FOSTER-LIS Gridded Data Products:

Updated Methods and Appended 2010-2011 Observations

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Contents

A. Summary

This is the second technical report (following Codiga, 2007) describing gridded data products (GDPs) resulting from the Ferry-based Observations for Science Targeting Estuarine Research in Long Island Sound (FOSTER-LIS) project. The purpose here is to explain updated methods used in developing the GDPs, and provide information about 2010-2011 ferry-based observations that have been appended in the GDPs. There are two types of GDP: velocities, and water properties. A new method for mapping the raw velocities to virtual stations, which is fractional-depth based as opposed to depth-based, has been developed and applied. It has the advantages that similar numbers of data are averaged together in all fractional depth ranges, and that each velocity profile assigned to the virtual station spans the full water column there and does not extend deeper than its mean water depth. An improved method for quality control of the water properties measurements has been applied that enables exclusion of poor-quality data from individual virtual stations, and treats temperature, salinity, and Chlorophyll separately. An independent dataset, the vessel-based water quality monitoring surveys by the Connecticut Department of Environmental Protection (CT DEP), has been used as ground truth to verify the accuracy of the ferry-based temperature and Chlorophyll observations. A new correction for drift of the conductivity sensor, over timescales of weeks and longer, has been developed and applied using the CT DEP observations. At timescales longer than weeks the drift correction yields an accurate seasonal cycle. At shorter timescales drift correction retains accuracy of spatial and temporal variability: for example, north-south gradients along the ferry crossing, and responses to river runoff events. Finally, new observations of velocities, temperature, and salinity (not Chlorophyll) collected from April 2010 to June 2011 have been appended. The new methods have been applied to the 2010-2011 observations as well as those from prior to 2006 that were described in Codiga (2007). The newly created GDP files contain all years of data and replace the prior versions.

B. Introduction

The first FOSTER-LIS report (Codiga 2007) described processing methods and gridded data products (GDPs) for oceanographic datasets of velocity profiles and near-surface water properties that were collected by a ferry in eastern Long Island Sound. The final products were (i) a GDP of velocity profiles that spanned a range of dates starting in late 2002 and extending through the end of 2006, and (ii) a GDP of water properties (including temperature, salinity, and Chlorophyll) that spanned a range of dates starting in early summer 2005 and extending through late summer 2006.

The two main purposes of the present follow-on report are to describe (a) updated processing methods that have been applied, and (b) inclusion of new observations, from a period beginning in spring 2010 and extending through early summer 2011, which have been appended to the two GDPs. The 2010-2011 observations include velocity profiles and temperature and salinity, not Chlorophyll.

C. Updated Processing Methods

C. 1. Velocities: Fractional-Depth Based Mapping to Virtual Stations

Individual ping data are collected by the acoustic Doppler current profiler (ADCP) each 2 seconds and averaged in groups of 16 to produce ensemble-mean values that have temporal resolution of 32 seconds. Each ensemble-mean velocity profile is assigned a location that is the mean of the longitude/latitude data collected during those 32 seconds, as well as a water depth that is the average of the corresponding bottom-track bathymetric measurements collected during those 32 seconds.

In the explanations to follow, reference is made to “virtual channels” and “virtual stations”; see Figure 1 in Codiga (2007) for their locations. Virtual channels are constant-width regions oriented along the estuary axis, with bottom depths that are the actual bathymetry and thus vary spatially along and across the channel. A virtual station is a point centrally located within a virtual channel. Using a statistically large collection of ensemble-mean water depths measured by the bottom-track ADCP pings from the ferry at points within a virtual channel during many months of crossings, the corresponding virtual station is assigned a mean water depth and a water depth standard deviation. The mean water depth assigned to a virtual station need not be equal to the true bathymetric depth at that location, but in practice the differences are minor. For virtual stations in areas of particularly rough bathymetry, the water depth standard deviation can reach a sizable fraction of the water depth.

Groups of ensemble-mean velocity profiles (typically 4-6) are collected within an individual virtual channel during an individual ferry crossing. A mapping must be applied in order to assign a single resultant velocity profile to the corresponding virtual station for that crossing. The two mappings that have been applied will now be explained.

The method used prior to the processing carried out for the present report is now referred to as "depth based" mapping, and was completed as follows. The group of ensemble-mean velocity profiles collected in a given virtual channel during a given ferry crossing was averaged on constant-depth levels. That is, velocities from a fixed depth range, or depth bin, in all of the ensemble-mean profiles measured in that virtual channel were averaged together regardless of the fact that the bathymetric depths of the ensemble means were variable. As a consequence, for depth bins in the upper water column (shallower than the mean water depth of that virtual station minus the standard deviation of its water depth) nearly all of the ensemble-mean profiles contribute to the average, but in contrast, for depth bins increasingly deeper than the virtual station's mean water depth, increasingly fewer ensemble-mean profiles contribute to the average. The advantage of this method is its simplicity and the fact that only velocities from the same physical depth ranges are averaged with each other. However, it is disadvantageous that the average profile assigned to the virtual station typically extends deeper than the mean water depth of the virtual station, and also that the data within the profile at increasingly deeper depths consist of averages that are based on increasingly fewer ensemble mean values.

Here, an alternative, second, independent "fractional-depth based" mapping has been applied. Each measured ensemble-mean bathymetric depth is used to convert the actual depths of the individual bins in that ensemble-mean velocity profile to fractional depths. The averaging of groups of ensemble-mean profiles measured within a single virtual channel is done using data from fixed intervals or bins of fractional-depth. The averaged profile is then assigned to the virtual station based on fractional depths relative to the mean water depth (from the average of a statistically large amount of bottom-track ADCP pings, as described above) of the virtual station. This type of averaging is often referred to as averaging on a terrain-following or "sigma" coordinate, for example in numerical modeling schemes. It involves averaging of data from different actual depth bins (same fractional-depth bins), which, though it typically has only a minor influence, may not always be well justified when the variations in bathymetric depths are strong. However, it has the advantage that, regardless of the distribution of water depths of the ensemble mean profiles, similar numbers of data are averaged together in each fractional depth range. It also ensures that the resulting averaged velocity profile assigned to the virtual station spans the full water column there and does not extend deeper than its mean water depth.

Two final products for the velocity GDP have now been produced. The first is the result of the "depth based" mapping described in Codiga (2007). The second is the result of the "fractional-depth based" mapping described here. Both products span the full range of dates during which velocities were collected, including the 2010-2011 data appended here in addition to all prior data.

For most applications, the advantages of the fractional-depth based GDP will make it more suitable and appropriate. However, the depth based GDP also continues to be provided; this is primarily for those users who downloaded the velocity GDP from the website prior to May 2012 (when only the depth based GDP was available) and used them, and who would also prefer to continue using the depth based GDP instead of transitioning to use the fractional-depth based GDP now that both are available.

D. 2. Water Properties

D. 2. a. Improved Quality Control

An improved quality control (QC) method was developed and applied to the water properties data from the new 2010-2011 observation period, and also the 2005-2006 measurements. The previous method (Codiga, 2007) involved a pass/fail designation, for each ferry crossing in its entirety. In the new method, pass/fail designations are applied for individual virtual stations, as opposed to the entire crossing (all 18 virtual stations) at once. This proved useful to isolate and remove poor-quality data that occurred during partial portions of a crossing.

The new QC method also enables different designations of pass/fail for temperature and salinity. This was incorporated because different factors are known to influence each sensor (for example, the conductivity sensor is more susceptible to bubbles in the sampling chamber than is the temperature sensor). However, in practice, it was found that the quality of one sensor output was different from that of another only during a very small percent of the observations. This is because the main factor that degraded data quality was the performance of the pump that draws water up via the hull intake and drives it through the sampling chamber. When pumping action was unreliable and/or resulted in excess bubbles in the sampling chamber (these conditions are influenced by sea state as well as certain routine crew operations) it generally caused all values of all sensors to be of poor quality. For Chlorophyll (2005-2006 only), the quality designations were set to be the same as those for temperature.

D. 2. b. Corrections for sensor drift using independent observations

The temperature and conductivity observations collected by the ferry (and Chlorophyll, collected during 2005-2006 only) have been compared to an independent dataset. The purpose is to detect and correct for sensor drift, which commonly occurs due to bio-fouling accumulation on the sensors over periods of weeks to months.

The independent observations are the conductivity-temperature-depth (CTD) profiles collected by the Connecticut Department of Environmental Protection (CT DEP) during vessel-based surveys it carries out nominally monthly year-round and twice monthly in the summer (Kaputa and Olsen 2000). The ferry intake is at approximately 2-3 m deep; only the data from the depth range 2 to 3 m in the CT DEP casts, from which an average is calculated, have been used.

During the 2005-2006 sampling (June 2005 through early Aug 2006), the ferry sensors were installed in an initial state free from bio-fouling two times: at the beginning of the record (June 2005); and about mid-way through the record (March 2006) following a cleaning (during a ferry maintenance period from roughly mid January to early March

2006). The ferry sampling interval from June 2005 through Jan 2006 is referred to as Period A, and that from March through Aug 2006 is referred to as Period B. During the 2010-2011 sampling the ferry sensors were installed free of bio-fouling once, in April 2010 and operated through June 2011; this period is referred to as Period C.

At the start of each of the three periods A, B, and C, the sensors were in good calibration; sensor drift that occurred was during the remainder of the period. The drift during Period C was expected to be less severe than during Periods A and B because during Period C the sensors were equipped with newly developed, more effective fouling deterrents from the manufacturer, including a copper sheath on the conductivity sensor.

The CT DEP observations were used to construct a time sequence of reference values (for temperature, conductivity, and Chlorophyll *a*) spanning each of Periods A, B, and C. The purpose of the reference is to serve as ground truth for variations on timescales longer than about 2 weeks, which is the highest frequency of CT DEP sampling. At these timescales the dominant signal is the seasonal progression. Sensor drift is driven by bio-fouling accumulation which occurs on timescales of weeks or longer and is therefore judged here mainly by comparison to the seasonal cycles of the reference.

The ground truth values are computed as the mean of the measurements at the K2 and M3 stations during a given CT DEP survey, and referred to as the K2/M3 reference. Relative to the central portion of the ferry crossing, the K2 station is several km to the west and the M3 station is several km to the east (see, e.g., Kaputa and Olsen 2000 for station location information). There were certain survey dates when K2 and M3 were not sampled, and the nearest station that was sampled during most such periods was I2, which lies about 30 km west of the ferry crossing. Furthermore, based on about 20 years of sampling, during the majority of which all of K2, M3 and I2 were sampled, there is a solid correlation between the K2/M3 reference and the I2 values (see Fig. 1 for the correlation of conductivities). For these reasons, during periods when K2 and M3 were not sampled but I2 was sampled, the K2/M3 reference was estimated using the correlation. There were also a small number of intervals during Periods A, B, and C when none of K2, M3, or I2, nor any other stations in Eastern LIS, was sampled but it was important to have a reference value. During these periods, the K2/M3 reference was estimated using an annual harmonic fit (see Fig. 2 for the annual harmonic of conductivity) to all years of available K2/M3 reference values. Table 1 summarizes the dates of the reference values, and the way each was estimated.

Uncertainties in the K2/M3 reference (Figs. 3-8) are chosen to represent naturally occurring variability at timescales of weeks. For directly measured values, based on both interannual variability in the CT DEP data and the ferry observations, uncertainties are taken to be 1 ^{o}C in temperature, 1 mS/cm in conductivity, 1 PSS in salinity, and 1.75 μg/l in Chlorophyll *a* concentration. For values estimated in the I2 regression, uncertainties are based on the error variance of the regression (e.g., Fig. 1). For values estimated using the annual harmonic, the uncertainties are taken to be 2.5 ^{o}C in temperature, 2 mS/cm in conductivity (e.g., Fig. 2), 1.5 PSS in salinity, and 2 μg/l in Chlorophyll a.

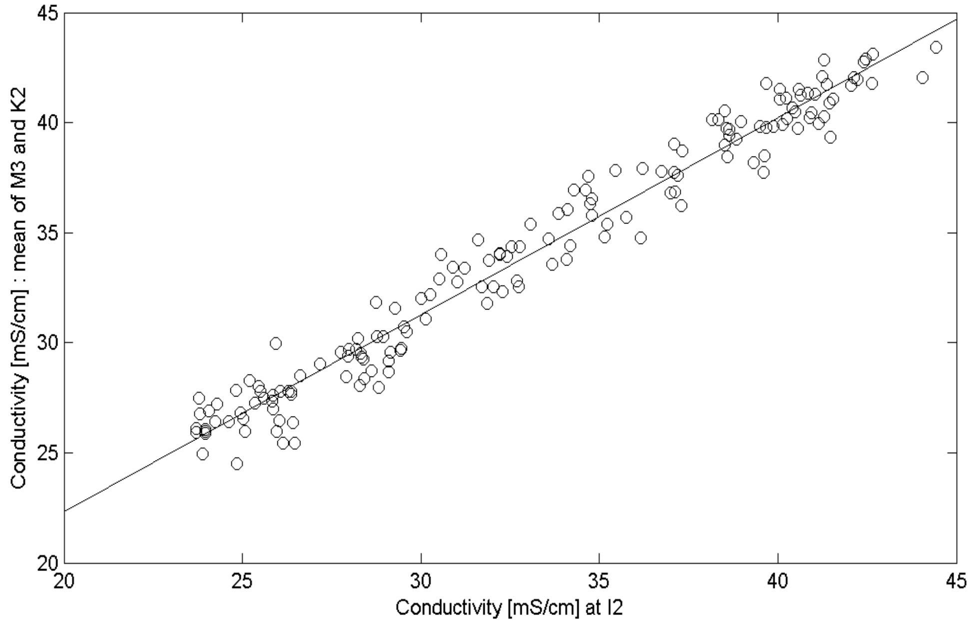

Figure 1. Regression of all years of CT DEP conductivity values (each an average over the 2-3 m depth range): Mean of the K2 and M3 stations ("K2/M3 reference") vs. the I2 station.

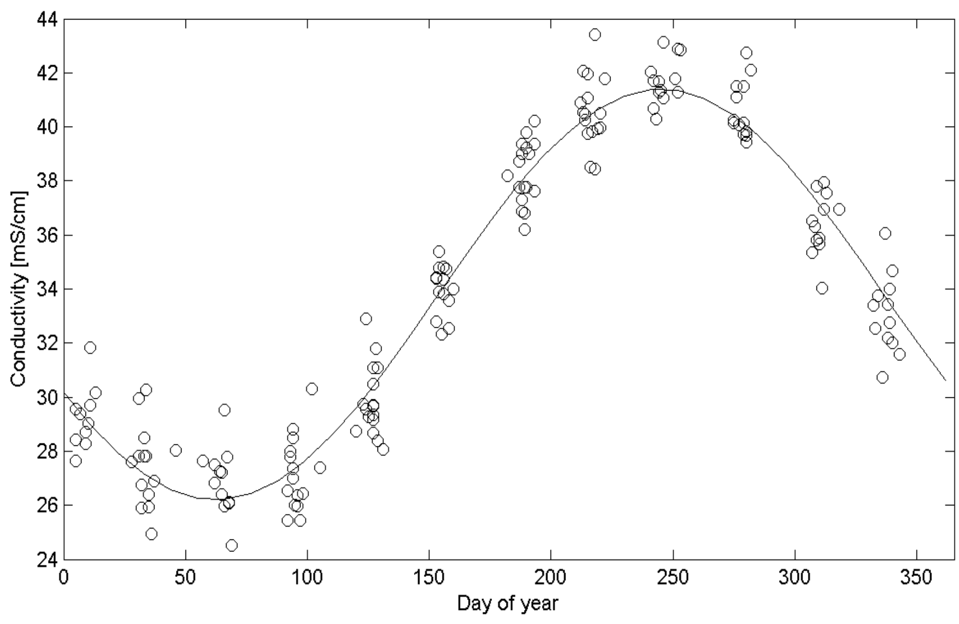

Figure 2. Seasonal cycle of K2/M3 reference based on all years of CT DEP conductivity values from 2-3 m deep, with annual harmonic fit.

Table 1. Dates and sources of K2/M3 reference values spanning the Period A, B, and C ferry sampling intervals. Direct samples are indicated by D; estimates based on correlation with I2 are indicated by I; estimates based on annual harmonic fit are indicated by F.

Period A		**Period B**		**Period C**	
(15 Jun 2005 – 5 Jan 2006)		(8 Mar 2006 - 1 Aug 2006)		(16 Apr 2010 - 5 Jun 2011)	
Date	***Source***	***Date***	***Source***	***Date***	***Source***
6 Jun 2005	D	5 Mar 2006	F	6 Apr 2010	D
7 Jul 2005	D	1 Apr 2006	D	3 May 2010	D
18 Jul 2005	I	2 May 2006	D	3 Jun 2010	I
2 Aug 2005	D	6 Jun 2006	D	1 Jul 2010	F
16 Aug 2005	I	6 Jul 2006	D	1 Aug 2010	F
29 Aug 2005	D	1 Aug 2006	D	2 Sep 2010	I
6 Oct 2005	D			6 Oct 2010	I
14 Nov 2005	D			3 Nov 2010	I
5 Dec 2005	D			29 Nov 2010	I
10 Jan 2006	F			6 Jan 2011	I
				31 Jan 2011	I
				14 Mar 2011	I
				12 Apr 2011	I
				2 May 2011	D
				31 May 2011	D
				5 Jul 2011	D

D. 2. b. i. Temperature

The ferry observations of temperature were consistently in a comparable range to the M3 reference during all periods of ferry data collection (Fig. 3). The thermistor in the ferry CTD instrument is the sensor known to require the least maintenance, be the least sensitive to fouling, and thus be least likely to drift. Therefore, lacking justification to modify the temperatures observed by the ferry, no corrections were made to them.

D. 2. b. ii. Conductivity and Salinity

The ferry conductivity values at the beginning of each period were sufficiently similar to the reference to confirm the sensor was in good calibration (Figs. 4 and 5). Subsequently during each period ferry values drifted. The drift was generally toward lower values, as is consistent with the influence of accumulated of bio-fouling within the conductivity measurement cell. The fastest rate of drift was such that over the course of a few months in late summer 2005 the ferry conductivity decreased by roughly 6 mS/cm relative to the reference, corresponding to a change in salinity of approximately 4 units on the practical salinity scale (PSS). As anticipated based on the improved anti-fouling measures in place during Period C, drift was the weakest during that period, changing by about 3 mS/cm in conductivity and about 2 PSS over longer than a year.

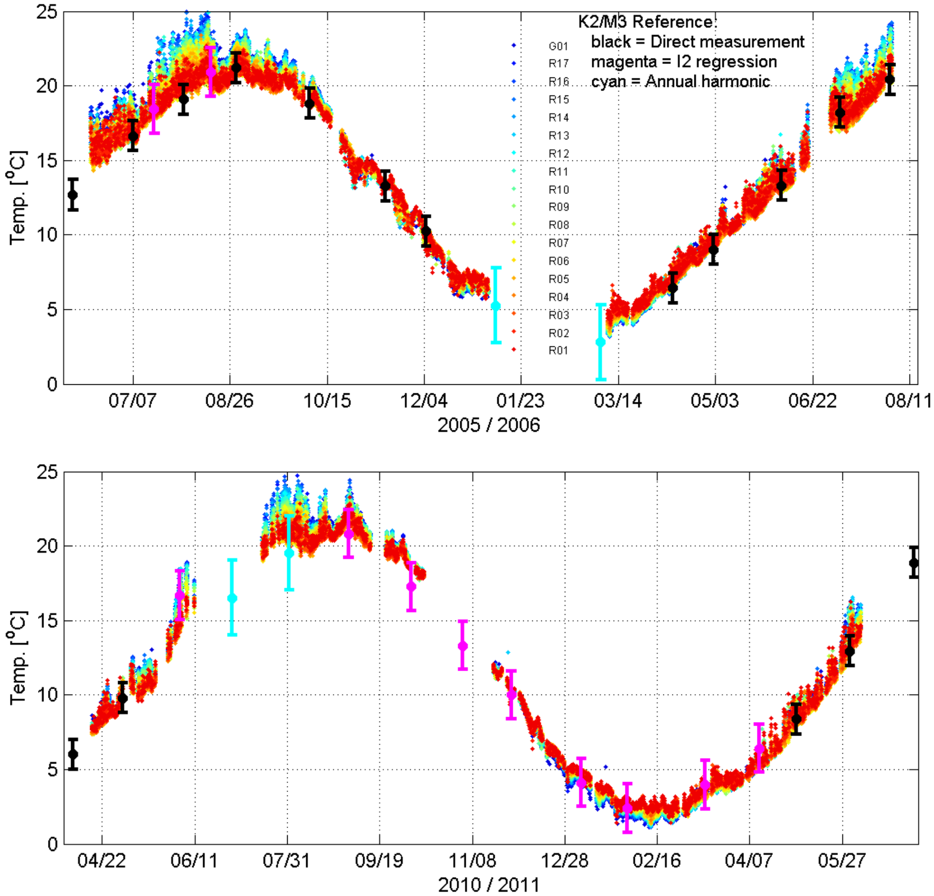

Figure 3. Temperatures. The K2/M3 reference values are black, magenta, and cyan (D, I, and F in Table 1, respectively). The ferry measurements are color-coded by virtual station (legend in upper frame) in a range spanning from red for the northernmost virtual station (R01) to blue for the southernmost (G01).

A correction, based on the K2/M3 reference, has been applied to the ferry conductivity observations, and the water qualities GDP distributed previously has been replaced with a new one with salinities computed from the corrected conductivities. The remainder of this section explains the correction.

The correction for an individual period A, B, or C is additive offset expressed

$$C_{corr}(t_f) = C_{uncorr}(t_f) + \Delta C(t_f)$$

where $C_{uncorr}(t_f)$ is the sequence of raw (uncorrected) conductivity values measured by the ferry along its sampling transect, including all virtual stations, at times t_f (subscript f for ferry); $\Delta C(t)$ is an additive correction offset (in mS/cm) function that varies only on timescales longer than about two weeks, constructed as an empirical fit as described below; and $C_{corr}(t_f)$ is the resulting corrected conductivities.

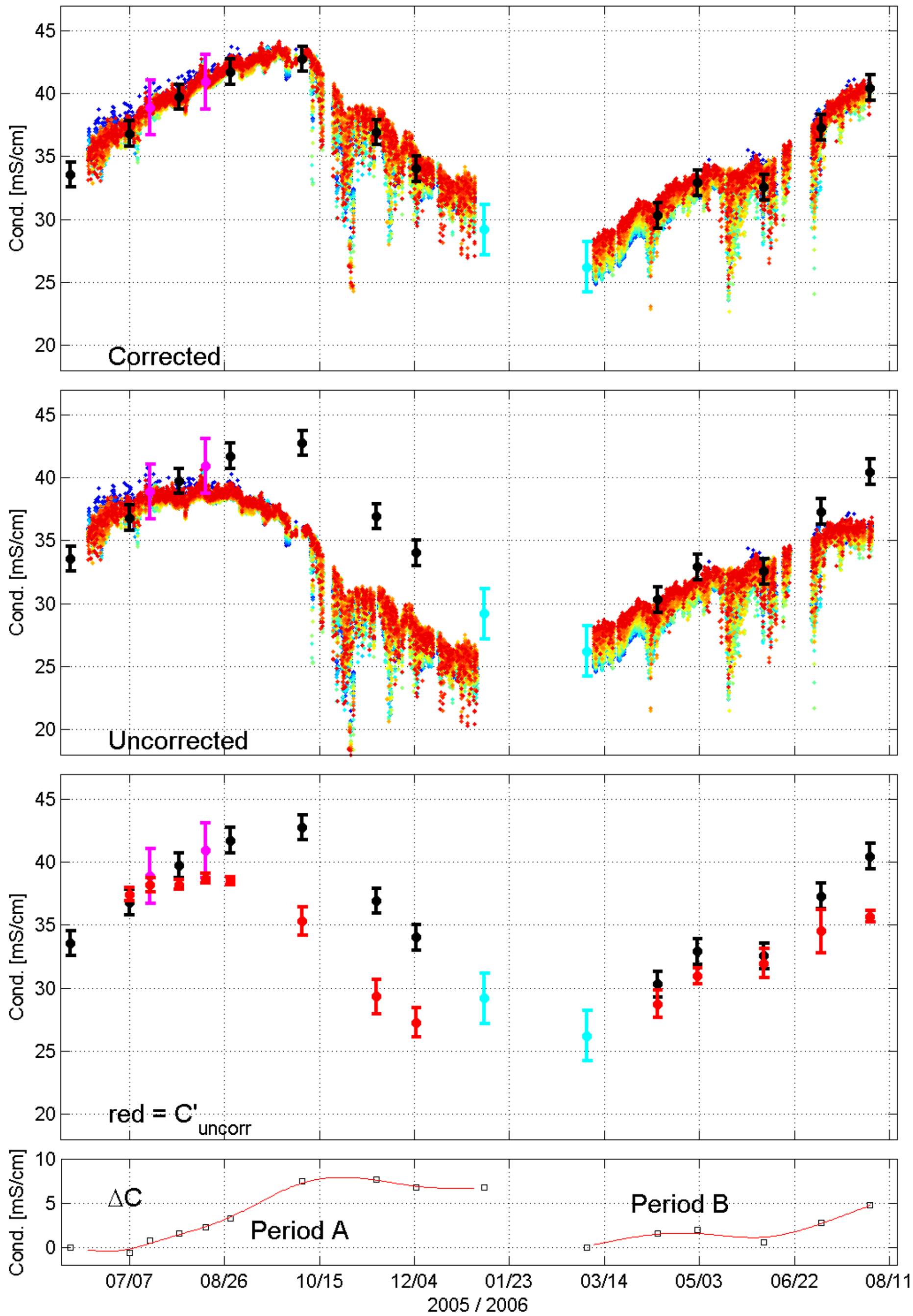

Figure 4. Conductivities, 2005-2006. The K2/M3 reference values are shown (black, magenta, cyan) in the upper 3 frames, as depicted in Fig. 3. The first and second frames show the corrected and uncorrected ferry measurements respectively, with color-coded depiction as in Fig. 3 (using the same color scale as shown in upper frame of Fig. 3). The third frame shows the $C'_{uncorr}(t_r)$ values in red. The fourth frame shows $\Delta C_{obs}(t_r)$ as squares and the empirically fit continuous function $\Delta C(t)$ as a red line for Period A (left) and Period B (right).

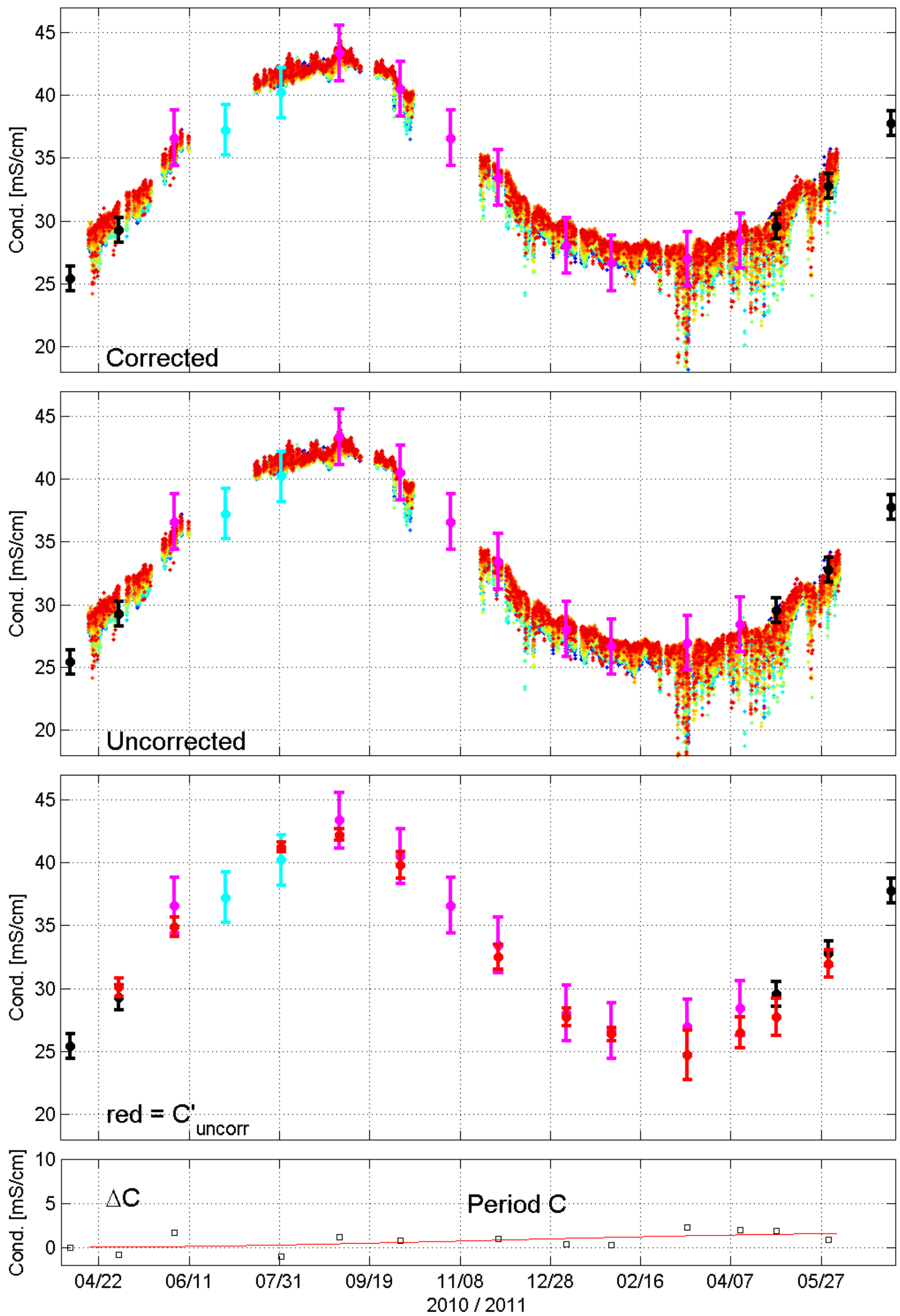

Figure 5. Conductivities, 2010-2011. As in Fig. 4 but for Period C.

The K2/M3 reference values are denoted $C_{ref}(t_r)$ and available at a small number of times t_r (subscript r for reference) as listed in Table 1. The temporal resolution of the reference value times t_r is about 2 weeks or longer. It is therefore only appropriate to compare the reference value at time t_r to the two-week average of ferry observations centered on t_r. For this purpose, denote by $C'_{uncorr}(t_r)$ the average of all $C_{uncorr}(t_f)$ values for which t_f lies in the range from t_r-Δt to t_r+Δt, where Δt is one week. For simplicity, to aid in its stability and representativeness, and because there is little justification or advantage for using a particular virtual station or subset of virtual stations, the two-week average $C'_{uncorr}(t_r)$ is computed using measurements from all virtual stations; the prime denotes the operation of computing two-week averages centered on reference times. The $C'_{uncorr}(t_r)$ values are shown in the third frames of Figs. 4 and 5, with uncertainties based on the standard deviation of the measurements used in the average.

The continuous function ΔC(t) was determined as a least-squares fit to the estimates of observed offsets ΔC_{obs} at the reference times,

$$\Delta C_{obs}(t_r) = C_{ref}(t_r) - C'_{uncorr}(t_r),$$

using all times t_r for which the ferry sampling was active and there is a corresponding C'_{uncorr} value. At the start of each period a value of $\Delta C_{obs}=0$ was included. For Period A, because there was no C_{ref} value within about a month of the end of the ferry sampling, the ΔC_{obs} value nearest the end of the period was repeated at the time of the K2/M3 reference value just after the end of the period. The fit used for Periods A and B is a cubic smoothing spline, implemented in Matlab using the function *csaps()*. For Period C, a cubic polynomial was used because the smoothing spline introduced undesired short-period variability in the fit. The resulting continuous function ΔC(t) is shown as a red line in the bottom frames of Figs. 4 (Periods A and B) and 5 (Period C).

The results of the corrections to conductivities are shown in Figs. 4 and 5. Corrected values of salinity, which result from the corrections to conductivity, are shown in Figs. 6 and 7, with comparisons to the uncorrected values.

Given the rate at which the drift occurred and nature of the correction, spatial and temporal variability in the corrected values at timescales of less than weeks are accurate, even though the absolute accuracies are more uncertain due to the correction. Thus the gradients in conductivity across individual ferry crossings from north to south remain accurate after the correction, as do temporal changes on shorter timescales. In contrast, at longer timescales, the corrected values include inaccuracies associated with how the empirical fits are impacted by limitations in the accuracy and infrequent temporal resolution of the reference.

D. 2. b. iii. Chlorophyll

The K2/M3 reference Chlorophyll are the result of post-calibrations using water samples with the Acetone method in the laboratory (Pers. Comm., Matt Lyman, CT DEP). Uncertainties assigned to them represent natural variability on timescales of weeks

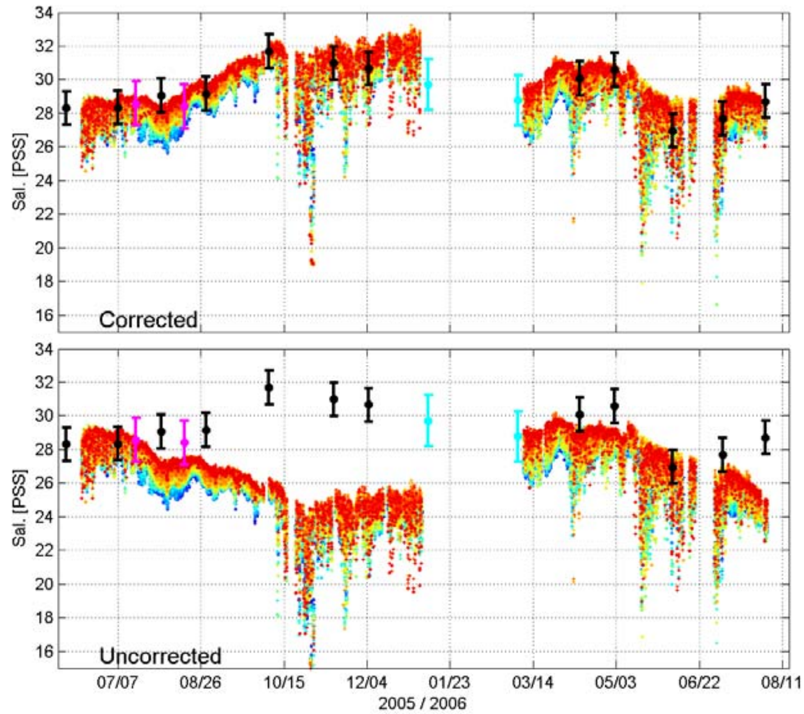

Figure 6. Salinities, 2005-2006. Shown as upper two panels of Fig. 4.

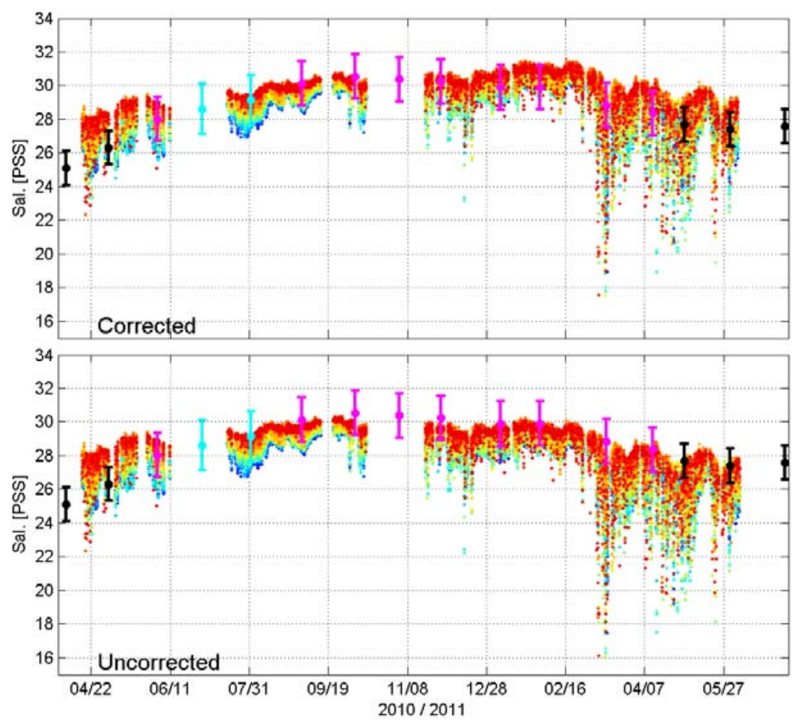

Figure 7. Salinities, 2010-2011. Shown as upper two panels of Fig. 4.

or longer, as explained above, and are relatively large in part because the regression of mean K2/M3 mean values against I2 values (not shown) was not as tight for Chlorophyll as for conductivity (Fig. 1), and also because for Chlorophyll the variability relative to the annual cycle (not shown) was far more pronounced than as for conductivity (Fig. 2).

The Chlorophyll measurements collected by the ferry compare reasonably well to the reference values (Fig. 8). The disagreement relative to the reference is not sufficiently large to justify applying a correction, given the high degree of variability in both datasets. Thus, the Chlorophyll values reported in the new GDP are uncorrected.

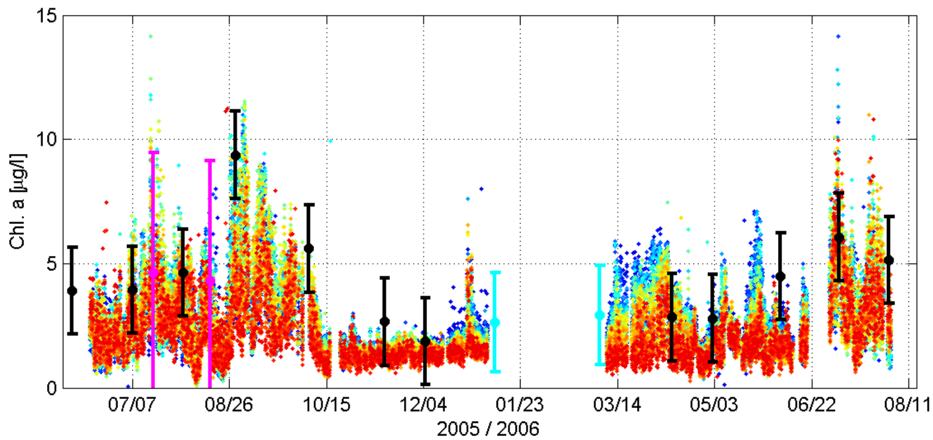

Figure 8. Chlorophyll *a*, 2005-2006. Shown as in Fig. 3.

The new Chlorophyll GDP differs in two important ways from the prior version, which was created in 2007 as described in Codiga (2007), and is no longer distributed. First, the new GDP includes uncorrected values, that have not undergone the three-point calibration based on Acetone-based lab analysis that was applied in the earlier analysis. Second, the new GDP reports the values as Chlorophyll *a*, not as Total Chlorophyll as the earlier GDP and the 2007 Technical Report (Codiga, 2007) incorrectly did.

E. Appended 2010-2011 Observations

The new sampling spans from April 2010 to early June 2011. It included collection of velocity profiles and near-surface temperature and salinity, but chlorophyll measurements were discontinued. All the same sensor systems were used as for the 2002-2006 observations, except that (as described above) the water properties sensor was equipped with more effective antifouling measures.

F. Final GDP files

F. 1. Velocities

There are two final GDPs for the velocities, both spanning all years of data. One GDP contains the velocities created using the new fractional-depth mapping, which will be the best choice for nearly all users. The second GDP contains the velocities created using the old depth-based mapping, and is included for completeness. It will be of interest mainly to those users who downloaded the velocity GDP from the website prior to May 2012 (when only the depth based GDP was available) and used them, and who also would prefer to continue using the depth based GDP instead of transitioning to use the fractional-depth based GDP now that both are available.

Each of the two velocity GDPs consists of 19 files: one file for each of the 18 virtual stations (file prefixes ‘R01vel’, ‘R02vel’, …, ‘R17vel’, and ‘G01vel’; with ‘_zmap’ appended in the case of the depth-mapped GDP), together with the grid file (prefix “grid”) containing the virtual station bathymetry, latitude, longitude, and depth grid information. In each of the 18 files are time sequences of eastward and northward velocity components at the corresponding virtual station, at a series of depth levels, together with the associated times. Each file has “readme” information explaining the details of its content and format.

All files are available in ASCII format, and as Matlab mat-files.

F. 2. Water Properties

The final water properties GDP consists of one file for each of the 18 virtual stations (file prefixes ‘R01swp’, ‘R02swp’, …, ‘R17swp’, and ‘G01swp’, where swp stands for surface water properties), together with the grid file (described above). In each of the 18 files is a time sequence of temperature, conductivity, salinity, and Chlorophyll *a* values, together with the corresponding times. For completeness the uncorrected conductivity and salinity data are also included. Each file has “readme” information explaining the details of its content and format. As with the velocities, the files are available in ASCII format and as Matlab mat-files.

It is important to note that new water properties GDP replaces the one that was created in 2007, which is no longer distributed. The new GDP has the 2010-2011 data appended, and provides the corrected conductivities and salinities (in addition to their uncorrected values). The new GDP also differs from the old GDP in that it reports the Chlorophyll values as Chlorophyll *a* concentration, not Total Chlorophyll, as noted above.

G. Acknowledgements

These datasets exist largely due to the generosity of Cross Sound Ferries, Inc. Thanks are due particularly to John and Adam Wronowski for their early and sustained support, in the form of in-kind use of the ferry for oceanographic sampling and providing the research team access to the vessel. Technical assistance from Dick Sise and the captains and crews of the *MV John H.* has been essential to project success.

Christopher M. Bryan, undergraduate URI Ocean Engineering major, carried out much of the instrument maintenance and data management that enabled the 2010-2011 ferry observations to be collected. In providing CTD survey results that were very recently collected, for the post-calibration of the ferry observations, Matt Lyman of Connecticut Dept of Environmental Protection was prompt and helpful. Dirk Aurin (NASA Goddard) assisted with the ground truth comparisons for Chlorophyll by properly re-interpreting his earlier work with the ferry measurements. Jim O'Donnell (UConn) did the initial comparisons to CT DEP data that indicated the need for conductivity/salinity post-calibration.

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6. References Cited

Codiga, D.L. 2007. FOSTER-LIS Gridded Data Products: Observed Current Profiles and Near-Surface Water Properties from Ferry-based Oceanographic Sampling in Eastern Long Island Sound. In, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI., pp. 14.

Kaputa, N.P., C.B. Olsen. 2000. Summer Hypoxia Monitoring Survey '91- '98 Data Review. In, Long Island Sound Ambient Water Quality Monitoring Program, State of CT. Dept. of Env. Protection.