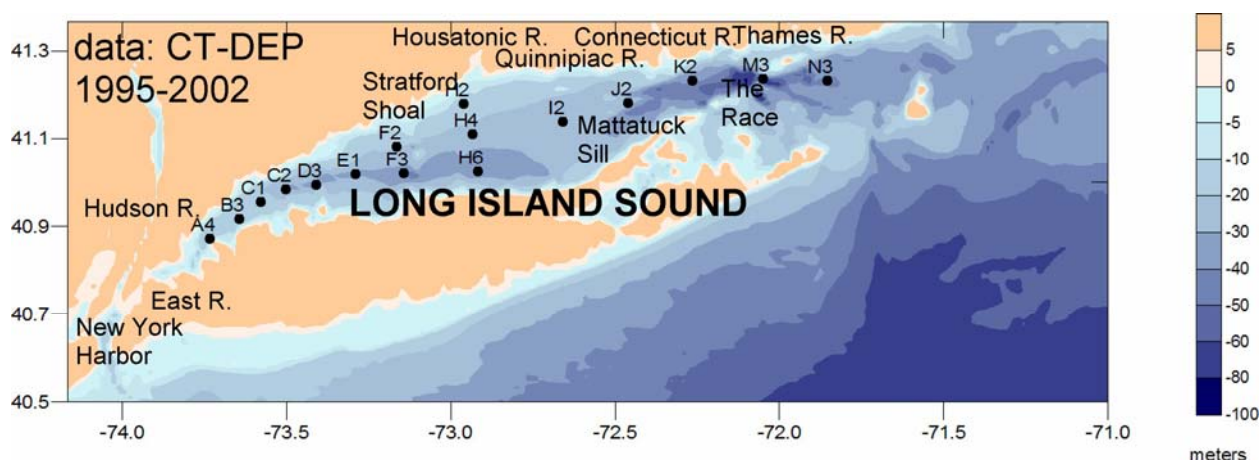
Figure 4. Map of the bathymetry of Long Island Sound and the adjacent shelf showing the locations of the CT DEP water quality survey stations.

This data set provides the longer term and larger space scale context for the observations acquired by the LISICOS program and thereby greatly complements the program. In addition, a project to perform an analysis of long term trends in the nutrients and chlorophyll-a distributions that was funded by the Environmental Protection Agency (EPA) Long Island Sound Study (LISS) will be facilitated by the availability of this data base.

The LISICOS program also supports three surface current measuring RADAR systems in Block Island Sound to monitor the exchange with the ocean. Two additional systems were purchased with LISICOS funds to observe the surface circulation in the western Sound. Locating suitable sites has been very difficult. However, one site was successfully installed at a US Coast Guard Station on Great Captain Island in May 2005. The second was installed at Stehli Beach in the Township of Bayville, NY, in July of 2005. Both control systems are mounted in specially designed instrument rack that is air conditioned. Data is telemetered to the central controller at the Avery Point Campus of the University of Connecticut where it processed, archived and distributed. Figure 5a show the antenna installation on the roof of the Beach Building, a task that called for considerable ingenuity. The site provides an excellent location from which to measure surface currents over a large area of western LIS. Figure 5b shows the antenna and the view the view from the beach.
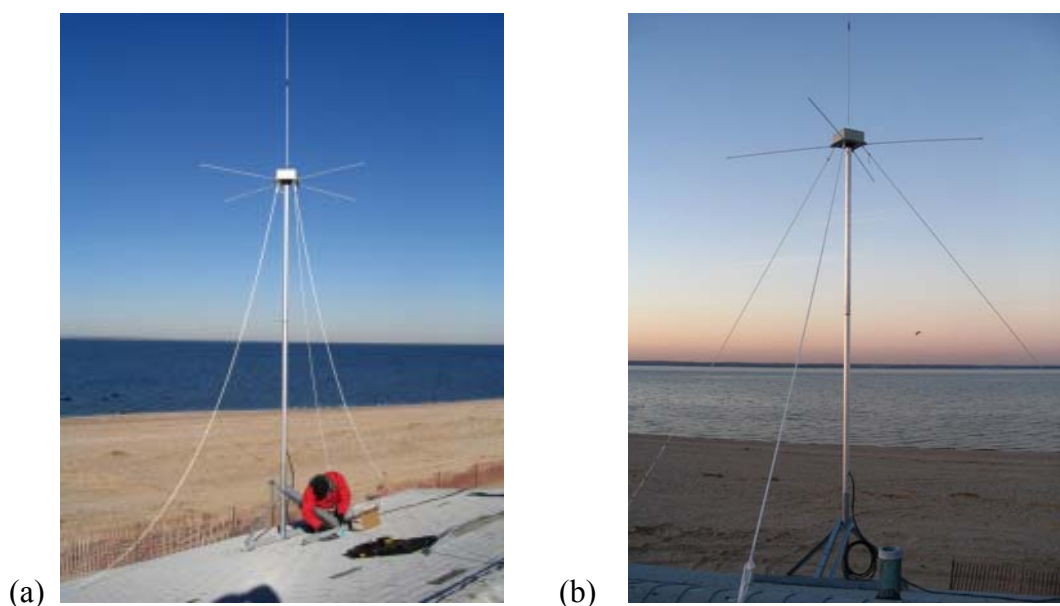
(a)   (b)

Figure 5. Photographs of the second LISICOS CODAR antenna. (a) The installation if the system on the roof of the beach center at Stahli Beach, Bayville, NY, and (b) the view of the unobstructed region of western LIS that is able to be observed by the antenna.

Table 2 **Parameter Description Detection Limit Analysis**

Code	Property	Detection Limit, units	Method
NH3	Ammonia	0.005 mg/L	Autoanalyzer
NOX-LC	Nitrate + Nitrite	0.002 mg/L	Autoanalyzer
CHLA L	Chlorophyll a	0.0005 mg/	Fluorometer
DIP	Orthophosphate	0.002 mg/L	Autoanalyzer
SIO2-LC	Dissolved Silica	0.005 mg/L	Autoanalyzer
DOC	Dissolved Organic Carbon	0.5 mg/L	High Temperature Combustion
Persulfate,	TDP Total Dissolved Phosphorus	0.01 mg/L	Autoanalyzer
TDN-LC	Total Dissolved Nitrogen	0.01 mg/L	Persulfate, Autoanalyzer
PN	Particulate Nitrogen	0.01 mg/L	High Temperature Combustion
PP-LC	Particulate Phosphorus	0.01 mg/L	HCl Extraction, Autoanalyzer
PC	Particulate Carbon	0.01 mg/L	High Temperature Combustion
BIOSI-LC mg/L	Biogenic Silica	0.04 mg/L	NaOH Extraction, Autoanalyzer
TSS	Total Suspended Solids	1.0 mg/L	Gravimetric
Temp	Temperature	Celcius	
Sal	Salinity	PPT	
Depth	Depth	Meters	
Do Titra	Dissolved Oxygen	mg/L	

The data return from the sites has been excellent and the area in which current vectors can be computed spans much of the hypoxic area of Western LIS. Figure 6 shows an example distribution of surface currents at 22:00 GMT on Feb., 17th 2006. At this time the current is ebbing throughout the region and the stronger currents in the eastern part of the domain are in the range 40-50 cm/s.
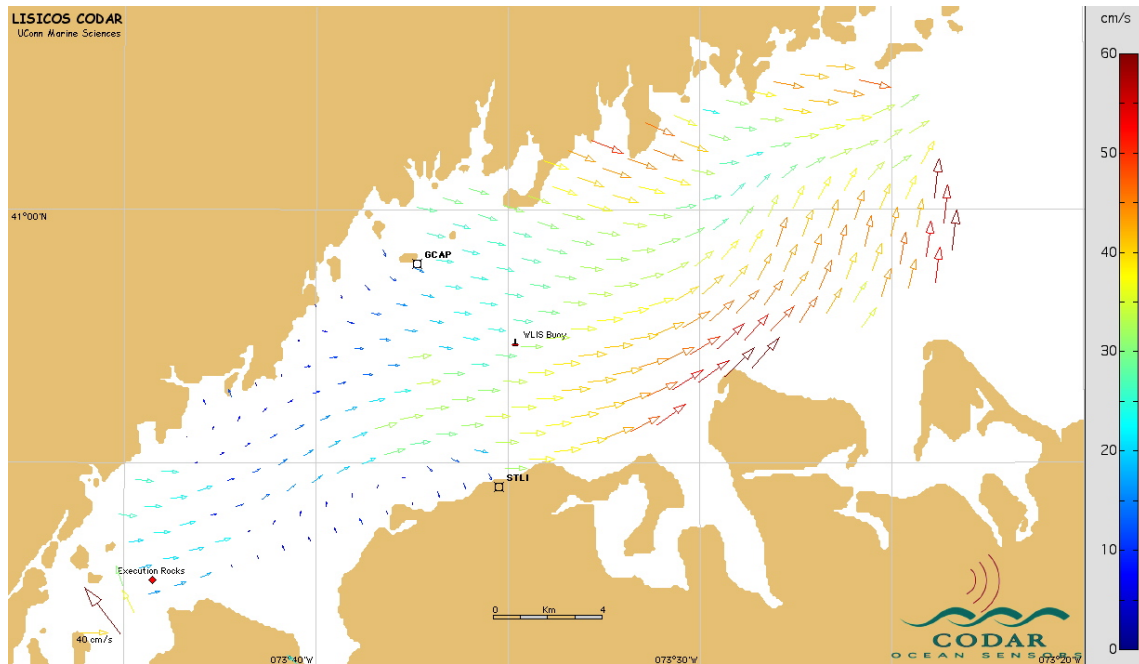
Figure 6. Surface currents estimated by the LISICOS CODAR system in Western LIS at 22:00 GMT on Feb., 17th 2006. The current magnitude is shown by the arrow colors and the key of provided on the right side of the figure. The locations of the CODAR sites at Great Captain Island, CT, Stehli Beach, Bayville, NY, and indicated by GCAP and STLI respectively. The locations of the LISICOS buoys at Execution Rocks and the WLIS site are also shown.

We have been collaborating with the US. Coast Guard, the University of Rhode Island, and Rutgers University, and several private companies to share CODAR data and develop an algorithm to turn the data into forecast products (see Ullman et al. 2004 and O'Donnell et al., 2005) for use in predicting the drift of search targets (O'Donnell et al., 2005 and Ullman et al. 2005b). This work attracted additional financial support from the US. Coast Guard and has been widely publicized to help motivate a nation-wide HF RADAR surface current monitoring system (OceanUS). Proposals to continue these collaborations have been submitted to NASA and NOAA. During this phase of LISICOS we have continued to provide current predictions in the Block Island Sound area and have prepared manuscripts for publication in the peer reviewed literature describing the technical details of the approach. The first paper, O'Donnell et al. (2005a) has been accepted, with revisions, the the Journal of Oceanic and Atmospheric Technology and the second, Ullman et al. (2005) has been accepted to the Journal of Geophysical Research-Oceans.

Task 3. Modeling and Data Analysis

The modeling and data analysis component of the program has several sub-tasks underway. A three dimensional circulation model is being compared to the observations from the in-situ observation array to assess the whether the inclusion of river discharge variability improves the model performance in simulating the observed hydrographic variability. At the moment, the East River transport is poorly monitored and we are seeking an approach that will allow us to circumvent the absence of freshwater flux estimates.

A semi analytic inverse approach shows promise. Following the modeling approach of Gay et al. (2004), we have developed an analytic model of the salt distribution in a converging channel and found a novel solution to the model equations. Figure 7 shows the geometry and the definition of the variables. Transport in the estuary is modeled by two parameters, one measuring the mean advective transport of salt Q_S and the second the rate of longitudinal dispersion, K, due to tidal motion and the residual circulation. In most estuaries Q_S is zero in steady state but in LIS the net transport through the east river carries salt with it. The volume flux has been estimated by Blumberg and Pritchard (1997) but there are no estimates of the salt flux other than that of Gay et al (2004).
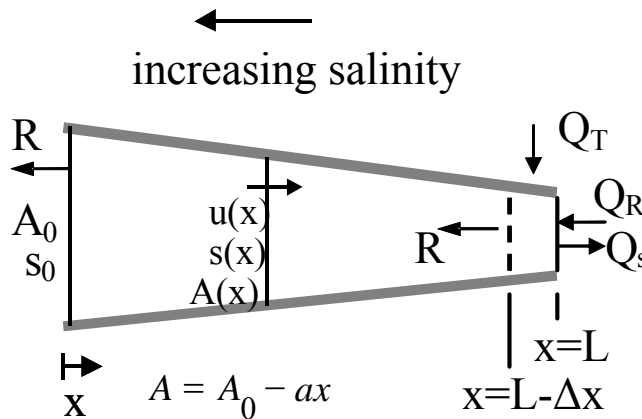

Figure 7. Sketch of the simple salt distribution model geometry. The ocean is to the left of and the low-salinity end is to the right. The segment is of length L. Thick gray lines indicate the linear decrease of the cross-sectional area from, A_0 at $x=0$, at the rate α. Q_s is the net flux of salt out of the up-estuary end of the segment. Q_R is the volume flux into the up-estuary end of the segment. R is the sum of Q_R and the fresh-water input, Q_T, from tributaries entering at the segment boundaries (between $L-\Delta x$ and , L, where Δx is small compared to L). The salinity at the seaward boundary is denoted s_0, and the salinity decreases in the direction of increasing x.

The solution of the salt distribution model demonstrates that the westward convergence of the cross-sectional area and the westward salt flux (or fresh water flux to the east) cause the salinity distribution to be curved near the east river. This is clear in Figure 8 which shows the long term average salinity distribution estimated from the CT DEP surveys and the model solution using objectively estimated parameters. We find that the salinity observation in the interior of the Sound are consistent with the Blumberg-Pritchard volume flux estimate and the Gay et al. salt flux estimate. A paper (Gay and O'Donnell,

2005) describing this work has been prepared for submission to the Journal of
Geophysical Research- Oceans.
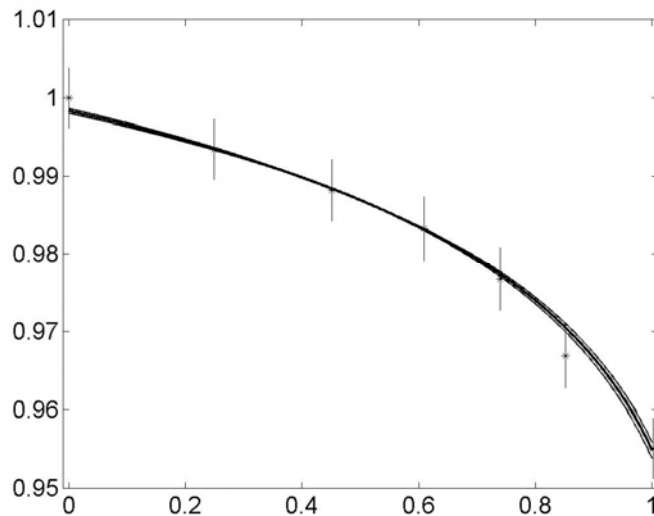
**Figure 8. The stars and error bars show the time- and depth-averaged salinity at axial CT-DEP
stations in western LIS (F3 at left and A4 at right). The thick line shows the depth-averaged salinity
predicted using the model of western LIS and the fitted dispersion coefficient of 50 m^2/s. The upper
and lower (thinner) lines are based on adding or subtracting the uncertainty of the dispersion
coefficient = 30 m^2/s**

Progress with simpler biological models has also been substantial. The BZI model has
now resulted in a paper that has been accepted for publication (Goebel et al., 2006). The
BZI model predicts primary production from phytoplankton biomass (B), the depth of the
euphotic zone (Z), and the surface light intensity (I). We are currently seeking to compare
a variety of box models of nutrient and oxygen budgets that exploit the moored array data
to infer rates of mixing, production and respiration.

Task 4. Process Studies

The central effort in the process studies were two programs of field observations in March
to characterize the spring bloom, and in July 2005 to observe the summer hypoxia period.
The cruises lasted 5 days in March and 10 days in July. The central goals were to measure
the rates and fluxes required to assess the relative importance of the terms in the mass
balances of C, N and O in a region of western Long Island Sound where summertime
hypoxia and anoxia has been documented since the late 1980's. These measurements are
essential to the effective validation and improvement of water quality models. Earlier field
campaigns have not resolved the water column and benthic respiration adequately, not did
they adequately measure the horizontal transport or rate of vertical mixing. Simultaneous
measurements of the rate of primary production, respiration and the settling flux of carbon
have not previously been attempted.

Each Cruise had two phases. The first phase comprised an extensive survey of the entire study area. Water samples and sediment cores were obtained at the corners and center of a diamond-shaped grid. Station locations are shown in Figure 9. Each station was sampled daily at least once. LISICOS observatory moorings and ADCPs were also located at the corners and center of the study area. In addition, at the easternmost station, another mooring was deployed equipped with PARFLUX sediment traps. One trap was deployed at the base of the euphotic zone and a second 3 m above the seabed. Six additional stations (labeled *a* and *b* in Figure 9) were located between the main stations and sampled once for DOC and nutrients during each cruise.

The second phase was a much more rapid, intensive spatial survey with very limited water sampling so that the consequences of tidal currents on the aliasing of the spatial structure of the hydrographic fields could be assessed and eliminated to the extent possible. The cruise track encompassed stations 4, 3 and 5 and salinity, temperature, dissolved oxygen and fluorescence profiles were obtained at stations 3, 3a, 3b, 4, 4a, 4b, 5, 5a and 5b on each loop. To estimate the vertical transport in a Lagrangian sense, we deployed GPS tracked drifters that supported sediment traps at 8m depth during the second phase of each cruise.
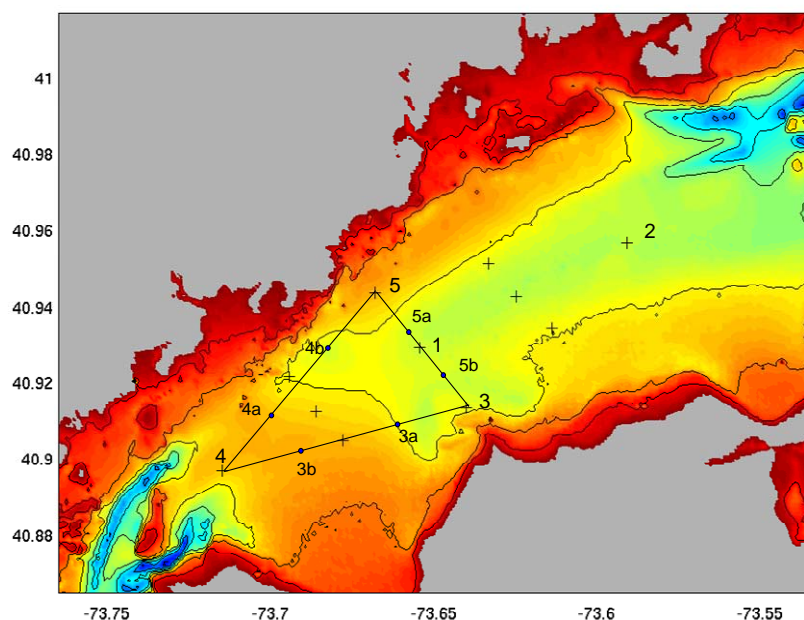
Figure 9. The bathymetry of western LIS showing the location of the principal sampling stations (1-5) used during the process studies. The solid lines show the track used during the rapid surveys to estimate the horizontal transport rates.

Water column measurements included profiles of temperature, salinity, nutrients (nitrate, nitrite, phosphate and ammonia) DO, DOC, POC, PON, bio-optical properties and chlorophyll size fractions. Particle loads in the water column were also measured and incubations were performed to estimate primary production and water column respiration rates. The samples from the drifting traps were analyzed to determine the flux of C, N, chlorophyll, and phaeopigments at the base of the euphotic zone and also the flux of zooplankton fecal pellets. The traps were deployed within the diamond and allowed to freely drift for periods of 24 h. Several deployments were made during each cruise. Incubations to measure zooplankton fecal pellet productions rates and the profile of fecal pellet abundance in the water column (July only) were also conducted. At all stations sediment cores were obtained using a multi-corer and incubations were conducted to measure benthic/sediment oxygen demand. In addition, sedimentary POC, PON, and pigments were characterized by HPLC. During each cruise 12-24 hour periods were dedicated to rapid surveys using a towed-undulating vehicle (Seascience Acrobat) and an ADCP to characterize hydrographic and DO variability within the diamond study area to allow estimation of horizontal fluxes.

Circulation and Hydrography

The vertical structure of the mean flow in the summer at the Execution Rock station is illustrated in Figures 10 (a) and (b) which show the east and north vector components respectively averaged between May 28, 2005 and August 1, 2005. The flow largely conforms to the standard estuarine circulation pattern with a northeastward component near the surface and a southwest flow near bottom. The tidal currents are much larger and spatially complex. The track of the drifters launched during the summer cruises for 24 hours intervals is shown in Figure 10(c). Particles trajectories follow almost elliptical orbits with a 5 km major axis.
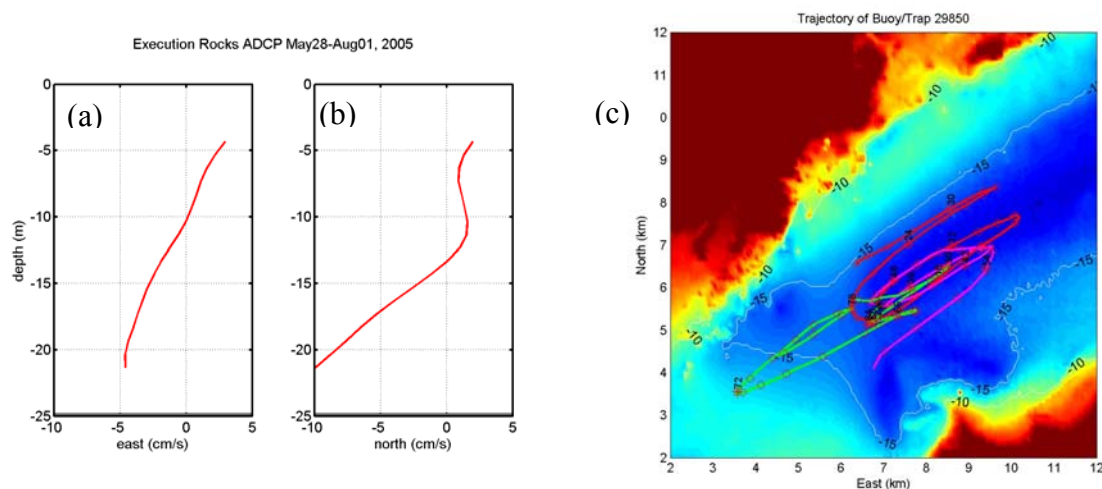
Figure 10. The vertical structure of the mean circulation at the Execution Rocks station in 2005. (a) shows the east component and (b) shows the north component. (c) Track of the Lagrangian drifter with sediment traps. Release points are denoted by the '*' symbols. The circles show hourly intervals.

The lateral structure of the hydrographic fields has not been resolved in this region before. Figures 11 (a) and (b) shows two perspectives of the three dimensional structure of the mean (detided) the salinity field as observed by the Acrobat surveys in July, 2006. The view in Figure 11(a) is from approximately Station 2 looking to the southwest with station

5 to the right and Station 3 to the left. The salinity scale is shown by the colored bar on the right of the figure. It is clear that the lower salinity water (~25.3) near surface is deeper on the southern side of the Sound and that the halocline slopes upwards towards the north. The view in Figure 11(b) is from the Long Island shore looking north. The halocline is almost horizontal but is intensified at the center of the transect.

The mean dissolved oxygen (DO) distribution is shown in the same way in Figures 12 (a) and (b). It is clear in Figure 12(a) that the lateral (south-north) gradients of DO are quite weak at 5-8 m compared to the corresponding salinity gradients. The lower stratification in the north side of the Sound appears to allow slightly deeper mixing of oxygen that is diffusing from the atmosphere and being produced in the upper few meters of the water column by phytoplankton. In the deeper water the lateral gradients are also very weak. At the beginning of this project we conjectured that vertical mixing near the shoreline of the Sound may cause the near bottom DO concentration to be higher and that lateral circulation could transport oxygen to the middle of the Sound. Figure 12(a) shows that the near-bottom DO is lower at both coasts and we must conclude that near-shore mixing and lateral transport is not a source of oxygen to the bottom waters of the western Sound.

The view in Figure 12(b) also shows that there is a weak along Sound gradient of near bottom DO in July with the lowest values in at station 4. At stations 3 and 5, approximately 40 km to the northeast, the DO concentration is 1 mg/l higher. This is consistent with the climatology developed by the CTDEP.

Chlorophyll Measurements
A total of 144 samples were collected during the spring 2005 cruise and 928 samples during the summer 2005 cruise. Most of these were obtained during the larger scale surveys. Extraction and chlorophyll measurements for these samples have been completed. The samples were analyzed using the Turner AU-10 fluorometer (winter) or a Turner TD-700 fluorometer (summer).

The total chl-a concentration in the surface water was 5 times greater in the summer compared to winter. During spring, the surface chl-a values from the five stations ranged from 4-10 µg chl-a/L, indicating a relatively homogenous chl- a distribution in the area. In contrast, there was a greater variation in the total chl-a concentrations in the surface waters during summer time where the values from the five primary stations ranged from 6-50 µg chl-a/L. During the spring cruise, the highest surface total chl-a concentrations, ranging from 8-10 µg chl a/L, occurred at stations 3 and 4 (Fig. 9). In the summer cruise, station 4 showed elevated total chl-a concentrations in the surface waters ranging from 18-50 µg chl-a/L but chl-a concentration at station 3 was low.

The vertical profiles of total chl-a during winter and summer generally showed a surface maximum and decreasing values with depth except in July 23 where there was a subsurface chl-a maximum at ~5-7 m depth at station 5. A relatively homogenous high chl-a level was found in the top 4 m at other stations on July 23 and stations 1, 2, 3, and 5 on July 22.
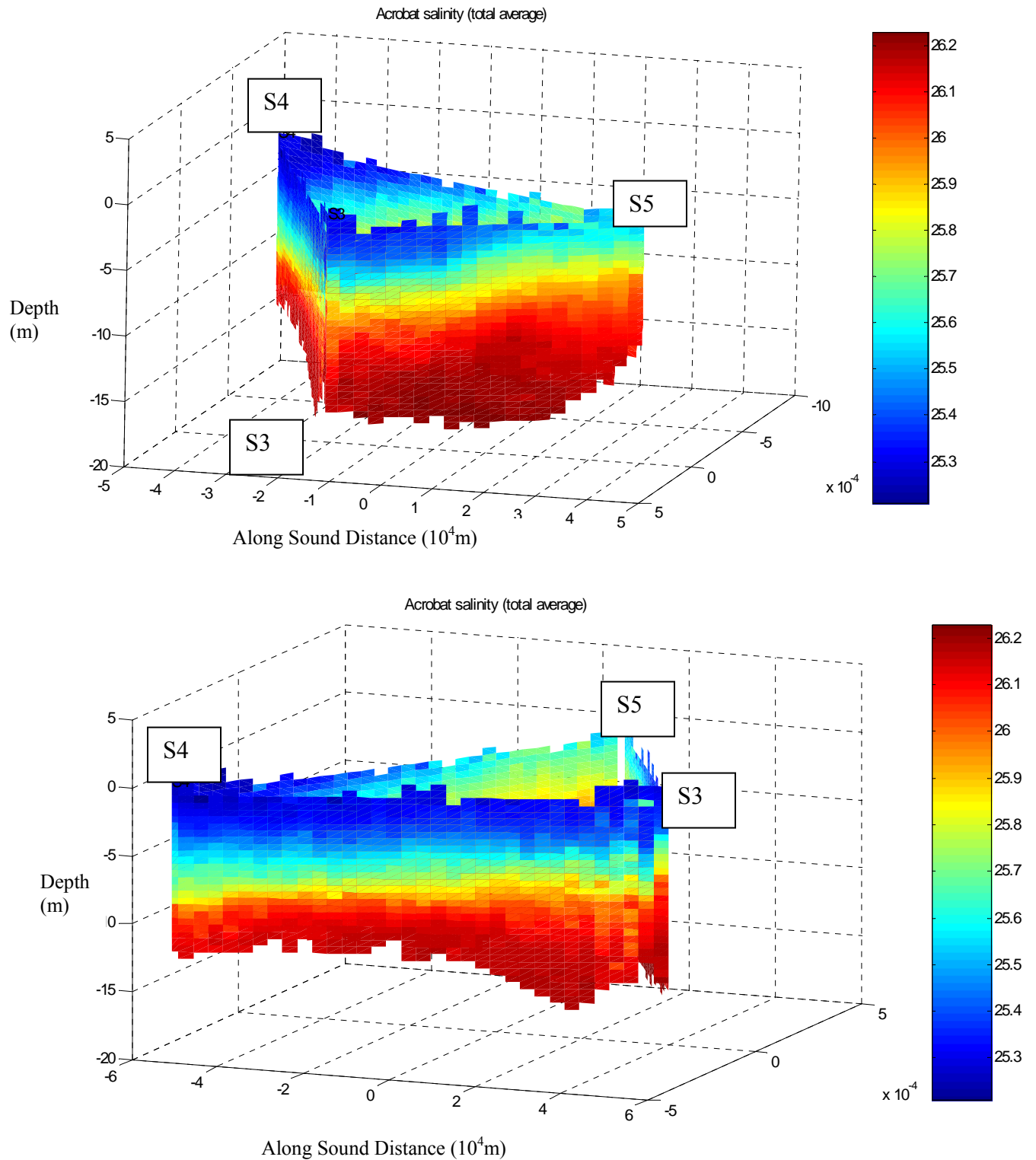
Figure 11. Three dimensional perspectives of the mean salinty field observed in western LIS during the summer surveys of 2005 computed by averaging Acrobat surveys. In (a) the view is looking westward from station 2. In (b) the view is from the south looking north.
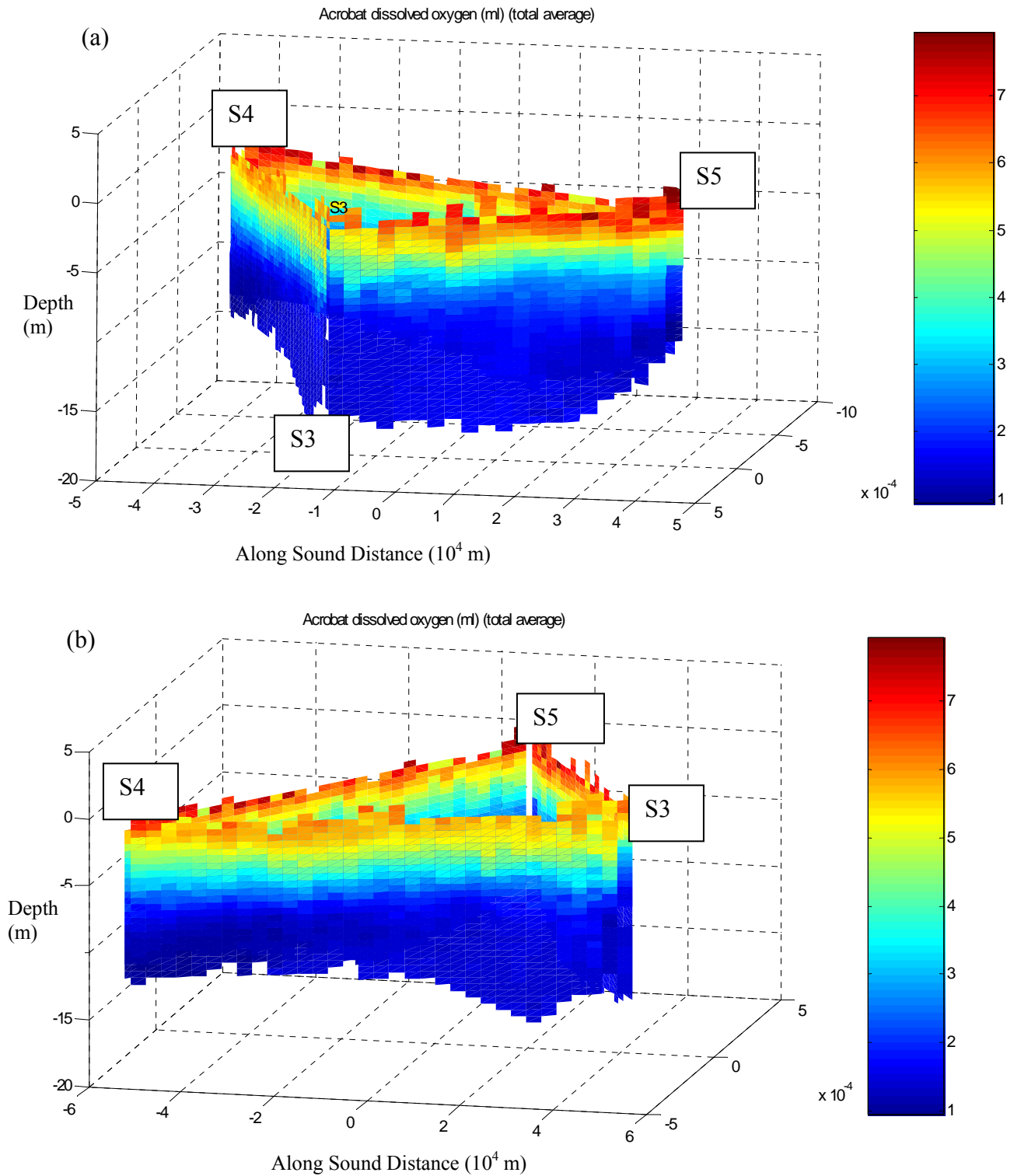
Figure 12. Three dimensional perspectives of the mean dissolved oxygen field observed in western LIS during the summer surveys of 2005 computed by averaging Acrobat surveys. In (a) the view is looking westward from station 2. In (b) the view is from the south looking north.

At all stations surface chl-a concentration varied markedly with time (Fig. 11). At all but stations 3 and 5, chl-a concentration was higher on July 21 and 22, then lower on July 23. Chl a concentration increased on July 27 and 28 at all stations. Though these observations do not resolve tidal and daily variations, they are invaluable to the calibration and interpretation of the in-situ fluorometer measurements.

Grazing

During the March and July 2005 cruises, we measured grazing rates by both microzooplankton and mesozooplankton. We used the dilution technique to measure microzooplankton grazing and the gut fluorescence technique to measure mesozooplankton grazing. At least, one microzooplankton grazing experiment was done each day of each cruise. Mesozooplankton grazing was done at least once during the day and once at night. Analyses for the March cruise are completed, and are underway for the July cruise. Preliminary results suggest that 50-80% of the primary production is grazed by microzooplankton and no more than 10% by mesozooplankton.

Water Column Respiration

During the Spring 2005 LISICOS intensive survey cruise photosynthesis-irradiance productivity series measurements were made on surface waters, and community respiration was measured at three depths (surface, mid, bottom) at the five main stations (1 through 5 in Figure 9). At the end of the cruise at stations 4, 1 and 2 were sampled again. The winter respiration rates were quite low, in many cases undetectable.
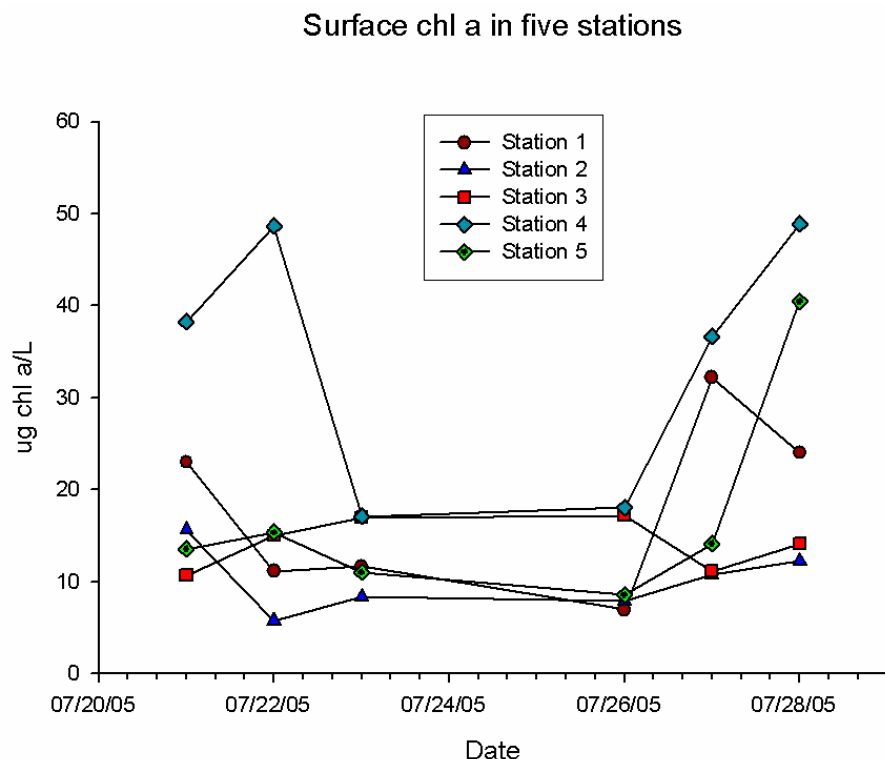
Figure 11. Surface chl-a values in five stations sampled during the summer cruise 2005.

During the summer 2005 cruise, stations 1 through 5 were sampled on four occasions for community respiration, and P-I productivity measurements were completed at each station one time (a total of five new P-I measurements). Productivity measurements were made on surface samples only, and respiration measurements were made at four depths (1, 4-5, 7-10, and 15-18m). For community respiration, 4-5 replicates of each initial and dark bottles were measured for each depth. Overall, for the summer cruise, we have approximately 4 depths x 5 stations x 4 days = 80 respiration measurements, plus the 5 P-I curves for rates of productivity. Our summer average +/- stdev (and range) in community respiration for the surface, mid-upper, mid-lower, and bottom of the water column are as follows: 0.26+/-0.20 (0.03 to 1.03), 0.14+/-0.09 (0 to 0.38), 0.11+/-0.15 (0 to 0.61), and 0.10+/-0.14 (0 to 0.59) mg/L/d. (These are preliminary calculations, which will be finalized by adjustments of the specific oxygen calibration factor for each analysis date, and by removing outliers. Calculations of the integrated productivity (e.g. mg O2 $m^{-2} d^{-1}$) await calibration of the CTD fluorometer profiles which is in progress.

Particulate Organic Carbon and Nitrogen and Particle Fluxes
Particulate organic carbon and nitrogen (POC/PON) in the water column and downward fluxes of POC/PON and pigments were measured during both the spring and summer process studies cruises of LISICOS. To date, we have analyzed all of the water column POC/PON samples, and calculated the downward fluxes of POC/PON. Analysis of the pigment fluxes are underway. In addition, Caroline Loglisci, one of the LISICOS supported students, carried out for her MS thesis a mass balance study of zooplankton fecal pellets during the July cruise. Analysis of the samples from this study is also underway. Finally, we have a collaborative effort with Heidi Dierssen's group in the analysis of particle size spectra.

Fourteen profiles (4 depths per profile) during March and 45 during July of POC/PON were obtained. During March, POC ranged from 532 to1033 μg L^{-1} and PON ranged from 74 to 204 μg L^{-1}, and the POC:PON ratio ranged from 4.5 to 9.7, with the great majority of samples having ratios between 6 and 7, indicating that most of the material was phytoplankton. During July POC ranged from 104 to 2423 μg L^{-1} and PON from 16 to 526 μg L^{-1}. POC:PON ratios varied from 2.0 to 17.0, with most of them being < 9. The higher C:N ratio in July could be indicative of higher nutrient limitation in the phytoplankton or a greater presence of detritus in the water column.

Downward C and N fluxes are key parameters in our models of the dynamics of hypoxia in Long Island Sound. Hence, we highlight these results in this report. Downward fluxes were measured near the surface (8 m below the surface) and near the bottom (3 m above the bottom) with PARFLUX traps, and with VERTEX –type free floating traps (8 m below the surface, duplicate arrays). Collection intervals for the moored traps were 48 h in February-March and 24 h in July. Drifting traps were deployed from 18-24 h during both cruises. In Feb-March, the moored traps were deployed three weeks prior to the Process study (March 3-7). During this time period, comparison of moored versus drifting traps is only for March 3-7. In July, collection periods for the moored and drifter times coincided. The downward fluxes are summarized in Tables 1 & 2. During both the March and July cruises, POC/PON fluxes for the moored traps were significantly higher near the bottom than near the surface (Cochran's T-test with unequal variance, p < 0.05). Between cruises, there was no significant difference in fluxes measured by the moored

traps at the surface, but the bottom fluxes were significantly higher in July than in March (Cochran's T-test with unequal variance, $p < 0.05$). For the drifting traps, the flux was significantly higher in July than in March (Cochran's T-test with unequal variance, $p < 0.05$). In March, fluxes from the drifter and the surface moored traps were not significantly different, but in July the drifter traps had significantly higher fluxes than the moored traps (Cochran's T-test with unequal variance, $p < 0.05$). Flux POC/PON ratios were 5.8 (drifting traps) both in March and July. For the surface moored traps the flux POC/PON ratios were 6.2 (March) and 6.9 (July), and for the bottom moored traps they were 6.0 (March) and 8.0 (July). These ratios indicate that the sinking material was not enriched in carbon relative to the suspended material.

Plankton Summary

During the summer hypoxia season phytoplankton biomass is relatively low < 1 µg chlorophyll L^{-1}, dominated by small phytoplankton (< 10 µm) in quasi steady state, and production is presumably driven by regenerated ammonia as nitrate levels are typically below detection levels. This contrasts with the results of the spring bloom field campaign during which phytoplankton biomass is high (5-20 µg chlorophyll L^{-1}), dominated by large cells (> 20 µm), and nitrate levels are plentiful (Peterson 1985). Because by definition a bloom implies a relaxation in grazing, it is presumed that a large portion of the accumulated phytoplankton biomass must be exported. Hence, the conditions for delivering material from the water column to the benthos are radically different during the spring bloom and during the hypoxia season. Likewise, because of the strong differences in temperature between the time of the spring bloom (Feb-March) and the time of hypoxia (July-August), the respiration and mineralization rates of material delivered to the benthos are expected to be radically different.

Benthos

The LISICOS ship-deployed multicorer was used to characterize the infauna community, bulk sediment characteristics and sediment oxygen demand at Stations 1-5 shown in Figure 9. Five replicate deployments were taken at each sampling time. Macrofaunal samples were sieved through a 300 um mesh screen; sample residues were preserved in 10% buffered formalin, transferred to 70% ethanol and stained with Rose Bengal. Samples were be sorted under a dissecting microscope and species were identified (to lowest possible taxon) and enumerated. Sediment oxygen demand was estimated using respirometry chambers, equipped with magnetic stirrers, and placed in a temperature-controlled water bath. After an appropriate acclimation period, chambers were fitted with an oxygen electrode and sealed. After oxygen consumption determinations, cores were sectioned and macro-infauna identified, enumerated, and weighed. Individual macrofauna were removed from chambers and dry-tissue mass was determined. Seasonal variability in bioturbation rates was estimated using down-sediment profiles of phyto-detrius using standard HPLC techniques. Table 3 summarizes the number of samples and state of sample processing for spring and summer cruises and Figure 10 summarizes the benthic oxygen demand measurements. The values obtained by coring and incubation range between 20 and 40 m moles/m^2/day. The measurements using the prototype benthic chambers are consistent with these estimates.
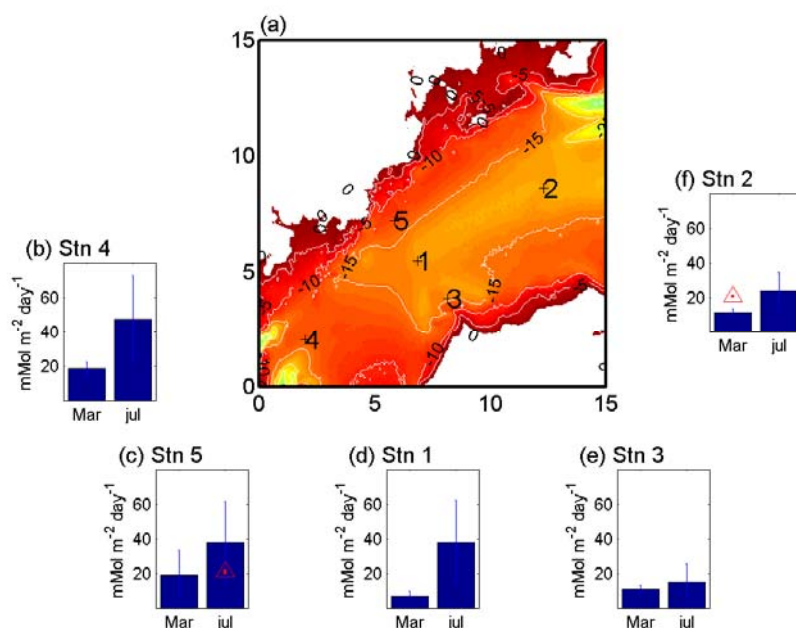
Figure 11. Summary of the benthic oxygen demand measured during the LISICOS 2005 intensive field campaign. The bars show the results of the core incubations and the red triangles show the estimates obtained by the prototype benthic chambers.

Table 3**. LISICOS 2005 Benthic Sampling Summary**

Spring 2005

Sample Type	Total Samples	Progress to date
Benthic Biodiversity	37	26 samples sorted
HPLC pigment analysis	60	New method and equipment have been set up. Test runs are underway
Sediment Carbon and Nitrogen Content	60	All samples have been processed and data has been tabulated.
Sediment grain size analysis	60	n/a
Benthic oxygen demand	32	Completed

Summer 2005

Sample Type	Total Samples	Progress to date
Benthic Biodiversity	29	n/a
HPLC pigment analysis	80	New method and equipment have been set up. Test runs are underway
Sediment Carbon and Nitrogen Content	80	~60 samples have been processed and tabulated. Slated for completion next week.
Sediment grain size analysis	80	n/a
Benthic oxygen demand	28	Completed

Water Column Nutrients and DOC
During the Spring 2005 LISICOS cruise a total of 95 discreet samples were collected for each and all have been analyzed. Surface concentrations of DOC ranged from 80 to 180 μM carbon. Elevations in DOC were observed to correspond to subsurface fluorescence maxima though the water column was fairly well mixed during this period. DIC values ranged from 1300 to 1780 μM carbon which is typical for bloom periods. Stable carbon isotope values ranged between -28.7 to –15.2 and –3.7 to –2.0 for DOC and DIC respectively. All samples have been run for organic and inorganic nitrogen (nitrate, nitrite and ammonia), phosphate and silicate.

More intensive surveys were conducted during the summer 2005 cruise where higher spatial variability was expected. 192 samples were collected for DOC, 189 were collected for DIC and 192 samples were collected for nutrients. To date, all phosphate, ammonium and nitrite, and DOC samples have been processed. Preliminary results will be presented in February 2006 at the ASLO meeting in a talk entitled "Dissolved Organic Carbon Fluxes in Western Long Island Sound" (authors: Cervinia V. Manalo and Penny Vlahos).

We have also purchased and tested an *in situ* nutrient analyzer from SubChem Systems. The instrument was deployed for a short period during the July cruise on a towed, profiler (a Seasciences Acrobat) and we have 20 minutes of continuous nitrite and ammonium data from this first deployment. We have a faculty member, research associate and graduate student who have received formal training on the instrument and plan to deploy it on the rosette for vertical casts in March 2006 and on the acrobat in July 2006. These high resolution concentration measurements are currently being compared to discreet measurements taken simultaneously to evaluate the effectiveness of the system.

Task 5. Data Management

We have purchased and installed new computers to facilitate data archiving and distribution. The database management software (Microsoft SQLserver) has been configured it to archive the real-time data from the LISICOS buoy array and the survey data acquired by the Connecticut DEP surveys. Figure 9 is shows a schematic of the data system architecture.

Data and model products are entered into the database by system managers. A data sharing policy has been established for those involved in the process studies and is published in the LISICOS web site. We have configured ESRI's ARCIMS software to take data from the database and prepare images for distribution via the internet using on-line forms. We also continue to provide meteorological and oceanographic data to the National Data Buoy Center and surface current observations with partners at Rutgers, and the University of Rhode Island.
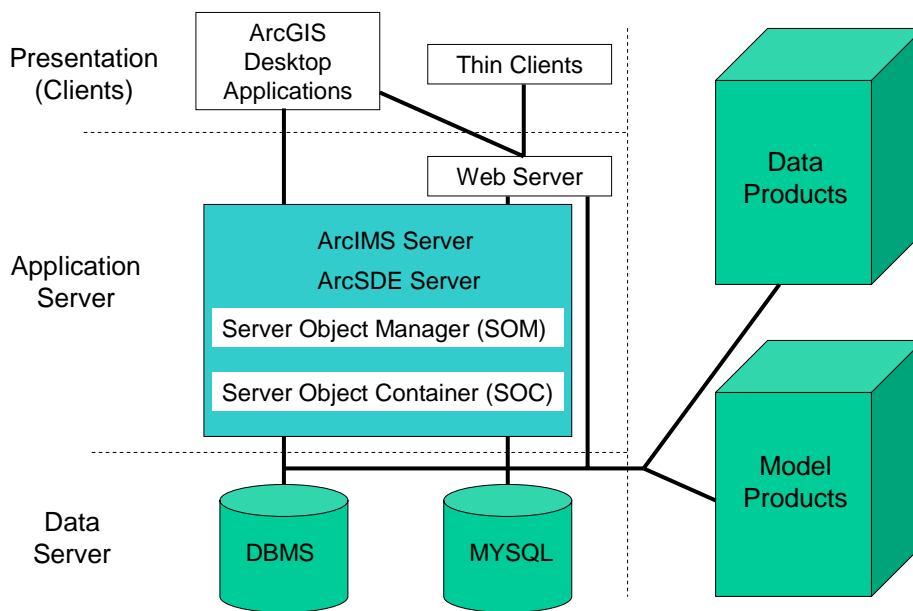
Figure 9. Schematic of the data archiving and data distribution system.

The data base has also been configured to distribute surface current predictions form the LISICOS numerical model of the circulation in the Sound. At the moment we are testing the model prediction quality prior to promoting the use of the system, however, we have provided built an operation mode product distribution system to identify potential problems while the model verification proceeds. In addition, we are currently testing an data archive and distribution system for all the LISICOS CODAR data and the CTDEP water quality survey data. The site can be explored at www.LISICOS.UConn.edu.

Task 6. Public, College and K-12 Education

The LISICOS team has developed a collaboration with the University of Connecticut's School of Education to develop science curriculum materials that exploit the LISICOS infrastructure. The collaboration resulted in a proposal to the COSEE program at NSF to establish an association with UConn's component of the Carnegie Foundations Teachers for a New Era (TNE) program. Unfortunately, this proposal was unsuccessful. In addition LISICOS collaborated with the National Undersea Research Center (NURC) at the University of Connecticut to create and fund teacher research opportunities through the Aquanaut Program. This research focused on observations obtained by the Long Island Sound Integrated Coastal Ocean Observing System (LISICOS). Eight teachers were recruited to work as part of a team including scientists from the National Undersea Research Center, the National Marine Fisheries Service and the University of Connecticut's Marine Sciences Department.

Task 7. Outreach to Users

We have met with the leadership of the Connecticut DEP and the EPA's Long Island Sound Study to discuss how the LISICOS infrastructure can be most useful to their missions. In the early stages of the program we have committed to cooperatively develop database infrastructure that is consistent with that already in use by the DEP managers and to provide a convenient interface for access. DEP manager also agreed to provide us with data from their survey programs. O'Donnell and Dam presented a summary of the LISICOS program to the Science and Technical Advisory Committee of the EPA's Long Island Sound Program.

We have coordinated with EPA's Long Island Sound study to coordinate surveys and equipment availability. We also collaborated with the U.S. Coast Guard, The University of Rhode Island and Rutgers University to provide CODAR-based current forecasts for search and rescue operations. Recently, we have engaged Science Applications Inc., of Mystic, CT, to collaborate on the development of improved CODAR data algorithms. This work has been completed and an extensive report submitted to the USCG (O'Donnell et al., 2005a). Two papers have also been submitted to peer reviewed journals describing this work (O'Donnell et al. 2005b and Ullman et al. 2005).

In addition to maintaining close ties to the local user community we have collaborated with Dr. Thoroughood of the University of Delaware to host a regional workshop to help establish the Middle Atlantic Coastal Ocean Regional Association (MACOORA). In November of 2004 we hosted a local meeting of the people interested in MACOORA to develop a contribution to the larger regional association planning process and are preparing a summary report.

In collaboration with, and the financial support of, citizens of Stonington we conducted a water quality monitoring program in Stonington Harbor from June to August 2005. The instruments were maintained and the water samples obtained by Mr. P. Olivier, a student of the University of Maine's Marine Biology program and summer intern at UCONN. We found very high levels of nitrogen in the estuary as a result of the Stonington sewage discharge and a significant reduction in the dissolved oxygen near the bottom. Levels of copper were also unusually high. We prepared a report for the citizens and the Commissioner of the Connecticut Department of Environmental Protection. This work is currently being used to help design a new strategy for the disposal of Stonington's water treatment plant effluent.

Task 8- Technology Development

Benthic in situ oxygen flux chambers have wide application and are integral to monitoring an important term in the oxygen budget of western LIS. We have built (based on a design provided by Gary A. Gill and colleagues, formerly of Texas A&M University, Galveston) an innovative and automated apparatus equipped with an oxygen electrode/data logger for time sequenced measurements of oxygen. The design also allows sequential manual sampling of waters from the flux chamber. Development of the chambers has required creative designing, engineering, and numerous field and laboratory tests. The benthic chambers yield high quality time series information on sediment-water exchanges, and they are poised to be automated further.

Benthic in situ flux chambers were developed and tested. These devices are dual chambered, offering a variety of flexible sampling protocols (e.g., replication, short spatial variability tests, time series water sampling). They were deployed at LISICOS sampling stations in western Long Island Sound (WLIS) to measure spatial and temporal variations in sediment/benthic oxygen demand (SOD) during March, June, and August 2005. Chambers were put in place and retrieved by skilled divers. UCONN's R/V Challenger, was used as sampling platform. Dissolved oxygen (DO) was measured using YSI 600 series sondes, and standard hydrographic data (DO, T, S, and depth) were almost measured continuously. The June survey was designed for method development related to oxygen monitoring and deployment of newly built benthic chambers. Chambers were deployed at the UCONN Avery Point pier in the eastern Sound (ELIS) in February and October 2005, which will provide near shore SOD's for comparison to the WLIS sites. In August, water was sampled from one chamber in WLIS as a technical/analytical test of the procedures and techniques for the determination of constituents associated with major biogeochemical cycling in sediments. The suite of measurements includes dissolved organic carbon, nutrients, and trace metals (e.g., Fe, Mn, Hg,). Fluxes of these biologically active constituents into and out of the sediment are key complements toward understanding the euthrophication dynamics in the water column and sediments.

Preliminary results for Sediment Oxygen Demand (SOD)

The behavior of the DO concentration when reacting with unlimited organic carbon in the benthic chambers should be

$$\frac{dC}{dt} = -k_1 C$$

which has a solution

$$c(t) = c(0)\exp(-k_1 t)$$

($c(t)$ and $c(0)$ are the DO content of the chamber at time t and at initial deployment, respectively; t is elapsed time from initial deployment; and k_1 is the benthic demand constant)

When calculating SOD, a Taylor's series expansion demonstrates that we can neglect quadratic effects for small values of $k_1 t \approx 0.1$. Therefore, a linear regression of the log of the scaled DO observations (c/c_0) and time yields an estimate of the benthic demand constant k_1. When the exponential decline is substantial, the initial phase (ca. 4h) of the oxygen record that was not influenced by start-up transients was chosen to estimate these rates. The initial 4h of data could be described well by either log linear or linear regressions. SOD ($k_1 c_0$) has been estimated from our benthic chamber deployments in WLIS (Table 4). The calculated SOD rates from duplicate chambers at the WLIS buoy in March 2005 were 834 and 871 μmol O_2 m^{-2} h^{-1}, indicating good agreement over small spatial scales, and k_1 ranged from 0.018 to 0.022. The deployment of duplicate chambers at the FB1 buoy in August 2005 produced SOD estimates of 928 μmol O_2 m^{-2} h^{-1} (k_1=0.148) and 824 μmol O_2 m^{-2} h^{-1} (k_1=0.120), which still indicates reasonable agreement on a small spatial scale. Although the SOD estimates are similar in March (2 ^{0}C) and August (19 ^{0}C), k_1 values were 6-7 times higher in August. The low ambient DO

(hypoxia) in the bottom waters of WLIS in August (22% oxygen saturation; Table 1) accounted for reduced SOD rates, even at elevated values of k_1. This suggests that enhanced SOD fluxes will be evident in the early summer and fall when aeration processes will produce substantially higher benthic water column DO in WLIS.

Table 4. WLIS sediment oxygen demand (SOD) measurements made in 2005 using in situ benthic chambers.

location/ sampling date	Water depth (m)	SOD (mmol O_2 m^{-2} d^{-1})	k (1/hrs)	r^2 (4 h) log C/C_0 vs time	Initial chamber O_2 (μM) / (mg/L)	Mean Temp. (^{0}C)	Mean Sal. (ppt)
March							
WLIS buoy Stn. 5 3/16-3/18/05	19-21	chamber A 20.1	0.022	0.99	399 / 12.77 (109% sat.)	1.6 (0.03)	25.7 (0.03)
		chamber B 20.9	0.018	0.99	381 / 12.18 (104% sat.)	1.5 (0.03)	26.0 (0.02)
August							
FB1 buoy Stn. 3 8/3-8/4/05	12-14	chamber A 22.2	0.148	0.99	51 / 1.62 [1] (21% sat.)	19.3 (0.1)	26.3 (0.02)
		chamber B 19.8	0.120	0.99	53 / 1.71 [2] (22% sat.)	19.3 (0.1)	26.2 (0.02)

Summary

The LISICOS program continues to proceed largely as planned. The delays associated with hiring of personnel have been resolved. The late delivery of the observatory support boat remains a difficulty that makes maintenance of the infrastructure more difficult; however the distribution of field and modeling work has allowed us to accommodate this difficulty without slowing our progress. Two extensive interdisciplinary process studies have been successfully completed and the analysis of the results is well underway. The infrastructure of the observatory has been reliably operating throughout the year and new users are integrating it to their businesses and research programs.

We have discovered short term ventilation event during the summer transition to the hypoxic conditions in the western part of LIS. This has been suggested by a prior stud with weekly water samples but the in-situ sensors have unprecedented resolution and have demonstrated the phenomena unequivocally. We now must understand the mechanisms that cause this variability.

The survey programs have eliminated the possibility that vertical mixing coupled with lateral circulation as a candidate mechanism for the source of oxygen Torgersen et al. (1997) noted must be present to reconcile the seasonal scale DO decline in the western Sound with the estimated benthic and water column respiration measurements. Our

extensive water column and benthic demand measurements also validates the earlier measurements. We must conclude that the puzzle pointed out by Torgersen et al. (1997) must be resolved by axial transport of DO or vertical mixing.

The establishment of the database system for the aggregation and distribution of observations and model products for LIS is now in a demonstration mode and we are seeking internal and external users to provide feedback to make it easier to use and more powerful.

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