BATS and HOT, 25 years of incredible productivity! CARIACO 18 years!

What should we focus on for the next 25 years?

Ken Johnson
Monterey Bay Aquarium Research Institute
Net community production, carbon export and nutrient supply at ocean time series sites. Should we expect consensus? Should fluxes agree?

Ken Johnson
Monterey Bay Aquarium Research Institute
Overarching goal – convince OCB community that we need a systematic assessment of major carbon fluxes (NCP, Export, ...) at time series station (HOT, BATS, CARIACO, ESTOC, Papa).
  • Perhaps an OCB working group?
  • How do methods compare?

I’ll argue that time series stations need to make quantitative observations of major carbon fluxes over time.
  • Are sediment traps at 150 m good enough?
  • Methods should be intercomparable.
  • Time series stations should serve as a benchmark for more expandable systems.

Ultimately we need global, carbon observing systems.

But first a little time series history!
HOT-1 Cruise Report
R/V Moana Wave
29 Oct. - 3 Nov. 1988

Narrative:

HOT-1 was the shakedown cruise of the HOT program, much of the
equipment had never been used, and there were some equipment failures. One conductivity cell and the General Oceanics rosette pylon failed. In addition, there were problems with the winch level-wind mechanism, and with the slip-rings. The Kahe Point station was abandoned because of these problems.

The sediment traps were tracked using ARGOS for two days after deployment, but we lost contact with them a few hours before they were due to be retrieved, and despite a 16-hour search, they were not found.
Cruise Report, BATS 1

Cruise dates: October 20, 1988 - October 21, 1988
R.V. Weatherbird

Cast 1 on deck at 0200.
Wire kinked. Decide not to put CTD back down.
Lat: 31.160 N; Long: 64.500 W
Nominal depths: 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200 m.
HOT-253: Chief Scientist Report
Chief Scientist: Susan Curless
R/V Kilo Moana
June 24-28, 2013

Investigator                              Project                                Institution
Matt Church                              Core Biogeochemistry                  UH
Dave Karl                                Biogeochemistry QA/QC                 MSU
Bob Bidigare                             Hydrography                            UH
John Dore                                Zooplankton dynamics                   SIO
Ricardo Letelier                          Optical measurements                   OSU

Ancillary programs:
Andrew Dickson                            CO₂ dynamics and intercalibration     SIO
Paul Quay                                DI¹³C                                   UW
Matt Church & Ricardo Letelier            Diversity and activities of nitrogen-fixing microorganisms    UH
Sam Wilson                                Reduced gases in the upper ocean: The cycling of methane, sulfide and nitrous oxide UH
Donn Viviani                              Bacterial production and EOC at Station ALOHA    UH
Sara Thomas                              Chemolithoautotroph experiment         UH
Adina Paytan                              O¹⁸ natural abundance                   UCSC
Christopher Schwartz                     Viral Dynamics at Station ALOHA and surface water collection for virus and phytoplankton culturing UH
Erica Goetze                             Temporal stability of copepod populations at Station ALOHA   UH
Irina Shilova, Brandon Carter, Matt Mills, and Zbigniew Kolber  Phytoplankton responses to different nitrogen sources in the North Pacific Subtropical Gyre UCSC
Scott Turn                               Storage Stability of Next Generation Biofuels   HNEI/UH
Stu Goldberg                              Nutrient and DOC cycling experiment      UH
What’s HOT?

Program objectives:

- Quantify time-dependent variability in key physical, biogeochemical, and ecological properties and processes

- Define relationships between plankton community structure and biogeochemical dynamics

- Quantify physical and biological processes controlling oceanic carbon uptake, transformation, and sequestration
Rising CO$_2$, Falling pH

Air trend: $+1.70 \mu\text{atm yr}^{-1}$
Ocean trend: $+1.92 \mu\text{atm yr}^{-1}$

pH trend: $-0.0018\ \text{yr}^{-1}$

Dore et al. (2009)
DOC (μmol kg\(^{-1}\)) dynamics at BATS (Carlson & Hansell)

Flux into mesopelagic zone
0.2 - 1.4 mol C m\(^{-2}\) y\(^{-1}\)
DOC Dynamics at BATS

DOC (µM)

Dissolved Combined Neutral Sugars % of DOC

Response of specific bacterioplankton lineages

Goldberg et al. 2009
Carlson et al. 2009
BATS/ Original Motivation and Objectives/

The Bermuda Atlantic Time-series Study (BATS) was initiated under the JGOFS umbrella with the overall motivation…

“*To determine and understand the time-varying fluxes of carbon and associated biogenic elements in the ocean and to evaluate the related exchanges with the atmosphere, sea floor and continental boundaries.*” (SCOR, 1987)

Original Objectives:

- To understand the seasonal and interannual variations in ocean physics, chemistry and biology
- To understand the processes that control surface $pCO_2$
- To understand the physical controls on biological rate processes
- To provide a test-bed for the validation of new methods and technologies
Steve Emerson, 2012 OCB Summer Workshop

**How well do we know the annually-averaged net community production?**

*Measurements at time-series locations*

---

**Can you explain the mass balance-sediment trap difference by DOC export and trap depth?**

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[Graph showing annual averages of NCP (net community production) with various markers indicating different data sources and years.]
Net Community Production (NCP) = Primary Prod. – Respiration at all trophic levels (Net production of C = C export on an annual basis)

NCP estimates near HOT to base of euphotic zone

<table>
<thead>
<tr>
<th>Method</th>
<th>NCP (mol C m^-2 y^-1)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>POC Flux</td>
<td>1.1±0.3</td>
<td>Karl et al. 1995</td>
</tr>
<tr>
<td>DI$^{13}$C mass balance</td>
<td>1.6±0.9</td>
<td>Emerson et al. 1997</td>
</tr>
<tr>
<td>Sum of C fluxes</td>
<td>2.0±0.9</td>
<td>Emerson et al. 1997</td>
</tr>
<tr>
<td>$O_2$ utilization rates</td>
<td>2.2±0.5</td>
<td>Sonnerup et al. 1999</td>
</tr>
<tr>
<td>$O_2$, Ar, N$_2$ mass balance</td>
<td>2.7±1.7</td>
<td>Emerson et al. 1997</td>
</tr>
<tr>
<td>$^{234}$Th C flux</td>
<td>2.7±0.9</td>
<td>Benitez-Nelson et al. 1995</td>
</tr>
<tr>
<td>DIC, DI$^{13}$C &amp; model</td>
<td>2.7±1.3</td>
<td>Quay &amp; Stutsman 2003</td>
</tr>
<tr>
<td>DIC &amp; model</td>
<td>2.8±0.8</td>
<td>Keeling et al., 2004</td>
</tr>
<tr>
<td>Moored $O_2$ sensor</td>
<td>4.0±2.0</td>
<td>Emerson et al., 2008</td>
</tr>
<tr>
<td>$O_2$/Ar</td>
<td>5.0±1.0</td>
<td>Quay et al., 2010</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>2.7±0.6 (90% CI)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>19 Years of Prof. Float $O_2$</strong></td>
<td><strong>3.4±0.4 (90% CI)</strong></td>
<td></td>
</tr>
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</table>
## Net Community Production at Station ALOHA

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<th>Method</th>
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<td>Mixed Layer O(_2) + Ar budgets</td>
<td>1.4 - 3.7 (± 1.0)</td>
<td>1992–2008</td>
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<td>DIC + DI(^{13})C budgets</td>
<td>2.7 - 2.8 (± 1.4)</td>
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<td>4.1 (± 1.8)</td>
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<td>0.9 (± 0.1)</td>
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<td>Sediment traps</td>
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<td>1989–2009</td>
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NCP appears constrained to ~2-fold variability
GPP estimated ~20-fold greater than NCP
What Is the Metabolic State of the Oligotrophic Ocean? A Debate

Hugh W. Ducklow¹ and Scott C. Doney²

¹The Ecosystems Center, A
                email: hducklow@mbl.edu
²Department of Marine Ch
                Woods Hole, Massachusetts

The Oligotrophic Ocean Is Autotrophic*

Peter J. le B. Williams,¹ Paul D. Quay,²
Toby K. Westberry,³ and Michael J. Behrenfeld³

¹School of Ocean Sciences, Bangor University, Menai
                United Kingdom; email: pjw@bangor.ac.uk
²School of Oceanography, University of Washington,
³Department of Botany and Plant Pathology, Oregon
                Oregon 97331-2902

The Oligotrophic Ocean Is Heterotrophic*

Carlos M. Duarte,¹ ² Aurore Regaudie-de-Gioux,¹ ⁴
Jesús M. Arrieta,¹ Antonio Delgado-Huertas,⁵
and Susana Agusti¹ ² ³

¹Department of Global Change Research, Mediterranean Institute of Advanced Studies,
                CSIC-UIB, 07190 Esopes, Spain; email: carlosduarte@imedea.uib-CSIC.es
²Oceans Institute and ¹School of Plant Biology, University of Western Australia,
                Crawley 6009, Australia
³Instituto Andaluz de Ciencias de la Tierra, CSIC-UGR, 18100 Armilla, Spain
⁴Spanish Oceanographic Institute, 33213 Gijón, Spain
IMPLICATIONS AND UNRESOLVED ISSUES

There are two key implications of our conclusions.

• A bias toward net heterotrophy in the \textit{in vitro} O$_2$-based measurements calls into question whether the same issues exist for other \textit{in vitro} measurements (i.e., $^{14}$C and $^{15}$N measurements)

• Net autotrophy....raises issues regarding sources of nutrients supporting positive NCP.

The Oligotrophic Ocean
Is Autotrophic*

Peter J. le B. Williams,¹ Paul D. Quay,² Toby K. Westberry,³ and Michael J. Behrenfeld³
Temperature effects on export production in the open ocean

Edward A. Laws,1 Paul G. Falkowski,2 Walker O. Smith Jr.,3 Hugh Ducklow,3 and James J. McCarthy4

New nutrient input = Net Community Production = Export = New nutrient input
DIC decreases each year, but there is no nitrate present!
from Karl et al. Chap. 10 in Fasham, “Ocean Biogeochemistry”
10.5.2 Case Study 2: A ‘Bermuda Triangle’ Carbon Mystery with Global Implications

The continued disappearance of salinity normalized dissolved inorganic carbon (N-DIC) in the absence of nitrate was first reported by Michaels et al. (1994). They reasoned that if nitrate was added by episodic wind mixing or mesoscale eddy motions, the nitrate would be delivered along with DIC, so simple enhancements of nitrate-supported new and export production could not be responsible for the repeatable summertime N-DIC

• from Karl et al. Chap. 10 in Fasham, “Ocean Biogeochemistry”
<table>
<thead>
<tr>
<th></th>
<th>Annual Flux mol N m(^{-2}) y(^{-1})</th>
<th>Annual Flux mol C m(^{-2}) y(^{-1})</th>
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<tbody>
<tr>
<td>NCP</td>
<td>0.50</td>
<td>3.3</td>
</tr>
<tr>
<td>Total N Flux</td>
<td>0.51</td>
<td>3.4</td>
</tr>
<tr>
<td>Eddy pumping</td>
<td>0.18</td>
<td>1.2</td>
</tr>
<tr>
<td>Winter Convection</td>
<td>0.17</td>
<td>1.1</td>
</tr>
<tr>
<td>Isopycnal Diffusion</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Large-scale Ekman pumping</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Atmospheric Dep.</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Diapycnal Diffusion</td>
<td>0.015</td>
<td>0.1</td>
</tr>
</tbody>
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Siegel et al., JGR 104, 1999
Carbon is at or above Redfield, relative to nitrate, at the base of the euphotic zone. Upward transport of sufficient nitrate also brings carbon and there is no annual drawdown.
Why do we care about getting C and nutrient fluxes right???
• Numerous studies point to climate and changing ocean phytoplankton/productivity links.

• Trend detection based primarily on remote sensing and results can be opposite to in situ time series observations.

• Need bio-chemical sensors to directly sense change in carbon cycle.
Mean 3D Biogeochemical model error for estimates of Net Primary Production at HOT

\[ = \log(\text{Model NPP}/\text{Obsd. NPP}) \]

\[ 10^{-0.56} = 0.27 \]
Time Series Represented at OCB
Time Series Workshop Nov. 2012

Observing system needed to get heat content

MBARI Chemical Sensor Lab
Nitrate
Oxygen
pH
Chl. Fluorescence
Optical Backscatter
60 obs. from 1000 m
300 profiles (4.5 y at 5 d/cycle)
pH can be measured robustly using Ion Sensitive Field Effect Transistors (Martz et al., L&O Methods, 2010). If you have pH, Dissolved Inorganic Carbon can be estimated to about 8 µmol/kg.
1. We need global scale, quantitative, autonomous observing systems for carbon.

2. We need to know time varying carbon flux at Time Series sites to ensure calibration of a global system carbon observing system.
Fig. 8.3.11 Sarmiento & Gruber
The real question is, how do phytoplankton manage positive net growth with no apparent N in the system. Redfield requires C/N of 106/16 = 6.6
Variability of chromophytic phytoplankton in the North Pacific Subtropical Gyre

Binglin Li, David M. Karl, Ricardo M. Letelier, Robert R. Bidigare, Matthew J. Church
HOT – nutrient supply Church

BATS – C drawdown mechanisms – Lomas

Bats – DOC/link to microbiology.....
The objectives of HOT specific to the JGOFS program are to:

— document and understand seasonal and interannual variability in the rates of primary production, new production and particle export from the surface ocean;
— determine the mechanisms and rates of nutrient input and recycling, especially for N and P in the upper 200 m of the water column;
— measure the time-varying concentrations of carbon dioxide in the upper water column and estimate the annual air-to-sea gas flux.
Lomas et al (2013)

- Document the seasonal, interannual and decadal scale variability in carbon and macronutrient cycle parameters and processes.

- Including, for example, an understanding of the controls on the coupling/decoupling (relative to the Redfield ratio) of elemental cycles.

- Document variability in planktonic community structure and function, and its impact on the ocean’s carbon cycle (including new and export production) and coupling with other macronutrient cycles.
Acidification signal = -0.0017 pH/year

Production/Respiration signal = 0.03 pH/year
On an annual scale, eddies appear to ‘average out’ their impact on biogeochemistry.
Annual cycle of productivity and export

Plankton community structure plays a key role in carbon flux to the deep sea
OCB time series success is a reflection of open data access policy

<table>
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<tr>
<th>Time Series</th>
<th>Publ. Interval</th>
<th>Number</th>
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<tbody>
<tr>
<td>HOT</td>
<td>1990-2012</td>
<td>549</td>
</tr>
<tr>
<td>BATS</td>
<td>1988-2012</td>
<td>480</td>
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<tr>
<td>CARIACO</td>
<td>1996-2012</td>
<td>89*</td>
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<td>Total</td>
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*Publications by CARIACO PI’s only.
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