LISS Hypoxia - Models

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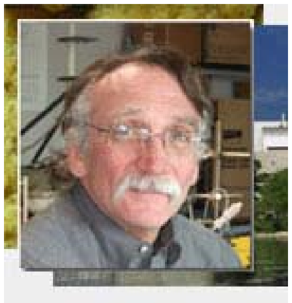
With the support of NOAA IOOS (NERACOOS & MARACOOS), EPA LIS Program, CT Sea Grant, CTDEEP, and UConn

and in collaboration with Jim Fitzpatrick, Frank Bohlen, Hans Dam, Todd Fake, Kay Howard-Strobel, Dave Cohen, Grant McCardell, Youngmi Shin, Ale Cifuentes and many others

Estuaries Vol. 20, No. 2, p. 328–345 June 1997

Calculations of Horizontal Mixing Rates Using ^{222}Rn and the Controls on Hypoxia in Western Long Island Sound, 1991



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$$h\frac{\partial C}{\partial t} = -\overline{\int_{-b}^{-b+h} \underline{u}.\underline{\nabla} c\,dz} + \overline{K\frac{\partial c}{\partial z}\bigg|_{-b+h}} - B - hR. \qquad (2)$$

[8] Here C and R are the vertically and time averaged concentration and respiration rate, i.e., $C(x, y, t) = \frac{1}{h}\int_{b}^{b+h} c\,dz$ and $R(x, y, t) = \frac{1}{h}\int_{b}^{b+h} r\,dz$. The flux of oxygen from the water column to the bottom sediments is expressed as $B = K\frac{\partial c}{\partial z}\Big|_{b}$ and the integral of production is omitted since the light levels below the pycnocline in LIS are insufficient to allow photosynthesis. Equation (2) is a model for the

$$h\frac{\partial C}{\partial t} = -\overline{\int \underline{u}.\underline{\nabla} C dz} + K\frac{\partial c}{\partial z}\bigg|_h - B - hR$$

Parameter Estimates

Respiration:

R= 8.6 mMoles/m^3/day in July

R=19.5 mMoles/m^3/day in Aug

B. L. AND F. C. ELLER. 1991. Mechanisms controlling
`oxygen depletion in western Long Island Sound. *Estuaries 14:265-278.*

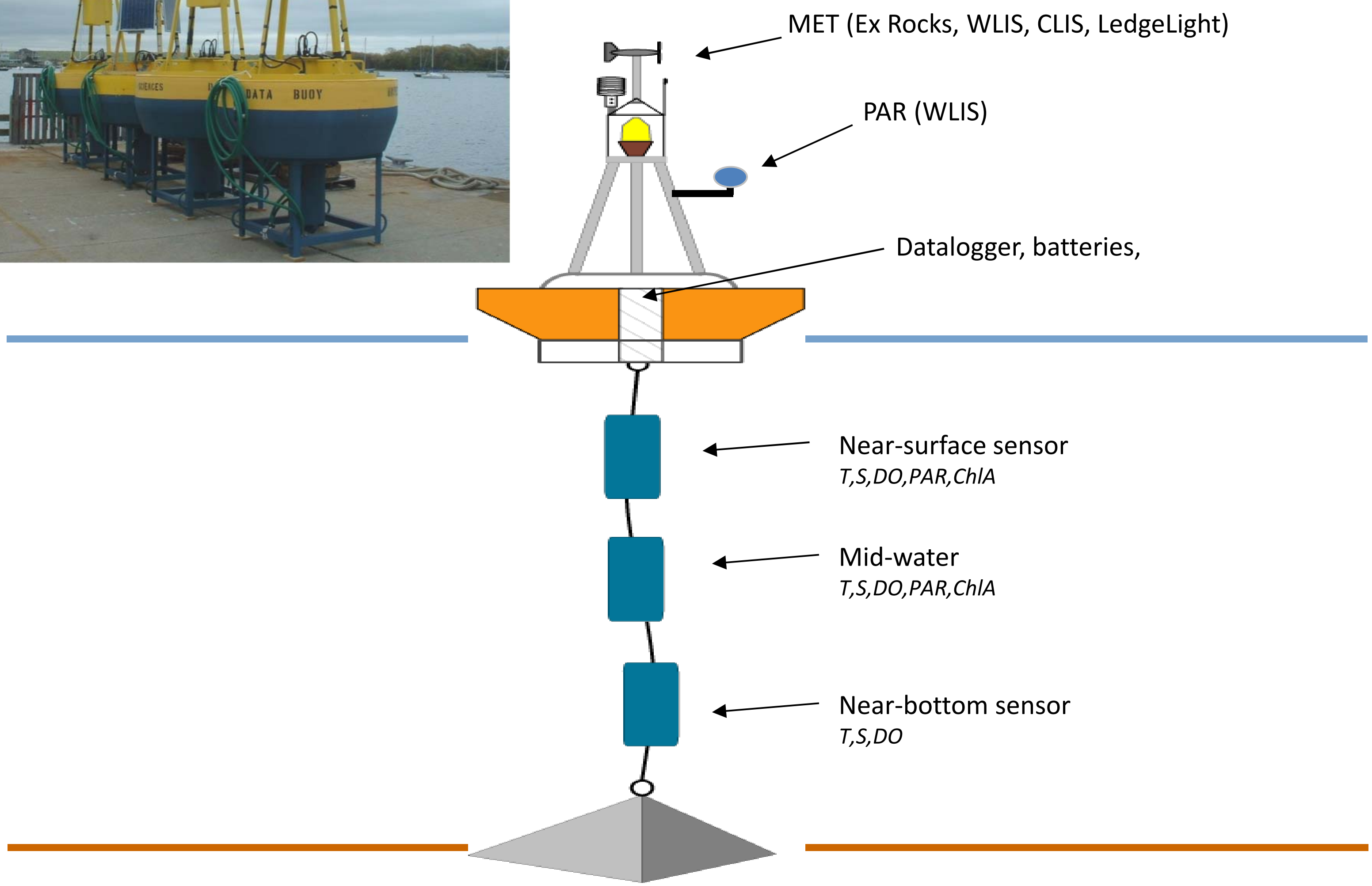
Benthic Demand: B= 40 mMoles m^{-2} day^{-1}

Aller, R. C. (1994), The sedimentary Mn cycle in Long Island Sound: Its role as intermediate oxidant and the influence of bioturbation, O2 and Corg flux on diagenetic reaction balances, J. Mar. Res., 52, 259– 295, doi:10.1357/0022240943077091.

-25 = Transport+ mixing - 40 - 150 (mM/m^2/day)

Conclusion: The oxygen balance REQUIRES either, or both, vertical and horizontal transport with magnitude of ~200 mMoles/m^2/day

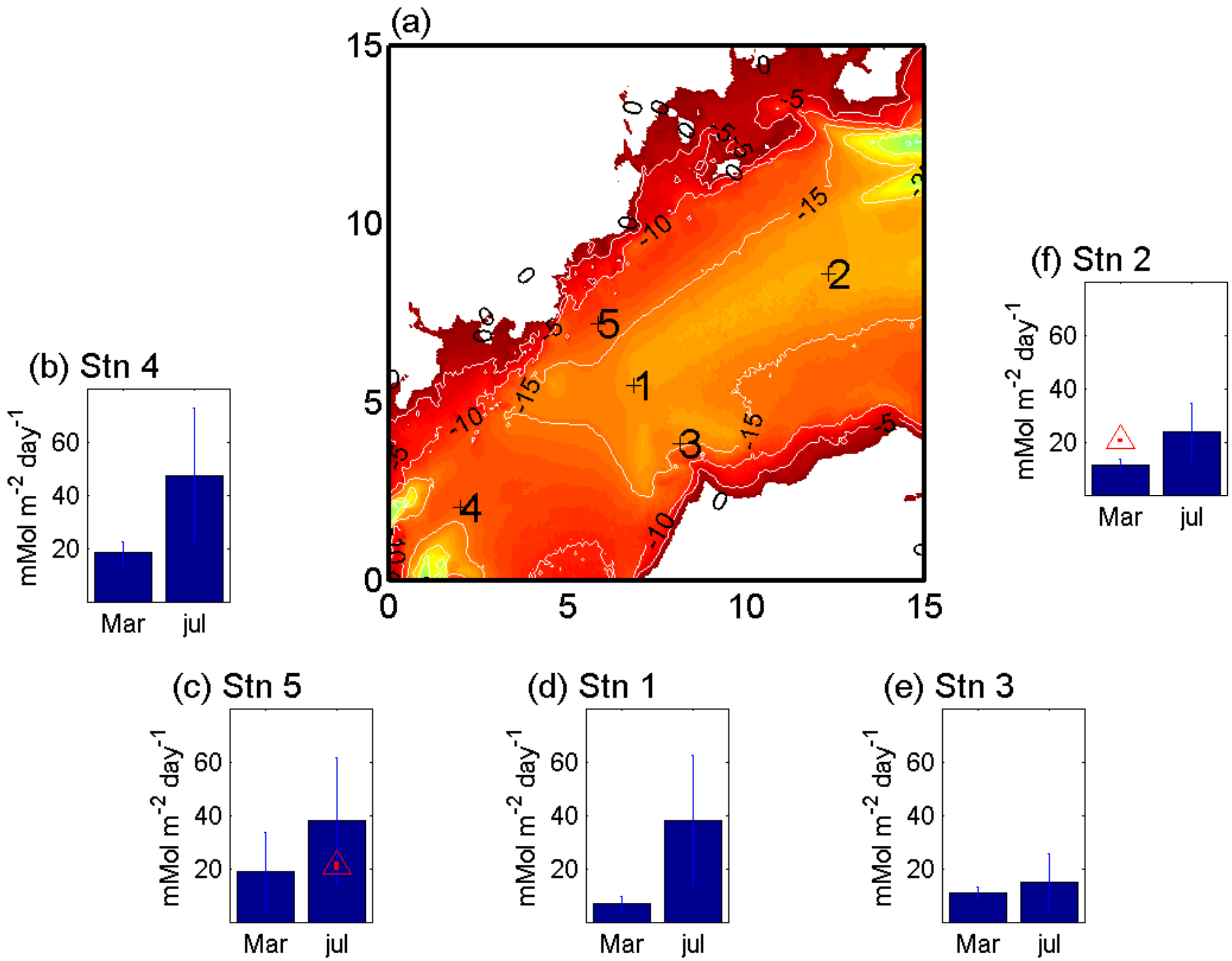

DATA BUOY


MET (Ex Rocks, WLIS, CLIS, LedgeLight)
PAR (WLIS)
Datalogger, batteries,
Near-surface sensor
T,S,DO,PAR,ChlA
Mid-water
T,S,DO,PAR,ChlA
Near-bottom sensor
T,S,DO

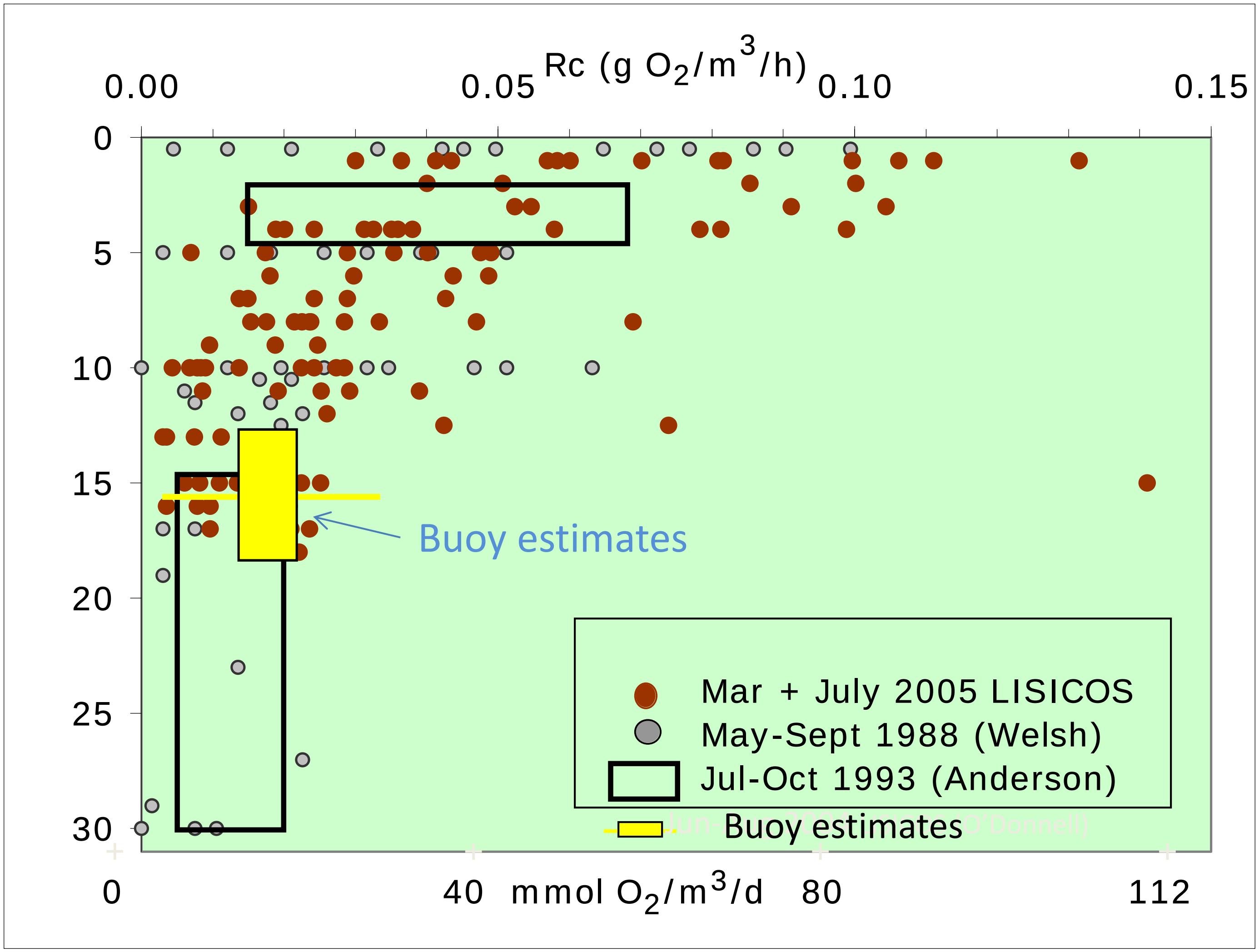
NOT TO SCALE

LISICOS05 Benthic Oxygen Demand Summary

(Whitlatch, Renaud, Fitzgerald and Balcom)

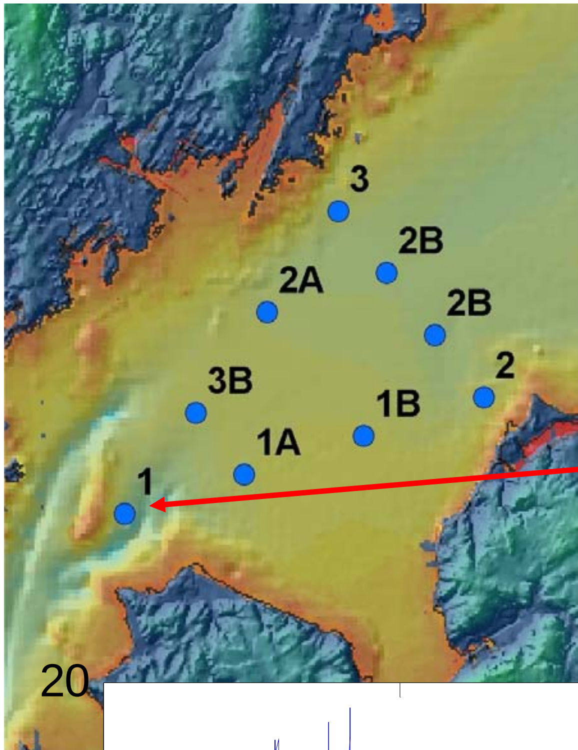


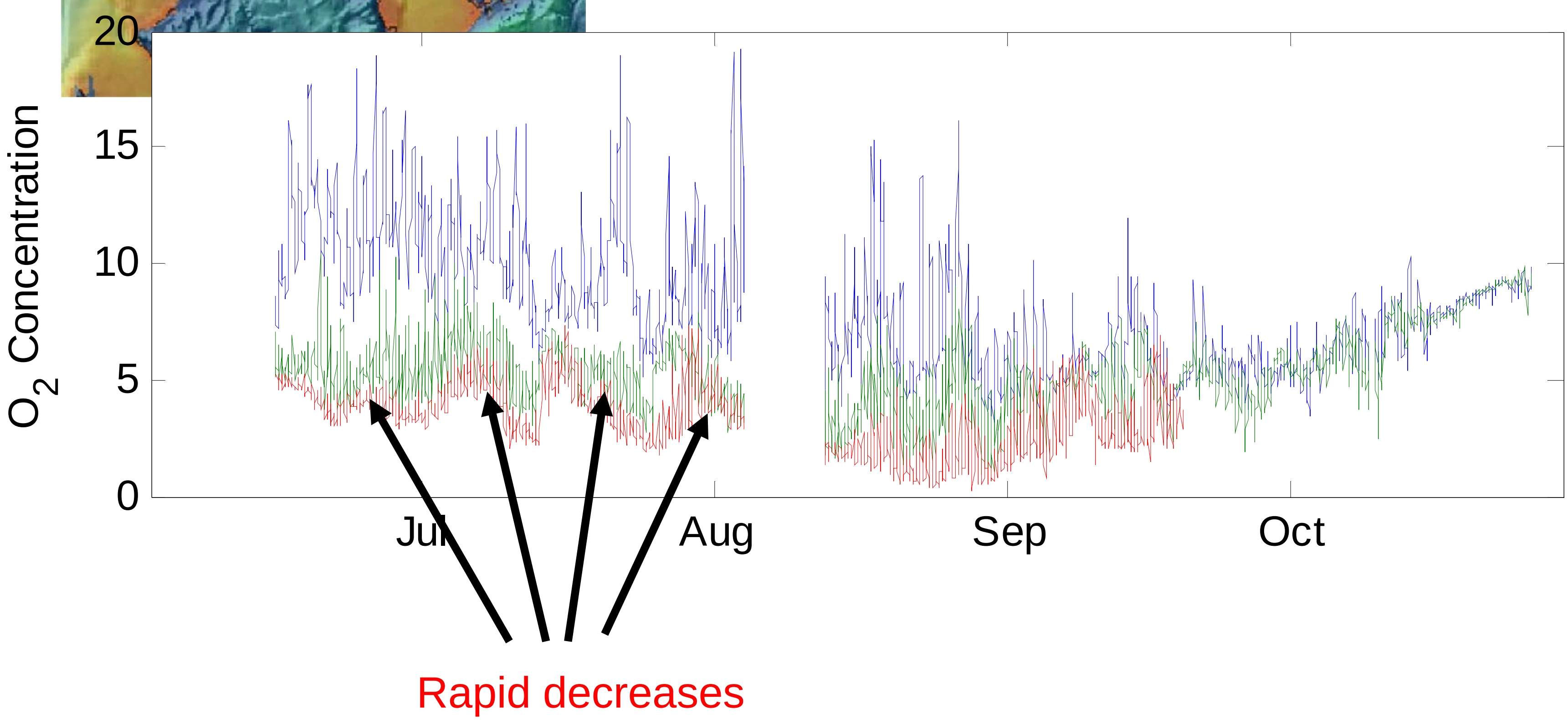
Respiration is underestimated relative to the LISICOS (Kremer) range



LISICOS refined the dilemma

And we got distracted by ventilation

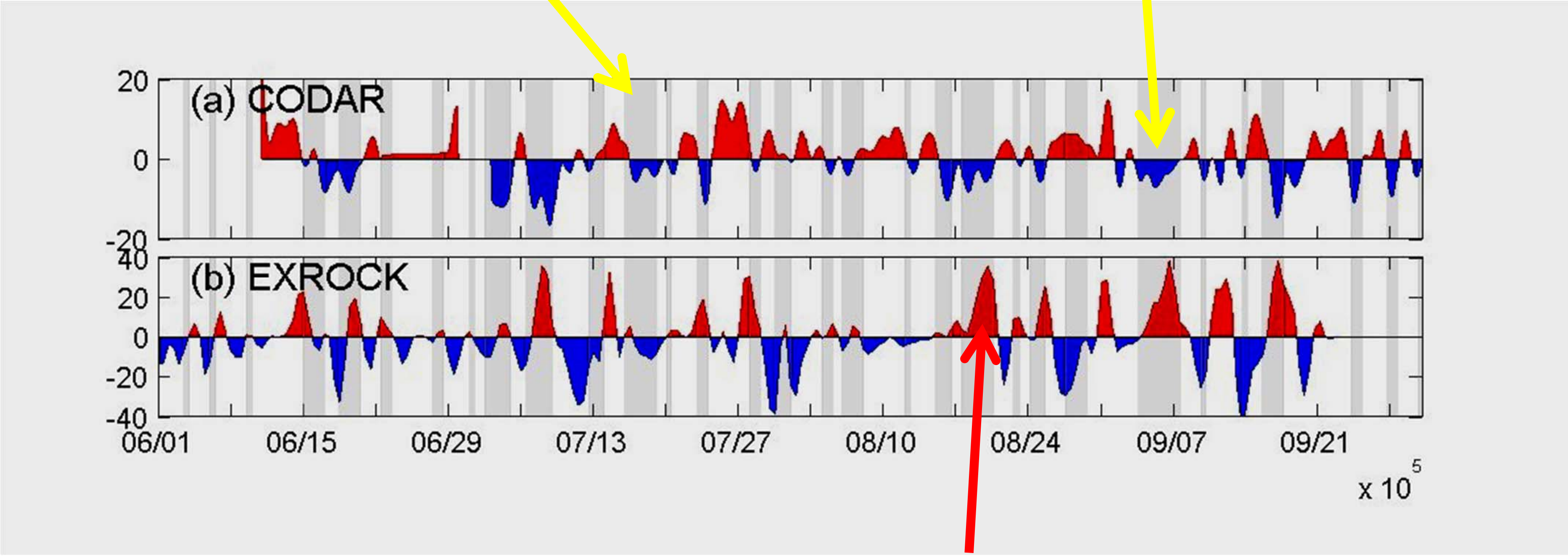




NE directed Surface Current from CODAR (2005)
Low-pass filtered rate of change of bottom DO at EX

Gray stripes show Winds from the NE

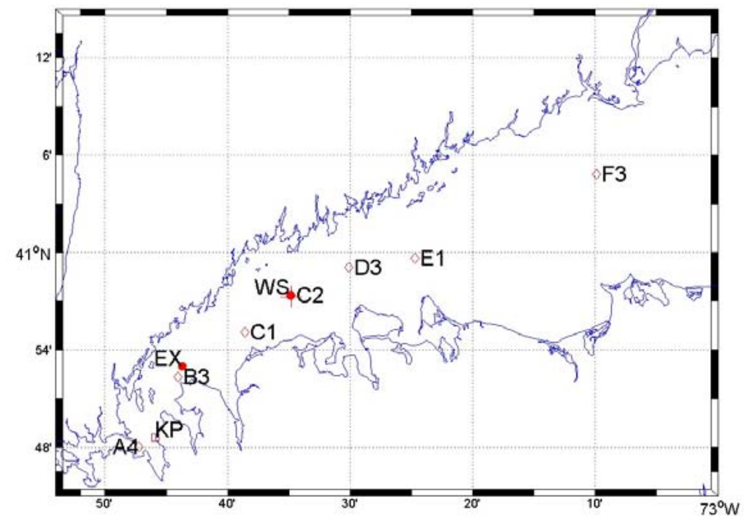
Blue dips show surface current anomalies towards East River

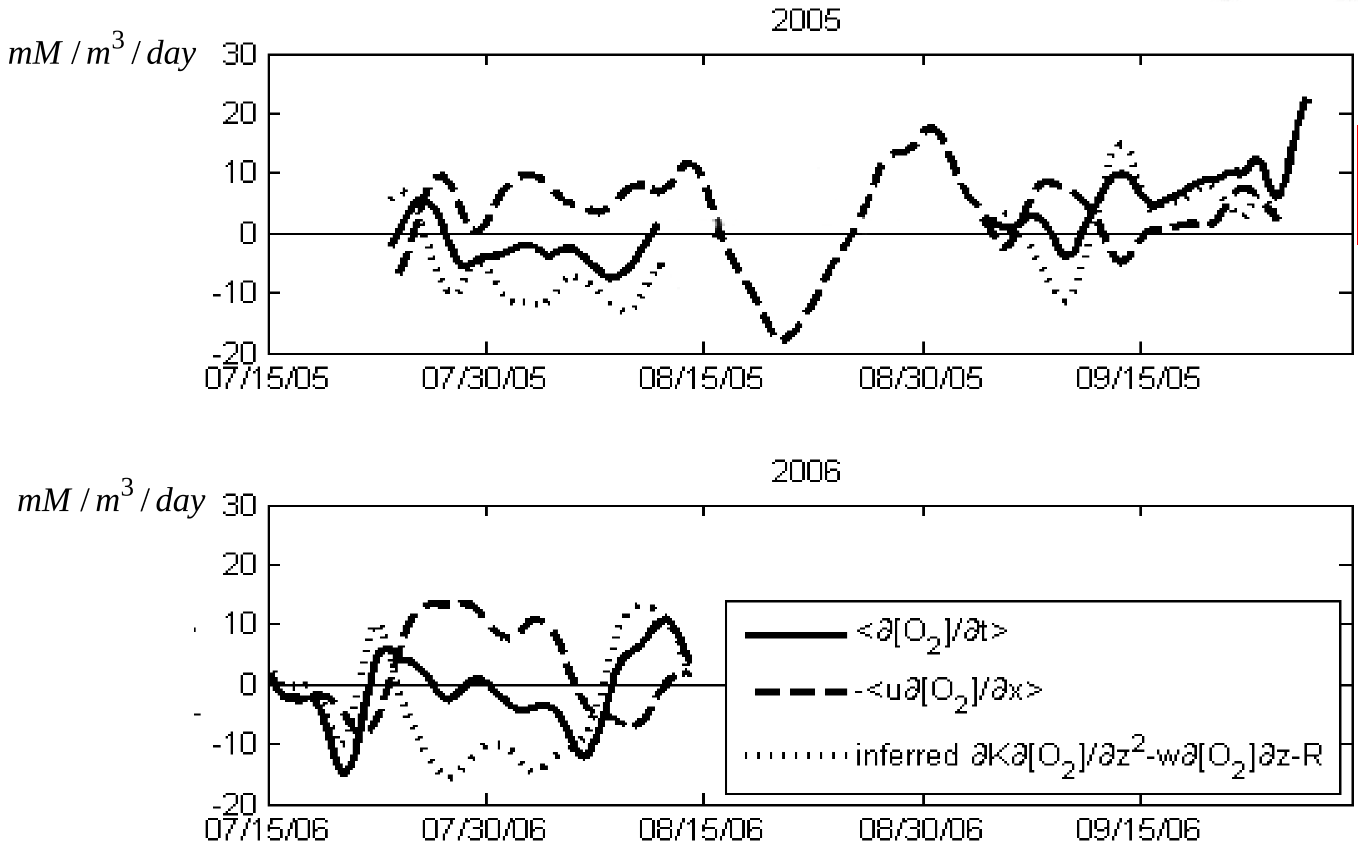


Interval of Increasing DO

Advective transport

McCardell, G.M. and J. O'Donnell (2014)
Estimates of Horizontal Fluxes of Oxygen, Heat, and Salt in Western Long Island Sound
J. Geophys. Res. (submitted)





Mean =4±6 $mM/m^3/day$

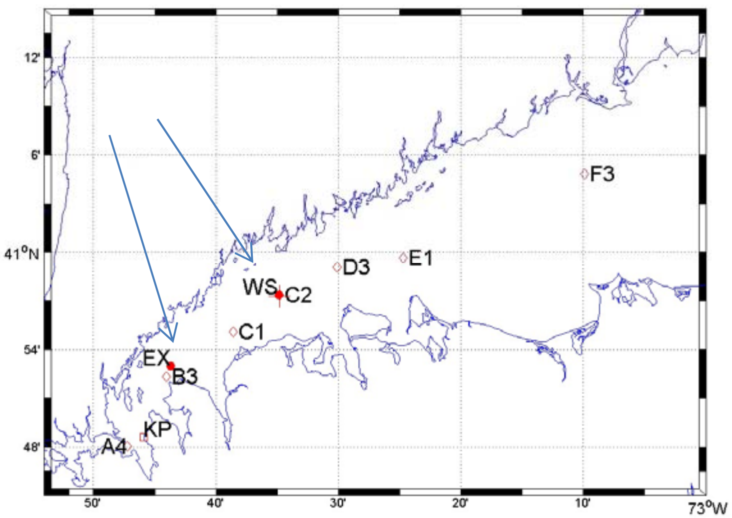
Returning to the budget:

$$-25 = \boxed{\text{Transport+ mixing}} - 40 - 150 \quad (\text{mMoles/m}^2\text{/day})$$

$$-25 = \boxed{40 + \text{mixing} - 40} - 150 \quad (\text{mMoles/m}^2\text{/day})$$

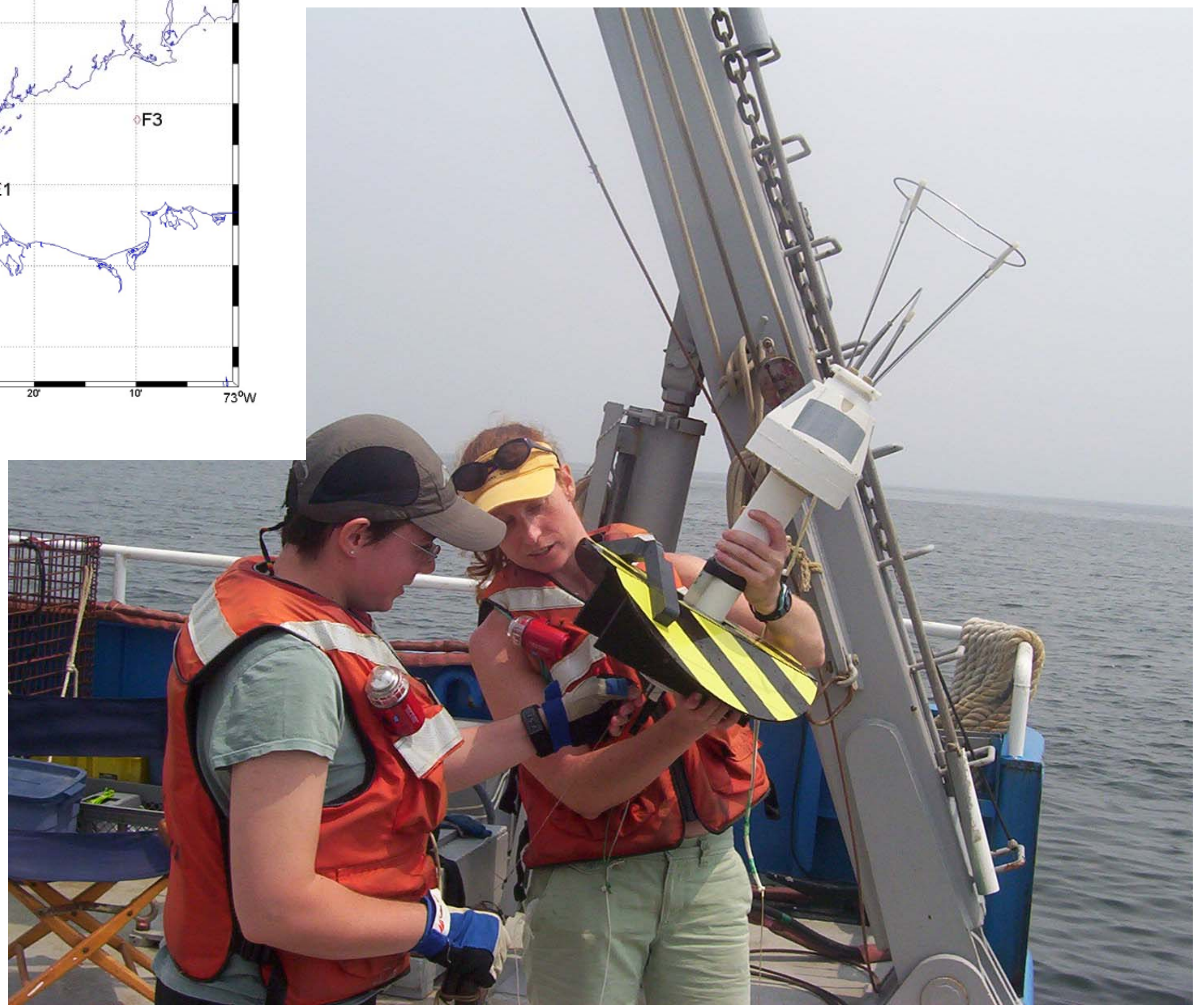
The convergence of the axial flux is about enough to offset the benthic respiration

Vertical mixing transport

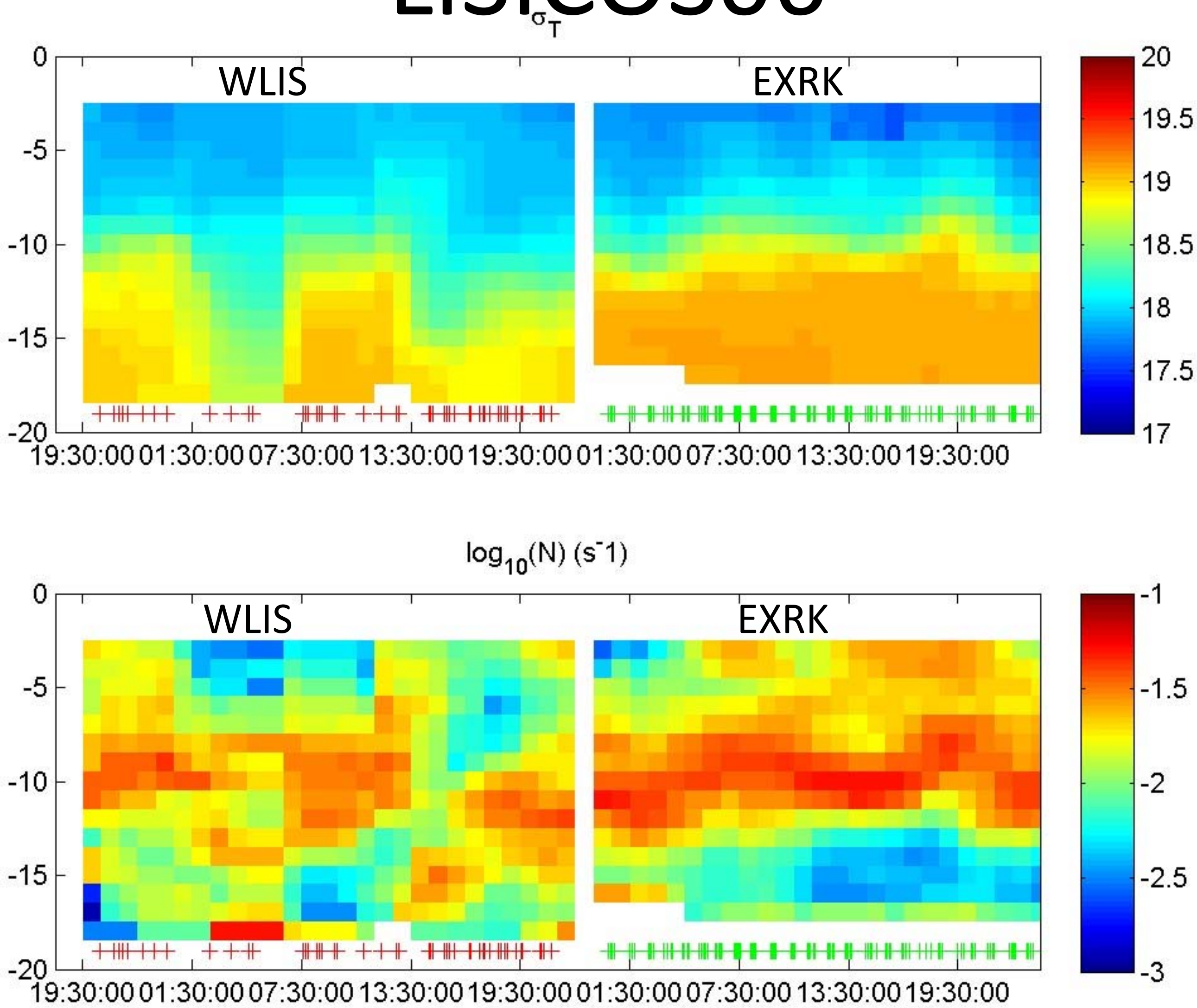


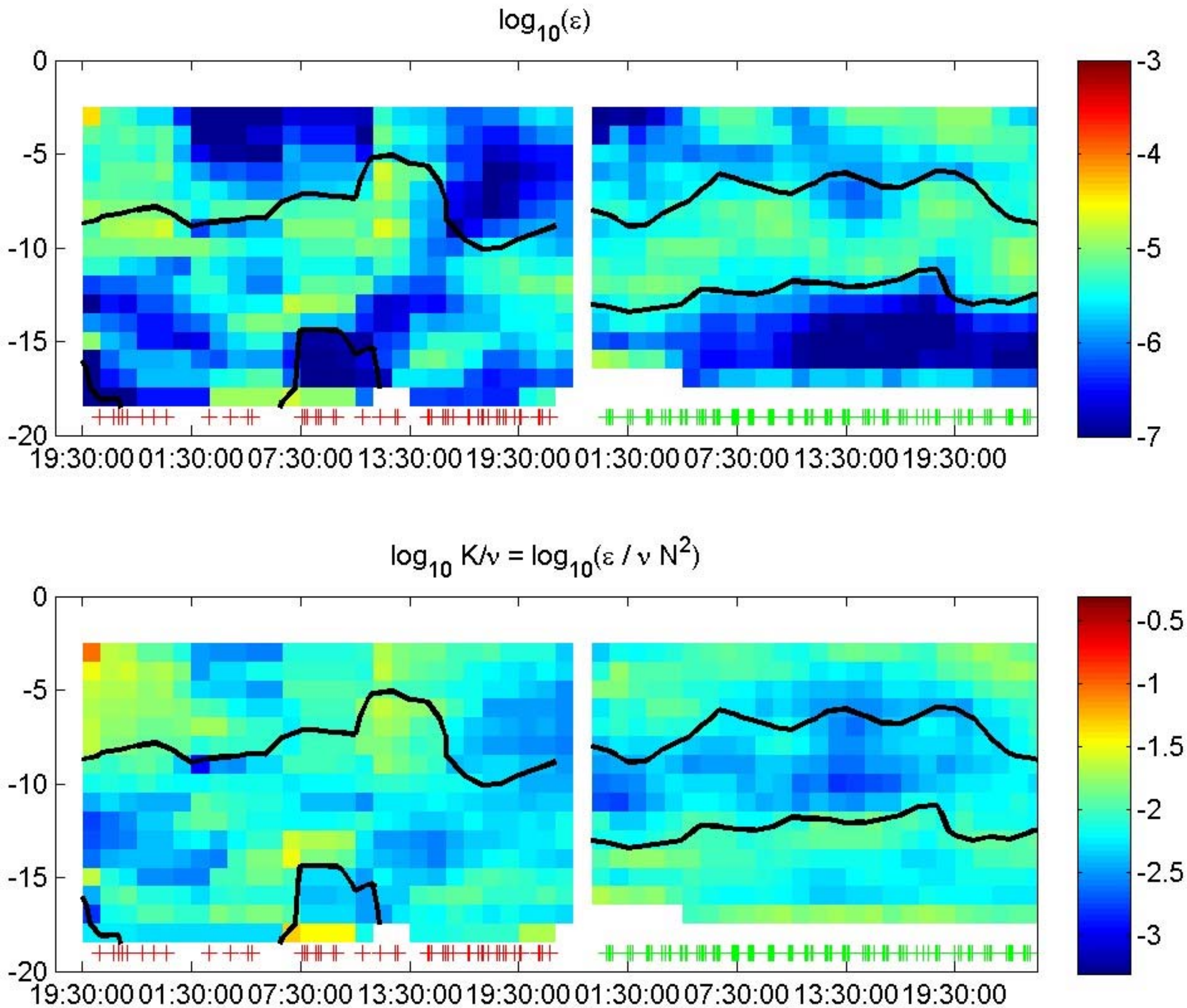
Profile 4 times an hour with 5-10 minute gaps.

24 hours at WS and 24 hours at EX



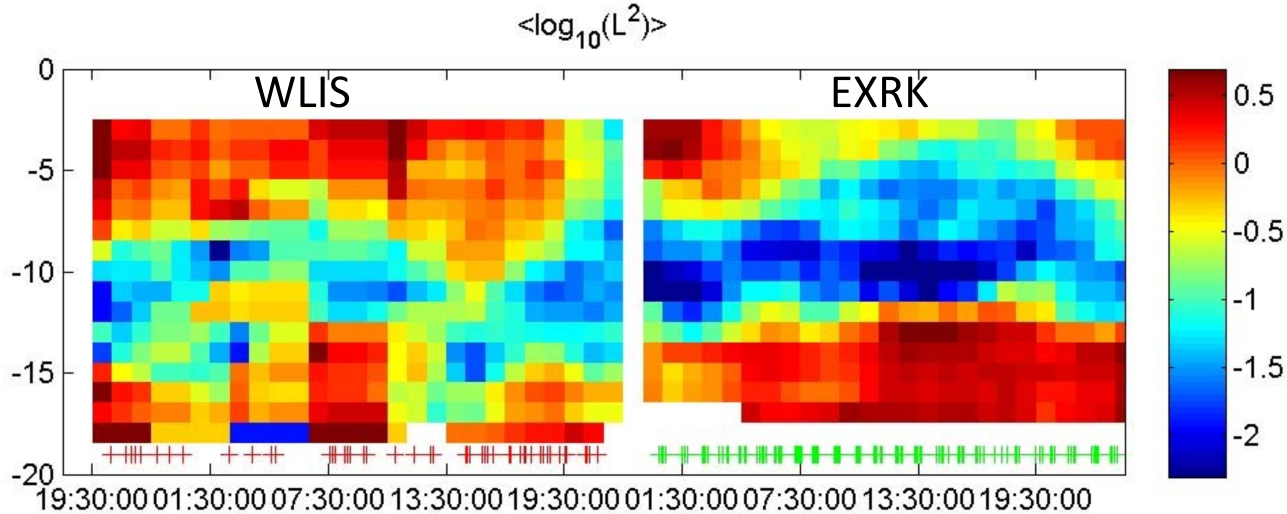
LISICOS06


σT
WLIS
EXRK
0
-5
-10
-15
-20
19:30:00 01:30:00 07:30:00 13:30:00 19:30:00 01:30:00 07:30:00 13:30:00 19:30:00
20
19.5
19
18.5
18
17.5
17
log10(N) (s-1)
WLIS
EXRK
0
-5
-10
-15
-20
19:30:00 01:30:00 07:30:00 13:30:00 19:30:00 01:30:00 07:30:00 13:30:00 19:30:00
-1
-1.5
-2
-2.5
-3

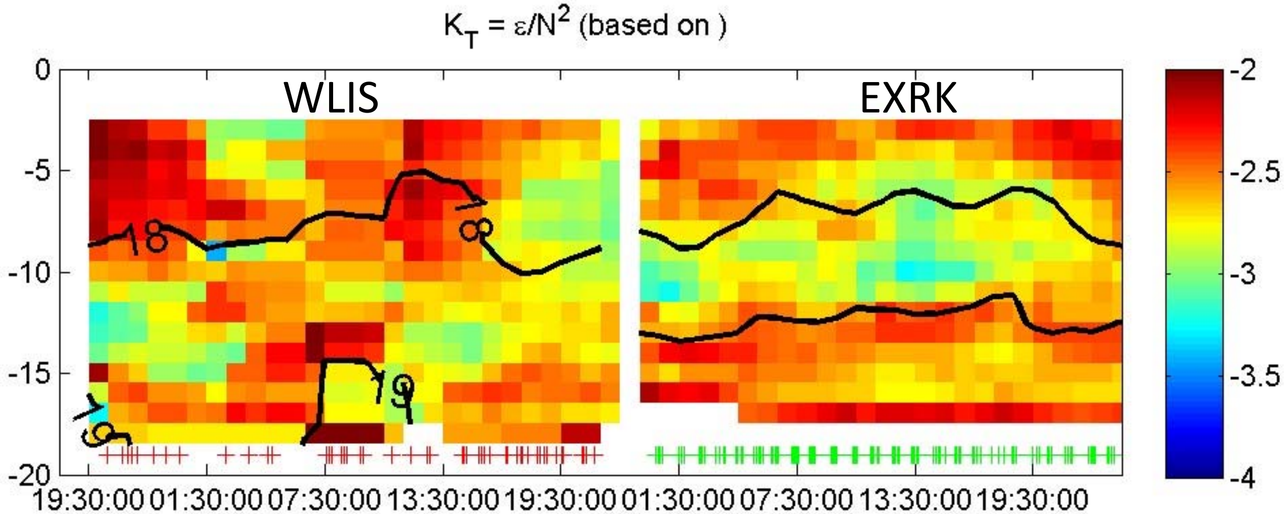


$\log_{10}(\varepsilon)$
0
-5
-10
-15
-20
19:30:00 01:30:00 07:30:00 13:30:00 19:30:00 01:30:00 07:30:00 13:30:00 19:30:00
-3
-4
-5
-6
-7
$\log_{10} K/\nu = \log_{10}(\varepsilon / \nu N^2)$
0
-5
-10
-15
-20
19:30:00 01:30:00 07:30:00 13:30:00 19:30:00 01:30:00 07:30:00 13:30:00 19:30:00
-0.5
-1
-1.5
-2
-2.5
-3

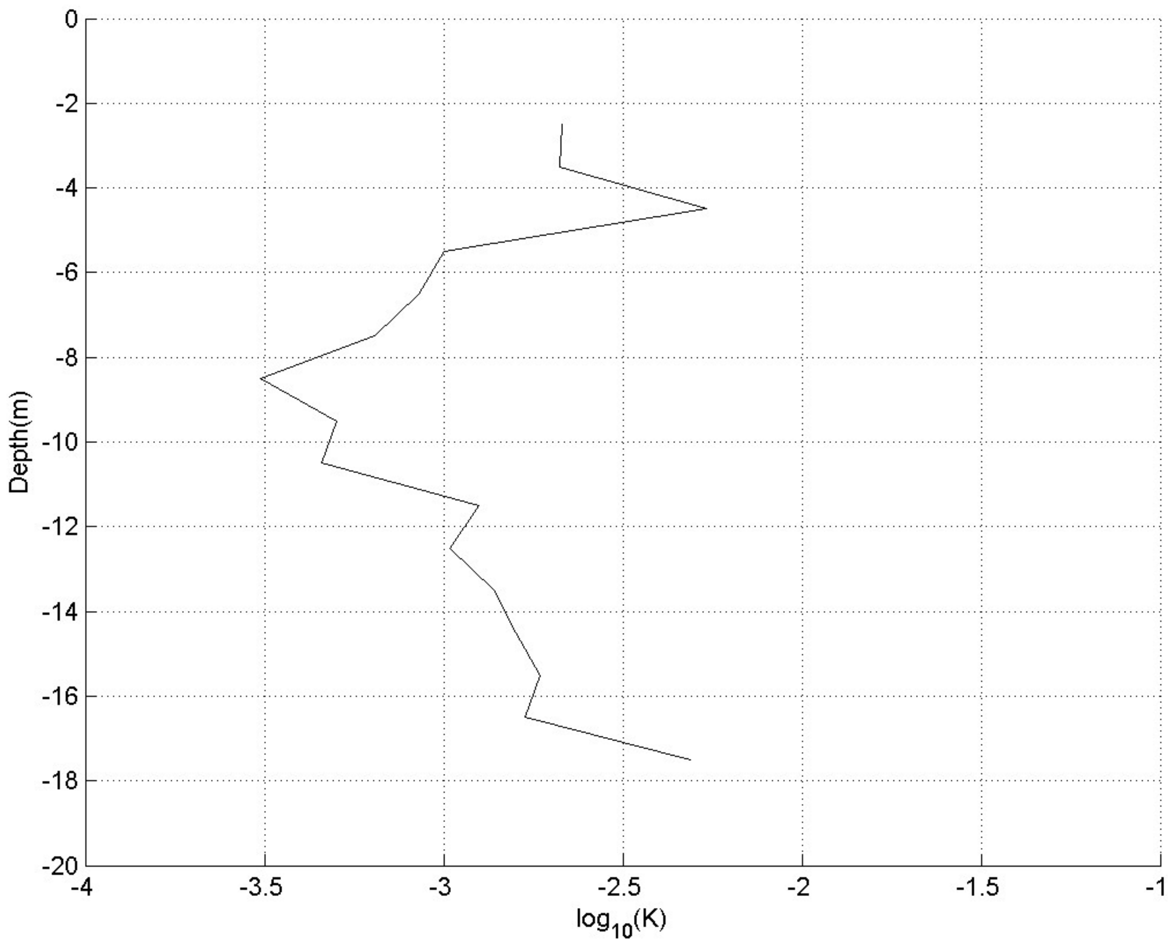
Log average, squared Thorpe Scales in 2 hour and 1m bins



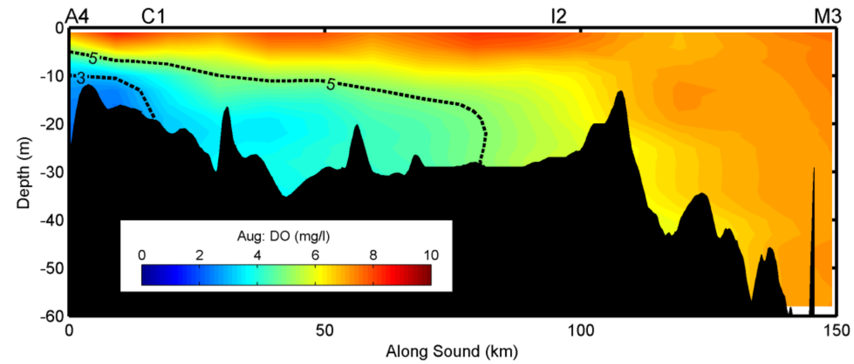
Eddy diffusion coefficient



Time mean eddy diffusivity at EXRK



Returning to the budget:



-25 = Transport+ mixing - 40 - 150 (mMoles/m^2/day)

-25 = 40 + mixing - 40 - 150 (mMoles/m^2/day)

The convergence of the axial flux is about enough to offset the benthic respiration

mixing $=2*10^{-4}$ (m^2/s) 62/5 (mM/m^2) 10^5 (s/day) (mMoles/m^2/day)

=200 (mMoles/m^2/day)

-25 = 40 + 200 - 40 - 150 (mMoles/m^2/day)

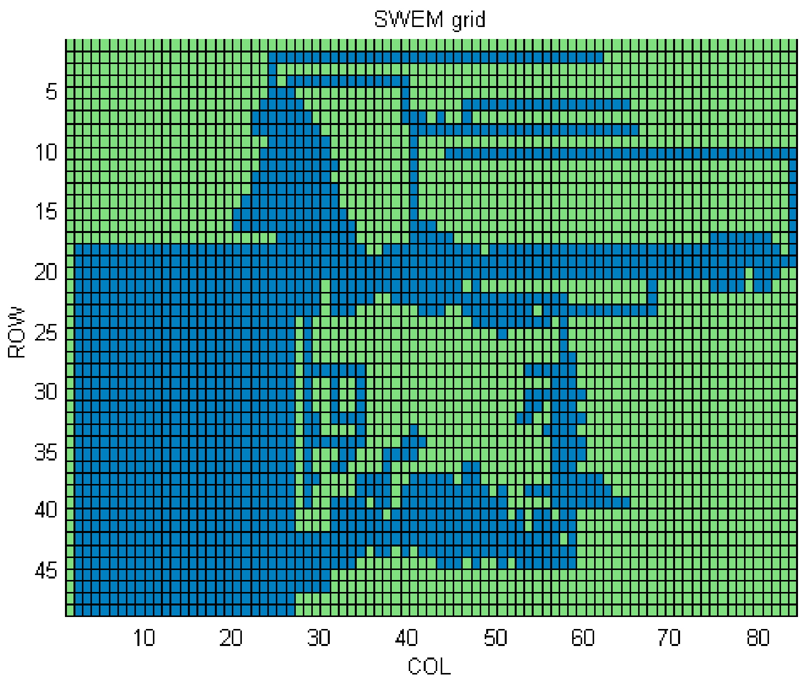
Modeling work began in 1987

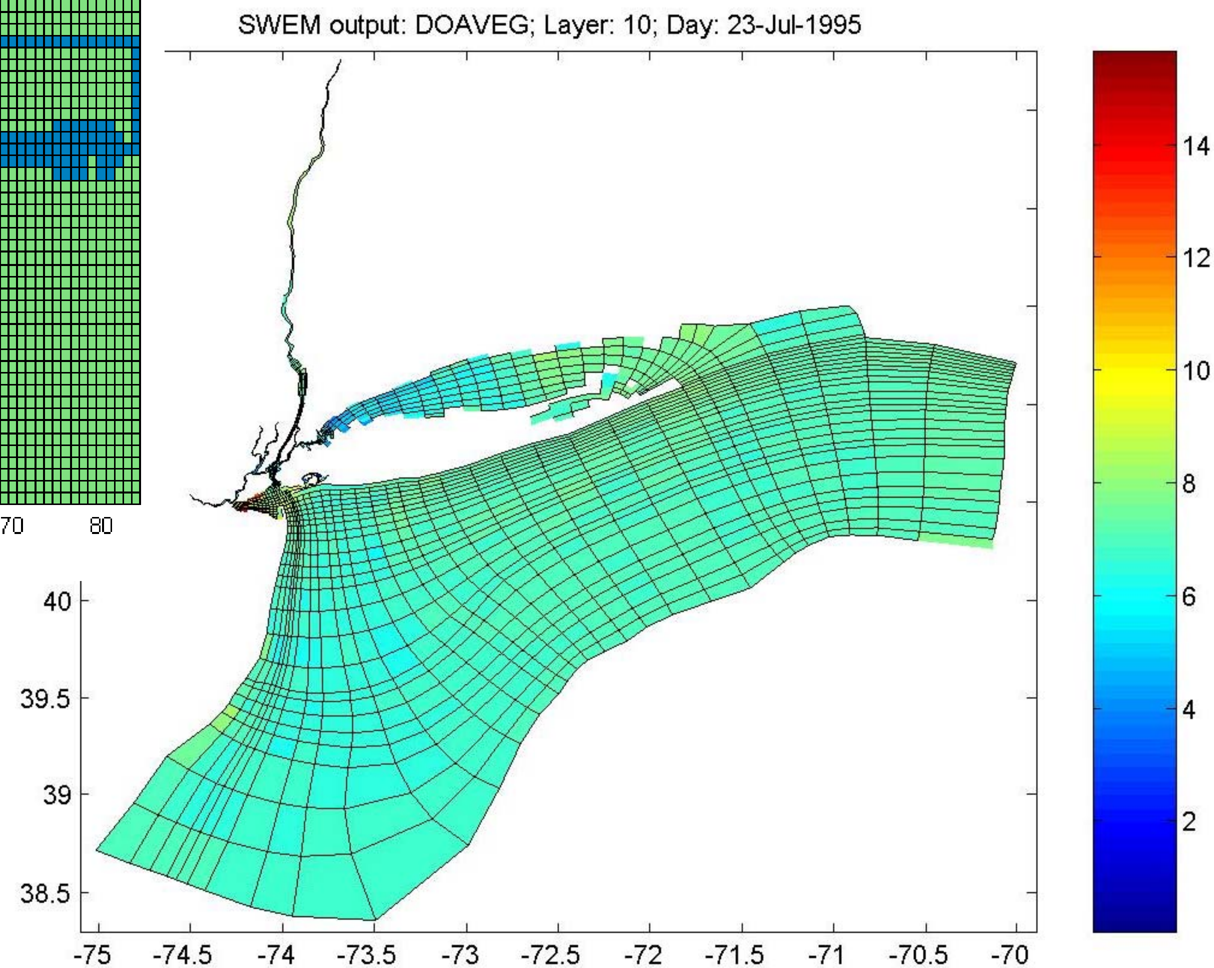
- Water quality – HydroQual
- Hydrodynamics – NOAA/HydroQual

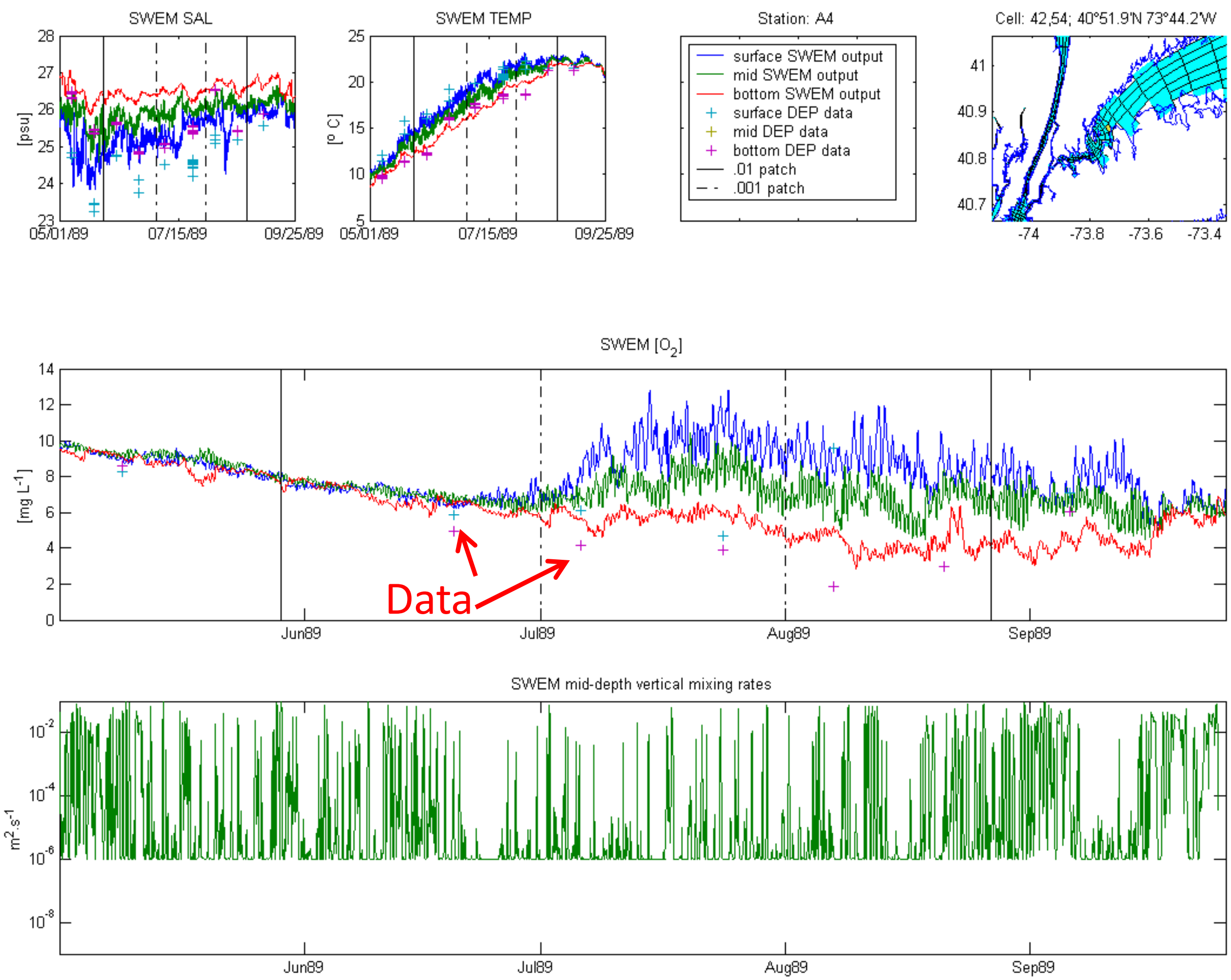
Four generations of water quality models

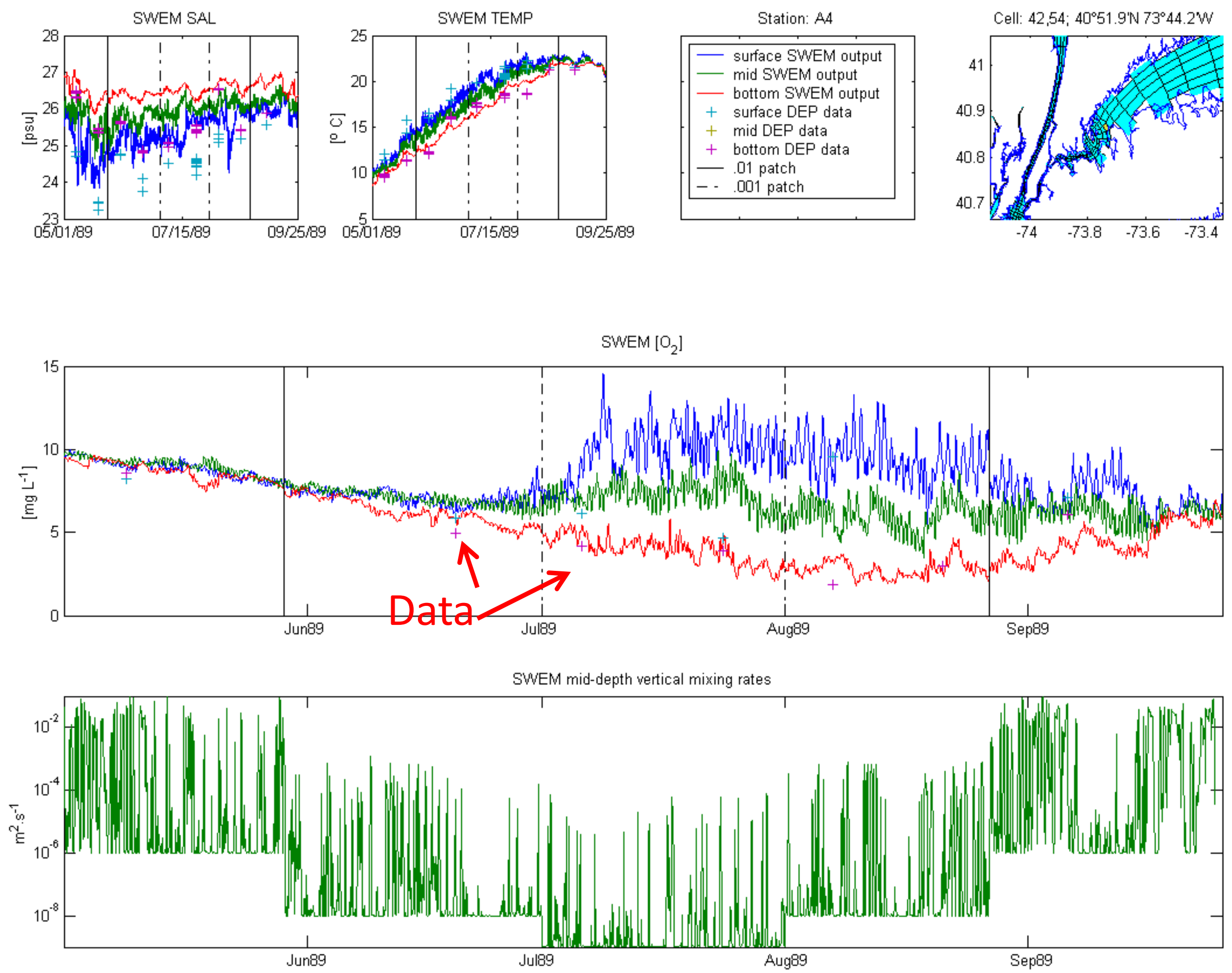
- LIS 1.0 – 2-D/steady-state
- LIS 2.0 – 2-D/time-varying
- LIS 3.0 – 3-D/time-varying
- SWEM – 3-D/time-varying/regional response

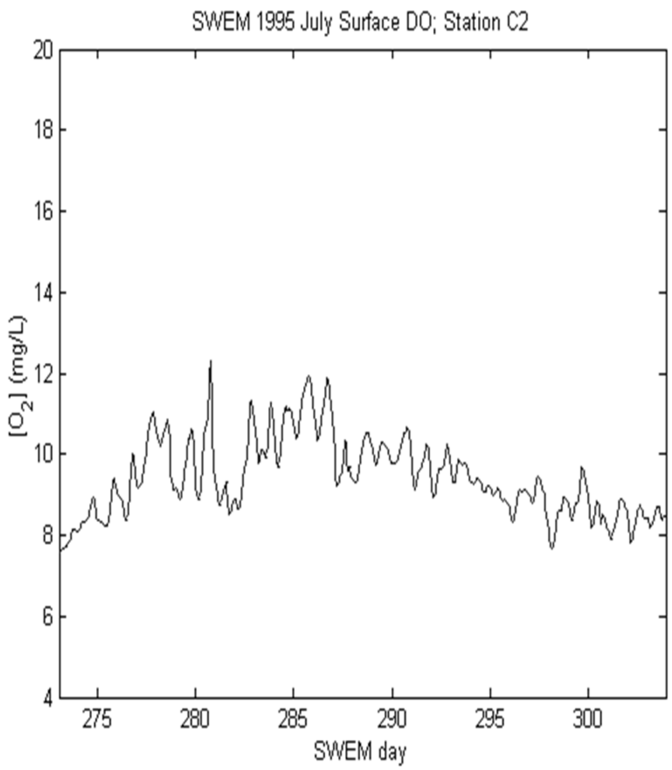
LISICOS Intensive Field Work 2004-2006
UConn SWEM Sensitivity Assessment -2012
Uconn+HDR Revisions -2014

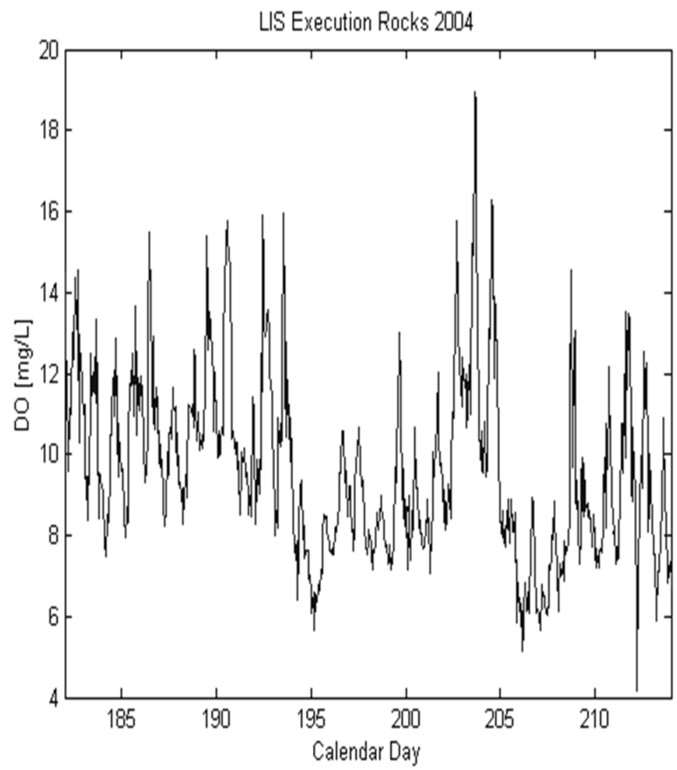

SWEM grid
ROW
COL
5
10
15
20
25
30
35
40
45
10
20
30
40
50
60
70
80

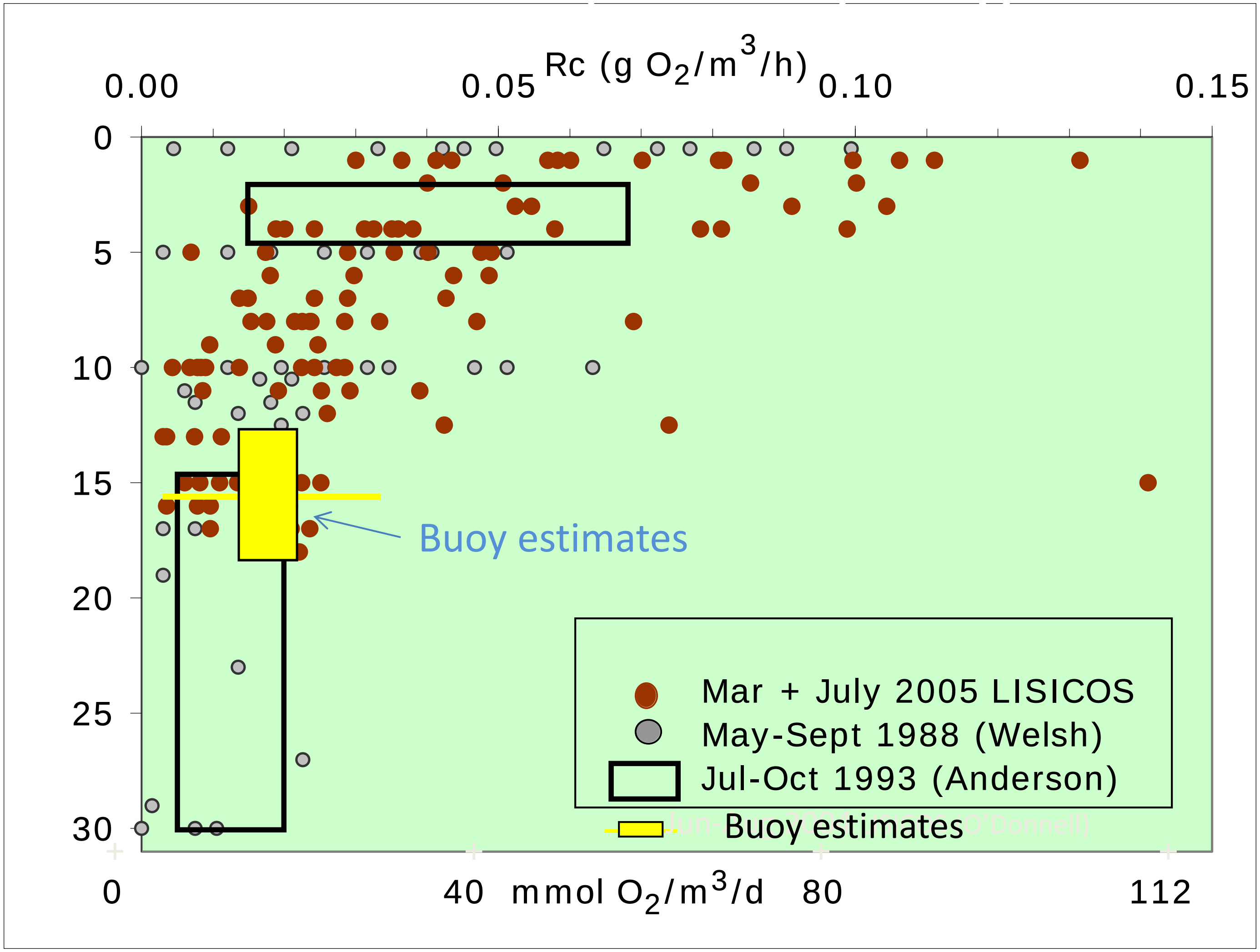

SWEM output: DOAVEG; Layer: 10; Day: 23-Jul-1995
40
39.5
39
38.5
-75
-74.5
-74
-73.5
-73
-72.5
-72
-71.5
-71
-70.5
-70
14
12
10
8
6
4
2


SWEM SAL
[psu]
05/01/89
07/15/89
09/25/89
SWEM TEMP
[° C]
Station: A4
surface SWEM output
mid SWEM output
bottom SWEM output
surface DEP data
mid DEP data
bottom DEP data
.01 patch
.001 patch
Cell: 42,54; 40°51.9'N 73°44.2'W
SWEM [O2]
[mg L-1]
Data
Jun89
Jul89
Aug89
Sep89
SWEM mid-depth vertical mixing rates
m2.s-1

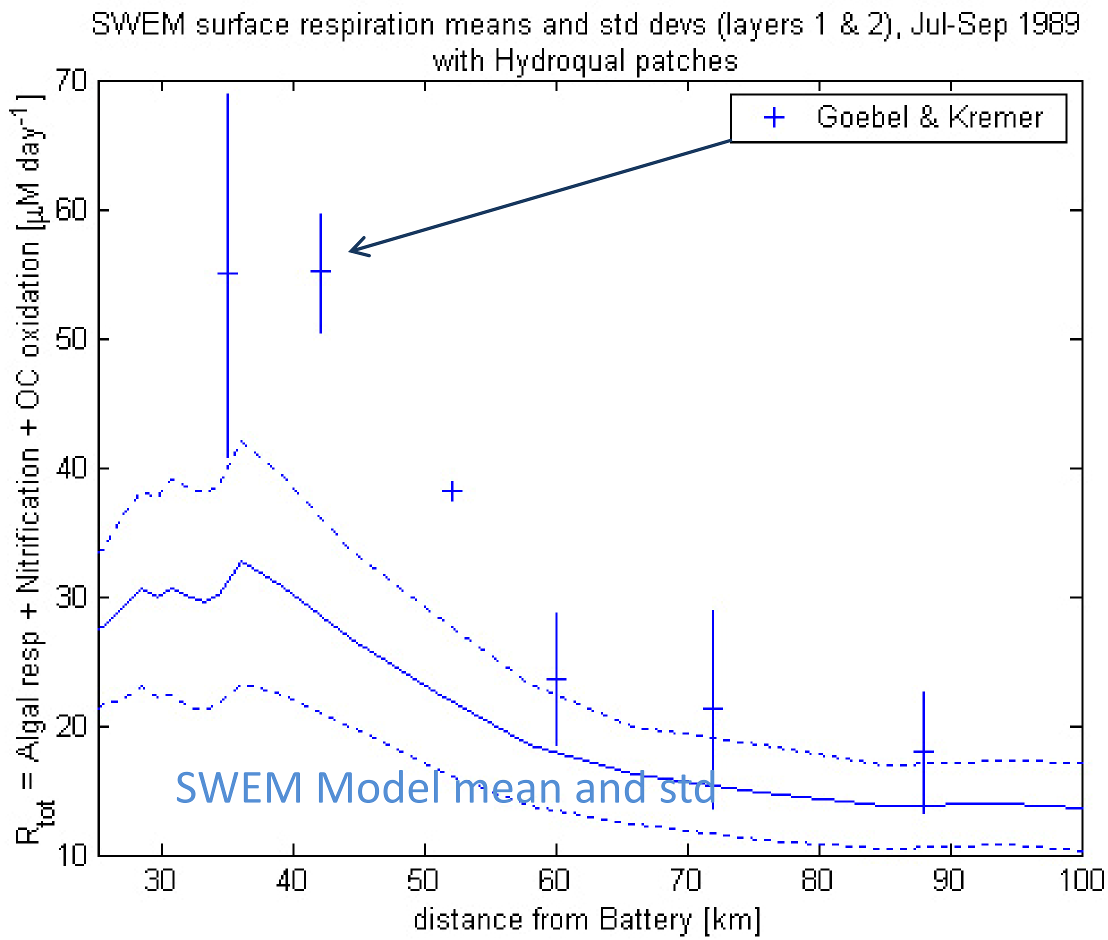

SWEM SAL
[psu]
05/01/89
07/15/89
09/25/89
SWEM TEMP
[º C]
Station: A4
surface SWEM output
mid SWEM output
bottom SWEM output
surface DEP data
mid DEP data
bottom DEP data
.01 patch
.001 patch
Cell: 42,54; 40°51.9'N 73°44.2'W
SWEM [O2]
[mg L-1]
Data
Jun89
Jul89
Aug89
Sep89
SWEM mid-depth vertical mixing rates
m2.s-1


SWEM 1995 July Surface DO; Station C2
[O2] (mg/L)
SWEM day
20
18
16
14
12
10
8
6
4
275
280
285
290
295
300


LIS Execution Rocks 2004
DO [mg/L]
Calendar Day
20
18
16
14
12
10
8
6
4
185
190
195
200
205
210



Rc (g O2/m3/h)
0.00
0.05
0.10
0.15
0
5
10
15
20
25
30
Buoy estimates
Mar + July 2005 LISICOS
May-Sept 1988 (Welsh)
Jul-Oct 1993 (Anderson)
Buoy estimates
0
40
mmol O2/m3/d
80
112



SWEM surface respiration means and std devs (layers 1 & 2), Jul-Sep 1989
with Hydroqual patches
Goebel & Kremer
SWEM Model mean and std
R_{tot} = Algal resp + Nitrification + OC oxidation [μM day^{-1}]
distance from Battery [km]
10
20
30
40
50
60
70
30
40
50
60
70
80
90
100

Assessment of V2

Water Year	DO Area-Days (km^2-days)	Model duration of hypoxia (days)	LISS/CTDEEP Duration (days)
1988-1989	569	20	63
1994-1995	642	12	35
1998-1999	2,060	17	51
1999-2000	5,530	31	35
2000-2001	6,930	36	66
2001-2002	1,480	24	65

`

- a open-source modular design that facilitates implementation of alternative parameterizations
- NETCDF input and output files
- a revision management system
- documentation
- solution file sharing
- complementary analysis and visualization tools
- an ability to work with alternative hydrodynamics models.

Some Open Scientific Questions

- What are the mechanisms controlling the magnitude and variability of respiration rate?
- Is there seasonal variation in the benthic respiration

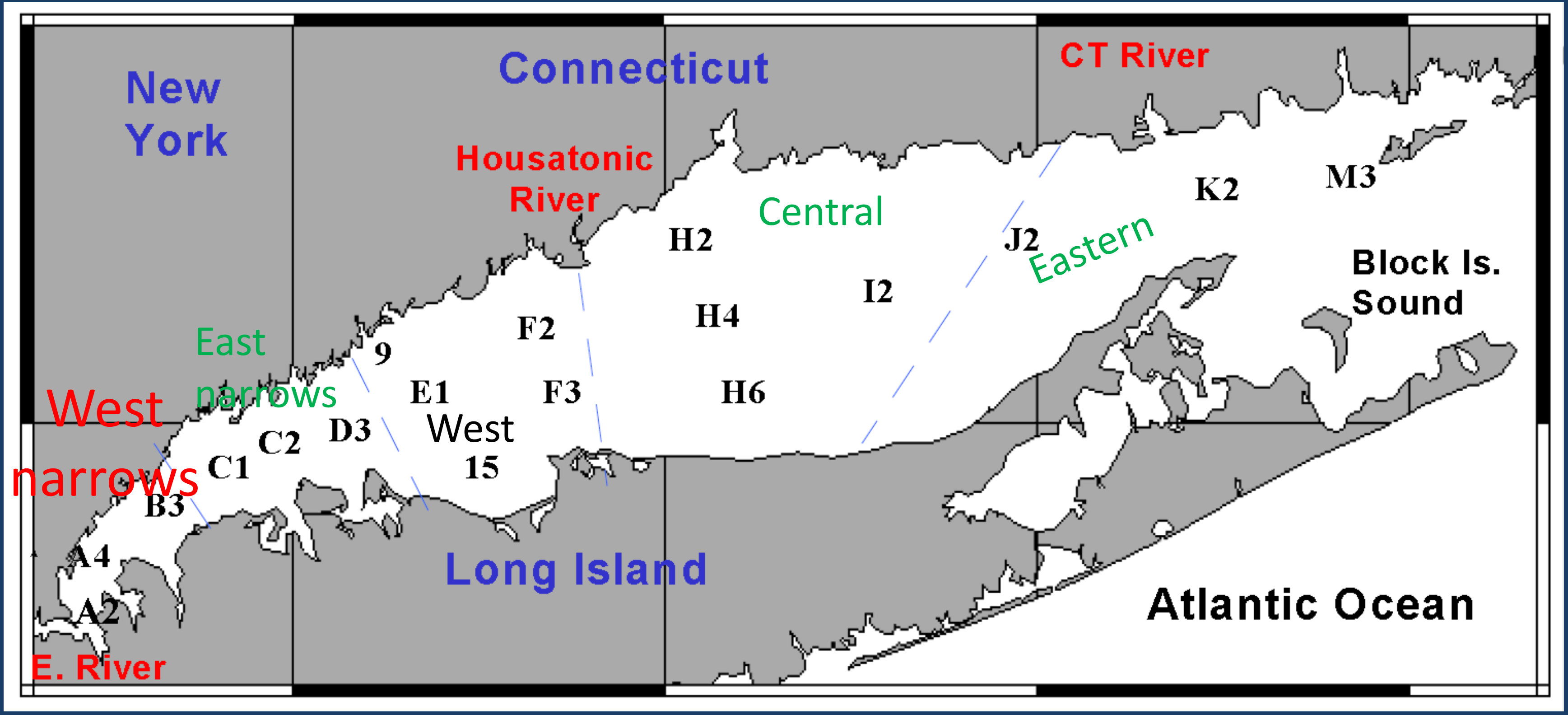
What is next?

- Modular model (in both PO, Ecosystem and Geochem)
- Sequential approach to increasing complexity
- Science working groups (in addition to MEG)
  - Production
  - Respiration
  - Benthic cycling
  - Mixing
  - Data sharing and analysis code sharing

The end

Thanks

Measuring Change in Long Island Sound



Long Term Trends in WQ

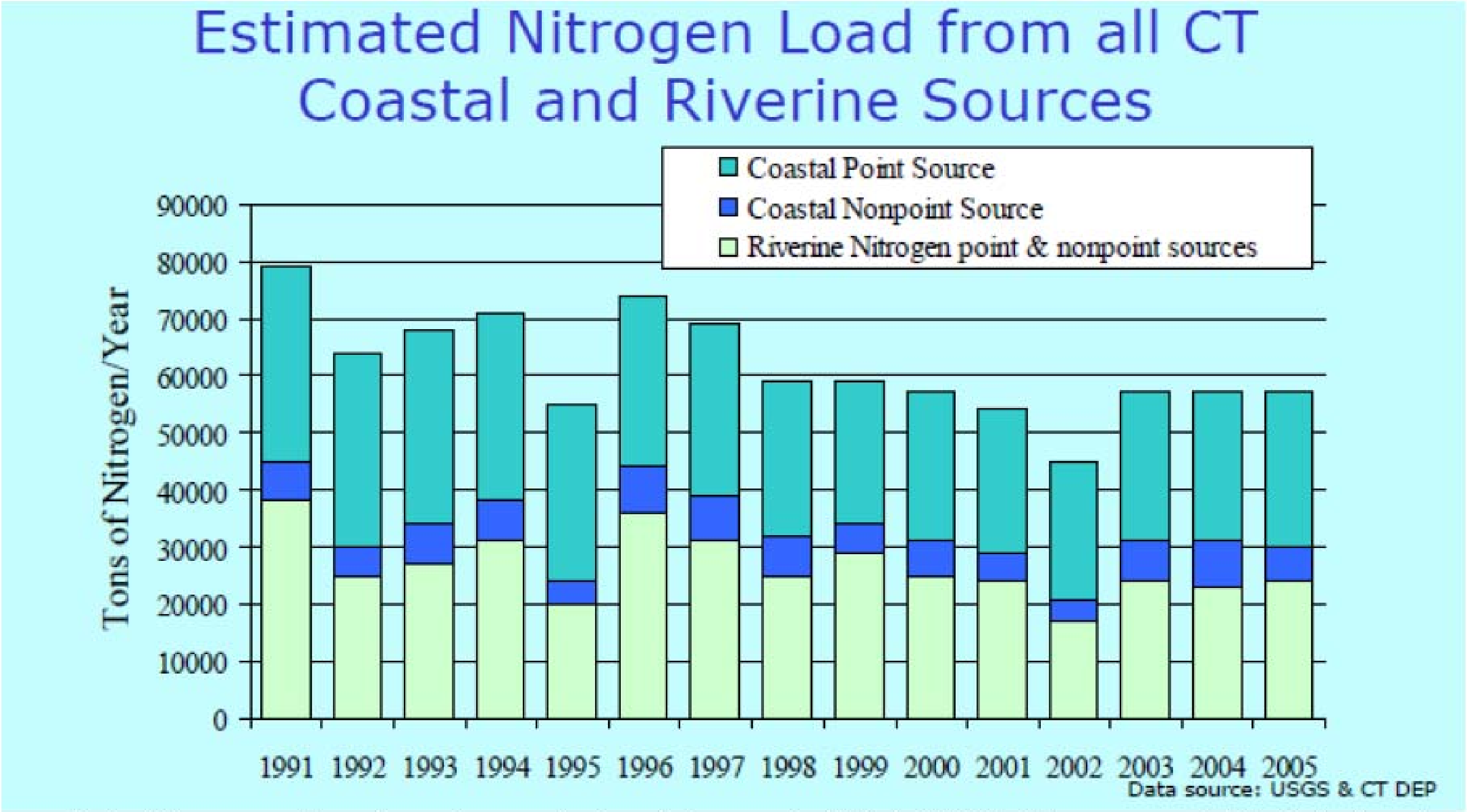


Figure 17. Nitrogen loads to Long Island Sound, 1991-2005 (Source: EPA LIS Study Office, http://longislandsoundstudy.net/wp-content/uploads/2010/02/section2.1_2008.pdf)

Western Narrows Nitrogen

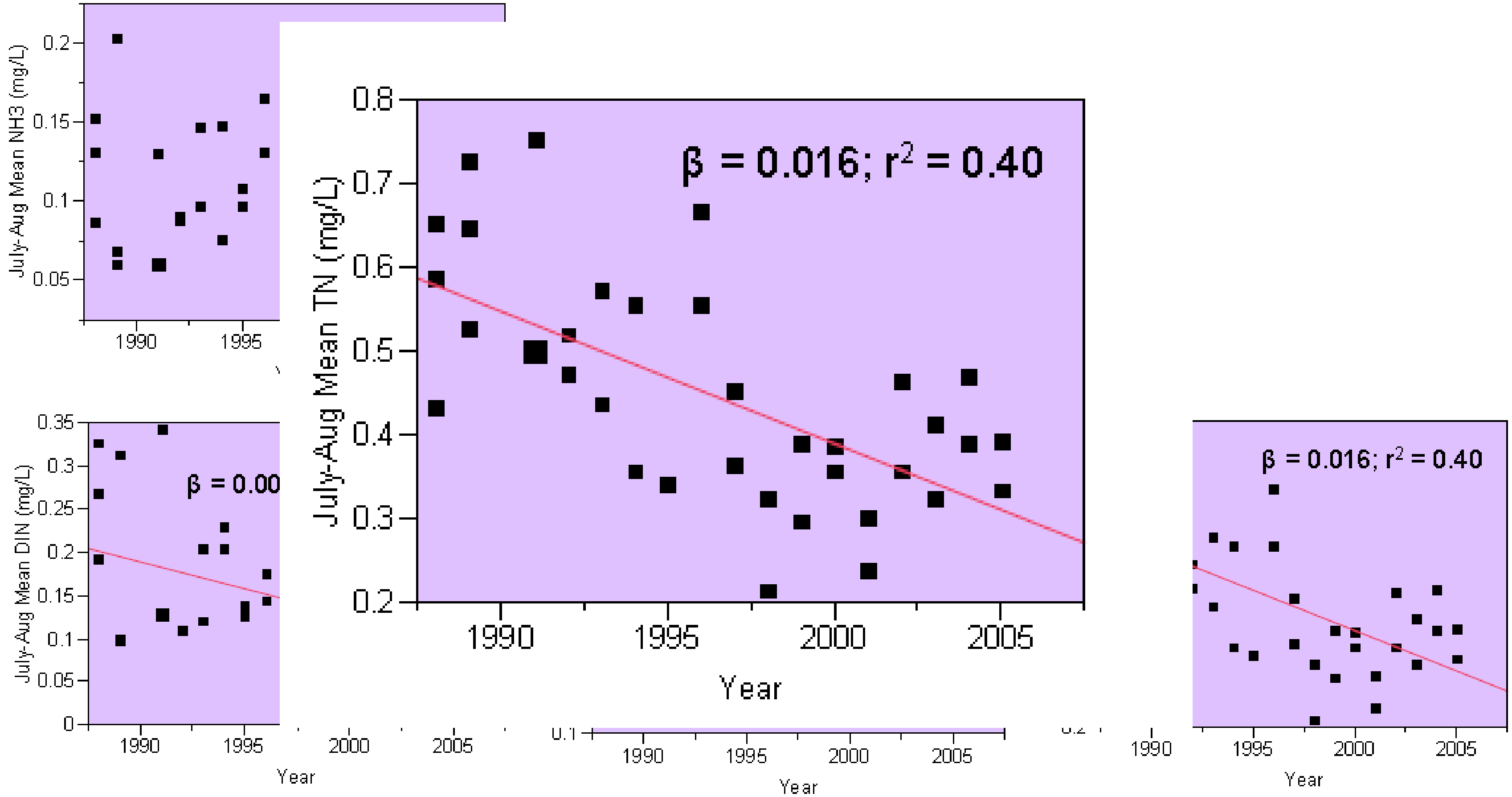
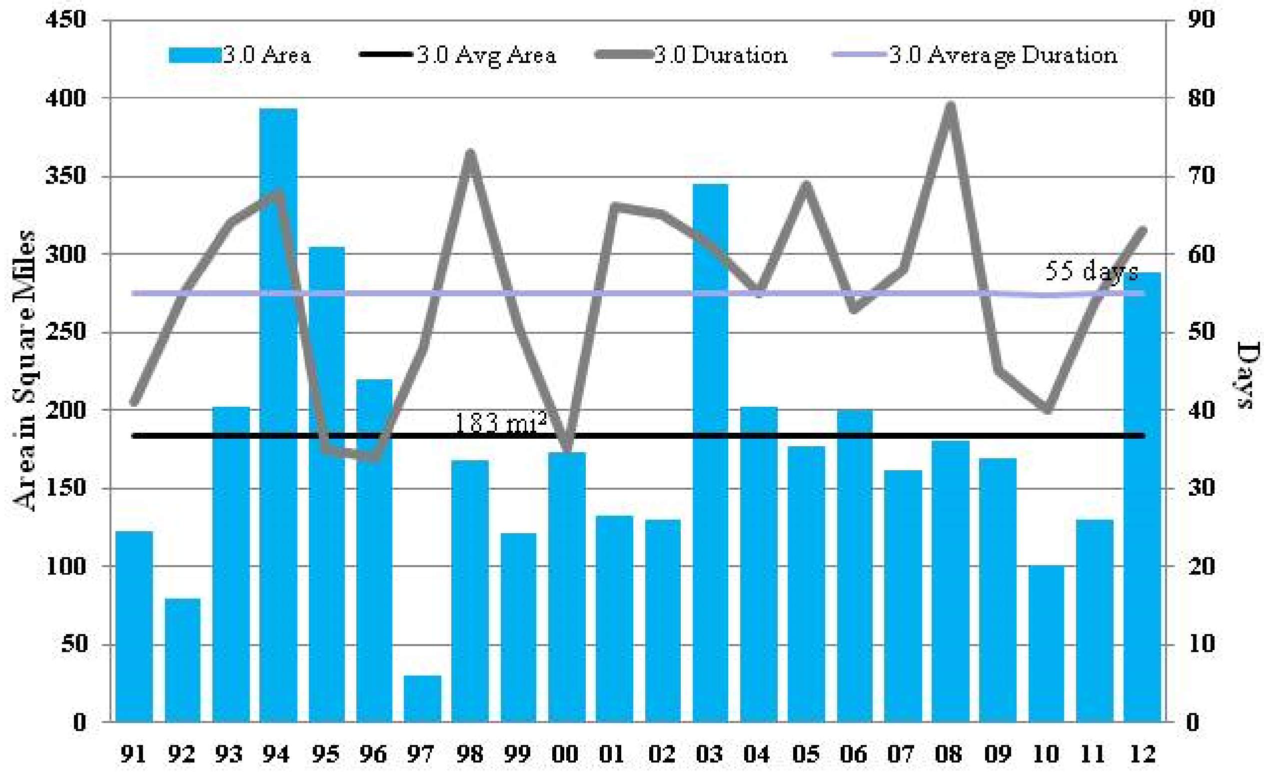


Figure 18. Bottom water nitrogen concentration versus time in the West Narrows region during the peak hypoxia period (July and August), 1988-2005. Points represent the two-month average of each of the three stations in the West Narrows region. Lines in plots represent statistically significant ($p < 0.05$) linear regression trends. There was no trend for NH_3.

Yearly Comparison of Maximum Areal Extent and Duration of Hypoxia

This graph utilizes the data presented on the previous page to illustrate the year-to-year differences in the maximum areal extent of hypoxic conditions. Based on the 3.0 mg/L DO standard the average areal extent was 183 mi^2 and the average duration was 55 days.

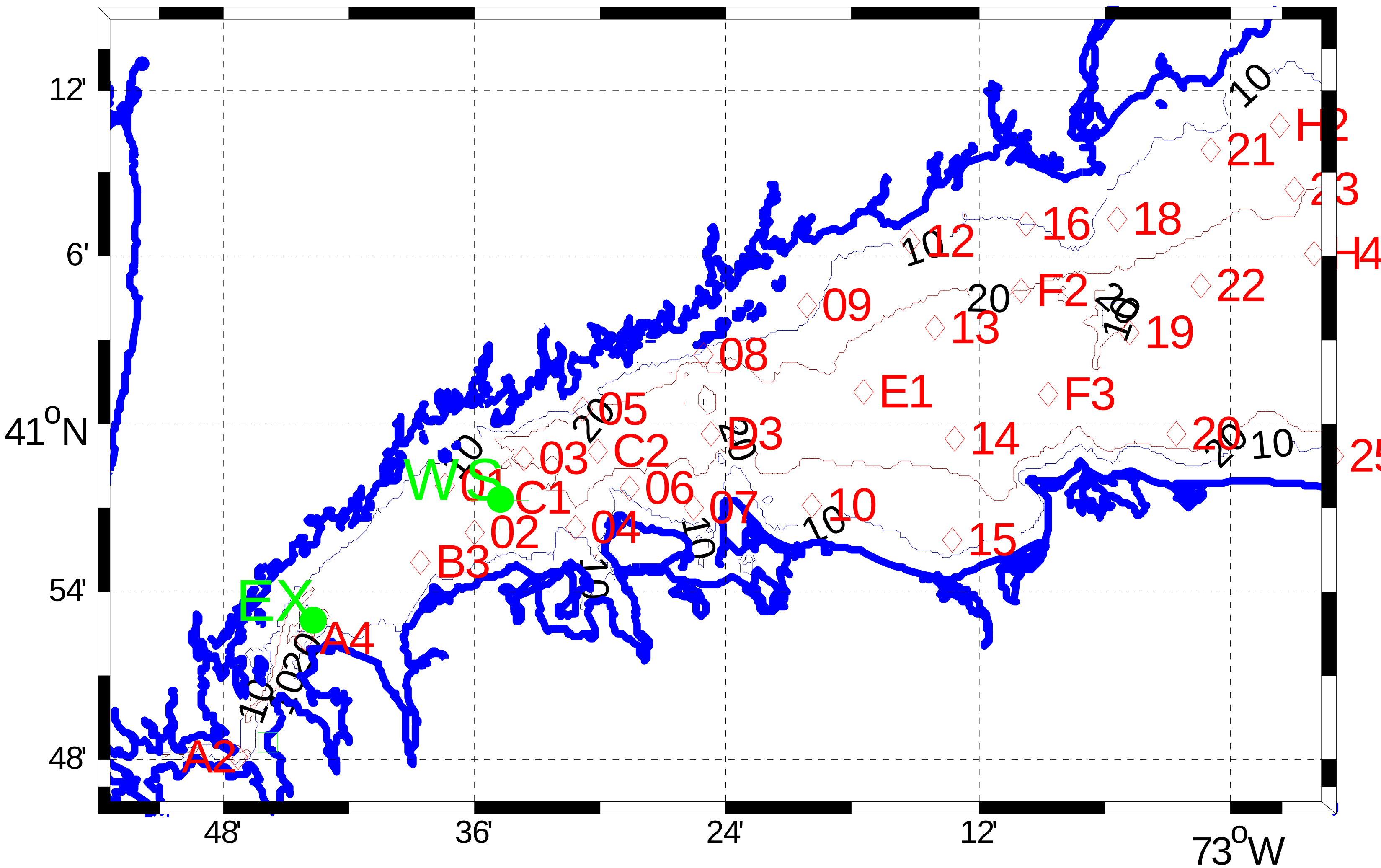
Area and Duration of Hypoxia (DO<3.0 mg/L)

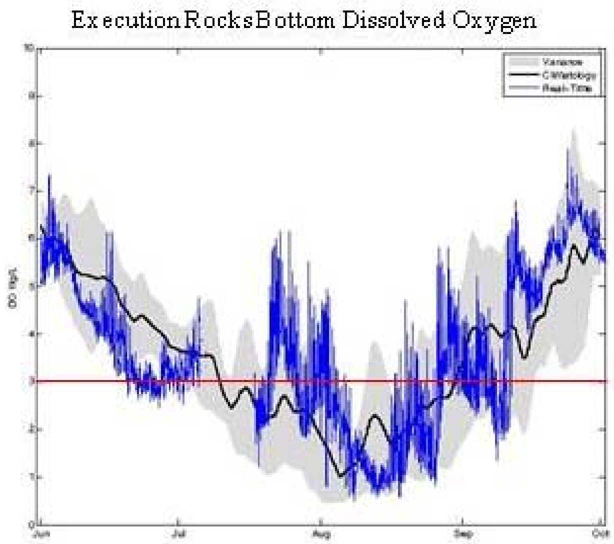


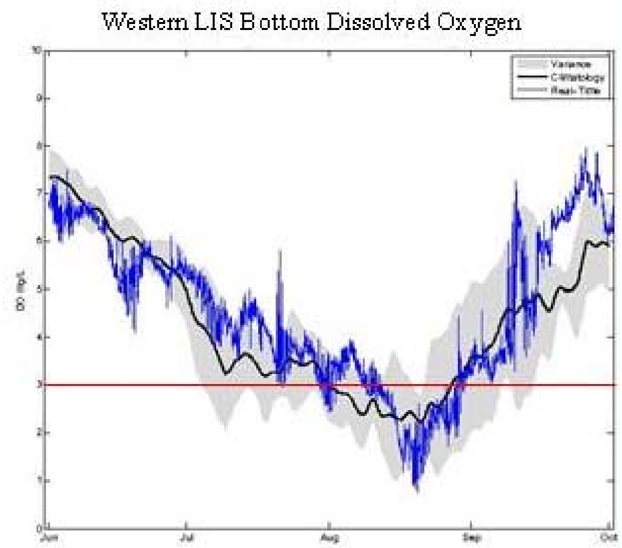
Nitrogen reduction is working, but hypoxia persists ?

- There is evidence of this in other area
- Nutrient ratio changes allow other species to bloom
- Nitrogen fixation?
- Climate shifts have led to more stratification and less ventilation.
- We are not measuring accurately enough
  - Aliasing of high frequencies
  - Amplitude of inter-annual modulation is large

Buoys reveal tidal, daily and weather-band variability and it is big.







Based on LISICOS Execution Rocks Buoy Data Collected Between 1 June to 18 October

Estimated Start Date	6/20/2012
Estimated End Date	9/11/2012
Duration below 3.0 mg/L (cumulative days)	42.17
Duration below 2.0 mg/L (cumulative days)	18.89
Duration below 1.0 mg/L (cumulative days)	4.04
Minimum DO value (mg/L)	0.52 on 8 August

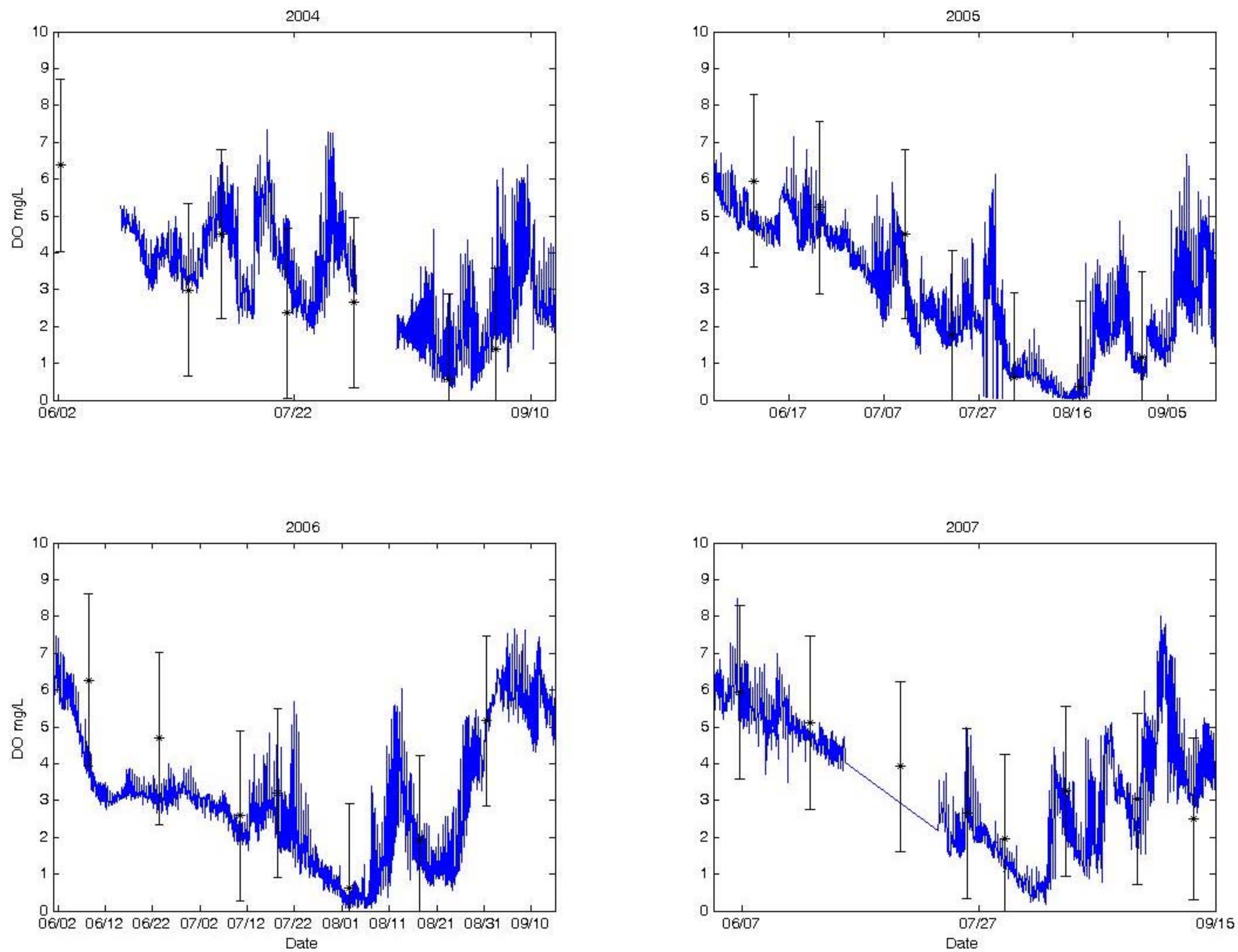
Data obtained from the LISICOS Execution Rocks Bottom Dissolved Oxygen Prediction Tool webpage (http://lisicos.uconn.edu/do_fcst.php?site=exrx). Data are also available for the Western Sound Buoy (http://lisicos.uconn.edu/do_fcst.php?site=wlis) where DO was less than 3.0 mg/L for 20.91 days. Duration is calculated by LISICOS by summing the time (in days) of the number of samples where DO was below the specified value (T. Fake, pers comm. 18 October 2012). ***Data are provisional and subject to change.***

Based on CT DEEP and IEC data

Estimated Start Date	7/10/2012
Estimated End Date	9/10/2012
Duration (days)	63
Maximum Area (mi^2)	288.5

The Long Island Sound Study has defined hypoxia as dissolved oxygen concentrations below 3.0 mg/L. On 25 February 2011, CT DEEP adopted revised water quality standards that specified dissolved oxygen in Class SA and SB waters (applicable to LIS) shall not be less than 3.0 mg/L at anytime.

Start date and end date are estimated by plotting DEEP and IEC data from stations A4 and B3 in Excel using a line with markers chart and then interpolating when the DO concentration drops below 3.0 mg/L.


2004
2005
2006
2007
DO mg/L
Date
06/02
07/22
09/10
06/17
07/07
07/27
08/16
09/05
06/12
06/22
07/02
07/12
08/01
08/11
08/21
08/31
06/07
09/15

How does the error influence the uncertainty in the hypoxic area?

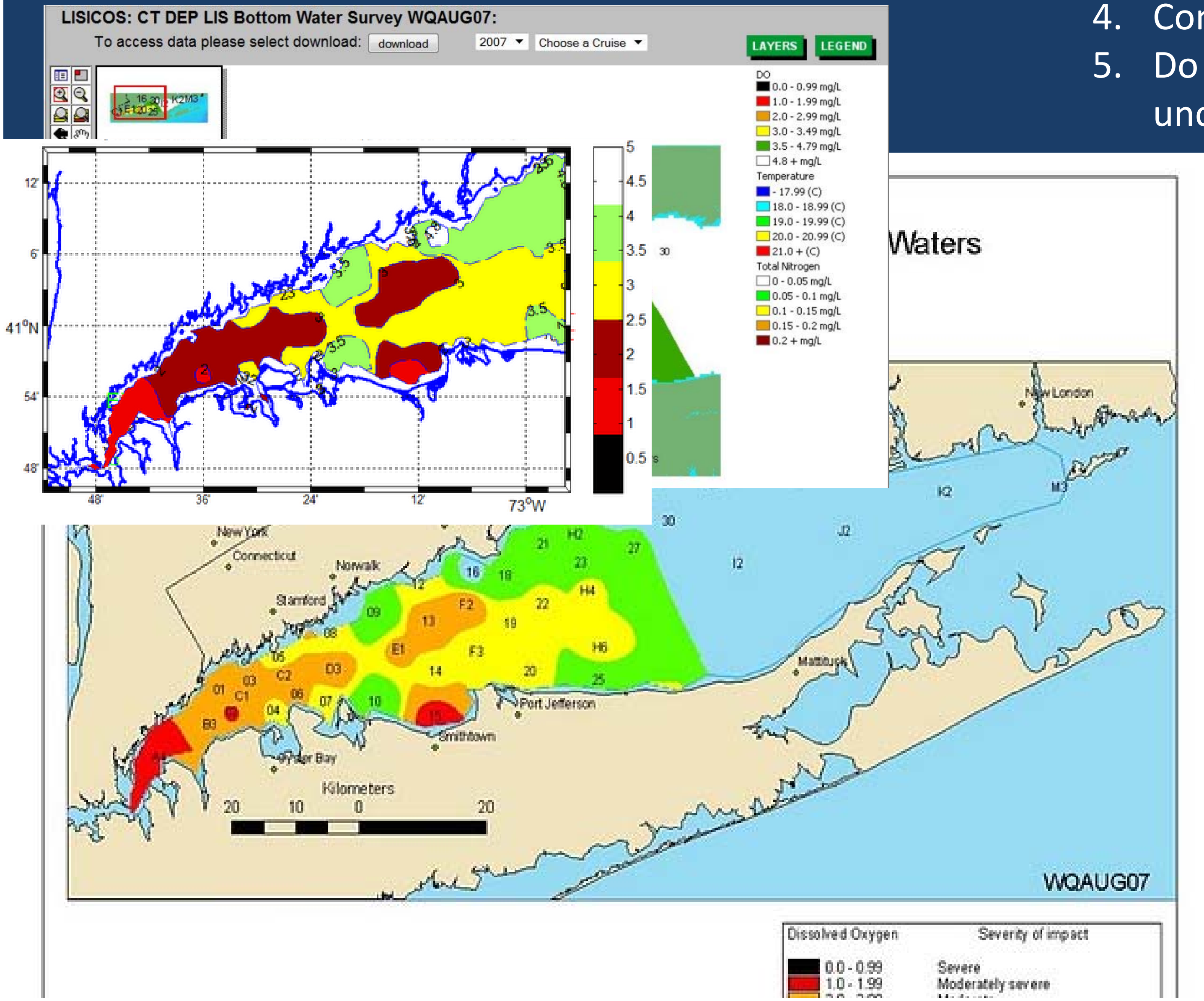
Monte Carlo Simulation

1. Assume the statistics of the error - gaussian normal with zero mean and std specified
2. Generate sample with these characteristics and add it to the data –compute A_i.
3. Repeat a large number (1000) times.
4. Compute standard deviation of A_i.

Need procedure to make contour maps and compute areas in the same way as CTDEP.

WQAUG07

1. Download cruise data
2. Make Map with inverse distance weighting
3. Compute area <3.5
4. Compare to CTDEP
5. Do MC simulation to get uncertainty



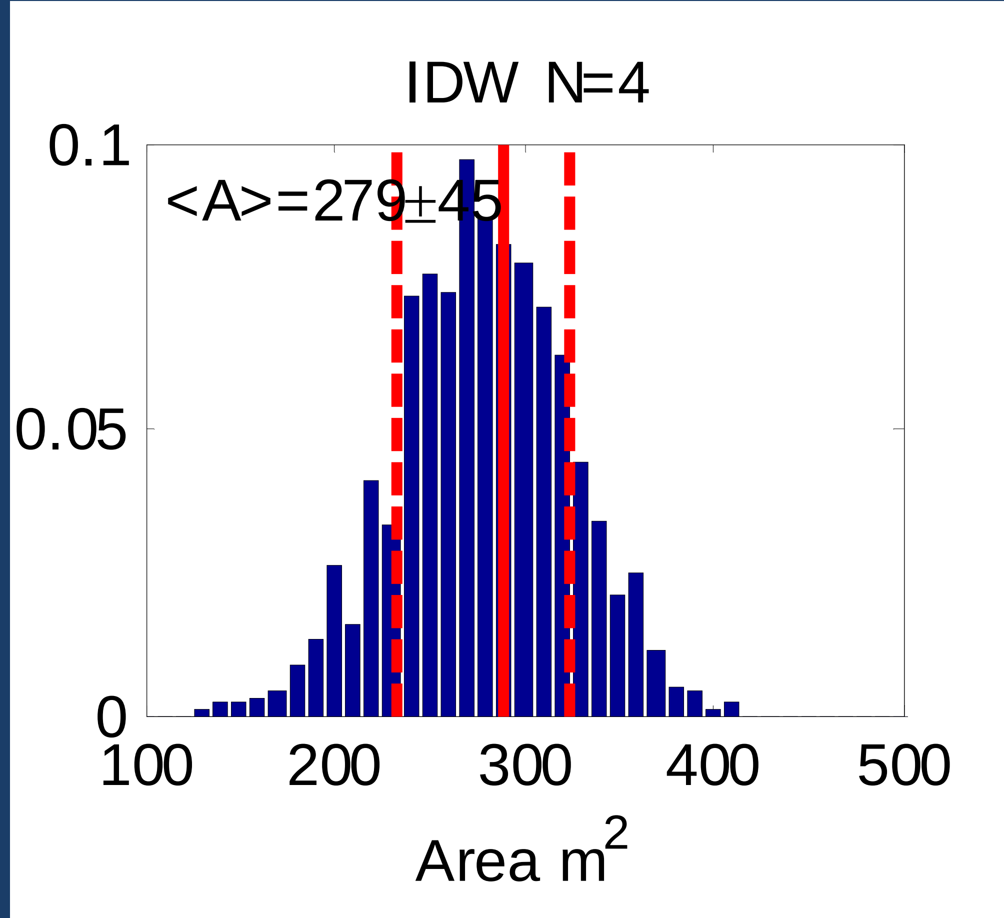
Uncertainty in the Area of hypoxia due to 2mg/l uncertainty in the survey data ~45 square miles or 15%.

Note the median is significanlty lower than the data alone value

This is a consequence of the sensitivity of the mapping algorithm to station spacing

N=4 makes maps lumpy when stations are widely spaced.

Map depends on the units chosen for the x&y dimensions.

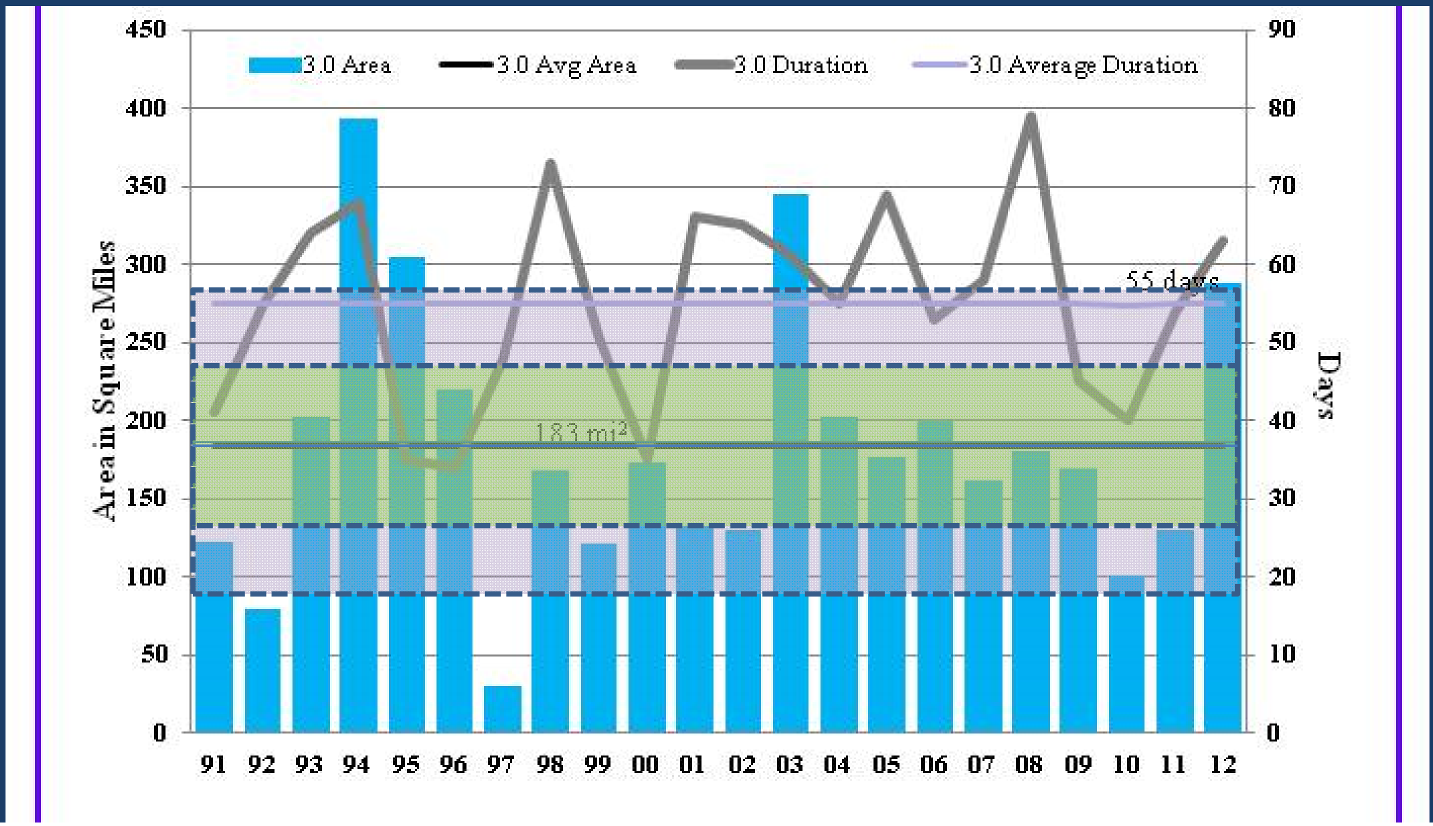


Gauss Markov/Krigging in space and time.

- This approach has a lot of advantages
  - Uses more data
  - Doesn’t require repeated stations
  - Can look for the largest areas if they occur between cruises.
  - This is what I used for the Temperature Stress Index

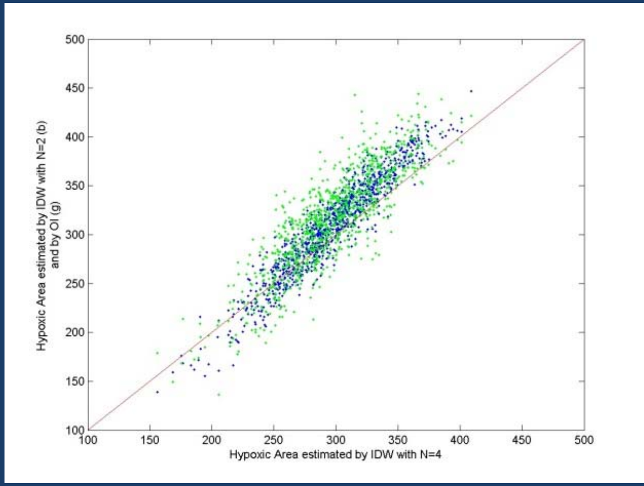
Area of Hypoxia with uncertainty intervals of 68 and 99%

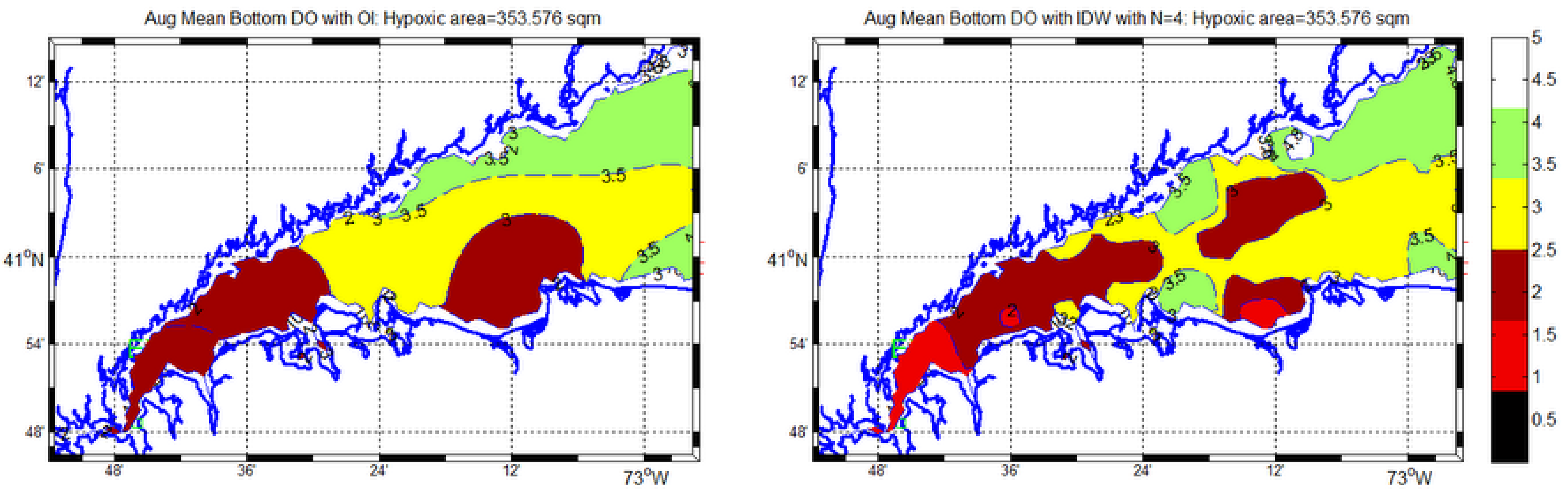
1994-5 and 2003 were bad, 97 was good



Other Mapping Approaches

- IDW with N=2
- Krigging/Gauss Markov Estimation/Objective Analysis
- They don't make much difference to the A but they do change the structure.





Recommendations

- Establish the consequences of the errors on SWEM in management decisions.
- Commit to support greater access to model code, parameter choices and results.
- Support greater data sharing.
- Develop analysis tools for hypoxic area, volume and duration with objective analysis and uncertainties.
- Commit to support sustained buoy observations and expanded instrument deployment (nutrients)
- Consider upgrades to ship surveys- production and respiration, species, currents, towed vehicles
- Integrate buoy observations to WQ goals.

Other more precise metric – duration of hypoxia at EXRK buoy