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

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• 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, \(b_{bp531nm}\))
Gulf of Maine North Atlantic Time Series (GNATS) is a NASA-centric Ship of Opportunity Program; M/V Nova Star 171 GOM crossings.
Background: Oceanographers have studied coastal carbon for about a century in the Gulf of Maine

- Henry Bigelow studied 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...

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

Y[+/−2.95x10^7] = 3.830x10^5 [+/−1.328x10^5]X - 6.42x10^8 [+/−2.618x10^8]
P<0.005; Fstat=8.32; R^2=0.09 ; DF=82

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

Tom Huntington, USGS Augusta
LOADEST2 estimated DOC fluxes from the Penobscot River
Empirically-based

DOC Export (Metric Tons/day)

2004 2005 2006 2007


Fall Discharge Events

Huntington, USGS

DOC Concentration (mg/L)

7 8 9 10 11 12 13 14
Changing DOC quantity: Regional Hydro-Ecological Simulation System (RHESSys) simulates DOC fluxes from the Penobscot Watershed into the Gulf of Maine; Analytically-Based

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Penobscot at Eddington</td>
<td>RHESSys</td>
<td>387,600</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>LOADEST</td>
<td>308,000</td>
<td>71</td>
</tr>
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</table>

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...

A. 

\[ y = 0.412x - 0.112 + 0.4733x^2 + 0.272x + 1.140 \]

\[ r^2 = 0.331 \]

B. 

\[ y = 0.200x^2 + 0.105x + 1.112 \]

\[ r^2 = 0.624 \]

C. 

\[ y = 0.0147x - 0.002 + 0.0305x + 0.968 \]

\[ r^2 = 0.670 \]

D. 

\[ y = -0.0486 + 23.903x + 0.279 + 0.0210a_925 - 0.8973a_925 \]

\[ r^2 = 0.810 \]
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, $a_{g412}$
Lag correlations of DOC discharge from rivers vs MODIS-derived DOC
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)

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(\lambda))

Luminance

\[
x = \frac{X}{X+Y+Z} \\
y = \frac{Y}{X+Y+Z} \\
z = \frac{Z}{X+Y+Z}
\]

Normalize out intensity

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...
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

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:

<table>
<thead>
<tr>
<th>Station</th>
<th>Color in percentage of yellow</th>
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<tbody>
<tr>
<td>10002</td>
<td>20</td>
</tr>
<tr>
<td>10004</td>
<td>20</td>
</tr>
<tr>
<td>10006</td>
<td>20</td>
</tr>
<tr>
<td>10007</td>
<td>14</td>
</tr>
<tr>
<td>10008</td>
<td>20</td>
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<td>10009</td>
<td>14</td>
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<tr>
<td>10010</td>
<td>20</td>
</tr>
<tr>
<td>10011</td>
<td>20</td>
</tr>
</tbody>
</table>

Various comparators have been devised for use on shipboard. For descriptions of the method employed on the Grampus see Bigelow, 1914, p. 38.
Bigelow 1912-1913
Ext. Eastern Maine Coastal Current Sept. 2014; 80Km from land...
Who cares? CDOM competes with chlorophyll for blue absorption...
Will the Gulf of Maine get yeller in the next century?
Projected DOC export by Penobscot River (Hadley Center Model- A1 Emission Scenario)

\[ Y^{+/+2.671 \times 10^8} = 4.27 \times 10^8^{+/+1.293 \times 10^5}X - 7.506 \times 10^8^{+/+2.663 \times 10^8} \]

\[ P<0.005; F_{stat}=1.0132; r^2=0.123; DF=78 \]

Huntington et al., USGS, submitted

30% increase predicted driven by increased precip and more floods
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!