“Gulf of Maine North Atlantic Time-Series (GNATS): Documenting change in a coastal marine ecosystem”

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with input from Tom Huntington[2], George Aiken[3], and Crystal Schaaf[4]

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Bigelow Laboratory for Ocean Sciences

USGS science for a changing world

UMASS BOSTON

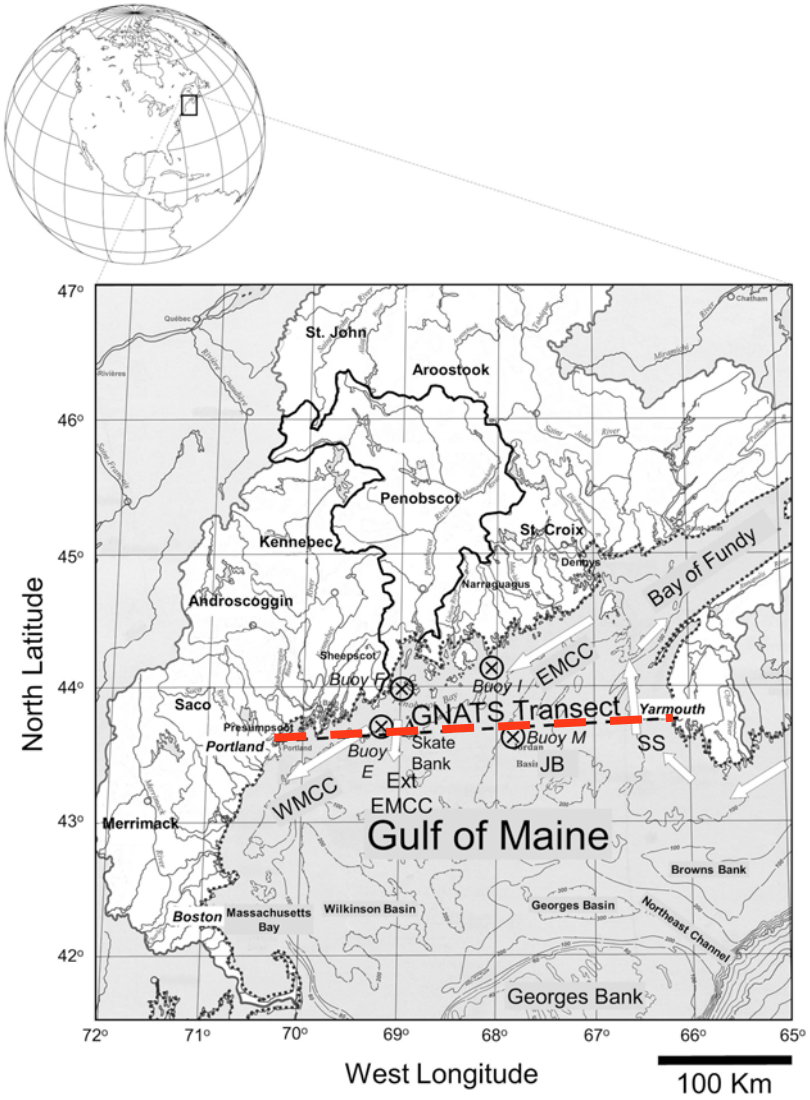
NASA

Acknowledgements

- D. Drapeau, B.C. Bowler, L. Lubelczyk, E. S. Booth, J. Goes, E. Lyczskowski, D. Alley, A. Wyeth(Bigelow Laboratory), L. A. Windecker (U.C. Santa Barbara), E. Olson (WHOI), R. Vaillancourt (Millersville Univ.), A. Ashe (U.Maine) + 70 others (occasional trips) for 171 crossings covering >44,000 km (the circumference of Earth) and 480 person days at sea over 17+ years.
- Erica Eames, Boothbay Regional HS- entry of historic data
- Kenna Butler, USGS- processing DOC samples
- Nick Bates (BIOS) processing DIC samples
- **Sustained support from NASA has made this possible!**

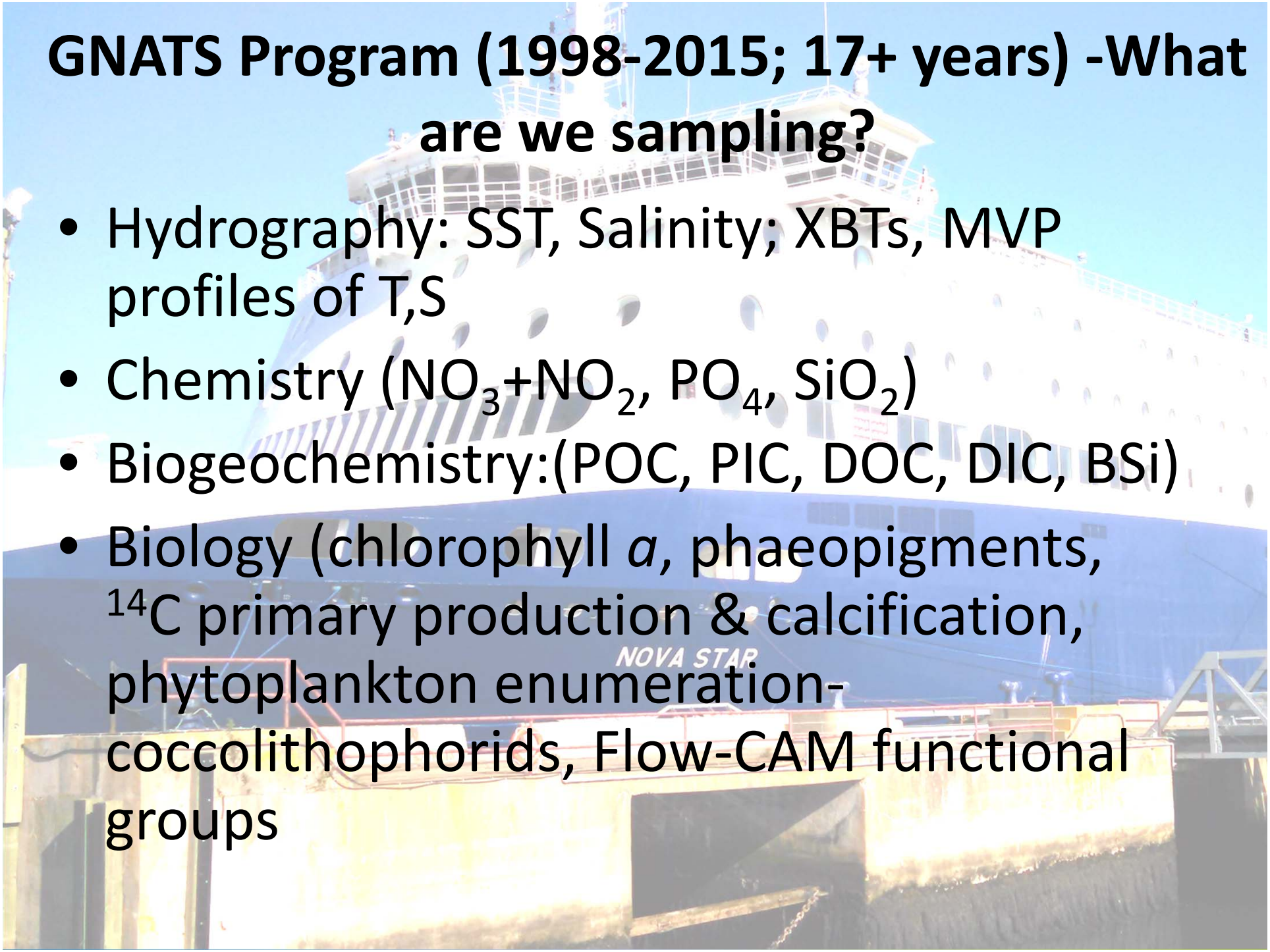
The Gulf of Maine North Atlantic Time Series (GNATS)

-Transect roughly east-west
-crosses 4 water masses
- 17 years (1998-2015)
-Well-documented water shed!
-NASA-supported with two major goals: 1) satellite calibration/ validation 2) coastal carbon time series/modeling



GNATS Program (1998-2015; 17+ years) -What are we sampling?

- Hydrography: SST, Salinity; XBTs, MVP profiles of T,S
- Chemistry (NO_3+NO_2, PO_4, SiO_2)
- Biogeochemistry:(POC, PIC, DOC, DIC, BSi)
- Biology (chlorophyll *a*, phaeopigments, ^{14}C primary production & calcification, phytoplankton enumeration-coccolithophorids, Flow-CAM functional groups



GNATS Program (1998-2015; 17+ years) -What are we sampling?

- Bio-Optical measurements
  - **Inherent optical properties** [spectral absorption (total and dissolved), scattering, elastic backscattering, acid-labile backscattering, volume scattering function, inelastic scattering (chlorophyll, CDOM fluorescence), nitrate absorption (SUNA)
  - **Apparent optical properties** [above-water spectral upwelling radiance, sky radiance, downwelling irradiance]
  - **Seasonal Slocum glider missions** along the GNATS transect (T, S, CDOM fluor, Chl Fluor, b_{bp}531nm)C

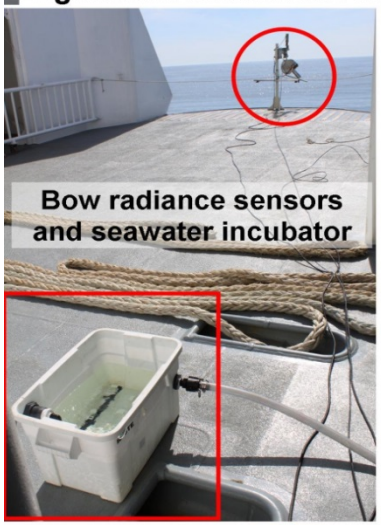
Gulf of Maine North Atlantic Time Series (**GNATS**) is a NASA-centric Ship of Opportunity Program; *M/V Nova Star*

171 GOM crossings.

M/S Nova Star ferry in Portland, ME, showing locations of bow-mounted radiance sensor and top-mounted irradiance sensor

Bigelow/NASA Mobile lab on deck 5

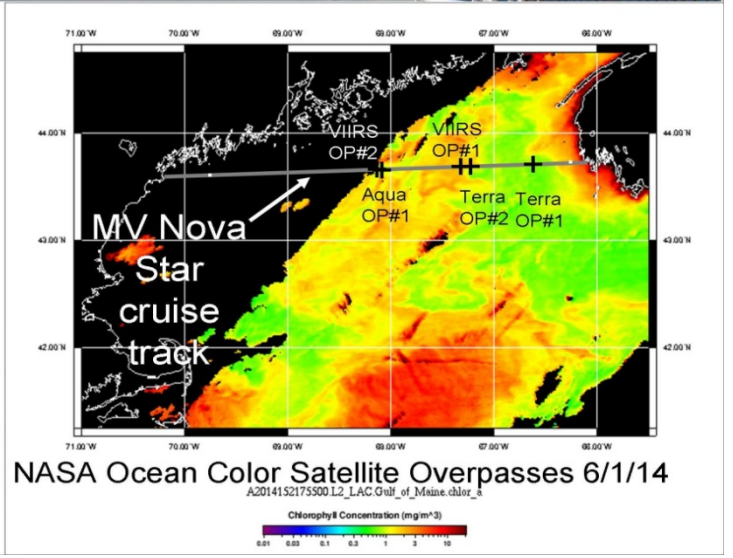
Self-steering radiance sensors (photo taken from below bow)



Bow radiance sensors and seawater incubator

Downwelling irradiance sensor on Helo-deck (deck 11)

Balch lab crew working in Bigelow/NASA mobile lab



NASA Ocean Color Satellite Overpasses 6/1/14

Background: Oceanographers have studied coastal carbon for about a century in the Gulf of Maine

- Henry Bigelow studied the the coastal Gulf of Maine from 1912 onwards in a series of one-month cruises.
- Father of modern oceanography (and with a decidedly coastal focus).

But now there is an intensifying hydrological cycle…

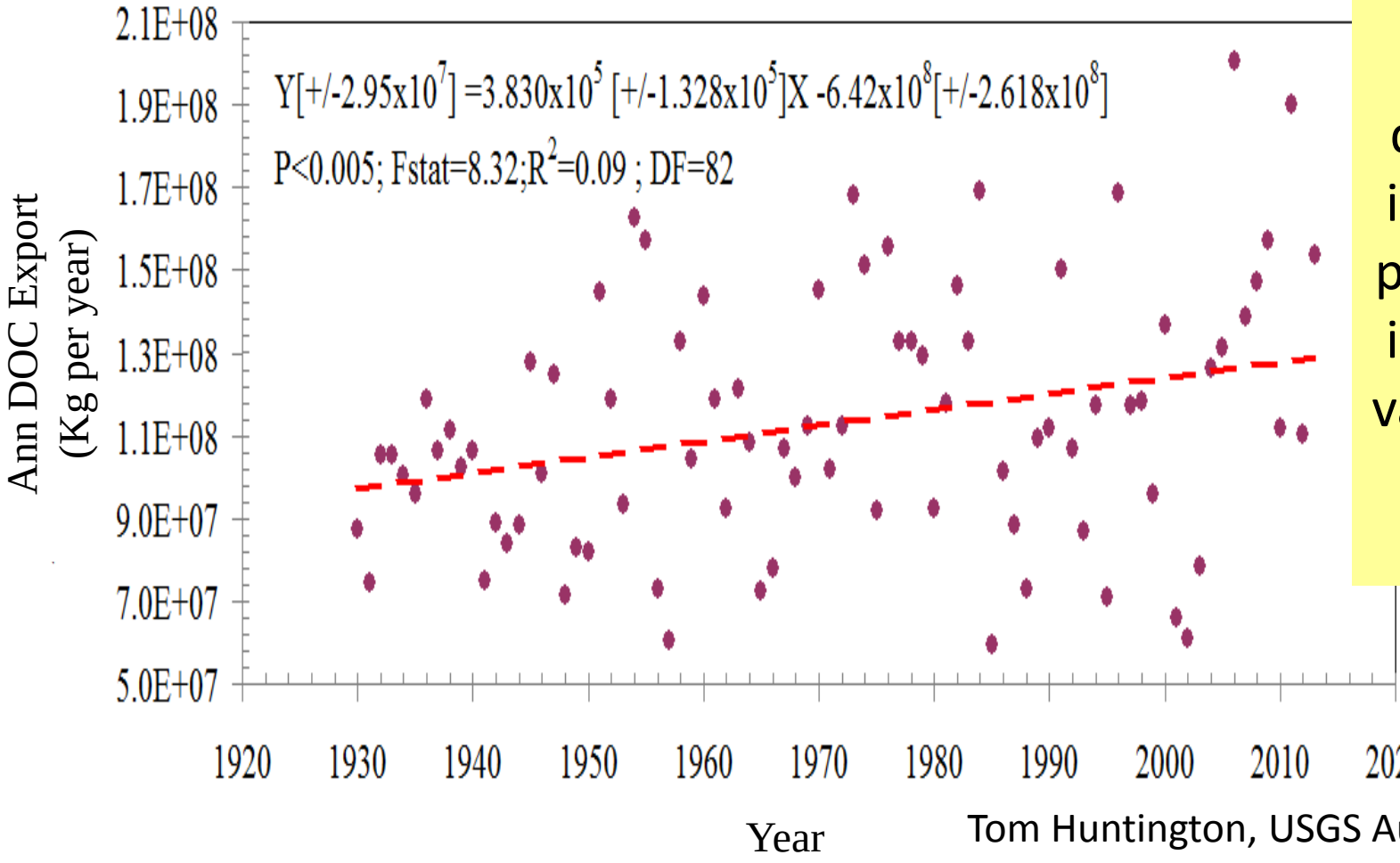
Clim Dyn (2007) 28:381–407
DOI 10.1007/s00382-006-0187-8

Past and future changes in climate and hydrological indicators in the US Northeast

Katharine Hayhoe · Cameron P. Wake · Thomas G. Huntington · Lifeng Luo · Mark D. Schwartz · Justin Sheffield · Eric Wood · Bruce Anderson · James Bradbury · Art DeGaetano · Tara J. Troy · David Wolfe

Focus: Changing DOC quantity…

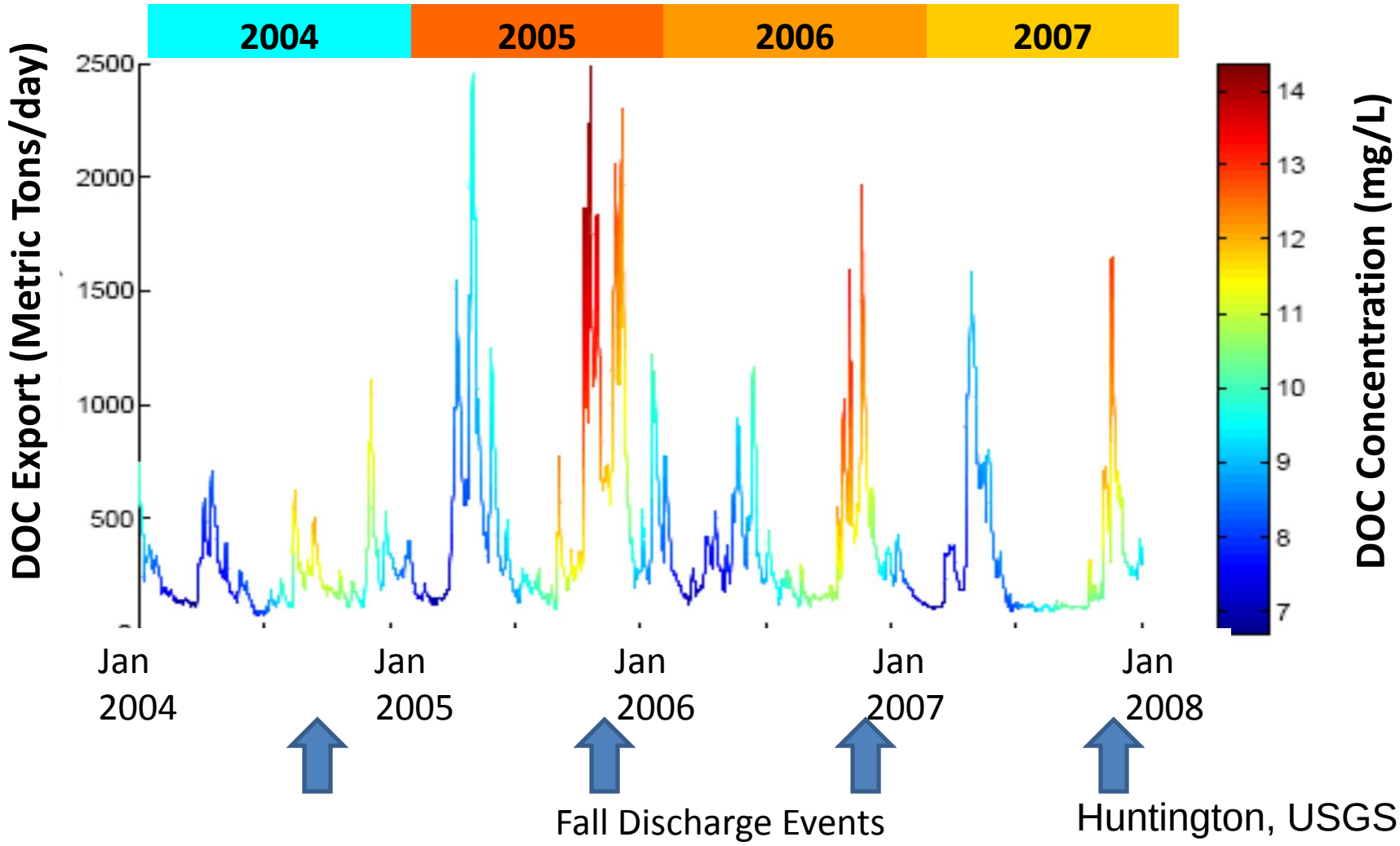
Penobscot River from 1930-present; based on LOADEST

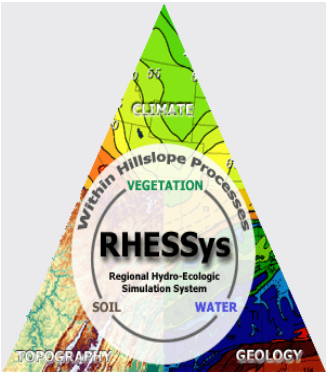


Tom Huntington, USGS Augusta

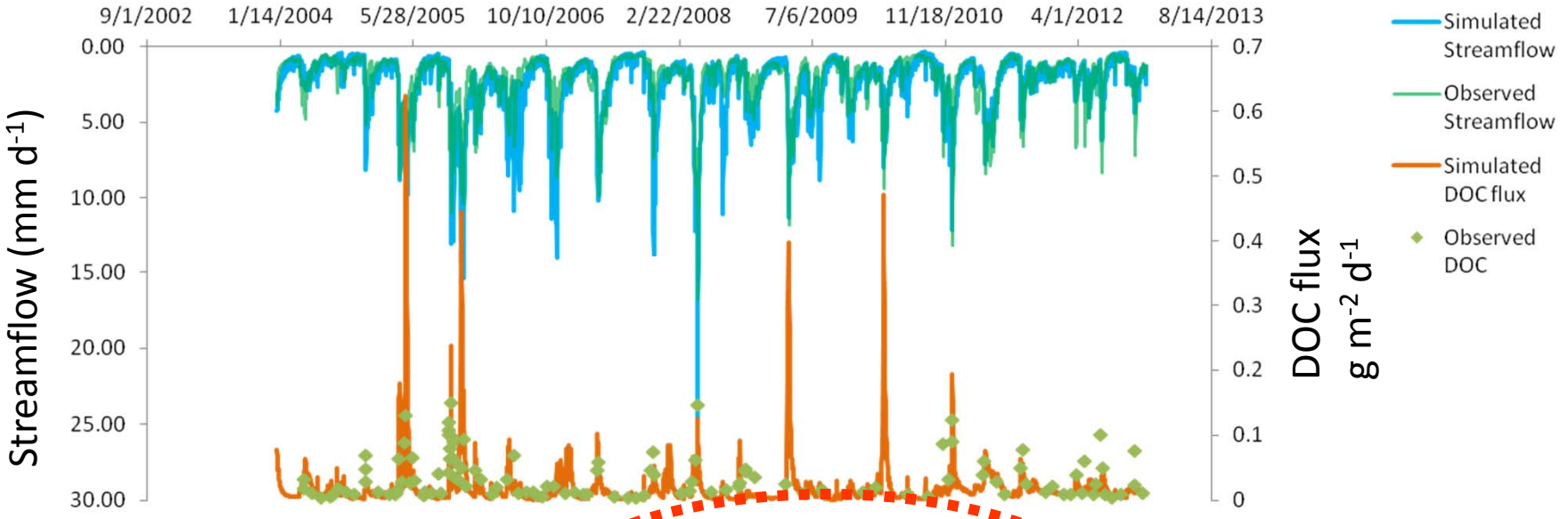
30% increase driven by increased precip and increased variance in precip

LOADEST2 estimated DOC fluxes from the Penobscot River
Empirically-based





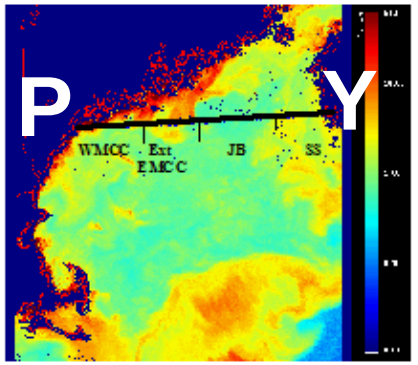
Changing DOC quantity: Regional Hydro-Ecological Simulation System(RHESSys) simulates DOC fluxes from the Penobscot Watershed into the Gulf of Maine; Analytically-Based

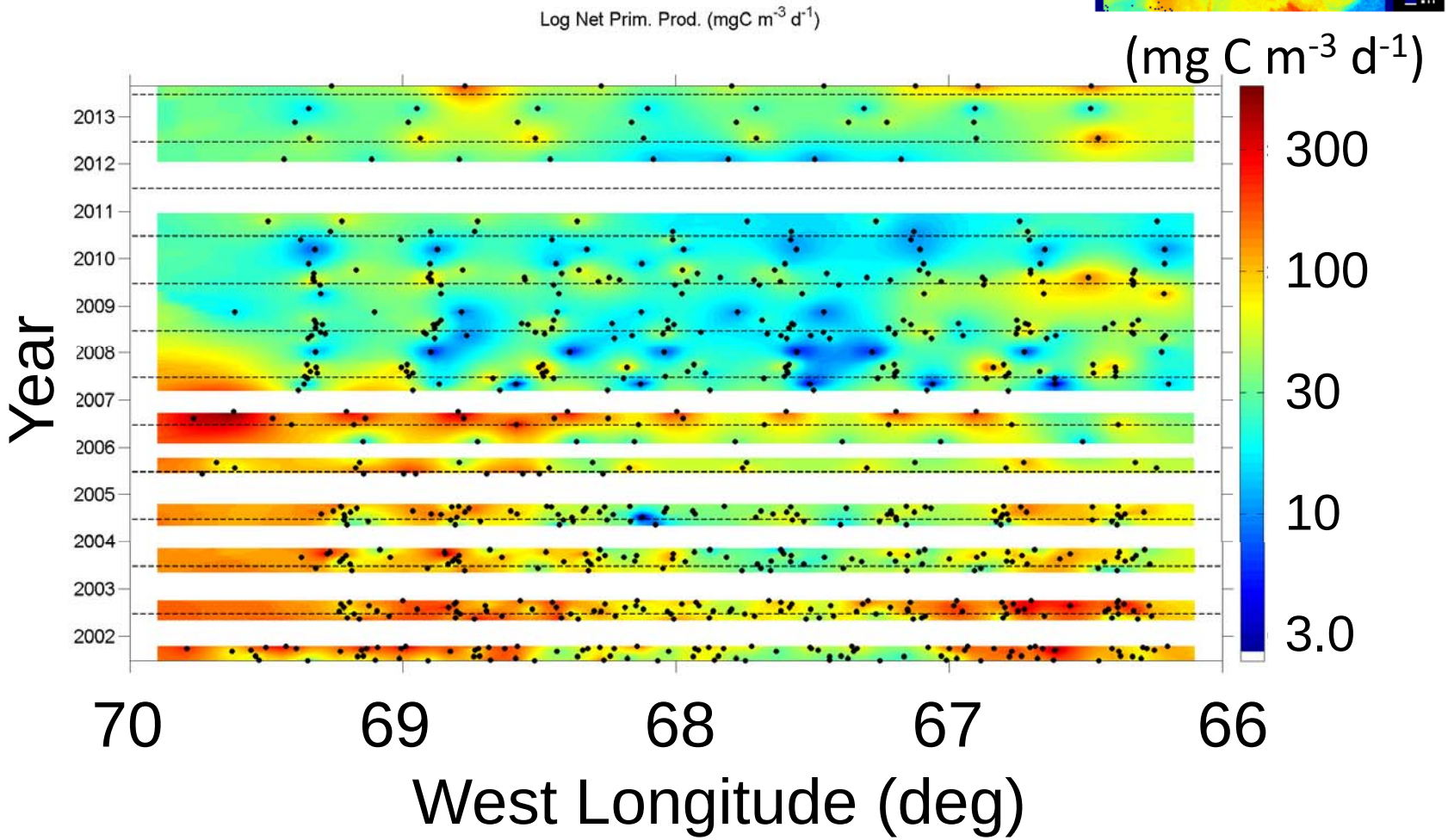


Gage Station	Model	Cumulative DOC flux (2004-2005) (Mt C)	DOC yield (2004-2006)(KgC/ha/yr)
Penobscot at Eddington	RHESSys	387,600	77
	LOADEST	308,000	71

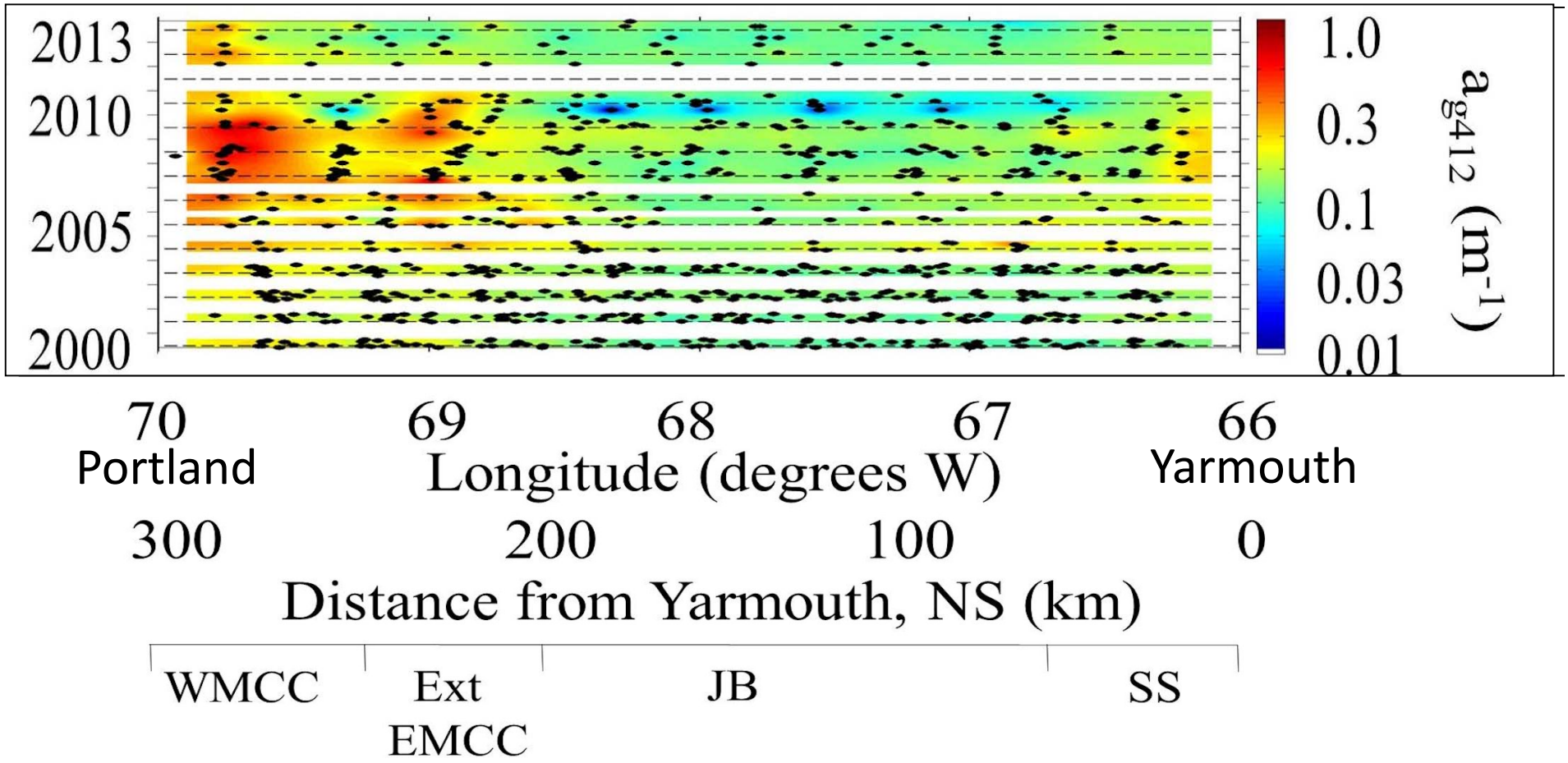
Crystal Schaaf and Shabnam Rouhani, U. Mass Boston

GNATS has observed a massive decline in primary productivity across the GOM



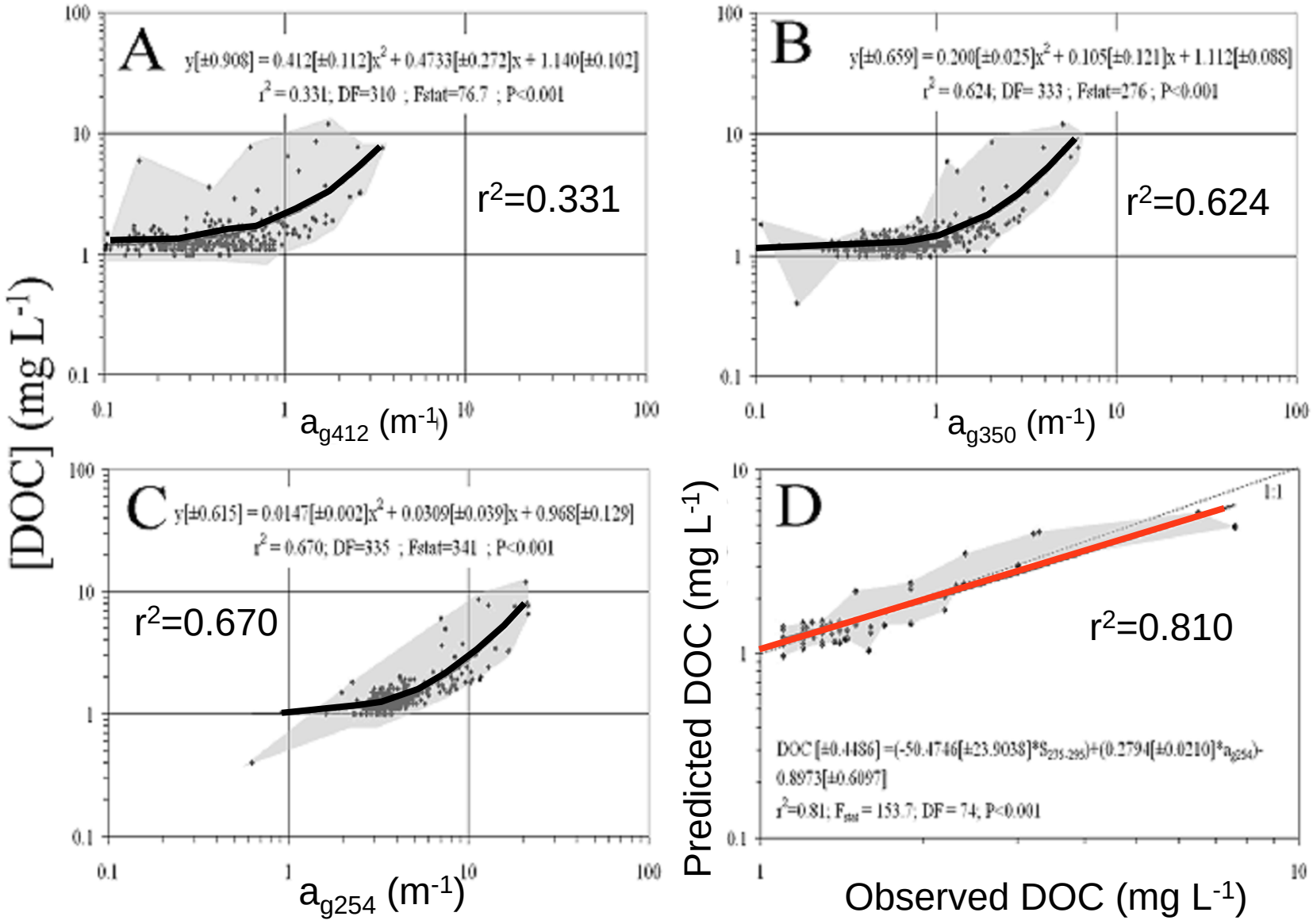


Space time variability in GNATS

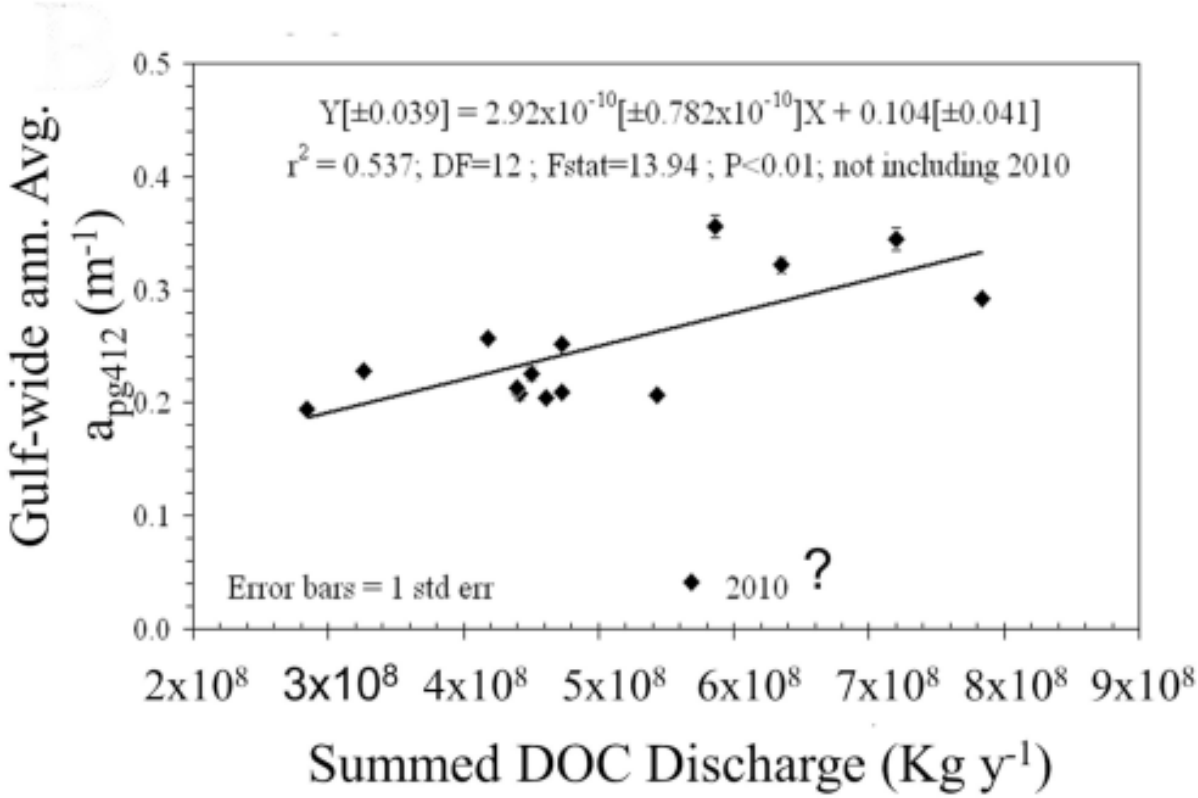


White bands= no data; dashed lines = summer solstice

CDOM absorption as an optical proxy of DOC quantity…

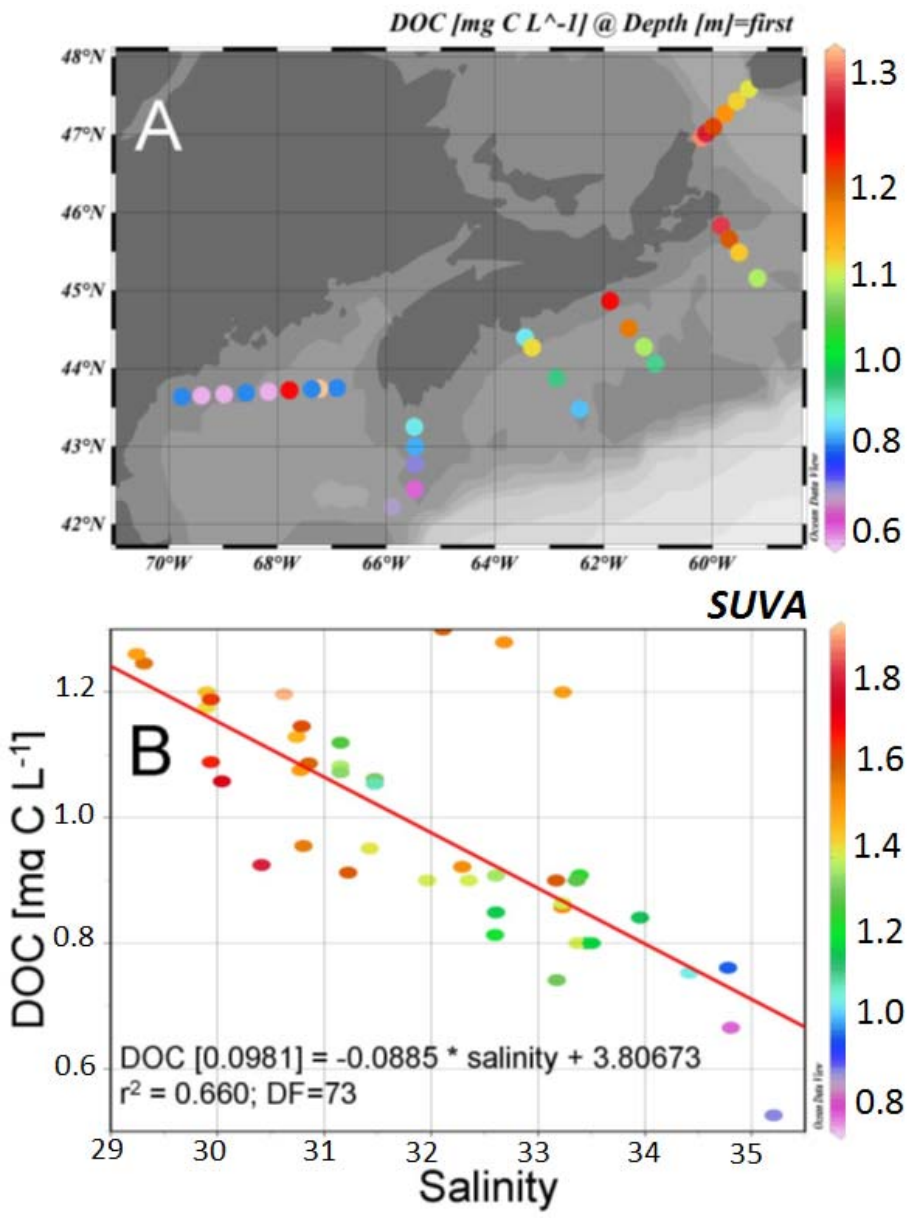


Does [CDOM] relate to river discharge?



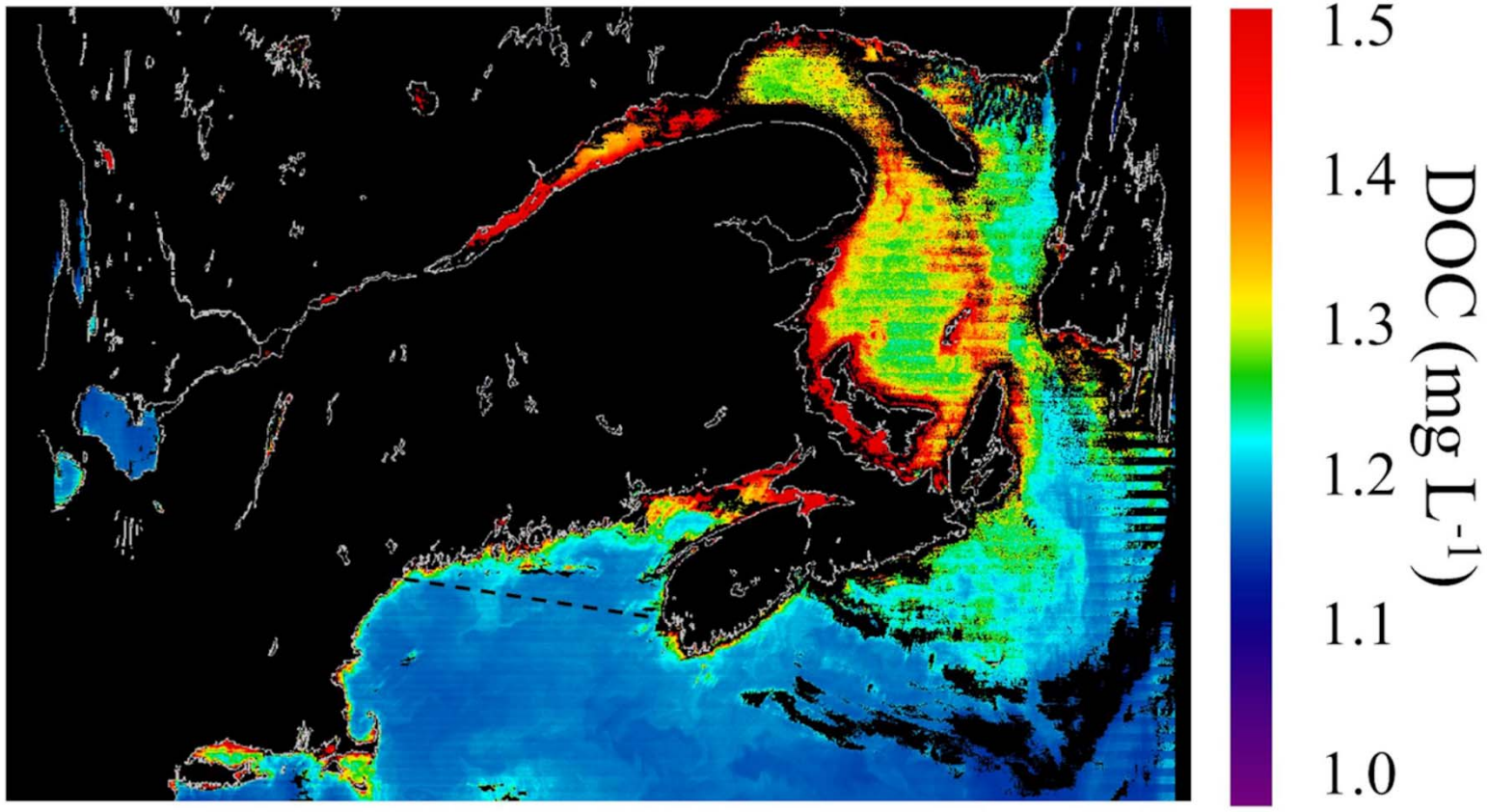
June-Sept cruises only

Large-scale distribution of DOC quantity and quality…



Aiken et al., USGS

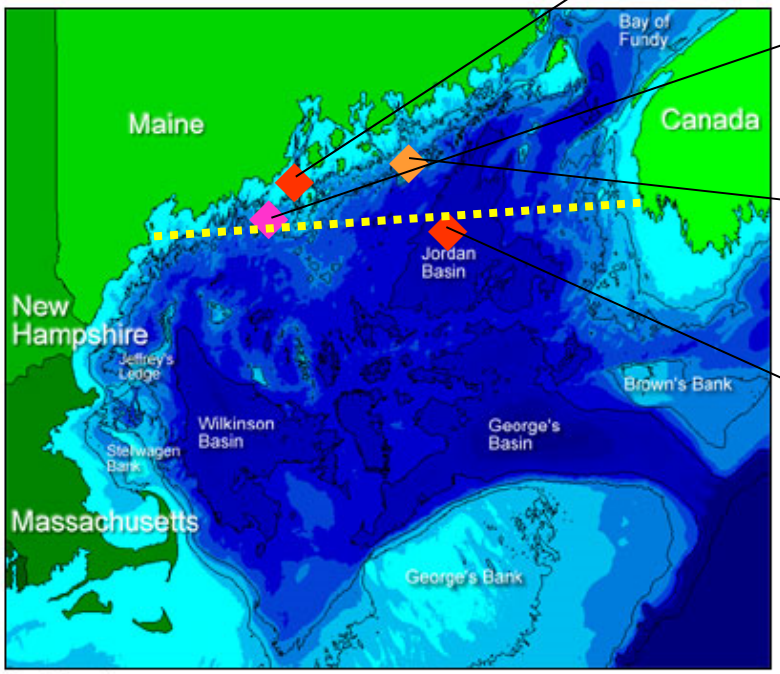
Satellite-derived DOC (MODIS Aqua) based on GIOP model, a_{g412}



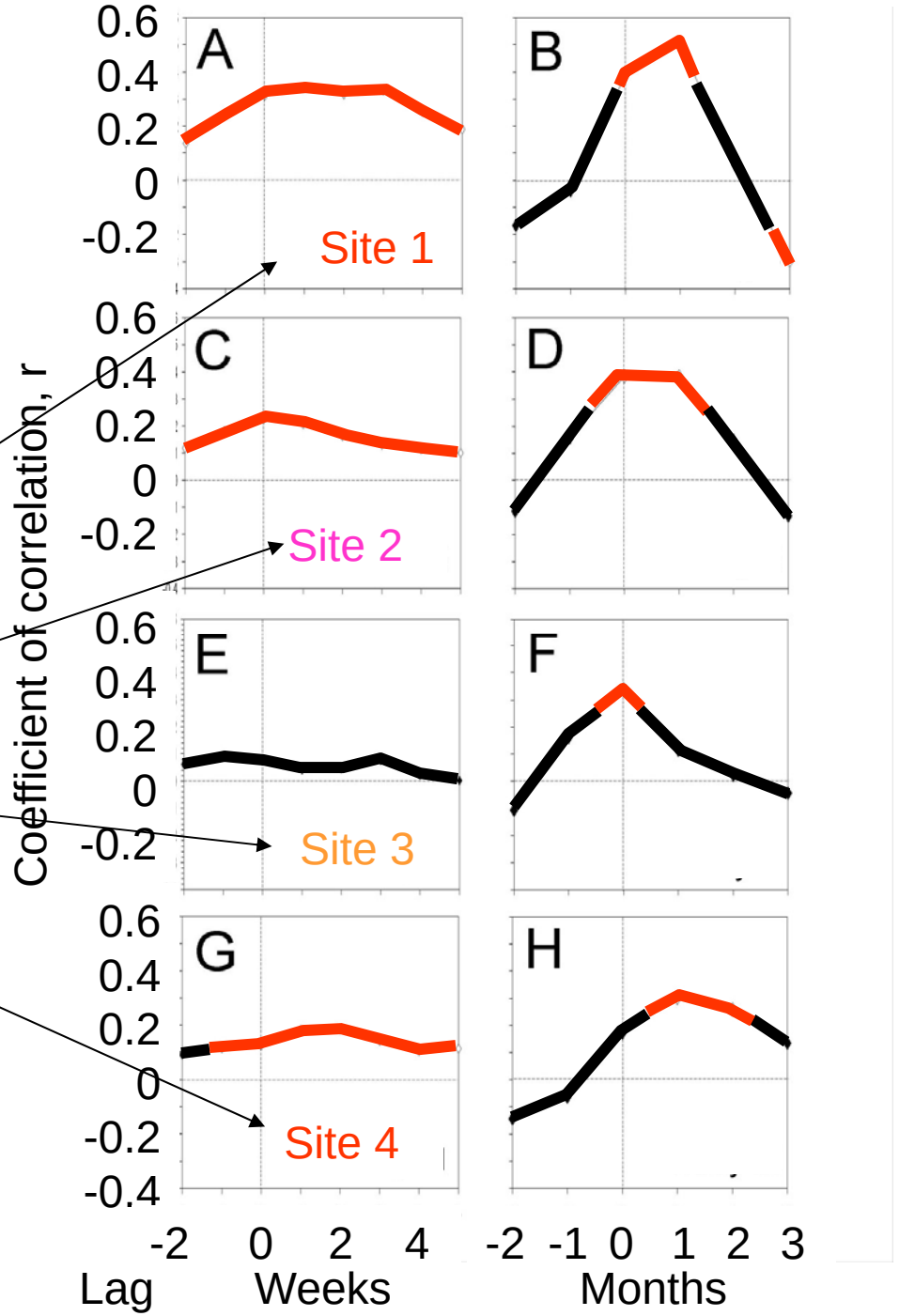
2 October, 2005

Werdell et al., Applied Optics 2013

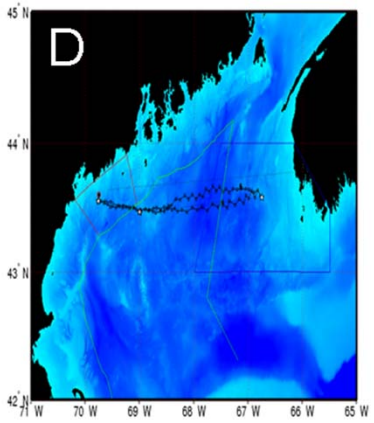
Lag correlations of DOC discharge from rivers vs MODIS-derived DOC

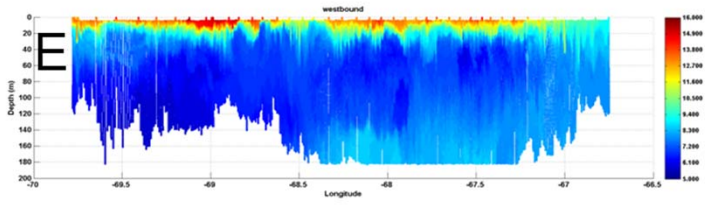


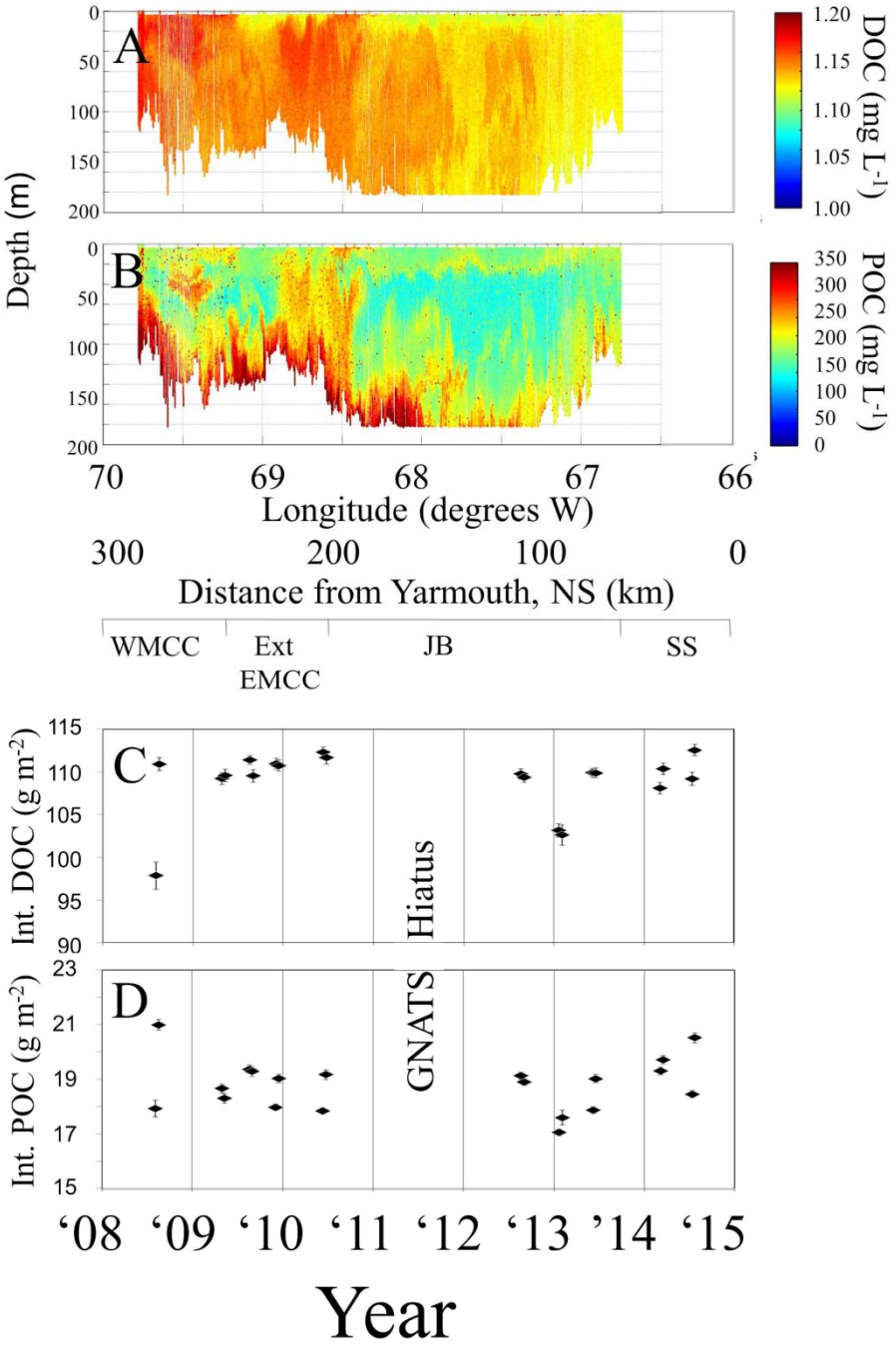
Ru Morrison



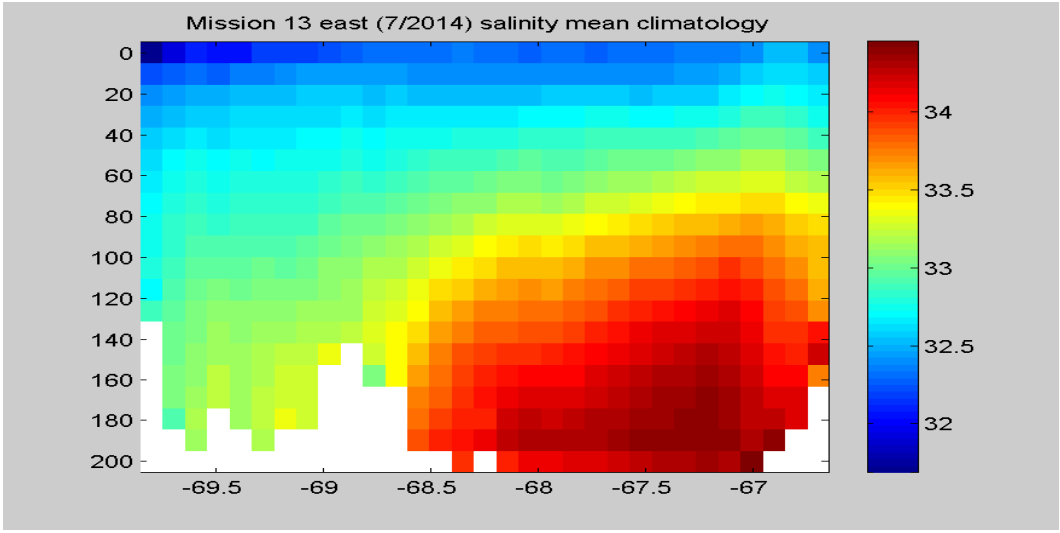
Glider crossings of GNATS transects

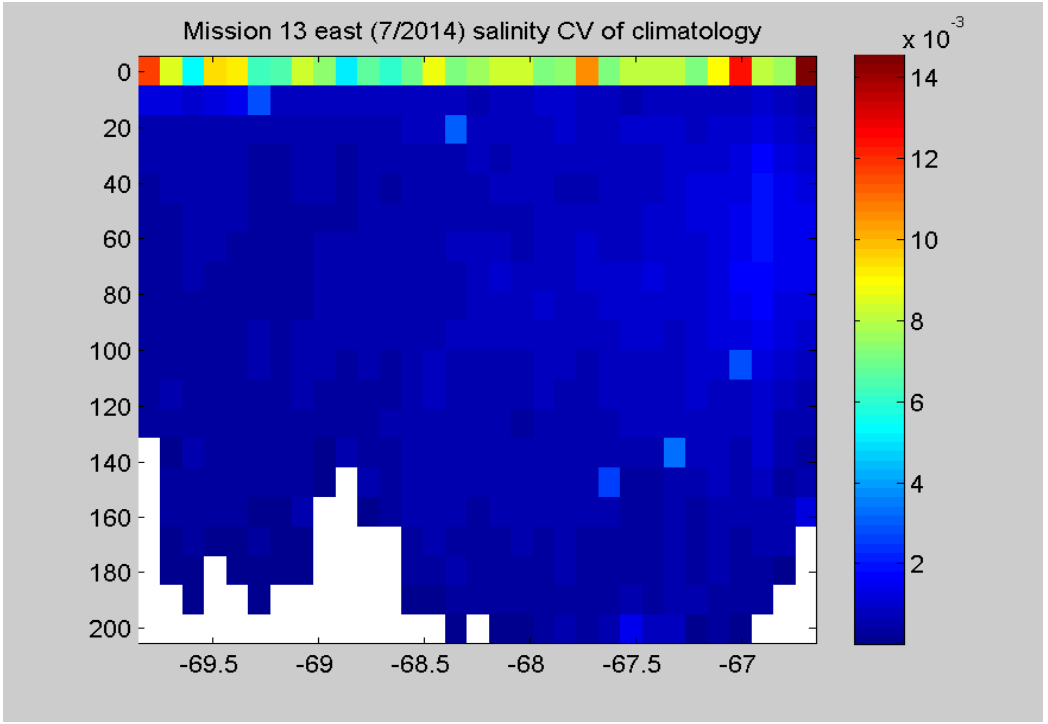




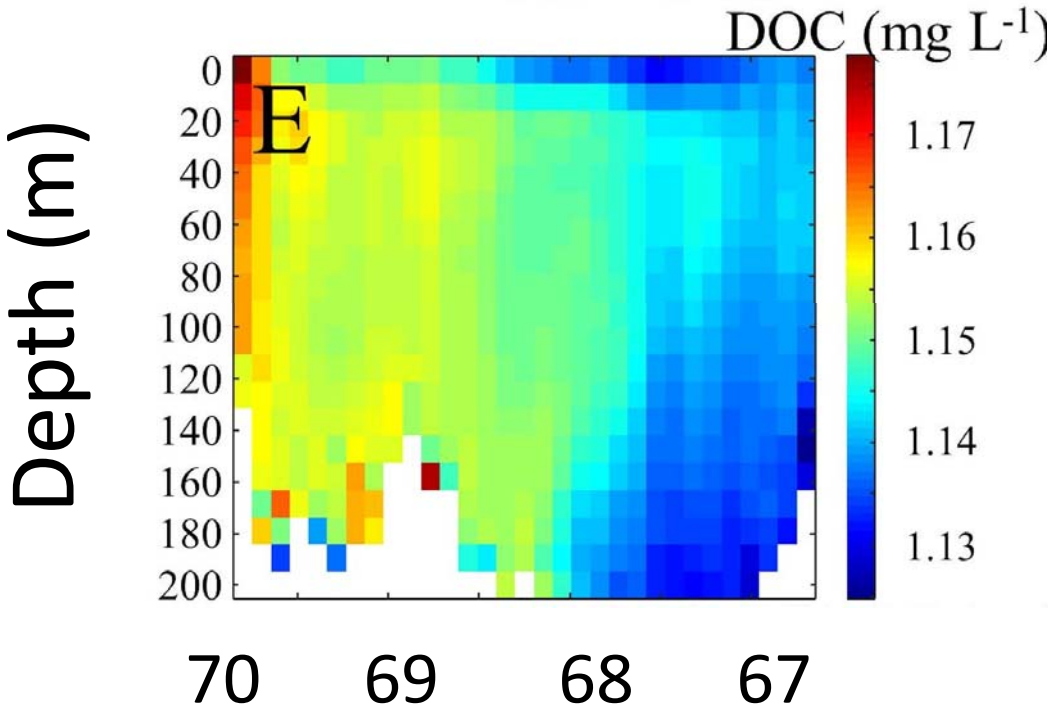


First look at the salinity climatology and CV from 20 crossings of the Gulf

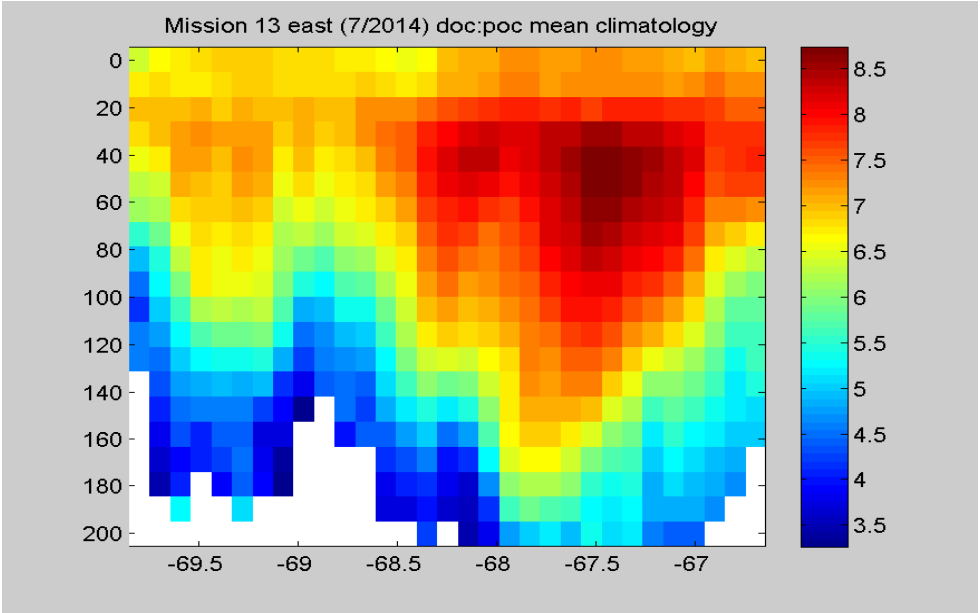


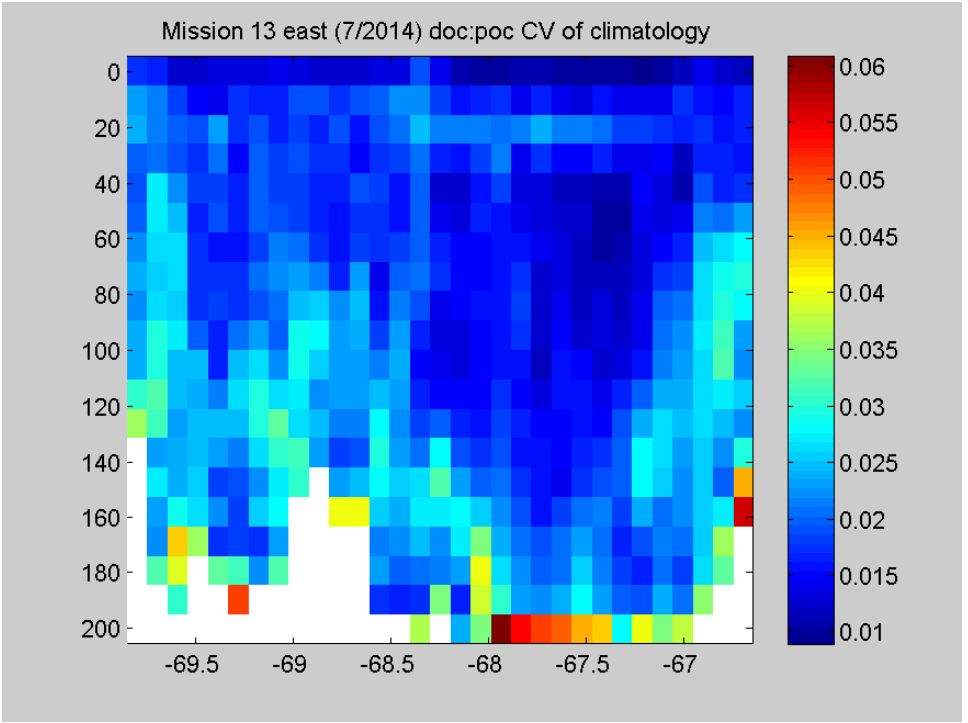


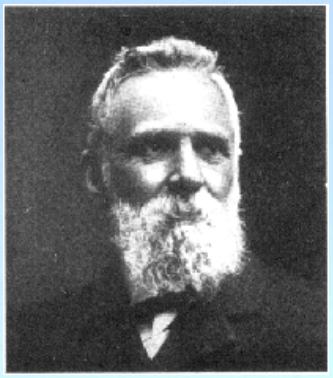
DOC concentration derived from 20 crossings of GNATS transect with an autonomous glider



DOC:POC ratio and CV based on 20 glider crossings.







François Alphonse Forel "founder of limnology"(1890) and Willi Ule (1892; limnologist)

- Composed a hand-held, color comparator scale, with tints varying from indigo-blue to "cola" brown. Used to quantify the color of seas, lakes and rivers.
- The Forel-Ule (FU) color scale has been calibrated to modern radiometric measurements (Wernand and van der Woerd, 2010).
- There is a comparatively large data set of older FU measurements
- Henry Bigelow made such measurements in the Gulf of Maine in 1912 and 1913. **We can compare Bigelow's measurements to GNATS radiometric measurements inferred through colorimetry**

Old and new FU color scales (Wernand and van der Woerd, 2010)

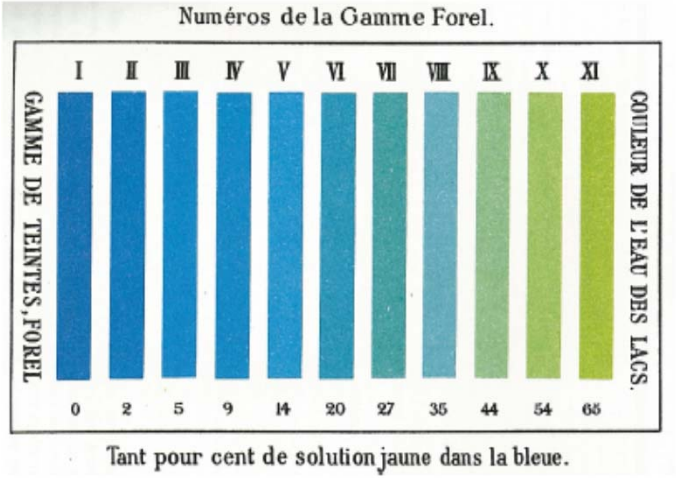


FIG. 4 A FU observation is taken, at the shady side of the vessel, above a submersed Secchi disc, with the disc lowered to a depth of approximately half the Secchi disc depth. The reading of the scale should be done in the shadow.

Iphone apps
"Citclops" Hommersom and Van der Woerd Ocean Sci. Discuss.
"Hydrocolor" Leeuw and Boss-

Chromaticity Coordinates-

Relating radiometry to photometry (human-perceived color)

Based on dimensionless tristimulus or "color-matching functions (Phototopic luminosity function; C.I.E. color coordinate system, 1936)

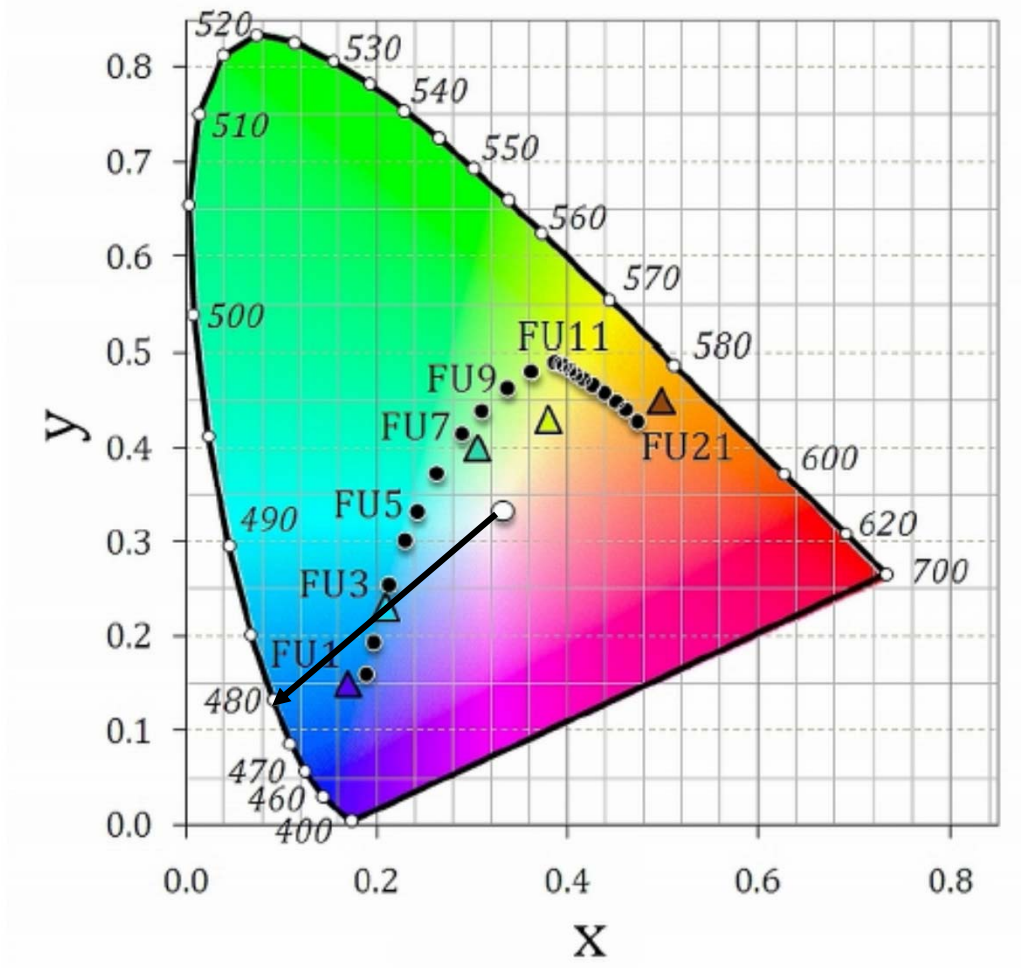
$$X = \int S(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int S(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int S(\lambda)\bar{z}(\lambda)d\lambda$$

Radiometric quantity (L(λ)

Luminance



Normalize out intensity

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

Wernand and van der Woerd (2010) measured spectral transmission of FU solutions

Henry Bryant Bigelow

Schooner *Grampus*, ~1914.

Henry Bigelow aboard schooner *Grampus*, ~1914.

Our window to past ocean color in the GoM…

Bigelow Ocean Color Data from

COLOR

The color of the gulf was measured by percentages of yellow[25] during the summers of 1912 and 1913 [illegible] gulf.

At the other extreme, we have invariably found the percentage of yellow greatest (27 to 35 per cent) in the coastal belt along the shore of Maine, out, roughly, to the 100-meter contour, with secondary smaller but very green areas (27 per cent of yellow) along the outer side of Cape Cod and in the German Bank region. The

[25] The color of the sea usually is measured by the "Forel" scale, based on a combination of blue and yellow, the former being 5-gram copper ammonia sulphate + 0.5 cubic centimeter ammonia in 95 cubic centimeters water; the latter 15-gram potassium chromate in 100 cubic centimeters of water. The combinations used are as follows:

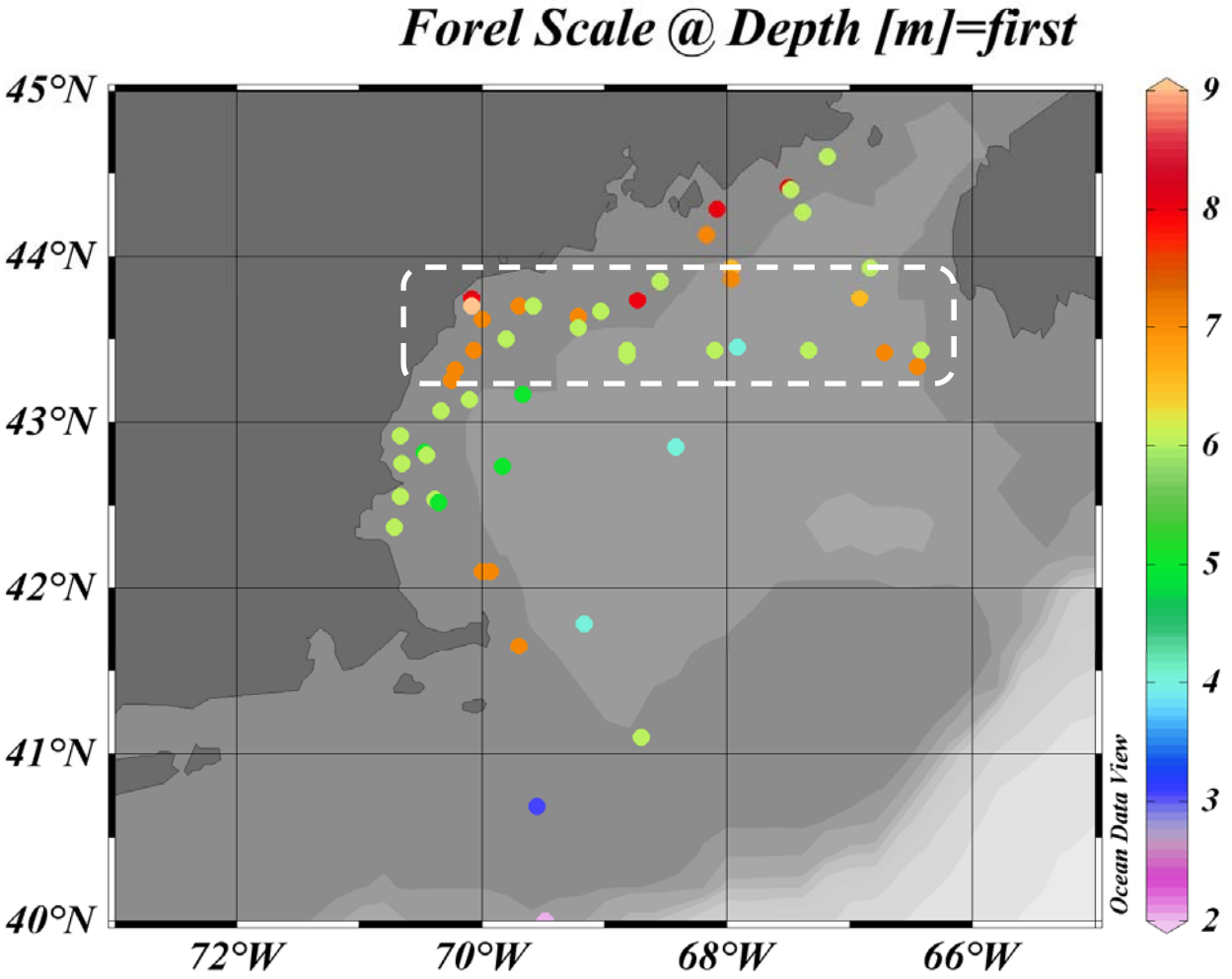
	1	2	3	4	5	6	7	8	9	10	11	12	13
Per cent blue	100	98	95	91	86	80	73	65	56	46	35	23	10
Per cent yellow	0	2	5	9	14	20	27	35	44	54	65	77	90

Various comparators have been devised for use on shipboard. For descriptions of the method employed on the *Grampus* see Bigelow, 1914, p. 38.

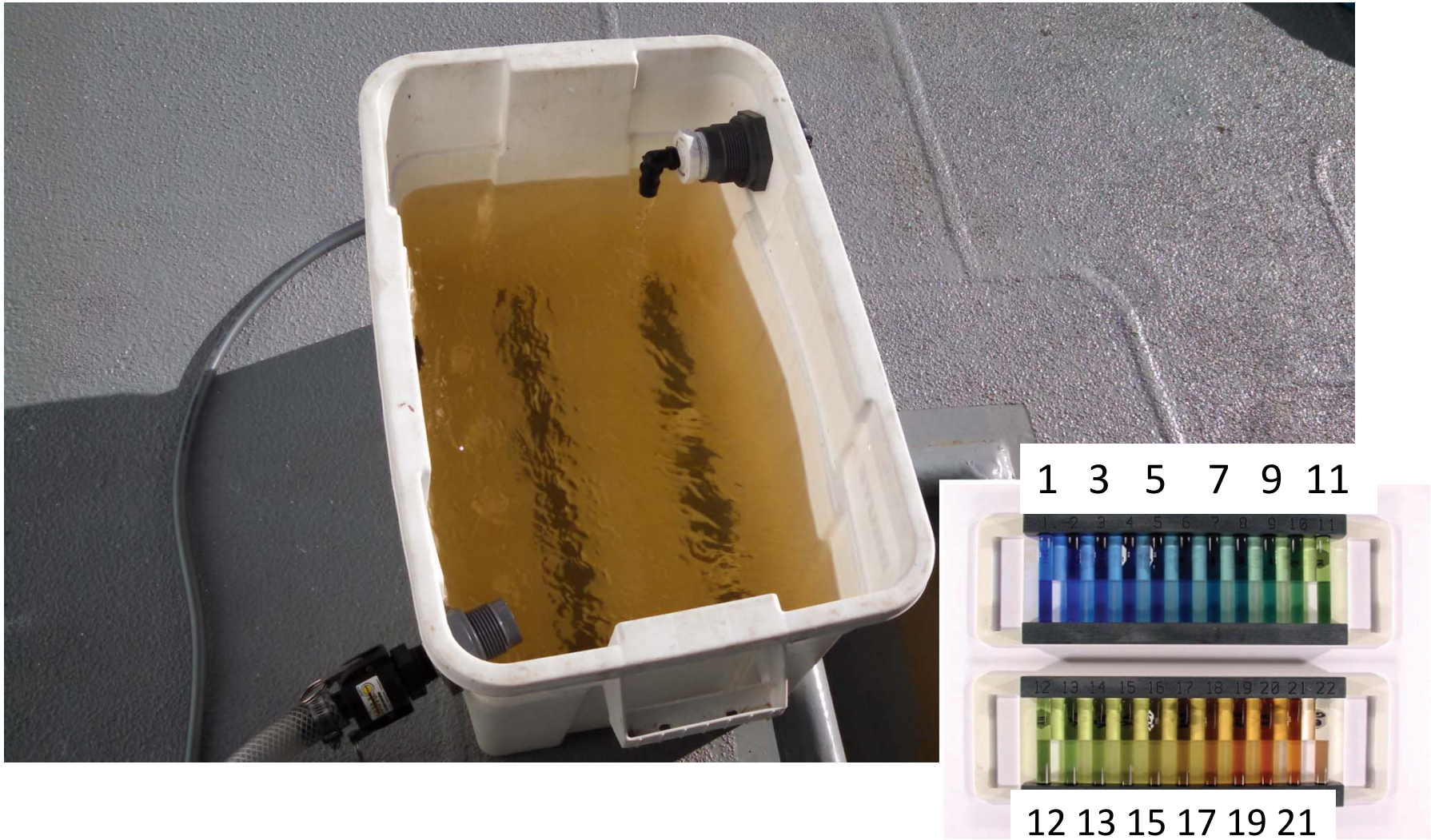
in earlier publications (Bigelow, 1914, p. 81; 1915, p. 225), the distribution of color

Date	General locality	Station	Color in percentage of yellow
1912			
July 10	Off Gloucester	10002	20
11	Near Gloucester	10004	20
13	Off Boston Harbor	10006	20
15	Basin off Cape Ann	10007	14
16	Ipswich Bay	10008	20
16	Northeast of Cape Ann	10009	14
16	Off Hampton, New Hampshire	10010	20
17	Near Isles of Shoals	10011	20

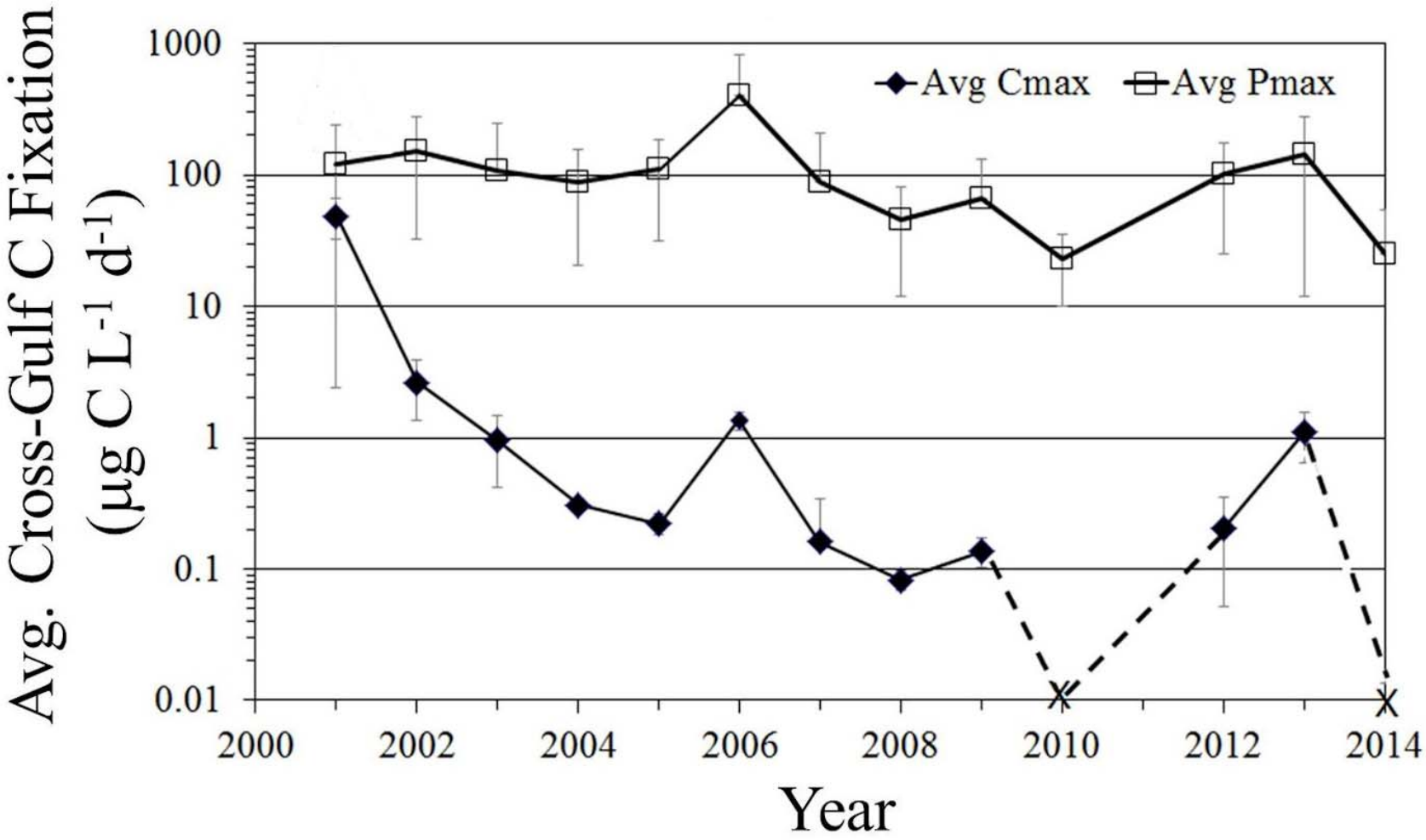
Bigelow 1912-1913



Ext. Eastern Maine Coastal Current Sept. 2014; 80Km from land…

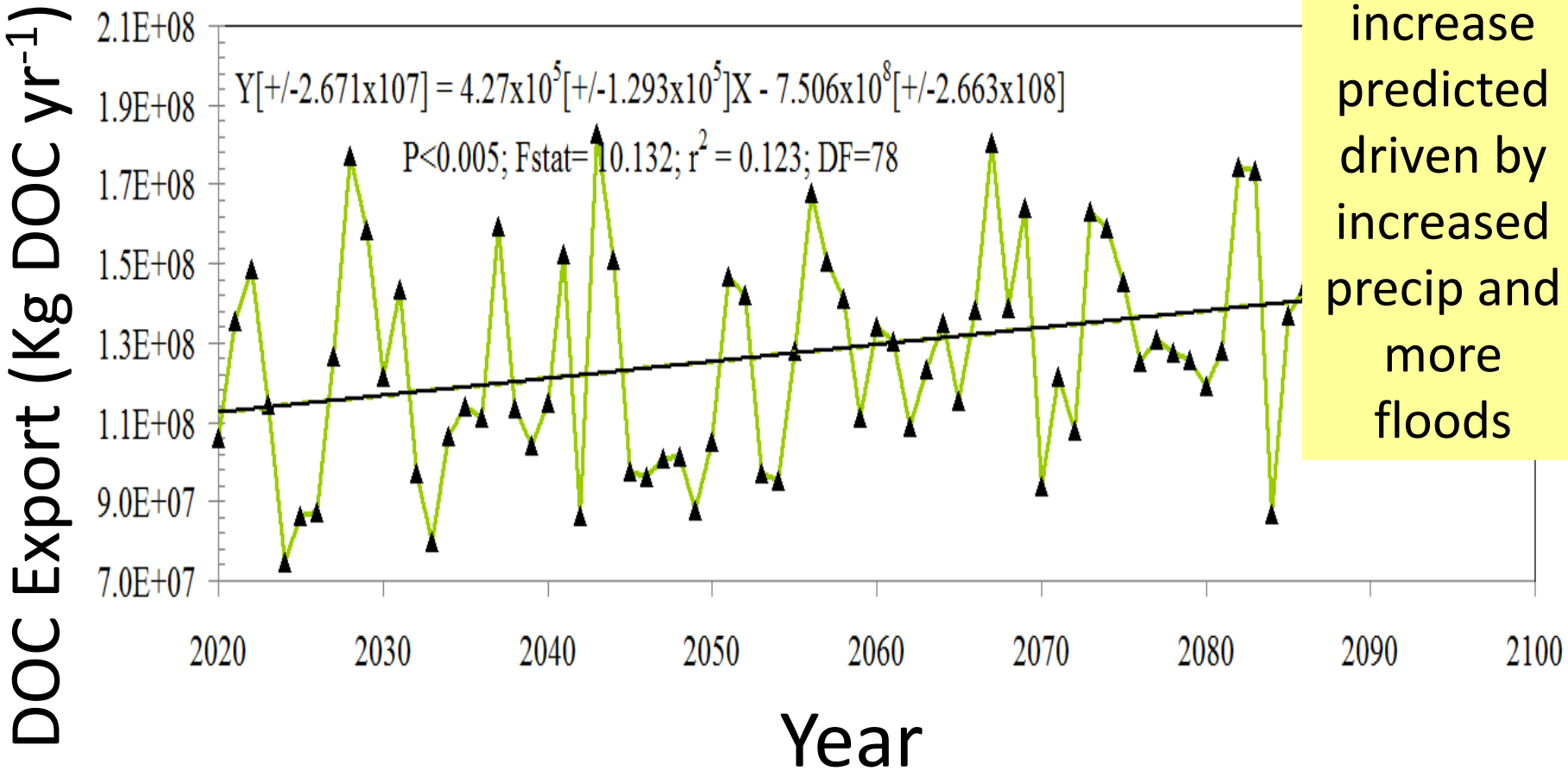


Who cares? CDOM competes with chlorophyll for blue absorpition…



Will the Gulf of Maine get yellower in the next century?

Projected DOC export by Penobscot River (Hadley Center Model- A1 Emission Scenario



30% increase predicted driven by increased precip and more floods

Huntington et al., USGS, submitted

Summary

- The power of GNATS is synoptic satellite and ship observations plus access to extensive watershed and coastal records
- GNATS has observed massive intrusions of CDOM and DOC associated with extreme wet years in the NE coastal environments
- GNATS has demonstrated that CDOM is a useful proxy for tracking DOC export from land to sea
- CDOM standing stock has increased in the Gulf of Maine over the last century
- Tough to differentiate between climate change or changes in land use
- We predict continued increases in Gulf of Maine DOC, w/ further yellowing with other potential ecological consequences.

Thank you!